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ENEWETAK RADIOLOGICAL SUPPORT PROJECT

FINAL REPORT

SEPTEMBER 1982

UNITED STATES DEPARTMENT OF ENERGY
NEVADA OPERATIONS OFFICE
LAS VEGAS, NEVADA

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FOREWORD

This final report thoroughly documents the technical and logistic accomplishments of the Enewetak Radiological Support Project. The reader will readily recognize the magnitude and significance of the effort. This document duly recognizes all aspects of the project except one, possibly the most important though not so obvious to the casual reader. This was truly a cohesive scientific "expedition" because of the achievements, both personal and collective, of all the participants from a variety of governmental and private agencies. Particularly impressive to visitors at Enewetak was the ability of this group of scientists, technicians and support personnel to work in an environment relatively hostile to the required sophisticated technology. Despite adverse conditions, this team collected samples of soil, performed radiochemical analyses on the samples, applied statistical analysis to the data, interpreted the results and provided guidance to the Joint Task Group virtually overnight so that the daily activities for removal of contaminated soil could continue. This concerted effort under the leadership of the Nevada Operations Office is remarkable; its absence would have severely hampered the accomplishments detailed in this report.

William J. Bair
Manager, Environment, Health
and Safety Research
Battelle - Pacific Northwest Laboratory

July, 1982

PREFACE

The work reported here may be said with some precision to have had its inception in September, 1975 with an agreement between the Energy Research and Development Administration (ERDA) and the Defense Nuclear Agency (DNA), committing ERDA to provide technical support to DNA in the cleanup of Enewetak. But in truth the effort had become an inevitable moral obligation of the United States many years earlier, in 1947, when the People of Enewetak were persuaded to leave their homeland to make way for our nation's atmospheric nuclear test activities. It might be said to have begun in April 1972 when Ambassador Franklin Haydn Williams and High Commissioner Edward E. Johnston promised the return of Enewetak to the administration of the Trust Territory. Or it might be said to have begun at Enewetak on May 20th, 1972, on the occasion of the first visit of the Enewetak leadership to their home atoll after 26 years away. On that latter occasion, Enewetak Magistrate Smith Gideon closed a four-day conference by saying to the United States officials, "We know that your people are going to help in cleaning up the place and preparing for our return to our home islands."

It was five years later that the mobilization for the cleanup occurred, and work began in earnest to prepare for the return. The intervening time had been used in surveying, establishing criteria, obtaining Congressional authorization and funding, planning, acquiring resources and developing equipment and techniques.

Radiological support to the cleanup was assigned as a mission to the ERDA Nevada Operations Office, which formed a project team known as the Enewetak Radiological Support Project (ERSP). For the most part, this is the report of that Project from its first authorization on February 23, 1977, to the completion of the cleanup. At this writing the ERSP remains in being on at least an informal basis, and will until this report goes to press.

A few brief words about the role of the ERSP are in order. The key word in the Project name is support. The Project Manager and his several Deputies did not direct the atoll cleanup action. They recommended, advised and assisted Department of Defense officials in carrying out the Congress' mandate for the cleanup. The Project takes full responsibility for its advice and recommendations, but often the decisions of the Director, DNA, the Commander, Field Command or the Commander of the Joint Task Group necessarily took into account overriding considerations of a non-technical nature. In these cases it was the responsibility of the ERSP Manager to define and articulate alternatives and their likely consequences and then to fully support the decisions and actions of the DOD. Another function which the ERSP did not perform was the establishment of criteria and standards. These were given to us in guidance received from AEC, ERDA, and later, DOE Headquarters. The ERSP management team interpreted these criteria and standards in terms suitable for direction of the field effort.

A special note of acknowledgement is due Bert Friesen, who served as Editor and a major contributor to this volume. The other members of the ERSP team are acknowledged and credited as appropriate elsewhere in this report. I feel confident that I speak for all of them in observing that it has been a rare privilege and a stimulating challenge to be a part of so unique a project of such high importance to so deserving a group of people. We wish the People of Enewetak health, prosperity, happiness and peace in their ancestral home.

Roger Ray, Project Manager
Enewetak Radiological Support Project
Nevada Operations Office

ACKNOWLEDGMENTS

Jobs are done by people; difficult jobs require special people with interest and dedication a cut above the normal work-a-day world. Planning, execution, and wrap-up of the Enewetak Radiological Support Project involved two categories of special people: those who put in a tour of duty on Enewetak Atoll, and those who performed their duties without the opportunity to participate first hand in this unique experience.

Duty rosters maintained during cleanup on Atoll list all of the following individuals as participants in the Enewetak Radiological Support Project. To these special people, and the organizations they represented, we express deepest thanks for a difficult job done well.

We wish also to acknowledge, with a special "thank you," the many people who did what they were paid to do as a part of their job, and are not named below, without whom the task would have been vastly more difficult.

For simplicity, individuals within each organization are listed in alphabetical order. Because organizations change names and people move to new jobs, we show the organization/employee relationship in effect during execution of the project. The exception to this rule is that all DOE employees are shown as DOE even though they worked for ERDA during the first few months of the project.

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ABSTRACT

From 1972 through 1980, the Department of Energy acted in an advisory role to the Defense Nuclear Agency during planning for and execution of the cleanup of Enewetak Atoll. The Nevada Operations Office of the Department of Energy was responsible for the radiological characterization of the atoll and for certification of radiological condition of each island upon completion of the project.

In-situ measurements of gamma rays emitted by americium—241 were utilized along with wet chemistry separation of plutonium from soil samples to identify and delineate surface areas requiring removal of soil. Military forces removed over 100,000 cubic yards of soil from the surface of five islands and deposited this material in a crater remaining from the nuclear testing period. Subsurface soil was excavated and removed from several locations where measurements indicated the presence of radionuclides above predetermined criteria.

The methodologies of data acquisition, analysis and interpretation are described and detailed results are provided in text, figures and microfiche. The final radiological condition of each of 43 islets is reported.

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ABBREVIATIONS AND ACRONYMS

ADC	Analogue Digital Converter.
AEC	Atomic Energy Commission. AEC was abolished on 19 January 1975 and many functions transferred to the newly created ERDA (cf).
Am	Americium. Specifically, the isotope ^{241}Am when the mass number is omitted.
AS	Amersham-Searle.
AFRRI	Armed Forces Radiobiology Research Institute.
BAF	Brush Attenuation Factor. More accurately BCF (cf).
BCF	Brush Correction Factor. Factor applied to the in situ gamma measurement to adjust for the presence of vegetation in the detector field of view.
BX	Base Exchange.
C	Commander; cf CJTG.
CDC	Control Data Corporation.
CEQ	Council on Environmental Quality.
CHEM	Chemistry. Usually refers to the wet chemistry component of the Enewetak Radiation Laboratory complex.
Ci	Curie. The quantity of any radioactive species undergoing 3.7×10^{10} nuclear disintegrations per second (dis/sec). Millicurie = 0.001 curie = 3.7×10^{7} dis/sec. Microcurie = 0.000001 curie = 3.7×10^{4} dis/sec.
CJTG	Commander, Joint Task Group.
cm	Centimeter.
Co	Cobalt. Specifically the isotope ^{60}Co.
CONEX	Container Express. Metal shipping container with approximate dimensions 4' x 6' x 8'.
CONPLAN	Concept Plan. An information technique used within DOD to provide general guidance for justifying a proposed major project. See OPLAN.
cpm	Counts per minute.
cps	Counts per second.
CR	Congressional Record.
CRT	Cathode Ray Tube.
Cs	Cesium. Specifically the isotope ^{137}Cs.
DEIS	Draft Environmental Impact Statement.

DF	Disposition Form. A memorandum form in common use by the military.
DIRDNA	Director, Defense Nuclear Agency.
DNA	Defense Nuclear Agency of the Department of Defense.
DOA	U.S. Department of Agriculture.
DOD	U.S. Department of Defense.
DOE	U.S. Department of Energy (established on 1 October 1977; absorbed ERDA).
DOI	U.S. Department of the Interior.
dpm	Disintegrations per minute.
DRI	Desert Research Institute. One component of the University of Nevada system.
EA	Enewetak Atoll.
EC	Enewetak Council.
EG&G	DOE technical support contractor for ERSP field measurements, Las Vegas, NV.
EIC	Eberline Instrument Corporation, Santa Fe, NM. Radiological support contractor for ERSP radiation instrument maintenance and calibration and for soil sample collection and analysis.
EIS	Environmental Impact Statement.
EOD	Explosive Ordnance Disposal.
EPA	U.S. Environmental Protection Agency.
ERDA	Energy Research and Development Administration; established 19 January 1975. Initial organization of ERDA included the AEC. Formation of the DOE included ERDA. ERDA was abolished on 1 October 1977 when the DOE was established.
ERSP	Enewetak Radiological Support Project (of the U.S. Department of Energy).
Eu	Europium. Specifically, the isotopes ^{152}Eu and ^{155}Eu.
FC	Field Command (element of DNA located at Kirtland AFB, NM).
fCi	Femto curies, 10^{-15} curies.
FCDNA	Field Command, Defense Nuclear Agency.
FIDLER	Field Instrument for Detection of Low Energy Radiation.
FPDB	Fission Product Data Base.
FRC	Federal Radiation Council.
FRST	Field Radiation Support Team. A military element (Air Force) of the Enewetak Joint Task Group.

FWHM	Full width at half maximum.
g	Gram
GAR	Gated Analogue Router.
GM	Geiger-Muller
GZ	Ground Zero. Land surface directly beneath or at the site of a nuclear test. SGZ and AGZ occasionally used to distinguish between tests at the surface and in the air.
h	hour, as in R/h.
H&N	Holmes & Narver, Inc., Orange, CA. Logistics and base support contractor for DNA and DOE.
HEPA	High Efficiency Particulate Air (type of filter).
Hg	Mercury.
HP	Hewlett-Packard. Electronics manufacturer, including desktop computers and laboratory equipment.
HPGe	High Purity Germanium - crystal for detection of gamma rays (also referred to as IG)
HQ	Headquarters.
HV	High voltage.
IAEA	International Atomic Energy Agency.
ICRP	International Commission on Radiological Protection.
IG	Intrinsic Germanium (detector). Also referred to as high purity germanium (HPGe) detector.
IMF	Instrument Maintenance Facility.
IMP	Not an acronym, but a trademark owned by the DeLorean Manufacturing Company. Although actually the manufacturer's name for the tracked vehicle used to house the in situ measurement equipment, this term was often used to refer to the entire system.
JCS	Joint Chiefs of Staff, DOD.
JTG	Joint Task Group.
KAFB	Kirtland Air Force Base.
keV	Kilo electron volt.
KT	Kilotons (nuclear tests are rated in thousands of tons of TNT).
LAB	Laboratory. See RADLAB.
LASL	Los Alamos Scientific Laboratory, Los Alamos, NM.
LARC	Landing Amphibious Recovery Craft.

LCM	Landing Craft, Mechanized.
LCU	Landing Craft, Utility.
LLD	Lower Limit of Detection.
LLL	Lawrence Livermore Laboratory, Livermore, CA (became LLNL in 1980).
LLNL	Lawrence Livermore National Laboratory.
LN	Liquid Nitrogen.
m	Meter.
MAC	Military Airlift Command.
MARS	Military Affiliate Radio System.
mCi	Millicurie.
MDA	Minimum Detectable Activity.
MFR	Memorandum For Record.
ml	Milliliter.
MILCON	Military Construction.
MILVAN	Military van. Military-owned container for transport of equipment and supplies.
MLSC	Micronesian Legal Services Corporation.
mm	Millimeter.
MPC	Maximum Permissible Concentration.
MPRL	Mid-Pacific Research Laboratory. (Formerly the Mid-Pacific Marine Laboratory, MPML.) Located at Enewetak, operated by the Univ. of Hawaii for the DOE.
mR	milli Roentgen.
mrad	millirad.
mrem	millirem.
MUX	Multiplex.
NBS	National Bureau of Standards.
ND	Nuclear Data (Corporation).
NIM	Nuclear Instrument Module.
NRC	U.S. Nuclear Regulatory Commission.
NTS	Nevada Test Site (of the DOE).
NV	Nevada Operations Office of the DOE (also NVO).

OMB	Office of Management and Budget.
OPLAN	Operations Plan. An operations plan is standard within DOD to provide specific guidance for conducting an approved major project. See CONPLAN.
ORNL	Oak Ridge National Laboratory, Oak Ridge, TN.
PACE	Pacific Cratering Experiments. Project included removal of soil down to coral rock in an area of 19 acres on the island of Sally.
PASO	Pacific Area Support Office (of DOE/NV), Honolulu, Hawaii.
pCi	Picocurie. 1×10^{-12} Curies.
pCi/g	Picocuries per gram.
PHA	Pulse Height Analyzer.
PGT	Princeton Gamma Tech, manufacturer of HPGe gamma ray detectors.
PIMM	Portable Instrument Maintenance Manual.
PLOWX	Plowing Experiment (site on Janet).
PM	Photomultiplier (tube).
PMEL	Precision Measurement Equipment Laboratory (electronics technician).
PNL	Battelle - Pacific Northwest Laboratory.
Pu	Plutonium. Specifically, the isotopes ^{238}Pu, ^{239}Pu, and ^{240}Pu. Context may imply the sum of these Pu isotopes.
QA	Quality Assurance.
QC	Quality Control.
R	Roentgen. A unit of exposure to ionizing radiation. It is that amount of gamma or X rays required to produce ions carrying 1 electrostatic unit of electrical charge in one cubic centimeter of dry air under standard conditions.
rad	Radiation absorbed dose. The basic unit of absorbed dose of ionizing radiation. One rad is equal to the absorption of 100 ergs of radiation energy per gram of matter.
RADCON	Radiation Control.
RADLAB	Radiation Laboratory. (Complex of trailers in which a radiation laboratory was established and used by DOE and ERSP contractors at EA.)
RCC	Radiation Control Committee (of the JTG).
REECO	Reynolds Electrical and Engineering Company, Inc., operating contractor for the DOE at NTS.
rem	A special unit of dose equivalent. The dose equivalent in rems is numerically equal to the absorbed dose in rads multiplied by the quality factor, the distribution factor, and any other necessary modifying factors.

ROM	Read-only memory.
RSAIT	Radiation Safety Audit and Inspection Team.
SAC	Scintillation Alpha Counter.
SATCOM	Satellite Communication.
SitRep	Situation Report.
SN	Serial Number.
SOP	Standard (or Standing) Operating Procedure.
Sr	Strontium. Specifically, the isotopes ^{85}Sr and ^{90}Sr.
TG	Task Group.
Tl	Thallium.
TRU	The transuranic elements. Specifically, ^{238}Pu, ^{239}Pu, ^{240}Pu, and ^{241}Am.
TWX	Teletype message.
TTPI	Trust Territory of the Pacific Islands.
U	Uranium. Specifically the isotopes ^{234}U, ^{235}U and ^{238}U.
UPS	Uninterruptible Power Supply.
USAF	United States Air Force.
Y	Yttrium. Specifically the isotope ^{90}Y.
μ	mu - Greek alphabet letter used to denote attenuation; also micro (10^{-6})
ρ	rho - Greek alphabet letter used to denote density.

CHRONOLOGY OF SIGNIFICANT EVENTS

DATE Y M D	EVENT	PAGE
440217	American forces invade Enewetak Atoll (EA)	2
471202	People of Enewetak moved to Ujelang Atoll.	5
480418	First nuclear test at Enewetak (X-RAY).	8
521031	First test of thermonuclear device (MIKE).	8
580818	Last (43rd) nuclear test at Enewetak (FIG).	10
710700*	AEC radiological reconnaissance of EA (supporting PACE). . .	19
720200	Interagency meeting to discuss potential cleanup of EA	**
720418	U.S. announced EA jurisdiction to return to TTPI	17
720512	Radiological reconnaissance of EA.	38
720518	First visit to EA by the people since 1947	18
720717	DNA directed to plan EA cleanup.	34
720817	First interagency meeting to plan cleanup.	34
720907	Second interagency meeting to plan cleanup	35
721012	Engineering and radiological surveys begun	36
721130	Director, DNA designated Project Manager for cleanup	35
730223	Meeting with Enewetak Council (EC) in Honolulu to discuss cleanup	
730415	Engineering survey results distributed.	36
730504	Meeting with EC in Majuro to learn people's desires	
730509	AEC established Task Group (TG) for Recommendations. . . .	39
730600	Master Plan meeting with Ujelang council in Majuro	
730625	Interagency meeting to review survey results	
731100	Enewetak Atoll Master Plan published	45
740101	Managerial Authority for EA transferred to DNA	
740201	Draft TG recommendations distributed for review	
740215	DNA presentation to AEC on cleanup philosophy	
740300	Radiological survey results distributed.	39
740306	Interagency meeting to discuss TG draft report	
740312	AEC response to DNA position	
740415	Draft EIS circulated for internal DNA, AEC review	
740419	Second draft of TG recommendation distributed	
740619	AEC TG recommendation published.	39
740820	DNA adopted TG recommendations	
740907	DEIS delivered to the people of Enewetak	46
740907	DOI promised early return to Japtan	
741207	Enewetak Council resolution requested title to Ujelang	
750103	DNA/DOI agreed on early return of people to Japtan	
750214	Conference on EA cleanup criteria	
750225	Enewetak Project policy meeting	
750300	Revised Master Plan published	
750415	Final EIS filed with Council on Environmental Quality.	46
750500	EIS accepted by EPA	
750910	DNA/ERDA interagency support agreement	50
751007	Congress authorized $20 million for EA cleanup	47
760119	Draft Radiological Cleanup Plan issued for comment	
760200	DIR DNA released EIS despite interagency questions	
760716	Congressional authorization for EA cleanup	49

*Double zero (00) in day (D) column means the day of the month is unknown, or that a span of time was involved such that a fixed day has no meaning.

**Events listed without a page number are not discussed in this report.

DATE	EVENT	PAGE
760900	Draft Cleanup Concept Plan (CONPLAN) released.	50
760916	Intergovernment agreements on rights to EA	
761117	Interagency coordination conference in Majuro	
770100*	Final CONPLAN published.	50
770204	First OPLAN conference held at KAFB..	**
770309	Second OPLAN conference held at EA	
770314	Initial mobilization for cleanup began.	51
770315	Early return of 56 people of Enewetak to EA	
770429	OPLAN 600-77 distributed	50
770429	Interagency OPLAN resolution conference	
770628	ERDA - Marshall Islands Workshop	53
770700	In situ cleanup characterization survey begun.	51
770818	Bair Committee agreed cleanup plans were reasonable.	60
770900	EPA proposed guidance for transuranic cleanup.	57
771122	EPA Transuranic guidance signed by Administrator	
780106	DNA/DOE agreement to include all transuranics in cleanup . .	57
780400	LLL draft dose assessment distributed.	63
780428	EA Advisory Group recommended more stringent criteria. . . .	63
780504	DNA issue/decision conference.	57
790916	Dome completion ceremony on Island Yvonne (Runit)	
800409	Cleanup completion ceremony with Enewetak people	

*Double zero (00) in day (D) column means the day of the month is unknown, or that a span of time was involved such that a fixed day has no meaning.

**Events listed without a page number are not discussed in this report.

CHAPTER ONE: BACKGROUND

by Bert Friesen
Holmes & Narver, Inc.

1.1 INTRODUCTION

> "The light - it was many times brighter than the sun. The mountains back of us showed as clear as in daylight. We were stationed ten miles away from the explosion. At the five-mile station, two men were knocked over by the blast. The immense ball of flame rapidly going up into the sky was followed by a cloud of dark dust. The hundred-foot steel tower on which the bomb was placed was completely evaporated. The surface sand around it for a thousand feet was melted into glass." (Compton, 1956.)

Thus was the birth of the Atomic Age witnessed in secrecy on 16 July 1945, with the first test of a nuclear bomb, code named Trinity, at Alamogordo, New Mexico. Three weeks later, on 6 August 1945 (local time), the second nuclear bomb was detonated over Hiroshima, Japan, followed by the third bomb over Nagasaki, Japan, on 9 August 1945 (local time). The successful detonation in combat of these powerfully destructive weapons brought a quick end to World War II. The devices had worked as planned but very little was known of either the immediate or the long-range aftereffects.

Although the war had ended and no further military use was anticipated in connection with WW II, military officials were anxious to learn much more about the newest weapon in their arsenal. Theoreticians could predict enough of the effects from a nuclear explosion to realize that additional testing would have to be conducted in an area far from any population centers to minimize the dangers of exposure to hazardous radiation. The fourth nuclear device, Test Able, was detonated about 500 feet above a fleet of surplus naval craft at anchor in Bikini lagoon on 30 June 1946. Test Baker followed on 24 July 1946. The Baker device was suspended beneath a small landing craft, LSM 60, with the burst point at 90 feet below water surface.

> "The air burst (of Test Able), despite the damage it had inflicted, scarcely had prepared observers for the wrath of sound, light, and volcanic shock that erupted within the lagoon. At the moment of explosion, a giant bubble, brilliantly lighted within by incandescent materials, burst from the surface of the water to be followed by an 'opaque cloud' which quickly covered about half of the ships of the target fleet. Within seconds, the cloud had vanished and a hollow column, 2,200 feet in diameter and containing some 10 million tons of water, rose from the surface of the lagoon to a height of more than a mile. The 26,000-ton battleship, Arkansas, broadside to the LSM 60 but more than 500 feet away, was lifted and upended in the column before she was plunged to the bottom. At the base of the column was a tumult of foam several hundred feet high, and the descent of the water back into the lagoon set up a base surge from which rolled waves eighty to one-hundred feet high. The waves subsided rapidly as they proceeded outward, and the highest wave recorded at Bikini Island, three miles away, was seven feet, not sufficiently high to pass over the island or to cause damage there." (Hines, 1962.)

The brief chronology and quotations presented above set the stage for the rest of this document. Enewetak Atoll became a critical component of the very large and complex program of nuclear testing conducted by the United States from 1946 to 1958. Detonation of 43 nuclear devices at Enewetak Atoll created radiological conditions deemed too hazardous for unrestricted use of the atoll by future residents. The U.S. Department of Energy (DOE), acting in advisory and support roles to the Defense Nuclear Agency (DNA), participated in the radiological cleanup of Enewetak Atoll, undertaken to prepare the islands for their return to the people of Enewetak. Most of this report is devoted to a detailed description of the conduct by the DOE and its contractors of what became known as the Enewetak Radiological Support Project.

Readers are directed to other sources for additional background on nuclear testing in the Pacific or details on related topics. Hines presents an interesting account of the problems and successes of conducting radiobiological studies in the Pacific Proving Ground concurrent with nuclear testing. Compton and Groueff provide excellent views of how the atomic age was conceived and carried full-term to Alamogordo and Japan. The problems of dislocation experienced by the people of Bikini

and Enewetak are well presented by Kiste, Tobin, and others. Various agencies of the U.S. Government and government contractors such as the University of Washington Applied Fisheries Laboratory and the Lawrence Livermore Laboratory have, over the years, documented the radiological condition at Bikini and Enewetak as conditions changed with time. The most extensive survey conducted prior to cleanup is reported in detail by the USAEC in Enewetak Radiological Survey. (NVO-140.) Findings of this survey were used to guide the fine grid survey of many of the islands at Enewetak during the cleanup phase.

But what made cleanup necessary? (The naive wording of this question is deliberate.) The paramount necessity arises from the fact that the owners of Enewetak Atoll were moved to another atoll as an accommodation to the United States Government so that Enewetak could be used for testing of nuclear bombs. The people of Enewetak wanted to return to their homeland and the United States had agreed to rehabilitate the atoll prior to their return. But the foregoing does not answer the question of cleanup necessity. If there were no aftereffects from a nuclear explosion, no cleanup of Enewetak would be necessary beyond removal of abandoned facilities and equipment. There are aftereffects. Read again the two quotations presented earlier. The immense ball of flame, cloud of dark dust, evaporated steel tower, melted sand for a thousand feet, 10 million tons of water rising out of the lagoon, waves subsiding from a height of eighty feet to seven feet in three miles were all repeated, in various degrees, 43 times on Enewetak Atoll. In the northern islands of the atoll, where most of the testing took place, the land surface was covered by falling radioactive dust or water, or inundated by waves of possibly radioactive water, or seared by a fireball of intense heat. Furthermore, some of the tests at Enewetak were many times more powerful than either of the detonations described above. The largest detonation at Enewetak was the thermo-nuclear device of Test Mike, rated at over 10 million tons of TNT—about 450 times as powerful as Test Baker.

As a consequence of the nuclear testing, the northern islands of Enewetak Atoll contain radioactive contamination on or near the land surface and at some depth on islands used as the site for one or more tests. The term "cleanup" encompasses those activities which were conducted to determine the location and degree of contamination on each island, to remove radiologically clean and contaminated debris from all islands, to remove contaminated surface and subsurface soil from wherever either was above certain guidelines, and to document the radiological condition of each island prior to the planned resettlement by the people of Enewetak.

Eniwetok* at the End of WW II. Eniwetok Atoll was considered an important target for invasion and occupation as part of the overall plan to drive the Japanese out of the scattered Pacific islands. The American invasion of the Marshalls, which had been mandated to Japan by the League of Nations in 1919, was scheduled for the end of January 1944, starting with Kwajalein then progressing to Eniwetok, which would be a natural staging area for air attacks on Truk and other islands of the Carolines. On 29 January 1944, carrier planes began the preinvasion air assault and attacked Kwajalein and Roi-Namur Islands in Kwajalein Atoll, Maloelap, Eniwetok, and Wotje. So thorough was the bombing that by the end of the day not one enemy plane east of Eniwetok remained operational. (Richard, 1957.)

Eniwetok had an airfield** well defended with guns and search radar and an excellent lagoon, two factors which would make it a valuable staging point for future attacks on the Carolines. The garrison was small because the Japanese never thought that they would have to defend it.

Carrier planes began bombing Eniwetok on 31 January and continued every day through 7 February, and again on the 11th and 13th. On D-Day, 17 February, American combatant ships appeared off the Atoll and concentrated their fire on Engebi Island, the main objective, pouring 2,800 tons of

*This was the name by which the atoll was officially known until early 1973 when the Enewetak people themselves made known that the name is made up of two Marshallese words: ene (island) and wetak (toward, or pointing toward the East). Spelling changes of many other names are described in Section 1.3. Until the end of Section 1.3, the atoll name is spelled in accordance with official usage during the period of time being discussed.
**The airfield was on Engebi (Janet) Island of Enewetak Atoll, not on Enewetak Island.

projectiles into this tiny area; by late the next day, the island was secured. On 19 February, Eniwetok Island was invaded and, after unexpected opposition, secured on 21 February. The Eniwetok expedition cost 195 Americans killed or missing and 521 wounded. The Japanese garrison had 2,677 killed and 64 taken prisoner. The people of Eniwetok suffered at least 18 killed. (Richard, 1957, V.I, pp. 125, 342.)

A Naval Construction Battalion arrived at Eniwetok Atoll immediately after D-Day and set about developing it into a Navy and Marine Corps air base and fleet anchorage. On Eniwetok Island the Seabees built an airstrip 6,800 feet long and 400 feet wide, two taxiways, facilities for major engine overhaul, housing, piers, and storage facilities. The first plane landed on the field on 11 March, and after 15 April, permanently based bomber squadrons flew missions from there. A seaplane base capable of supporting one squadron of patrol bombers, a marine railway, and a boat repair shop were built on Parry Island. At Engebi aviation facilities, including a fighter strip 3,950 feet by 225 feet, and a pier were constructed. U.S. Naval Base Eniwetok, built at a cost of over $23 million, was commissioned on 10 May 1944.

On 18 February 1944, a Marine Corps civil affairs officer and one enlisted man landed on Engebi Island with the headquarters unit of the invading task group. The thirty inhabitants had all moved to unoccupied islands along the eastern fringe of the atoll and were hungry and in need of medical attention. The people were gathered into a temporary camp on Engebi and given food and medical supplies. On 19 February a landing was made on Eniwetok Island where 50 Marshallese were found and given shelter. Food was sent ashore and its distribution assigned to the two chiefs, Johannes of Eniwetok and Abraham of Engebi. A bomb crater was enlarged by the engineers and a tarpaulin erected over it to provide shelter from the sun. The people were given blankets, clothing, rice, and cooking utensils. As other Marshallese were found, they were brought to the shelter. On 23 February a landing was made on Parry Island where 17 Marshallese were found and moved to Eniwetok Island. The Marshallese at Eniwetok spent that day collecting and salvaging Japanese food, clothing, soap, and dishes which they divided among themselves.

The Marshallese at Eniwetok camp were moved to Aomon on 24 February. The chief and his people had selected the site, a former village island, where a few houses and some trees were still standing. The next day the Marshallese on Enjebi were transferred to Aomon and eventually 117 people were gathered in the camp.

The camp on Aomon continued as the residence site for the people of Eniwetok until late in 1947, except for a short period in 1946 when they were temporarily relocated to Meik Island of Kwajalein Atoll during conduct of Operation Crossroads at Bikini. Upon return from Meik Island, the contingent from Engebi moved to a new camp on Bijire at their own request, as this island was owned by the people of Engebi whereas Aomon was owned by the people of Eniwetok.

1.2 SELECTION AND EVACUATION OF ENEWETAK ATOLL FOR NUCLEAR TESTING

Plans for atomic tests under controlled conditions were being discussed by military and political leaders in the weeks following the end of World War II. Detailed plans for testing were developed by the Joint Staff and approved by President Truman on 10 January 1946. The first tests were known as Operation Crossroads at Bikini Atoll in the Marshall Islands. Planning and conduct of the atomic tests of 1946 was a joint military enterprise relying heavily on support of the scientific community. Testing was conducted under the control of the newly created Joint Task Force One.

The search for a site for the test operation had been started even before the task force was created. The specifications set out by the planners called for selection of a site within the control of the United States, uninhabited or subject to evacuation without imposing unnecessary hardship on large numbers of inhabitants, within 1,000 miles of the nearest B-29 aircraft base (in expectation that one atomic device would be delivered by air), free from storms and extreme cold, and offering a protected anchorage at least six miles in diameter and thus large enough to accommodate both the large fleet of target vessels and the additional vessels that would have to be used in support of the operation. Also required were distance from cities or concentrations of population, winds predictably uniform from sea level to 60,000 feet, and predictable water currents not adjacent to inhabited shore lines, shipping lanes, or fishing areas--all in recognition of the need to reduce or eliminate the possibility of radioactive contamination of the fleets or inhabited areas.

Sites in the Atlantic, the Caribbean, and the Pacific were reviewed. In the Pacific were little islands set in great reaches of otherwise empty ocean and enjoying the warm and stable climate of the trade-wind zone. In the Marshalls, so recently captured from the Japanese, were coral atolls that had been little disturbed by the war, that were inhabited only by small communities of Micronesians, and over which an interim control was exercised by the United States through the Navy Military Government. Among these was Bikini Atoll. Bikini fulfilled all the conditions of climate and isolation. It was distant, 2,500 miles west-southwest of Honolulu, 4,500 miles by air from San Francisco, but it also was accessible to the military support facilities that still existed at Kwajalein Atoll, to the southeast, and at Eniwetok, to the west. Its inhabitants, who then numbered 162, could be moved to another atoll during the period of the tests.

Joint Task Force One went out of existence on 1 November 1946 following detonation of Tests Able and Baker at Bikini and subsequent reduction of the site to an interim status. The Atomic Energy Act of 1946 created the U.S. Atomic Energy Commission which took over the responsibilities of the Manhattan District of the U.S. Army Corps of Engineers on 1 January 1947. The Commission was to conduct a program of atomic energy development, including improvement of nuclear weapons and, of necessity, a program of proof testing in the field. In July, 1947, the commission announced that it was establishing proving grounds in the Pacific for routine experiments and tests of atomic weapons. The place selected was not Bikini, but Eniwetok Atoll. (Hines, 1962, p. 78.)

The process of selection of Eniwetok included a review of possibilities that had been examined prior to the earlier selection of Bikini. A location within the continental United States was initially considered with a view toward finding a site suitable for a permanent establishment. A return to Bikini apparently was not contemplated at any time, not only because Bikini was in an interim status and scheduled for further observation, but because the land areas were neither large enough nor properly oriented to the prevailing winds to permit construction of a major airstrip.

Sites in the Indian Ocean and in Alaska were studied, and some thought was given to Kwajalein. The review of all practical sites concluded that Eniwetok offered all of the advantages found earlier at Bikini plus the presence of established airstrips and facilities. Westward, in the direction in which the prevailing winds might carry radioactive particles, lay hundreds of miles of open sea. The tentative selection of Eniwetok was followed by an inspection of the atoll and conferences with the leaders of the people of Eniwetok. The site was approved by President Truman on 2 December 1947. On the same day, the United States representatives to the United Nations notified the Security Council that effective 1 December 1947, pursuant to the provisions of the Trusteeship Agreement, Eniwetok Atoll was closed for security reasons in order that necessary experiments relating to nuclear fission could be conducted there. The people of the atoll were to be moved to a new home, and the press release by the Atomic Energy Commission noted:

> "Eniwetok Atoll was selected as the site for the proving grounds after the careful consideration of all available Pacific Islands. Bikini is not suitable as the site since it lacks sufficient land surface for the instrumentation necessary to the scientific observations which must be made. Of other possible sites, Eniwetok has the fewest inhabitants to be cared for, approximately 145, and, what is very important from a radiological standpoint, it is isolated and there are hundreds of miles of open seas in the direction in which winds might carry radioactive particles."
>
> "The permanent transfer elsewhere of the Island people now living on Aomon and Bijiri Islands in Eniwetok Atoll will be necessary. They are not now living in their original ancestral homes but in temporary structures provided for them on the two foregoing islands to which they were moved by United States forces during the war in the Pacific, after they had scattered throughout the Atoll to avoid being pressed into labor service by the Japanese and for protection against military operations. The sites for the new homes of the local inhabitants will be selected by them. The inhabitants concerned will be reimbursed for lands utilized and will be given every assistance and care in their move to, and re-establishment at, their new location. Measures will be taken to insure that none of the inhabitants of the area are subject to danger; also that those few inhabitants who will move will undergo the minimum of inconvenience." (Richard, 1957, V. III, p. 553.)

The scheduling of the first Eniwetok nuclear test in the near future necessitated the immediate removal of the people. On 3 December the Governor of the Marshalls flew to Eniwetok and proposed to the chiefs that they move to Ujelang Atoll, which was then being prepared as a relocation site for the Bikini people. The two Eniwetok chiefs, Johannes and Abraham, were flown to Ujelang on 4 December and later returned to Eniwetok after selecting sites for dwellings and community buildings. Temporary living quarters were ready for the people of Eniwetok when they went ashore from an LST on 21 December 1947. Permanent facilities on Ujelang were constructed in the spring of 1948 by 35 enlisted men and 15 Marshallese.

On 28 May 1948, the Governor of the Marshalls reported to the High Commissioner of the Trust Territory of the Pacific Islands that resettlement of the Eniwetok people was completed. The three nuclear tests of the Sandstone series were completed by 14 May 1948 and no additional tests were conducted at Eniwetok until 1951.

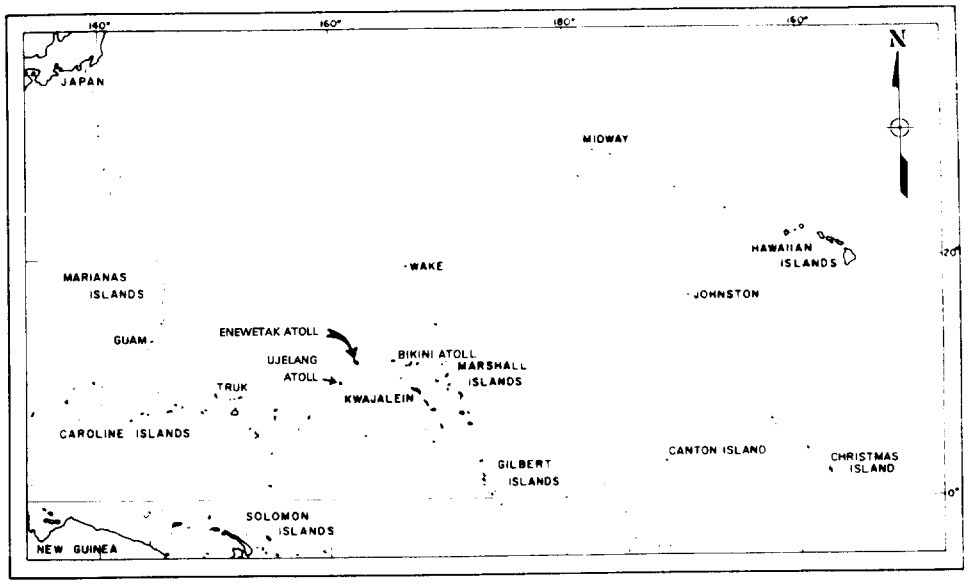
The people of Enewetak have continued their temporary residence on Ujelang since December 1947. Living conditions on Ujelang during this period, and other anthropological considerations, have been reported by Tobin, Mason, and others. The viewpoint of the people as expressed by their leaders before House and Senate subcommittees is available in the Congressional Record (incorporated in testimony before the House Appropriations Military Construction Subcommittee on 23 June 1975).

1.3 ISLANDS IN THE ATOLL

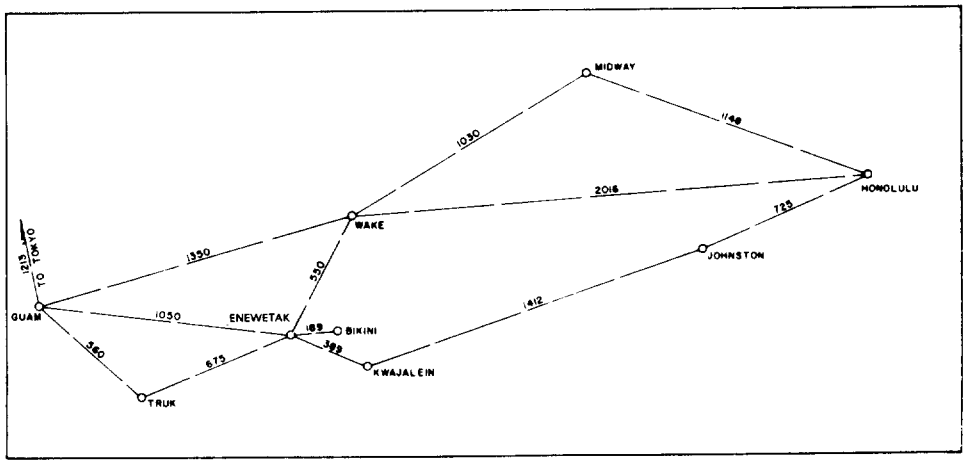
Eniwetok Atoll is located at approximately 11°21'N and 162°21'E in the northwestern portion of the Marshall Islands, 2,740 miles west-southwest of Honolulu and 1,200 miles east of Guam (see Figure 1-1). The atoll has about 388 square miles of lagoon and about 2.75 square miles of dry land. The land area consists of 46 islands irregularly spread around the lagoon perimeter. Rainfall in the vicinity of Eniwetok averages about 60 inches annually, somewhat less than at locations nearer the equator. The soils are basically coral rock and coralline sands with minimal organic content and limited water holding capacity. The Pacific trade winds, generally from ENE to E, average 18 mph during the period December to April, and 12 mph from May through November. The area is subject to infrequent destructive typhoons, and occasional westerly storms are experienced. The marginal rainfall, marginal water-holding capacity of the soil, and the nearly constant windborne salt spray, especially on the windward side of the islands, are not conducive to growth of lush tropical environments usually associated with the islands of the Pacific.

The geologic evolution of a coral atoll is a dynamic process with changes in island shape and size evident even in a short period of time. The direction, duration, and intensity of each passing storm have an influence on the size and location of sand bars, on erosion of exposed points of land, and on deposition along protected stretches of beach. Maps of Eniwetok made about 1960 show a named sandbar on the western reef. The sandbar that was on the western reef is no longer there, but one new islet has formed in the past few years. Recent documents pertaining to the atoll variously indicate 39, 40, 42, or 43 islets or islands. This report will discuss 46 islands and islets, and 2 named coral heads as shown in Figure 1-2.

Names by which the islands of Eniwetok Atoll--and the atoll itself--are known seem also to be undergoing dynamic change. As presented by Hines, the coral reefs were first given a documented European name in 1794 by Captain Thomas Butler who was engaged in the China trade. Butler called the reefs Browne's Range, a Mr. Browne being the factor of his firm at Canton. For many years Browne's name clung persistently to Eniwetok even after the final "e" was lost. In World War II, the Japanese frequently referred to Eniwetok as Brown and, on recent U.S. hydrographic charts, Eniwetok is identified as "Eniwetok or Brown Atoll." Table 1-1 presents the island names as they appeared on charts of 1946 and 1968, as listed by Bryan and as determined by Tobin in 1973. Table 1-2 lists a few additional names that have appeared in various documents since 1946. The exact source of the flower and shrub names listed by Bryan has not been located; however, some of these names appear in military histories of the capture of Eniwetok in World War II, so the flower names may have been assigned during invasion planning.



REGIONAL MAP



AIRLINE DISTANCES MAP

NO SCALE

FIGURE 1-1. ENEWETAK ATOLL LOCATION MAPS

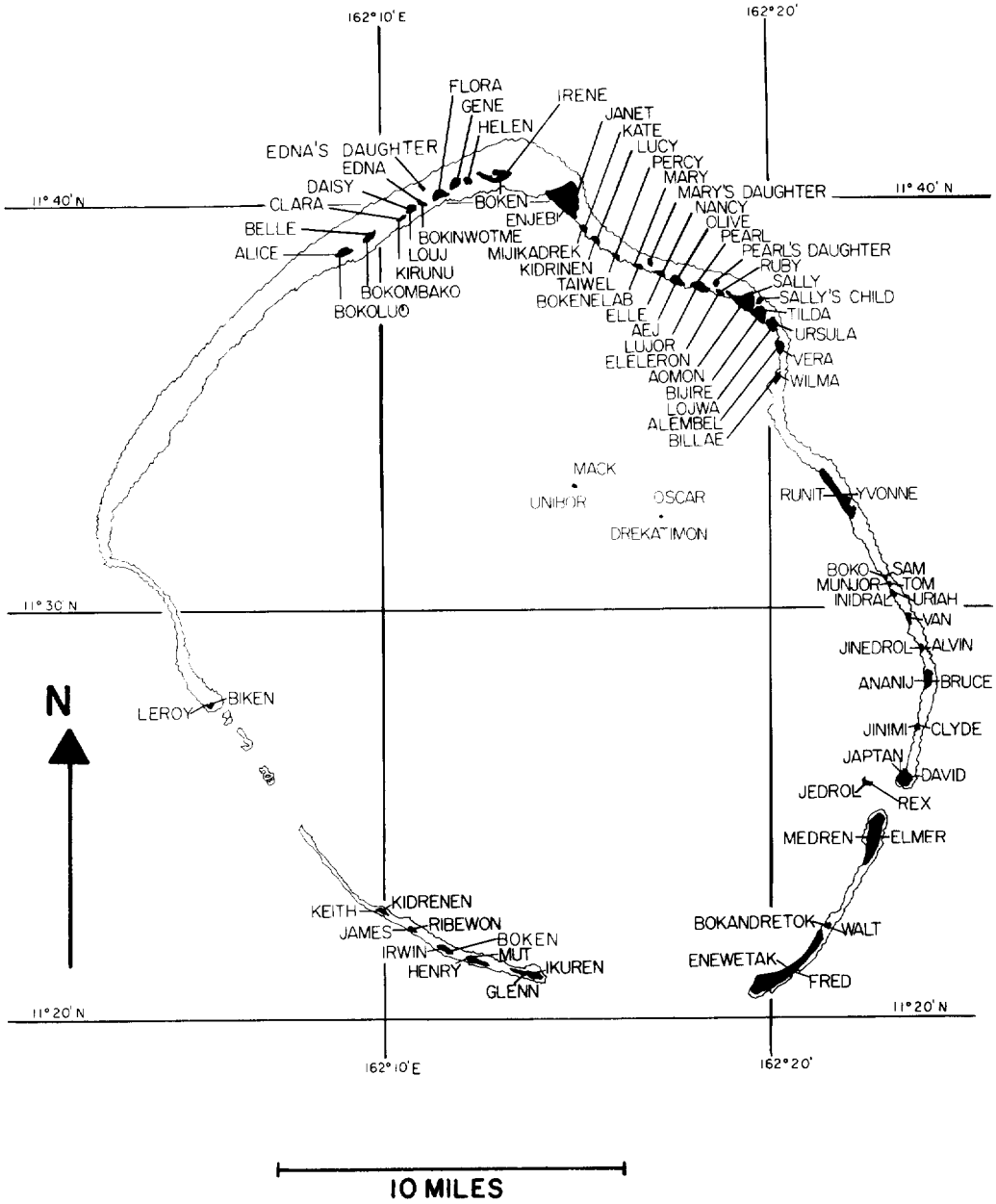


FIGURE 1-2. ISLANDS OF ENEWETAK ATOLL WITH MARSHALLESE NAMES SHOWN ON THE LAGOON SIDE AND ENGLISH CODE NAMES ON THE OCEAN SIDE

TABLE 1-1. COMPARISON OF SITE AND NATIVE NAMES

Site	Native Names From U.S. Hydrographic Office 1946	1968	From Bryan 1971	From Tobin, 1973 Native names [a]
ALICE	Bogallua	Bogallua	Peony	BOKOLUO
BELLE	Bogombogo	Bogombogo	Petunia	BOKOMBAKO
CLARA	Ruchi	Eybbiyae	Poinsettia	KIRUNU
DAISY	b	Lidilbut	Primrose	LOUJ
EDNA*	b	b	Rambler	BOCINWOTME[c]
EDNA'S DAUGHTER	b	b	b	b
FLORA*	Elugelab	b	Sagebrush	b
GENE*	Teiteiripucchi	b	Sunflower	b
HELEN*	Bogairikk	Bogeirik	Violet	BOKAIDRIK
IRENE	Bogon	Bogon	Zinnia	BOKEN
JANET	Engebi	Engebi	Fragile	ENJEBI
KATE	Muzinbaarikku	Mujinkarikku	Arbutus	MIJIKADREK
LUCY	Kirinian	Billee	Aster Blossom	KIDRINEN
PERCY	b	b	b	TAIWEL
MARY	Bokonaarappu	Bokonarppu	Bitterroot	BOKENELAB
MARY'S DAUGHTER	b	b	Bluebonnet	b
NANCY	Yeiri	Yeiri	Buttercup	ELLE
OLIVE	Aitsu	Aitsu	Camellia	AEJ
PEARL	Rujoru	Rujiyoru	Canna	LUJOR
PEARL'S DAUGHTER	b	b	Carnation	b
RUBY*	Eberiru	Eberiru	Columbine	ELELERON
SALLY	Aomon	Aomon	Clover	AOMON
SALLY'S CHILD	b	b	Dandelion	b
TILDA	Biijiri	Biijire	Daisy	BIJILE[c]
URSULA	Rojoa	Rojoa	Delphinium	LOJWA
VERA	Aaraanbiru	Arambiru	Gardenia	ALEMBEL
WILMA	Piiraai	Piirai	Goldenrod	BILLAE
YVONNE	Runit	Runit	Hawthorn	RUNIT
SAM	b	b	b	BOKO
TOM	b	b	b	MUNJOR
URIAH	b	b	b	INEDRAL
VAN	b	b	b	b
ALVIN	Chinieero	b	b	JINEDROL
BRUCE	Aniyaanii	Japtan	Jasmine	ANANIJ
CLYDE	Chinimi	Chinimi	Lavender	JINIMI
DAVID	Japtan	Muti	Ladyslipper	JAPTAN
REX	Jieroru	Bogen	Lilac	JEDROL
ELMER	Parry	Parry	Heartstrings	MEDREN
WALT	b	b	b	BOKANDRETOK
FRED	Eniwetok	Eniwetok	Privilege	ENEWETAK
GLENN	Igurin	Igurin	Lantana	IKUREN
HENRY	Mui	Buganegan	Mimosa	MUT
IRWIN	Pokon	Bogan	Mistletoe	BOKEN
JAMES	Ribaion	Libiron	Oleander	RIBEWON
KEITH	Giriinien	Grinem	Oca	KIDRENEN
LEROY	Rigili	Rigile	Posy	BIKEN
OSCAR (coral head)	b	b	b	DREKATIMON
MACK (coral head)	b	b	b	UNIBOR

[a]As confirmed by the Enewetak people during the Ujelang field trip of July 1973.
[b]No name reported.
[c]BOKINWOTME and BIJIRE are preferred according to current literature and are so spelled in this report.
*Original island destroyed by nuclear tests except for small portions of EDNA, HELEN, and RUBY.

TABLE 1-2. ADDITIONAL NATIVE NAMES FROM THE LITERATURE

	HINES, 1962	TOBIN, 1967[a]	PACIFIC ISLANDS YEAR BOOK, 1972	NVO-140, 1973, p. 492	OTHERS
DAISY				Cochiti	
EDNA				Sanildefonso	
FLORA		Eluklab			
GENE		Dredrelbwij			
JANET					Arthur I.[b]
KATE	Muzin			Muzinbaaiku	
SALLY					Aoman[c], Aranit
VERA				Aaranbiru	
YVONNE			Ruunitto		
BRUCE				Aniyaani	
REX			Jeroru		
FRED	Browne				Brown
KEITH				Giriinian	

[a]Doctoral Dissertation
[b]Bryan, 1971
[c]Applied Fisheries Laboratory, University of Washington

During the period 1963-73, new orthographies were developed by the Pacific and Asian Language Institute at the University of Hawaii. American linguists were sent to each district to work with a committee of local people to develop acceptable letter forms for each sound. Anomalies of pronunciation are generally solved in the orthographies by adding extra letters and syllables. For example, an old text was entitled "Pilung Nu Maday" using the system developed by early missionaries; in the new system it was "PIILUUNG NUU MADAAY." Island leaders did not like the new orthographies which made everything look strange and unusual, so they agreed to drop the double vowels ii, ee, ea, ae, uu, oo, oe, and aa. (Nevin, 1977.)

It is difficult to trace the exact effect of the developing orthographies on the spelling of island names at Enewetak because of other influences. Pronunciation and spelling of place names were affected first by the hard sounds of the German language, then by the r/l differences of the Japanese language. Removing the effects of outside influences to arrive at the pronunciation and spelling preferred by the people of Enewetak produces some drastic changes as shown in Table 1-1. These changes have become generally accepted since distribution of NVO-140 in 1974.

The site names listed in Table 1-1 were assigned during the atomic testing period, except for the "daughter" islets which were named during the 1972-73 survey or 1977-80 cleanup. Assigned names start with Alice, at about 11 o'clock on the roughly circular atoll, and proceed through the alphabet going clockwise. Letters not used in the female names include Q, X, and Z.* Island Percy, located between islands Lucy and Mary, must have been given a site name later than the other northern islands. Principal sites in the southern portion were assigned male names from Alvin through Oscar, then Rex through Walt. However, these sites were not named in a straightforward, clockwise order. Throughout this report, islands and islets will be referenced by English site name only. Three exceptions to this rule are noted: Enewetak will be called Enewetak, not Fred; the Aomon Crypt will be called the Aomon Crypt, not the Sally Crypt; and, in Chapter 7, the first reference to each island name will include the native name in parentheses spelled according to Tobin, 1973. From this point forward, the spelling of the atoll name will be Enewetak unless the name appears in a quotation, in which case the source spelling will be followed.

*The letter Z was assigned to Zona, a small islet southeast of Yvonne, which is no longer there.

1.4 THE TESTING PERIOD

1.4.1 Nuclear Tests

After World War II, field testing of nuclear devices first occurred at Bikini Atoll during Operation Crossroads in 1946. Tests Able and Baker were conducted there in June and July of that year. In July 1947, the Atomic Energy Commission announced that it was "establishing proving grounds in the Pacific for routine experiments and tests of atomic weapons." Operation Sandstone was conducted during April and May 1948, at Enewetak Atoll. This series of tests consisted of three devices detonated atop 200-foot steel towers, one each on islands Janet, Sally, and Yvonne. Figure 1-3 shows where each of the 43 tests was conducted during the entire test period from 1948 through 1958. Table 1-3 summarizes relevant data on all tests conducted at Enewetak.

The next series of tests was conducted in Operation Greenhouse during April and May 1951, when four more devices were placed on steel towers and detonated. Island Janet was selected for two of the tests, while Ruby and Yvonne were each sites for one test. Tests Mike and King were conducted during Operation Ivy in the fall of 1952. Mike was the first thermonuclear device tested by the United States. Island Flora (Elugelab) was selected for the test; a crater in the reef about one mile across and 180 feet deep now marks the spot where Flora used to be.

Operation Castle involved only Test Nectar at Enewetak in May of 1954, but five other large-yield tests were conducted at Bikini, including Test Bravo, rated at 15 million tons of TNT and the most powerful device detonated by the United States to that time. In terms of the number of tests conducted, the pace of activity was significantly increased two years later during Operation Redwing when 11 devices were detonated at Enewetak and 6 more at Bikini. Redwing was the last series to utilize a steel tower for device placement. Towers were constructed on four islands with two on Sally, two on Yvonne, and one each on Ruby and Pearl. Surface tests were conducted on Yvonne, where the Lacrosse Crater now is, and on Irene where the Seminole Crater was produced.

Testing of nuclear weapons and other devices by the United States, Russia, and Great Britain had, by 1956, produced worldwide fear of the hazard created by radioactive fallout. Following U.S. participation in discussions with the other nuclear powers in Geneva, Switzerland, President Eisenhower announced in August 1958, that the U.S. would negotiate with any other country suspension of nuclear weapon tests. The offer was accepted by the USSR and a moratorium on testing was set at 31 October 1958. The United States had anticipated the possibility of a halt to testing, so had assembled a large array of devices to be tested before the start of the moratorium. Operation Hardtack, Phase I, conducted in the Pacific from April through August 1958, included 22 tests at Enewetak, 10 at Bikini, 2 in the Johnston Atoll area, and one at 86,000 ft. over the sea between Enewetak and Bikini. In addition, three tests were conducted in the South Atlantic during August and September in Operation Argus. Operation Hardtack, Phase II, took place at the Nevada Test Site in September and October 1958, with the detonation of 18 nuclear devices. By the time the test moratorium became effective, the U.S. had conducted 43 tests at Enewetak, 22 of them in 1958.

The Enewetak tests of 1958 included 16 devices detonated on barges, 7 in the lagoon southwest of Janet, 8 in the lagoon west or southwest of Yvonne, and 1 on the reef southwest of Alice. Two underwater tests were conducted to the southwest of Enewetak Island, one in the lagoon north of Glenn, and one in the ocean south of James. Surface tests included Cactus, which formed the Cactus Crater on the north end of Yvonne; Koa, which formed a very large crater where Gene used to be; and Quince and Fig in the north central part of Yvonne. The Quince and Fig tests were responsible for spreading unburned plutonium fuel over a large area of Yvonne. No additional tests were conducted at Enewetak or Bikini.

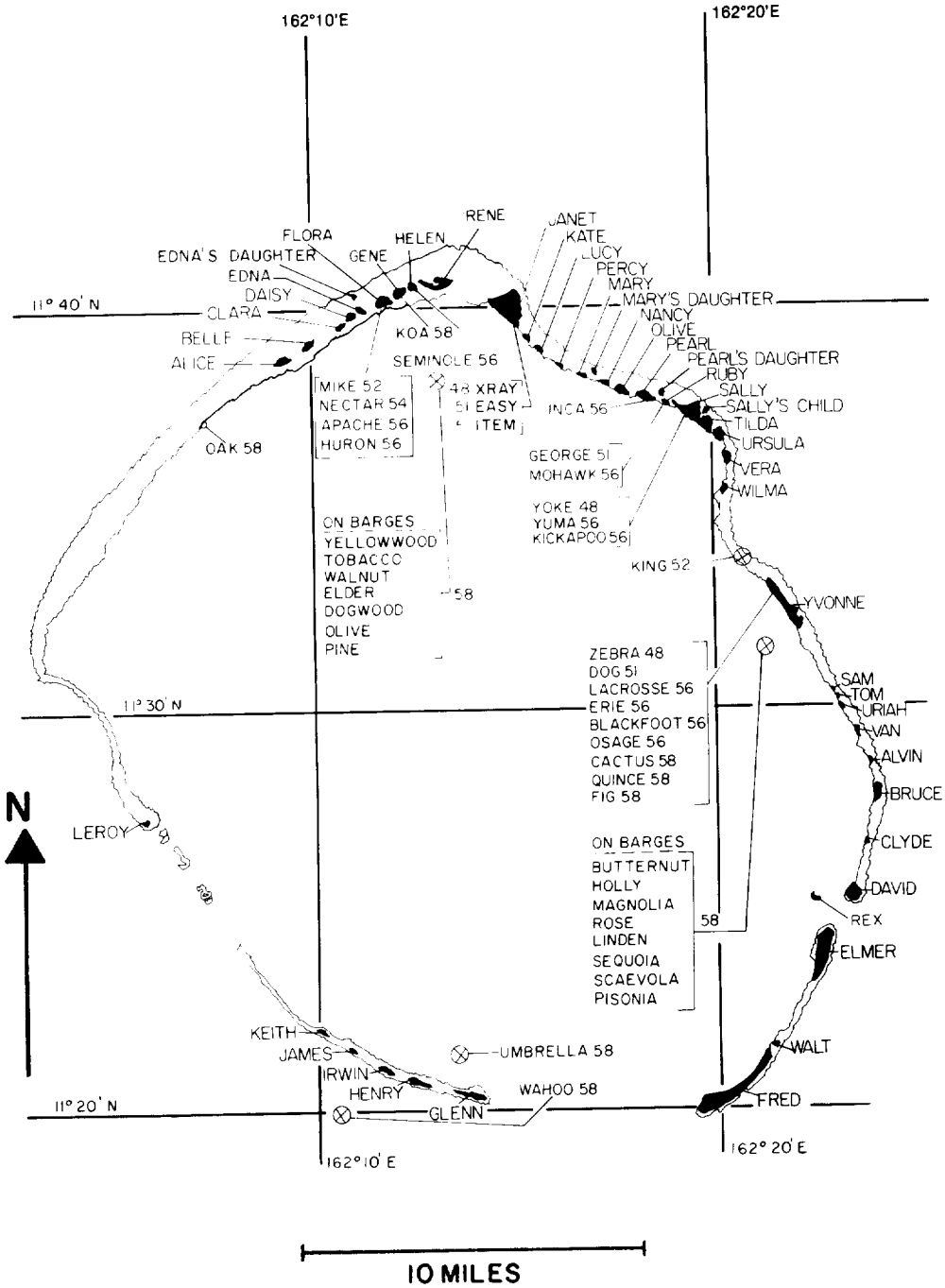


FIGURE 1-3. ENEWETAK ATOLL NUCLEAR TESTS WITH NAME, YEAR OF DETONATION AND APPROXIMATE LOCATIONS INDICATED IN THE LAGOON. Flora and Gene no longer exist, and only small portions of Edna, Helen and Ruby remain.

TABLE 1-3. NUCLEAR TESTS AT ENEWETAK ATOLL

Operation Event Name	Date	Type & Height, ft	Yield	Location
SANDSTONE				
X-RAY	4/14/48	Tower 200	37 KT	Janet, west tip
YOKE	4/30/48	Tower 200	49 KT	Sally
ZEBRA	5/14/48	Tower 200	18 KT	Yvonne, north end
GREENHOUSE				
DOG	4/7/51	Tower 300	-	Yvonne, north end
EASY	4/20/51	Tower 300	47 KT	Janet, west tip
GEORGE	5/8/51	Tower 200	-	Ruby
ITEM	5/24/51	Tower 200	-	Janet, north tip
IVY				
MIKE	10/31/52	Surface	10.4 MT	Flora
KING	11/15/52	Airdrop 1500	500 KT	Yvonne, 2000' N
CASTLE				
NECTAR	5/13/54	Barge	1.69 MT	Mike Crater
REDWING				
LACROSSE	5/4/56	Surface	40 KT	Yvonne, north end
YUMA	5/27/56	Tower 200	-	Sally, west tip
ERIE	5/30/56	Tower 300	-	Yvonne, by airstrip
SEMINOLE	6/6/56	Surface	13.7 KT	Irene
BLACKFOOT	6/11/56	Tower 200	-	Yvonne, middle
KICKAPOO	6/13/56	Tower 300	-	Sally, north tip
OSAGE	6/16/56	Airdrop 670	-	Yvonne, middle
INCA	6/21/56	Tower 200	-	Pearl
MOHAWK	7/2/56	Tower 300	-	Ruby
APACHE	7/8/56	Barge	-	Mike Crater
HURON	7/21/56	Barge	-	Mike Crater
HARDTACK, PHASE I				
CACTUS	5/5/58	Surface	18 KT	Yvonne, north end
BUTTERNUT	5/11/58	Barge	-	Yvonne, 4000' SW
KOA	5/12/58	Surface	1.37 MT	Gene
WAHOO	5/16/58	Underwater 500	-	James, 7400' S
HOLLY	5/20/58	Barge	-	Yvonne, 2075' SW
YELLOWWOOD	5/26/58	Barge	-	Janet, 6000' SW
MAGNOLIA	5/26/58	Barge	-	Yvonne, 3000' SW
TOBACCO	5/30/58	Barge	-	Janet, 4000' SW
ROSE	6/2/58	Barge	-	Yvonne, 4000' SW
UMBRELLA	6/8/58	Underwater 150	-	Glenn, 7400' N
WALNUT	6/14/58	Barge	-	Janet, 6000' SW
LINDEN	6/18/58	Barge	-	Yvonne, 2000' SW
ELDER	6/27/58	Barge	-	Janet, 4000' SW
OAK	6/28/58	Barge	8.9 MT	Alice reef, 3 mi. SW
SEQUOIA	7/1/58	Barge	-	Yvonne, 2000' SW
DOGWOOD	7/5/58	Barge	-	Janet, 4000' SW
SCAEVOLA	7/14/58	Barge	-	Yvonne, 561' SW
PISONIA	7/17/58	Barge	-	Yvonne, 12000' W
OLIVE	7/22/58	Barge	-	Janet, 4000' SW
PINE	7/26/58	Barge	-	Janet, 8500' SW
QUINCE	8/6/58	Surface	-	Yvonne, middle
FIG	8/18/58	Surface	-	Yvonne, middle

1.4.2 Testing Effects on the Islands

Test program effects of concern to this report are primarily those which led to the radiological condition that existed when the cleanup project began. In a broad sense, this must include: (1) construction activities carried on in preparation for a test; (2) the test and its direct effects; (3) post-test actions taken to reduce exposure hazard to workers entering the area, to recover specimens used in the experiment or to modify the area so collection of information by uncleared persons or persons with no need to know would be more difficult; and (4) post-test actions taken to place the proving ground in a caretaker status until the next series of tests. Many of the documents describing tests and immediate post-test actions remain classified; however, a useful picture can be constructed from unclassified sources.

Test Preparations. Pre-test construction for the first test on each island is not of as much concern as for the second and succeeding tests on the same island because first construction on an island did not mix radionuclides downward into the soil. Test Easy on the west tip of Janet had virtually the same ground zero (GZ) as did Test X-ray three years earlier. Site preparation for Easy included regrading and paving the area, placement of new tower pads, placement of new anchor blocks for the tower cables, and laying of new signal cables used to arm, fire, and monitor the device. Photographs of the area taken from the top and the base of the tower, viewing east by southeast, show two long mounds of earth each about five feet high extending from the tower base to distant bunkers. Burial of coaxial cables was typically performed by digging a trench to a depth five feet above the water table, laying in the cable, backfilling the trench, then covering the cable run with a mound of soil five feet above grade. Cables were also sometimes excavated for re-use and the resulting trench again backfilled. Locations of the Test Easy cable runs are readily identifiable in aerial photographs taken in 1972, even though some of the mounds were no longer present when the photo was taken. Additional pre-test construction was performed in the X-ray/Easy GZ area in preparation for a test in Operation Redwing. Cable anchor blocks of concrete were poured but the tower base pad was never placed and the test was not conducted.

Results from early testing led to speculation about the cause of certain measured phenomena. Specifically, there was a difference in exposure rates between vegetated and denuded areas when measured in the days immediately following a nuclear test over land. One experiment included in Test Inca on Pearl consisted of removing all vegetation from about half of the island while the other half was essentially undisturbed. The line of demarcation extended from the vicinity of ground zero east across the island. Radiation measuring devices were strategically placed throughout both cleared and uncleared areas at various heights above ground. Results and conclusions of this experiment are not relevant here; but of interest to the cleanup project is the knowledge that the experiment was conducted. Several nuclear tests were conducted upwind of Pearl prior to the Inca event, so fallout on Pearl should have been substantial prior to the devegetation. The act of brush clearing should have mixed the fallout contamination into the top several inches of soil whereas the insoluble fallout would have stayed on the surface in the uncleared area. Gamma-scan data collected during 1977-79 do not show a line of demarcation, possibly because the radioactivity from test Inca was high enough to mask the lesser fallout activity or possibly because of post-test actions that disturbed the surface soil.

Test preparations on Irene were extensive prior to several tests. For the Mike event, an earthen causeway was built interconnecting Flora, Gene, Helen, and Irene. All evidence of a causeway has been obliterated by subsequent events. Ivy station 200, a large bunker at the east end of Irene, was built prior to Mike in 1952 and subsequently used for other tests. Material thrown out by the Seminole event in 1956 formed a ridge around the landward side next to the crater. This ridge was pushed aside by bulldozer to provide a line-of-sight (LOS) from Ivy station 200 to the Mike Crater where two more devices were tested a month after Seminole. It is not clear if some of the material was pushed back into the crater or just to the side on land. The surface topography found in 1977 gives no indication of a ridge next to the crater. Subsurface contamination in this area suggests extensive soil disturbance to depths of 100 cm or more.

The sequence of events that affected Sally is not entirely clear; however, helpful deductions can be derived from the limited records available. Test preparation on Ruby affected the radiological conditions on Sally, as these two islands were connected by an earthen causeway after the Yoke test of 1948 and before the George test of 1951. The roadway to Ruby passed next to the Yoke GZ area then onto the causeway which may have included contaminated soil scraped up in the vicinity of

Yoke. Tests Yuma on Sally and Mohawk on Ruby in 1956 resulted in further soil disturbance on Sally. The Yuma GZ was only a short distance from the earlier Yoke GZ, so one may suppose that some decontamination actions occurred during preparations for Yuma, but available records give no indication as to the disposition of contaminated soil.

Following some of the earliest surface tests, it became common practice to put down a layer of asphalt in the GZ area for dust suppression so that detonation-time photography would be enhanced. Available documents do not indicate how often, nor where, this practice was followed, but for one test the records are helpful. Preparations for Test Dog on Yvonne included laying 3 inches of asphalt within a 400-foot radius of the GZ, then 1-1/2 inches to a distance of 1,000 feet. The Dog GZ was about 175 feet from the site of Zebra, conducted 3 years earlier, so the construction area was probably contaminated when preparation began. Records do not indicate the disposition, if any, of contaminated soil. The area may have only been graded prior to placement of asphalt. The asphalt was, for the most part, consumed in the nuclear detonation. Some evidence of the presence of an asphalt layer could be seen in the lip of the Cactus Crater before that area was modified by cleanup actions.

Direct Test Effects. A nuclear detonation can aptly be described as awesome as indicated in the accounts presented earlier. Quite apparent are the immediate effects of the intensely hot fireball which can consume a 300-foot steel tower or plate nearby objects with a thin film of plutonium and fission products; of the giant waves that can wash over everything nearby if the device is detonated under or near a water surface; of the massive cloud of radioactive particles that rise to great heights then slowly drift to earth or wash out in a subsequent rain. Not so apparent are the effects that linger for years after the flash and blast have stilled and ground zero has cooled back to normal. Within a few years after the event, most of the radioactivity has been reduced by natural decay of the nuclides with short half-lives. (Half-life is the time required for the natural decay processes to reduce the initial amount of a radioactive species by one half.) The longer half-life nuclides make up the residue that can create a problem in man's environment.

The dominant long-lived radionuclides of concern from nuclear testing are plutonium and americium which are health hazards if inhaled, ingested, or introduced to the body as through a skin wound; and cesium and strontium which are absorbed by plant roots and may be incorporated in the parts of the plant used by man as a source of food. Man's body, in turn, incorporates the cesium and strontium in certain parts where the possibility of deleterious effects is enhanced. The half-life of plutonium-239 is nearly 25,000 years, essentially forever in terms of human time scales. On the brighter side, the half-lives of cesium-137 and strontium-90 are less than 30 years--a short enough period for activity levels to reduce to one-fourth the initial value in one human lifetime. Cesium and strontium generated by the first nuclear tests at Enewetak have already decayed through one half-life, but for practical purposes the inventory of plutonium-239 is unchanged. If measurement of the level of activity of ^{239}Pu were accurate to within one percent, it would take 250 years of natural radioactive decay for the change to be measurable. (This degree of accuracy is realistically achievable in the austere conditions of a field laboratory; higher accuracy is attainable in more ideal laboratory environments.)

Nuclear detonation effects are not limited to the immediate vicinity of the detonation site. In an extreme case, it was reported following the Mike event that the trees on Leroy, 9 miles distant, were scorched on the side facing the site. All the islands from Alice around to Yvonne were within a 9-mile radius of the Mike GZ; close-in islands received far greater effects than more distant islands. Pre- and post-event photographs taken as part of the Mohawk test on Ruby show healthy vegetation on Ursula reduced to small stubs. The distance was about 8,200 feet. Plants on Belle were burned nearly to the ground by Test Nectar conducted 2.7 miles away. (Palumbo, 1962.) Heat and shock waves transmitted in the air would travel much faster than the following water waves, if any were generated. Radioactive contaminants might initially be uniformly deposited on the soil surface, then swirled around and redeposited in irregular fashion by a series of inundating waves. Later tests, conducted at a distance great enough that no direct blast or wave damage would occur on a given island, might generate a new uniform blanket of fallout on that given island.

The above descriptions are intended to help explain the complexity of the radiological conditions encountered in early surveys and later in the detailed efforts of the actual cleanup. But the story doesn't end here; post-test action contributed further to the heterogeneous mix of radionuclides and soil found on some islands.

Post-Test Actions. Details of post-test activities are not available for all tests, but records reviewed for some tests present enough information to construct a hypothesis of the usual pattern of activity. Readings of the level of radioactivity following a test would be obtained with instruments in a low flying helicopter. When the level had fallen low enough for protected personnel to enter the area, recovery teams would go in to take additional readings, to evaluate scientific experiments and to recover specimens from the test area. In some cases, it was necessary to grade the roads to reduce exposure to re-entry crews. Following the Quince test on Yvonne, the contaminated soil was hurriedly pushed aside by bulldozer so preparations for the Fig test could start immediately. Documentation of this soil movement is better than for most of the tests.

The following account of post-test actions illustrates the extreme case of soil disturbance. The Erie event on Yvonne produced heavy contamination. The behavior of the device was such that much debris remained in the GZ area. Also, Erie was heavily instrumented to evaluate weapons effects on missile structures and materials. Six arrays of test specimens were arranged west of the tower at 45° from horizontal and below the tower such that the specimens would impact west of ground zero. Specimens were recovered as far as 450 feet from GZ and generally from northwest through southwest and at depths of up to five feet. It is reported that earth was excavated up to six to eight feet deep and that 100,000 cubic yards of earth were moved in the recovery operations. The recovery procedure involved making 6-inch cuts with a "carry-all" and spreading the earth in 2-inch layers. The earth was removed from the impact area and spread in a pile about 300 feet long and three swaths wide northwest of the GZ along the ocean side of the island. Not all specimens were recovered. The pile was later returned to the impact area and the area graded.

One unsubstantiated but plausible story has been told about activities following the X-ray event on Island Janet. The story says that a Russian submarine was spotted at sea northwest of Janet in the days before and after the test. Fearing that the Russians might land a party on Janet to collect samples which could reveal useful information about the fuel used in the X-ray device, a bulldozer was sent into the area as soon as it was safe for the operator, and dirt was pushed around willy-nilly to mix the radionuclides into the soil. Other objects in the area were deliberately moved around so that test effects would not be readily discernible. This may be only a story, but the observed radiological conditions in the vicinity of the X-ray GZ would make more sense if the story were true.

Caretaker Actions. Actions taken to place the proving ground in caretaker status are not well documented from the standpoint of the effect of these actions on the radiological conditions. Once photographs had been taken to document effects, and apparatus used in scientific experiments had been retrieved, work crews dismantled the more valuable or delicate equipment and facilities and removed them to Elmer or Enewetak for storage, as long as they were not contaminated. For the most part, these actions would not complicate the radiological conditions. The notable exception was re-excavation of trenches to recover buried cables. This was not always done as is evidenced by the large amount of cabling found during the cleanup of 1977-79.

1.5 POST-TESTING PROGRAMS

The last test of a nuclear device at Enewetak Atoll occurred in August 1958, but the Atoll continued to be used for various Defense Department programs from then up to the start of cleanup in May 1977. During the 1960's, Enewetak was the target and impact area for tests of Intercontinental Ballistic Missiles. Concurrently, laboratories involved in studies of marine biology continued their investigations, making Enewetak the most studied coral atoll in the world. (Helfrich, 1972.) Although these studies were not primarily concerned with radiological conditions, the basic understanding of atoll processes would be valuable in ongoing studies of radiation in the environment. In the early 1970's other programs were developed with Enewetak Atoll as the base. In the sections that follow, emphasis will be on the effects these programs had on cleanup or their contribution to the understanding of the complex radiological conditions encountered during cleanup. The historical sequence of events is not intended to be complete; instead, it will be limited to the background necessary to understand why and how certain conditions came about. Additional details may be obtained from sources listed in the bibliography.

1.5.1 High Energy Upper Stage (HEUS) Rocket Tests

During the time that the atoll was under the control of the Air Force, two test firings of a developmental rocket motor were conducted on Island Janet, one in 1968 and the other in 1970. The High Energy Upper Stage (HEUS) motors each contained 2,500 pounds of propellant, of which 300 pounds were beryllium. The first test, in April 1968, resulted in a high order detonation which scattered propellant over the western tip of the island. The engine started operating normally, but after a short time exhibited uncontrolled burning which resulted in detonation of the engine. The detonation caused spalling of the concrete blockhouse to which the engine was attached, and spread beryllium metal and oxides over a wide area in a nonuniform manner. Some decontamination was performed prior to the second test.*

The second test was successfully conducted in January 1970. The U.S. Air Force Environmental Health Laboratory took soil samples before and after the test and following decontamination procedures. The highest degree of contamination was found in a blackened area adjacent to the pad slightly behind the nozzle where the surface soil was scraped up, bagged, and removed from the area. Areas of soil known to be contaminated were soaked with water and the surface soil removed by bulldozing. (No statements are made regarding final disposition of the bagged soil nor indicating to where the soil was "removed" by bulldozing.) The question of beryllium contamination on Janet surfaced early in the cleanup project. Review of previous decontamination procedures, coupled with results of new soil samples and an air sampling program, satisfied DNA that no real beryllium hazard to cleanup personnel existed and the matter was given little additional consideration.

1.5.2 Pacific Cratering Experiments (PACE)

The U.S. Air Force has participated in numerous programs involving the detonation of charges of high explosives (HE) at various locations within and outside of the United States. Participation has included detonation of at least 49 HE charges ranging in size from 20 to 500 tons during the period from 1951 to 1972. The Pacific Cratering Experiments (PACE) program was to be conducted on Enewetak Atoll during 1972-73. (PACE, 1973.)

The PACE series of tests was designed to provide a means for predicting the impact of nuclear detonations upon strategic defense installations. The program was composed of PACE 1, whose purpose was to assess the nuclear cratering effects by means of geological and geophysical exploration of existing Pacific nuclear craters, and PACE 2, designed to provide an experimental link between craters in the Pacific and craters in continental areas.

The PACE 2 program consisted of a series of detonations of conventional explosive charges of various sizes and configurations. The series was divided into three subsets with the designations Micro Atoll, Coral Sands, and Mine Throw II. The calibration tests of Micro Atoll consisted of 15

*Available source documents are open to question regarding decontamination efforts and no clear picture emerges. In a project report (Good and Woodmansee, 1968) it is stated that, "The high tides during the lapse period (18 hour period between test fire and sample collection) would have inundated a good percentage of the soil sampling points and thus altered the true concentrations at these points." A later report (Robles and Mesman, 1970) states "No actual endeavor was made at the time to determine location or extent of the contamination. An investigation was made at a later date, but the results were equivocal because of the random nature of the contamination pattern." A copy of a Memorandum for Record dated 26 July 1972 was obtained from DNA files. The MFR notes that in a conversation with a member of the staff at Vandenberg AFB the statement was made that, "Decontamination had consisted of washing down the surface area with salt water and plowing under contaminated surface soil." On 16 March 1973, DNA requested by letter 2 copies of the Robles and Mesman report noted above. Attached to this letter is an unsigned brief statement, dated 15 March 1973, regarding beryllium contamination on Site Janet. The statement says, "A decontamination crew thoroughly wet the area of the explosion for a radius of 100 feet and then scraped dirt from the surface and buried it in the resulting crater." The statement goes on to say, "Since that time (1971) erosion of the western tip of the island has occurred to such a degree that much of the contaminated area has been lost to the sea."

detonations of 1,000-pound charges designed to establish cratering efficiency curves for low-yield detonations, provide ground motion calibration data, verify planned data acquisition techniques, evaluate operational procedures, and to verify the predicted impacts of the detonations on the environment. Twelve of the anticipated fifteen tests were actually conducted. Micro Atoll was planned to also include detonations up to 100 tons but these were not conducted. The Coral Sands and Mine Throw II tests were deleted before the program was approved later in a court order.

The Air Force conducted investigations, including radiological reconnaissance of several islands as part of the PACE site selection phase, and finally decided to use Sally for the Micro Atoll segment of PACE 2. The program plan required that the ground surface be carefully prepared in order to measure and evaluate the crater and ejecta field under controlled conditions. Site selection on Sally and Yvonne, beginning in September 1971, consisted of exploratory drilling of approximately 30 holes, seismic profiling, and material properties testing. Work on PACE 2 continued in January of 1972 with preparation of the Sally test bed where large earth scrapers were used to remove vegetation and about 6 feet of overburden from a roughly triangular area of about 19 acres on the lagoon side of the island. Approximately 185,000 cubic yards of soil were moved—90,000 of it was used to fill a saltwater pond along the west tip of the island; the rest was dumped onto a 10-acre site in the center of the island, raising the elevation by about 6 feet.

By May 1972, completed activities related to PACE 1 included drilling about 190 holes into various islands of the atoll. Thirty-five holes drilled by the rotary method were cased, 15 of these with 4-inch plastic pipe and 20 with 2-inch plastic pipe. The holes were predominantly less than 200 feet deep, with one hole extending to about 305 feet. In addition, 86 trenches had been cut into various islands with backhoe equipment. The average dimensions of the trenches were 3 feet wide by 6 feet long by 7 feet deep. The purpose of the trenches was to investigate and sample the soil profiles of the islands down to the water table and to sample the water itself. All soil was piled next to the trenches during the studies and later replaced. Completed activities related to PACE 2 affected, in summary, a total of 34 acres on Sally. Nineteen acres had been lowered in elevation by about 6 feet, 10 acres had been raised by an elevation of about 6 feet, and a 5-acre saltwater pond had been filled in. In addition, about 30 exploratory holes had been drilled on Sally and Yvonne.

Announced Release of Enewetak. On 18 April 1972, Edward E. Johnston, High Commissioner of the Trust Territory of the Pacific Islands, and Ambassador Franklin Haydn Williams, the President's Personal Representative for Micronesian Status Negotiations, made the following joint announcement concerning the United States Government's land requirements in the Trust Territory:

> "The future land needs of the Department of Defense were set forth during the third round of status negotiations which took place at Hana, Maui in October 1971. There Ambassador Williams stated that in regard to our security related land requirements in the Marshalls the need for research and development activities at Kwajalein would not disappear in the foreseeable future. He, however, qualified this remark with the following statement: 'It may some day become possible to consolidate our testing activities in the Pacific and concurrently reduce our land interests in the Marshalls.'
>
> "The United States Government appreciates the importance that Micronesians place on land and has no desire to retain Micronesian land that it does not need. Whenever it can consolidate or eliminate activities in order to reduce or terminate the lands required for security purposes, it will do so.
>
> "In this respect, the status of Enewetak Atoll has been under study by the various departments and agencies in the United States Government ever since the possibility of returning Bikini Atoll was first considered. Over the years the Department of Defense has been striving to bring its work on Enewetak to a close. Ambassador Williams and I have taken a personal interest in this matter and this afternoon we are extremely pleased to announce that the United States Government has in fact been able to structure its research plans and programs in such a way as to permit an early return of the atoll to the people of Enewetak.

"I am therefore authorized to announce that 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.

"The Trust Territory Government will in the coming months be working with the Department of Defense and the people of Enewetak to settle the details of transfer and to make the arrangements for the survey, cleanup and rehabilitation of Enewetak. In the meantime the United States is completing some research and development testing on the atoll which will not involve nuclear detonations of any kind or type. These tests will in no way interfere with an early commencement of the rehabilitation process and will be completed by the end of 1973.

"Prior to the actual resettlement 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. This schedule will be drawn up as soon as practicable.

"As an initial step the United States plans to commence the survey of the atoll probably late this summer. The cleanup and rehabilitation of the three islands--Parry, Japtan, and Aniyaanii--in the southeastern part of the atoll, will receive first priority.

"The Trust Territory Government looks forward to working with the people of Enewetak on the actual planning of the rehabilitation and return of the atoll. They will be able to help us decide upon time schedules and actual locations for the building program and the agricultural rehabilitation. The people of Enewetak will be invited at an early date to visit Bikini and Enewetak in order to familiarize themselves with the program utilized for Bikini and the requirements for Enewetak.

"We hope by this joint planning effort to carry out the rehabilitation program in an efficient and well thought-out manner as well as to meet local desires as much as possible.

"The Trust Territory Government will enter into immediate consultation with the people of Enewetak to commence the above process and to conclude any necessary legal arrangements."

PACE Halted By Court Order. In May following the announcement, six elected leaders of Enewetak were permitted to visit the atoll for the first time since 1947. They were accompanied by their lawyers, officials of the Trust Territory Government, a PACE Project Officer and several AEC representatives from Nevada. The leaders of Enewetak "were deeply gratified to be able to visit their ancestral homeland, but they were mortified by what they saw." (PACE, 1973, p. G-10.) Unhappy with the activities of PACE, the People of Enewetak sought and obtained a court order halting the PACE programs in October 1972. There followed almost a year of political and legal maneuvering before a limited, restructured version of PACE 1 was allowed to continue.

Exploratory Program on Enewetak (EXPOE). The 12 June 1973 court order which allowed work to continue included the following conditions: (1) The PACE 2 program would not be carried out on Enewetak; (2) Core drilling and seismic refraction surveys could continue but could not exceed 200 profiles on 16 named islands, and the program would be renamed Exploratory Program on Enewetak (EXPOE); (3) One Cavity In Situ Test (CIST) experiment could be conducted on the Sally test bed, but the site would be returned to pre-test conditions; (4) The conduct of EXPOE could not interfere with planning, preparation, or conduct of the decontamination and rehabilitation program being planned for the atoll, nor with the return of an advance party of Enewetakese to Japtan; (5) The 1971 contours of the island of Sally would be restored, or the area regraded to other contours if the desired contours could be achieved with the available earth; (6) No objection would be raised to the conduct of EXPOE, as described, since these actions would have no significant adverse impact on the quality of the human environment. EXPOE proceeded with only minor revisions and the program was completed in September 1974, except for restoration of the excavated area on Sally. The EXPOE program added 46 drilled holes to the inventory during 1973-74. (EXPOE, 1975.)

Planning for the decontamination and rehabilitation of the atoll was in progress during conduct of EXPOE. AEC recommended restoration on Sally be delayed for execution concurrent with cleanup. This plan was accepted by all concerned parties and was accomplished during the spring of 1979.

Significance to Radiological Characterization. The programs of PACE 1 and EXPOE produced drill holes and test wells which proved to be valuable assets for a later program designed to gain understanding of the radionuclide and groundwater dynamics of a coral atoll. Several of the early exploratory holes, and some added to the inventory at the request of the AEC, are still in use for ongoing water lens studies. Among other things, these studies explore the rate of movement of radionuclides through the soil above the water table, and the rate of dispersion of radionuclides within the water lens. Both of these phenomena are significant to computation of long-term radiation dose to individuals utilizing the islands of Enewetak.

Radiological reconnaissance conducted as part of the PACE site selection indicated that no significant radiological hazard could be expected in the designated area on Sally. However, actions taken in support of PACE 2 introduced an added level of complexity to the task of compiling a radiological characterization of Island Sally. The concentrations of radionuclides in the surface soil removed from the 19-acre test bed, and on the surface of the 10-acre dump site, are unknowns. The inference can be made from available information that the brush and surface soil from the 19-acre area may have been put into the saltwater pond first. The last overburden soil to be removed, and presumably the least contaminated, would have been placed on the top of the 10-acre area. Soil sampling for determination of radionuclide concentration of the surface that existed prior to dumping in the 10-acre area would be imprecise, at best. During the process of refilling and grading of the excavated area, most of the 10-acre mound was pushed back by bulldozer. Radionuclide concentrations that did exist in the PACE 2 area have been thoroughly mixed and dispersed by the original soil movement and subsequent restoration activities.

The 86 trenches that were dug by backhoe on various islands, then refilled, present the possibility of generating anomalous data during later characterization efforts. Soil samples could, by chance, be taken from the spot where a trench had been dug. Such a spot would not be representative of the surrounding area due to the mixing of soil that would result from digging and refilling operations.

1.5.3 Mid-Pacific Research Laboratory (MPRL)

The Enewetak Marine Biological Laboratory (EMBL) began operations in 1954 under the auspices of the Division of Biology and Medicine of the U.S. Atomic Energy Commission. It was and is operated by the University of Hawaii, currently under contract to DOE's Nevada Operations Office. Until 1975 the laboratory was run as a part-time field station visited and used by a variety of investigators. In 1974, the AEC decided to expand laboratory operations to a year-round schedule, with corresponding increases in laboratory personnel and support staff. The lab was re-named the Mid-Pacific Marine Laboratory (MPML). (In the same year the spelling of the atoll name was changed to Enewetak, to reflect the pronunciation and meaning of the name as used by the Enewetak people.) The laboratory name was again changed, to the Mid-Pacific Research Laboratory (MPRL), in 1979. These name changes were intended to reflect a broadening of the laboratory's role as a center for research on all aspects of atoll ecosystems.

Research supported by the laboratory was chosen by an advisory committee which evaluated written proposals covering a broad spectrum of marine and terrestrial science. Studies involving the biological effects of radioactivity received some attention during the early years but, in general, studies have become quite diverse during the past decade. The scope of research projects can be reviewed in NVO-628-1 which contains reprints of 223 papers generated from Enewetak-based research during the period 1954 through 1979. During the planning for the cleanup, the preparation of the Environmental Impact Statement and the cleanup itself, the laboratory assisted with baseline information and advice on a variety of subjects and issues.

EMBL was first housed in a small facility on Island Elmer. The laboratory was moved to Enewetak Island in 1961 and to an alternate location on the same island in 1969. With the laboratory expansion of 1974 came a need for larger facilities. In addition, the buildings then occupied were scheduled to become part of the village complex upon resettlement of the Enewetak people. By coincidence, the U.S. Coast Guard abandoned its facilities on the northeast end of Enewetak Island in December, 1977, and the laboratory was moved into these quarters, where it resides as of this writing.

Modification of the Coast Guard facilities to laboratory requirements, addition of trailers for housing and supply storage, and installation of water tanks have given the laboratory a self-contained, stand-alone capability. Diesel powered generators were already present and water catchments, cisterns and a distillation unit were added. The DOE continues to support the MPRL and the people of Enewetak have indicated their desire that the laboratory continue as a permanent feature of their community.

In preparation for the cleanup, laboratory scientists were consulted on a number of matters. MPRL's review of the Environmental Impact Statement was most helpful, and the specific advice received regarding dumping sites in the lagoon, restoration of the topography of Sally (after PACE) and exploitation of the groundwater resources was notable. During the cleanup of Boken the laboratory hosted a visiting scientist (W. Templeton) who, using laboratory resources and his own observations, studied the behavior of the bird population. He provided valuable advice which minimized the impact of cleanup measures upon a very large population of nesting terns.

1.6 PHOTOGRAPHS OF HISTORICAL INTEREST

Activities at Enewetak Atoll were shrouded in secrecy during the atomic testing period, and only official photography was permitted. All photographs were evaluated for security classification purposes with a large number remaining classified to this day. However, many thousands of early-day photos and film strips have been declassified and are available for review with appropriate approvals. Twelve photos (Plates 1-12) dating from 1943 to 1958 are included here as an aid to understanding the events that took place on the islands of Enewetak Atoll. Especially with regard to Island Janet, a comparison of the old photos with recent photos appearing in Chapter 6 illustrates both the severity of changes which occurred and the surprising ability of the land to recover from man-induced shock. The appearance of Island Janet has undergone a larger number of changes than any other island of the atoll, although the changes to Islands Irene, Sally, and Yvonne were, perhaps, more drastic and longer-lasting. The Plate captions point out items of special note.

As of 1980, there are several archives containing photos of activities at Enewetak beginning with aerial reconnaissance photos taken in 1943. Photo archives are not generally open to the public for random browsing, but may be accessed for purposes of legitimate research. Archives exist at the following locations:

1. DOD Nuclear Information and Analysis Center (DASIAC)
   Operated by General Electric
   Santa Barbara, California
   (For the Defense Nuclear Agency)
   (Testing period photos, 1948-58)

2. Holmes & Narver, Inc.
   Energy Support Division
   Las Vegas, Nevada
   (For the Department of Energy)
   (Photos from the test period, 1948-58, and from the rehabilitation period, 1977-80)

3. Field Command, DNA
   Kirtland Air Force Base, New Mexico
   (Cleanup and rehabilitation, 1977-80)

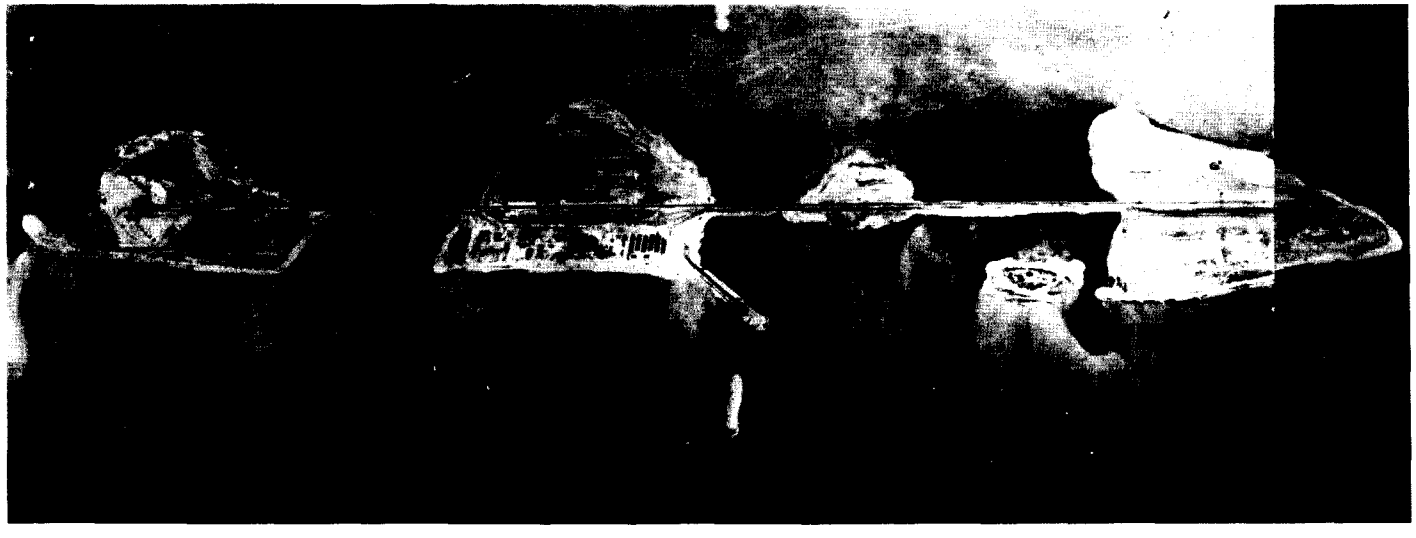


PLATE 1. ISLANDS FLORA TO IRENE, FALL, 1952. *Islands, left to right, are Flora, Gene, Helen and Irene shown prior to the MIKE test. The MIKE device was located in the black building on Island Flora. The line-of-sight facilities extended about 9000 feet from the MIKE building to a bunker near the east end of Irene. Following the MIKE test, Island Flora was gone and in its place was a crater about 5800 feet across and 190 feet deep. The later KOA test removed Island Gene and generated a crater about 4300 feet across and 170 feet deep and extending into the MIKE crater. Wave patterns and water currents were changed by the presence of the craters, resulting in erosion of Island Helen and the development of a long crescent-shaped sand bar extending from Island Irene out to about the area where Helen was.*

PLATE 2. ISLAND JANET (ENJEBI), DECEMBER, 1943. *Janet was one of the few islands in the Atoll that could accommodate a runway properly oriented with respect to the predominant wind direction. The heaviest hand-to-hand combat among U.S. and Japanese troops occurred near the center of the island where coconut trees, blown down by the pre-invasion bombardment, afforded the best surroundings for this type of combat.*

PLATE 3. ISLAND JANET, MAY, 1944. *The transformation of Janet into a significant air base was accomplished in about three months. There are at least 57 single-engine and 9 two-engine aircraft on the ground. Altogether there are about 700 tents and other structures visible.*

PLATE 4. ISLAND JANET, 30 MARCH 1948. *Preparations for the 14 April X-RAY detonation included laying asphalt for dust suppression within a radius of 1000 feet of the test tower. The cleared area (the runway) is the only evidence that a fighter base existed here three years earlier.*

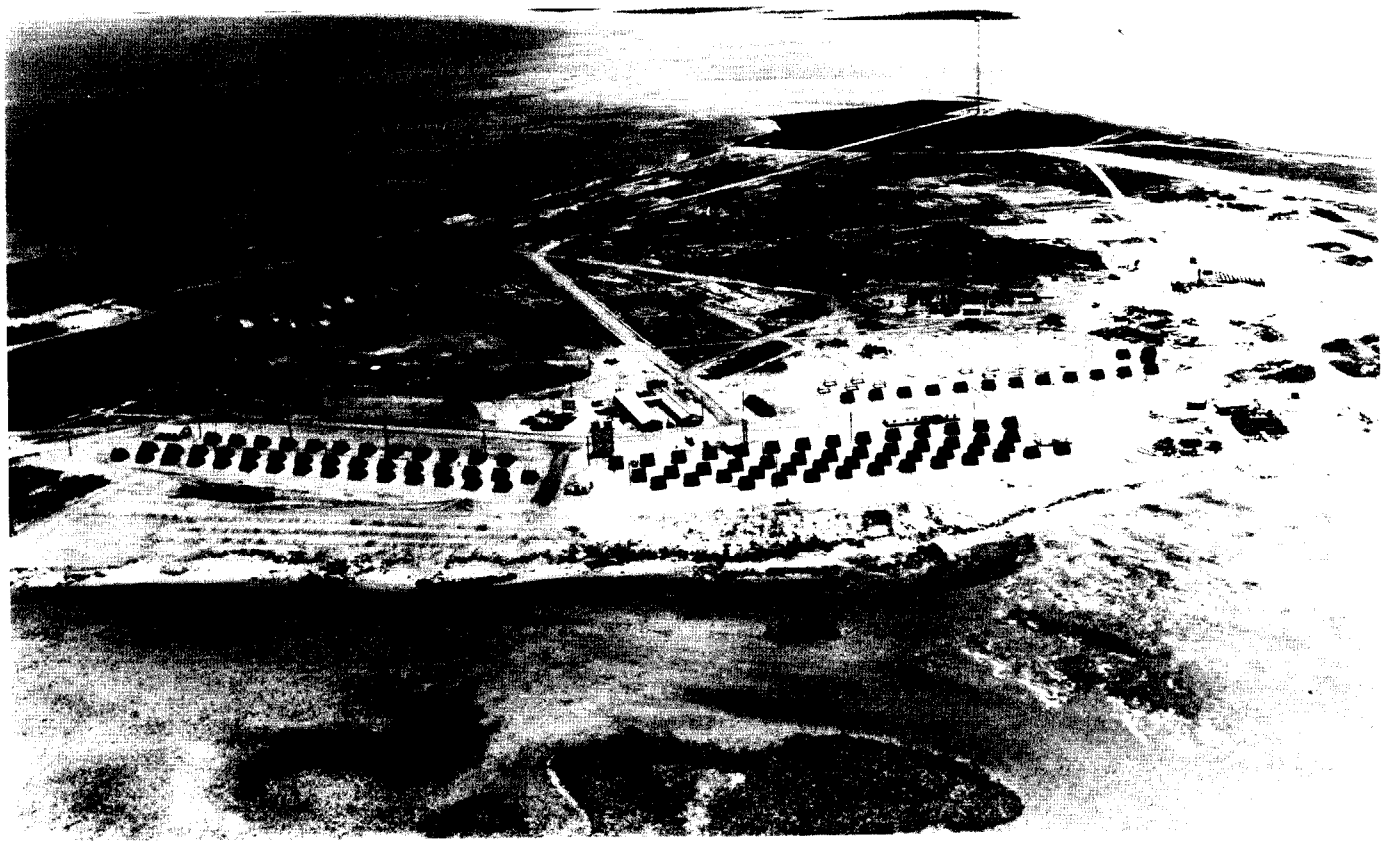


PLATE 5. ISLAND JANET, 10 JULY 1950. *The tower and paving for the EASY test detonation are in position. Construction is in progress on the multistory test building, Station 3.1.1 (located toward the island center).*

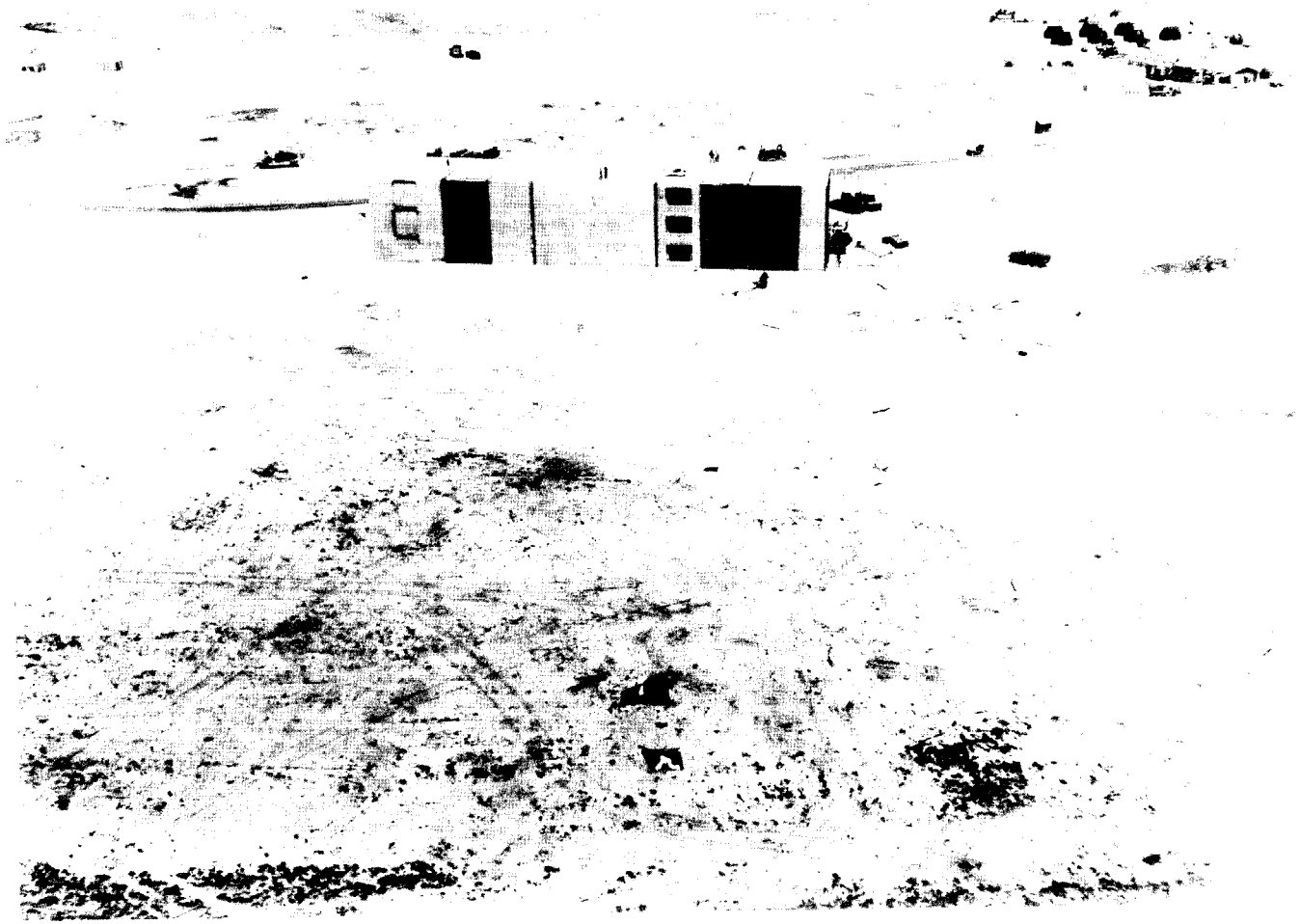


PLATE 6. ISLAND JANET, 25 APRIL 1951. *The island was swept clean by the EASY test five days earlier. A minimal crew has returned to conduct inspection and recovery operations.*

PLATE 7. ISLAND JANET, 2 JUNE 1958. *No nuclear tests had been conducted on the island surface since May, 1951. The runway was restored for use in connecton with tests on barges nearby in the lagoon. Vegetation has begun to return. Rocket motor tests in 1968 and 1971 using beryllium enriched fuel, utilized the large blockhouse in the left foreground.*

PLATE 8. ISLANDS TILDA AND SALLY, 30 MARCH 1948. *Tilda is in the foreground, with Sally next, then Ruby, Pearl and Olive in the distance. The newly constructed sheetpile causeway, where the Aomon Crypt was later located, can be seen connecting Tilda with Sally. The tower for the YOKE test is located at the Ruby end of Sally.*

PLATE 9. ISLAND SALLY, NORTH TIP, SPRING, 1956. *The tower for the KICKAPOO test was located on a jetty extension of the north tip of Sally. This positioning eliminated the need for dust suppression measures. Islands Tilda, Ursula and Vera are in the background.*

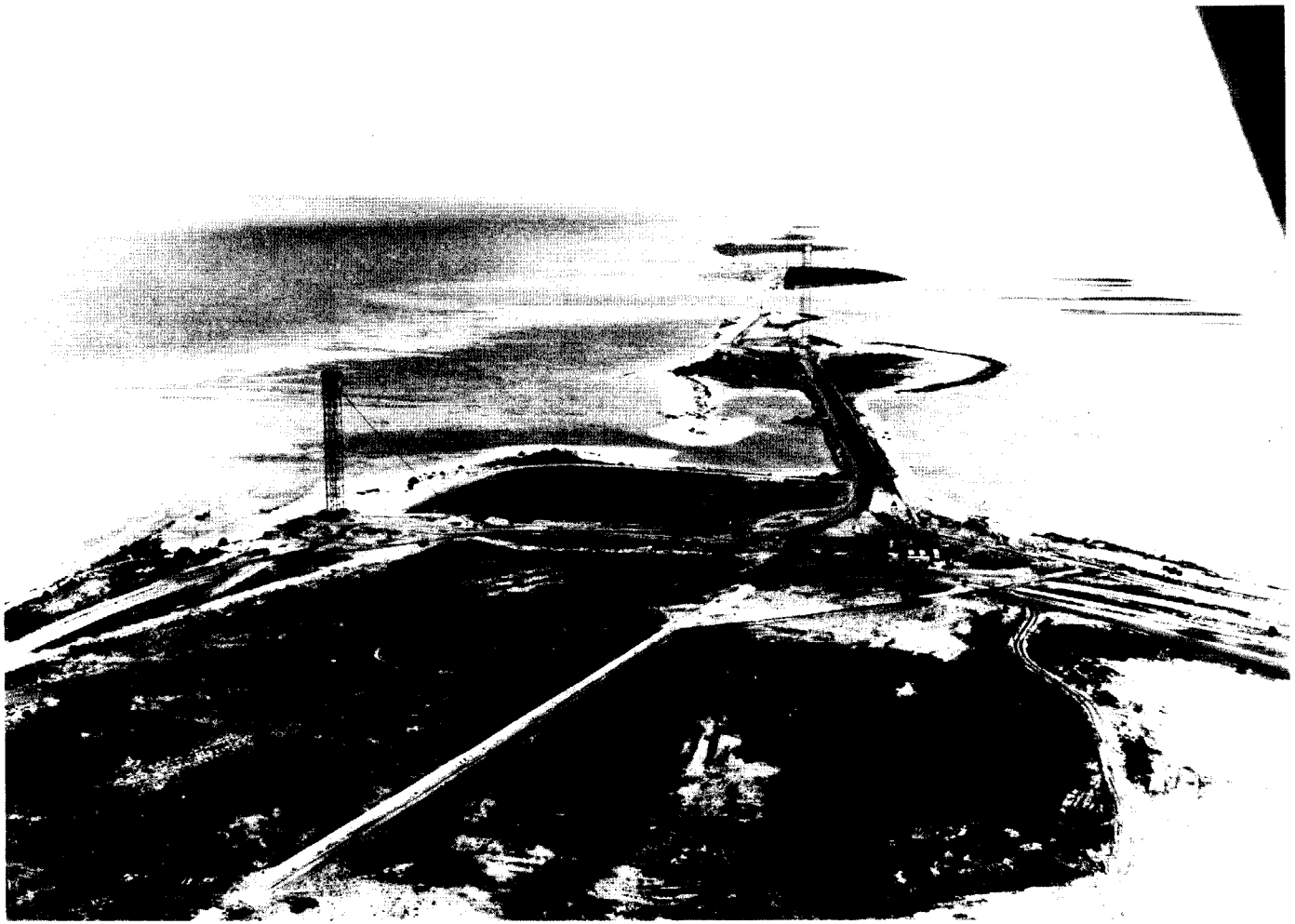


PLATE 10. ISLANDS SALLY AND RUBY, SPRING, 1956. *Towers are in place for tests YUMA, MOHAWK (on Ruby), and INCA (on Pearl). The south half of Pearl was devegetated prior to the INCA test. The MOHAWK test removed most of Ruby, but the connecting causeway remained to become an extension of Sally.*

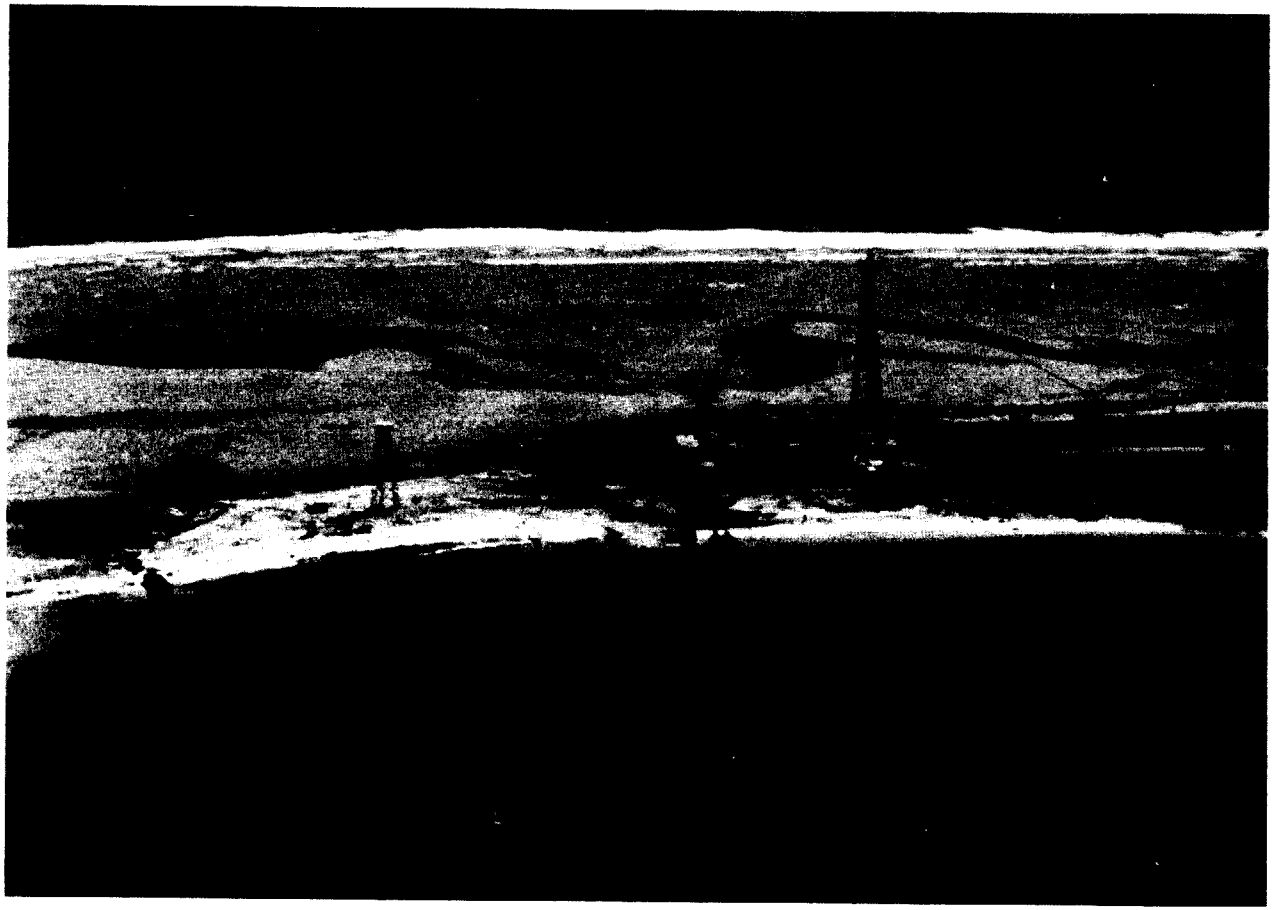


PLATE 11. ISLAND YVONNE, 30 MARCH 1948. *Preparations for the ZEBRA test are nearing completion. The CACTUS test, 10 years later, was located about midway between the ZEBRA tower and the smaller photo tower. The LACROSSE test was located on the reef just above the photo tower.*

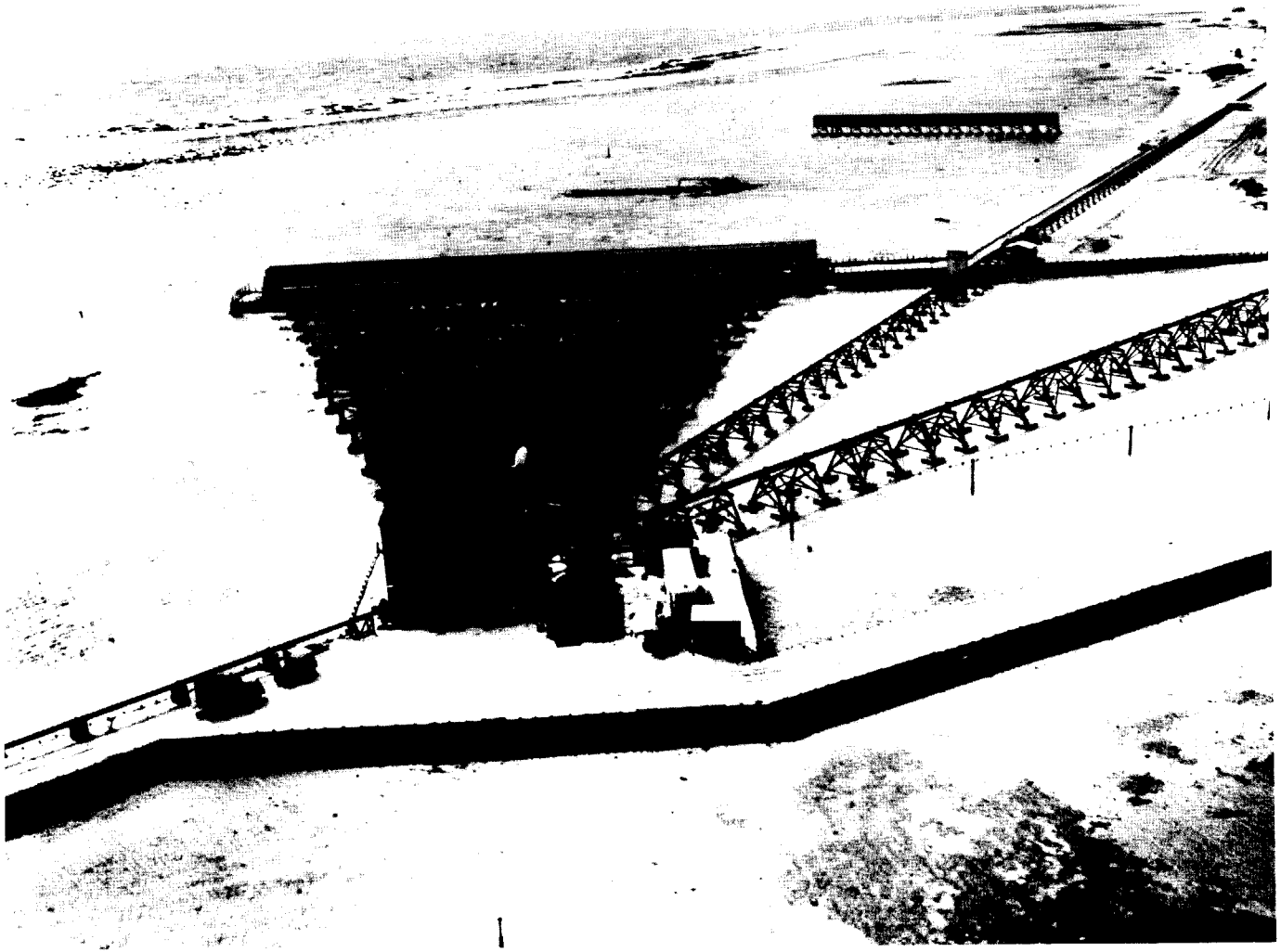


PLATE 12. ISLAND YVONNE, NORTH END, SPRING, 1956. *Facilities for the LACROSSE test were the most elaborate of all tests, although not as massive as for the MIKE test. Most of the facilities shown here were consumed by the test, but a significant volume of contaminated debris remained. The line-of-sight pipe, exiting the photo at upper right, went into Station 1310.*

CHAPTER TWO: DOE ROLE
by Roger Ray, DOE
Bert Friesen, Holmes & Narver, Inc.

2.1 PRE-CLEANUP EVENTS TO 15 JUNE 1977

2.1.1 Introduction

Responsibility for the administration of operation and maintenance activities at Enewetak Atoll was assigned to a succession of federal agencies between 1947 and 1972. However, the Atomic Energy Commission (AEC) remained cognizant of certain matters which would eventually be identified as within the responsibilities of the Commission. As a legacy of atmospheric nuclear testing, the radiological condition of Enewetak was appropriately a matter within the purview of the Nevada Operations Office (NV) of the AEC. The situation at Enewetak, as viewed by the Manager, AEC/NV, was clearly stated in a letter to the General Manager, AEC/HQ dated 8 June 1972. With only a few minor deletions, the letter is quoted at length because it sets the stage for many of the decisions and actions of the next seven years:

> "During the past approximately one year, NV has become aware of, and I have become increasingly concerned about, certain conditions and activities at Eniwetok Atoll. My concern stems from three facts:
>
> "a. It has appeared probable that Eniwetok, which has not yet had a Bikini-style radiological cleanup, would soon be a candidate for rehabilitation and return to the Marshallese. Since mid-April, 1972, this probability has become reality, with a public commitment by the United States to return Eniwetok to the Trust Territory of the Pacific Islands by the end of 1973.
>
> "b. It has been known, due to the nature of the testing which was conducted at Eniwetok, that cleanup and rehabilitation when it did occur would be significantly more difficult and more costly than had been similar activities at Bikini. It was also suspected that increased environmental sensitivity and political and public visibility would be complicating factors in an Eniwetok rehabilitation.
>
> "c. There were and are on-going activities of the Department of Defense and other public and private agencies which could aggravate the known (and unknown) radiological problems and which could subject their participants to unnecessary and unacceptable radiological exposures."

(A brief chronology of NV actions pertaining to Enewetak from July 1971, through May 1972, was presented here.)

> "For the most part the above actions have been taken without at least specific Headquarters direction although they have been discussed from time to time with the staff. However, at the present time it seems appropriate to seek policy direction and to recommend certain Washington level actions. Most fundamentally, there appears to be no question that a cleanup and rehabilitation of Eniwetok will be undertaken in the reasonably near future and that the AEC will have an essential and vital role in the planning and execution of that action. It would appear that the Commission's role would be the provision of technical support, advice and assistance to whatever agency is assigned overall responsibility. Pending such assignment, it seems clear that the AEC has an obligation to advise and assist from a radiological standpoint any agency which is pursuing a legitimate activity at Eniwetok. NV requires direction as to the extent to which this office should continue to take the initiative in this regard.
>
> "With a date certain established for the return of Eniwetok to the Trust Territory, the time available for planning a cleanup has now been fixed and is running.

Before a coordinated plan can be developed, responsibility for the plan and for its execution must be assigned. In addition, a far more comprehensive survey of the Atoll must be accomplished. No assignment of responsibility for such a survey has yet been made. Presumably a large part of the rehabilitation effort (including cleanup) will occur after the transfer to the Trust Territory Administration. However, it would seem highly desirable to have the nature, scope and details of the cleanup agreed before the transfer rather than to have to negotiate them later. Included in these agreements should be a common understanding of cleanup standards and criteria.

"Our recent experiences with Eniwetok have demonstrated an urgent need for agency-level coordination of future United States actions pertaining to that Atoll.

". . . . The thrust of the visit (to Enewetak by the Marshallese in May, 1972) as evidenced by a close-out meeting on May 20th was the urgency of an early return, the determination on the part of the Marshallese to determine their own destiny by drawing up their own specifications for rehabilitation, their dismay at the continuing use of their lands for a variety of apparently unrelated and uncoordinated purposes and, specifically regarding the(ir) lawyers, their clear intention to document in detail current and future United States actions for later use in behalf of their clients. (By a separate informal memorandum, this latter point has been brought to the attention of the General Counsel, HQ.)

"Because there was no designated spokesman for U.S. Government interests at the May 20th meeting and because there were issues and questions of multi-agency concern, my representative who attended at the request of the Deputy High Commissioner accepted responsibility for two actions:

"a. to convey to appropriate national level authorities the need for central U.S. Government coordination of all future actions pertaining to Eniwetok.

"b. to convey to the same authorities the desire and the need of both the Marshallese and, in their behalf, the Trust Territory Administration for current and accurate information regarding United States actions and intentions. (In this connection, it is noted that there is in the tape recorded record of the meeting an acknowledgement by the Deputy High Commissioner that until March 1972 the Trust Territory Administration was not aware of the PACE Program, although quite substantial efforts on that program had then been underway at Eniwetok for some months.)

"I believe that the conditions set forth in this memorandum strongly suggest the establishment at the Washington level of a single manager for all future United States actions pertaining to Eniwetok. I recommend that the Commission seek to have such a designation made at the earliest possible time in order that timely funding, planning, coordination and execution may replace the currently uncoordinated action-reaction cycle." (Miller, 1972.)

A few weeks later, on 17 July 1972, the Assistant Secretary of Defense issued a memorandum to the Director, Defense Nuclear Agency (DNA), and the Chairman, AEC. In the memorandum, DNA was requested to initiate planning to identify the scope of work and the resources necessary for the Department of Defense (DOD) to accomplish the disposal of radioactive debris and other hazardous materials on the islands of Enewetak Atoll. The memorandum also authorized necessary coordination with the AEC, the military services and other governmental agencies to gather data for the cleanup task. It was planned that the DOD, with the technical support of the AEC, would conduct the cleanup.

An initial interagency meeting was held 17 August 1972 at AEC/HQ. Topics discussed were of general nature and conclusions reached were only agreements in principle. However, conferees agreed that it would be appropriate during some part of the radiological survey (already planned to

start in October 1972; see Section 2.1.4) to conduct an engineering survey (reported in Section 2.1.3). They also recognized that at some point there would be a requirement for some agency external to the AEC and perhaps external to the United States Government to be satisfied as to the cleanup standards. (As reported in Section 2.1.5, the AEC Task Group was assembled to formulate recommendations and much later, the so-called Bair Committee was convened to review cleanup standards as reported in Section 2.2). The August 1972, meeting was not without controversy. At issue was the concept of conducting several tasks concurrently versus staging the same operations sequentially such that one task could be completed and evaluated prior to starting the next task. The first proposal envisioned cleanup of one island, survey of another and perhaps even rehabilitation of a third to be occurring simultaneously. The opposing view held that it would be necessary to complete the radiological evaluation and the biological/food chain evaluation before cleanup criteria could be established for any island. There was considerable discussion at this time of the possibility that the food chain problem could be serious enough to make it impractical to repopulate any part of the Enewetak Atoll. In the opinion of an AEC/HQ representative, it was therefore considered undesirable to undertake cleanup actions before the food chain question was resolved.

The Enewetak Cleanup Project was conducted as a series of concurrent tasks between July 1977, and September 1979. The food chain question was not completely resolved before cleanup started, but work toward this resolution was initiated, as reported in Section 2.1.7, continued during cleanup, as discussed in Section 6.11, and may not be finally resolved until some time after trees planted in 1979 bear fruit (about 1986). (Continued evaluation of radionuclide uptake by coconut trees at Bikini could reduce the time required to resolve the food chain question.)

As mentioned above, the 17 August 1972 meeting produced several agreements in principle. The topics of these agreements were discussed further at an interagency meeting held on 7 September 1972. Additional meetings were held during the fall of 1972 to clarify and resolve several remaining points of uncertainty. Details of these agreements and remaining questions will be omitted, but the most important points will be summarized to lead off the discussions of Section 2.2.

In the letter of 8 June 1972 quoted previously, it is strongly suggested that a single manager be established at the Washington level to manage all future U.S. actions pertaining to Enewetak. This suggestion was endorsed at the August and September interagency meetings and in part implemented by a memorandum dated 14 November 1972 from the Secretary of Defense to the Chairman, Joint Chiefs of Staff (JCS). The memorandum requested the JCS to designate the Director, DNA, as the DOD Project Manager for matters concerning the Enewetak Cleanup. Being a single agency memorandum, however, this directive fell far short of placing "all U.S. action, pertaining to Eniwetok" under a single manager. As will be seen later, funding and policy direction came from three separate departmental sources in Washington. Nevertheless, during the actual cleanup phase under the leadership of the Director, DNA, a single integrated program did evolve.

The 14 November memorandum provided the following guidance to the DOD Project Manager:

> "1. The Clean Up Phase is limited to the removal of vegetative overgrowth, debris, and structures or materials residual from the use of the atoll by the DOD, which could pose radiation or other hazards to inhabitants, interfere with their reasonable use of the atoll, or preclude safe, continuous habitation.
>
> "2. The AEC, in coordination with the other appropriate government agencies, has agreed to establish radiological criteria for the program to return Eniwetok to the TTPI, and will provide technical support to the DOD Project Manager during the clean up phase.
>
> "3. The handling and removal of contaminated material will be conducted such that radiological exposure to clean up personnel will be within acceptable standards as interpreted by the AEC.
>
> "4. The composition of the actual clean up work force may consist of contractor-provided personnel, DOD personnel, native labor (except for the handling, collecting or removal of contaminated material), or a combination of these.

"5. The use of certain equipment and other assets available to the DOD may be in the best interest of the U.S. Government. These assets, to the extent possible, will be utilized for the clean up phase.

"6. An environmental impact statement concerning the ecological implications of clean up will be required prior to a decision on whether or not to perform the clean up operation.

"7. Funding guidance will be provided separately to the Project Manager by the Secretary of Defense." (Rush, 1972.)

2.1.2 Early Surveys and Reports

The University of Washington Applied Fisheries Laboratory (AFL), later to become the Laboratory of Radiation Biology (LRB), then the Laboratory of Radiation Ecology (LRE), was involved in radioecology studies at Bikini and Enewetak starting with the first nuclear tests conducted at the Pacific Proving Ground in 1946. Throughout the testing period and continuing into the late 1970s, Laboratory personnel returned many times to investigate and document the biological effects of nuclear testing. Laboratory emphasis was placed on gaining an understanding of the mechanisms whereby radionuclides were absorbed by marine and terrestrial biota and documenting the short and long term effects of these radiation sources. (A complete list of University of Washington publications resulting from the Enewetak studies appears in the bibliography.)

Lawrence Livermore Laboratory (now LLNL), of the University of California, provided the lion's share of technical effort in the Enewetak Radiological Survey of 1972-73, reported in NVO-140. With more than 100 laboratory personnel involved in that effort which extended well over a year, it was natural that the commitment and interest of some would lead to continued involvement. In 1974 and beyond, emphasis was placed upon studies of the Atoll's ecological systems and the significance of radiological contaminants in these systems to the safety and well-being of returning populations. From time to time the LLL investigators were called upon for advice pertaining to the cleanup and, in turn, the data base generated during the cleanup made a substantial contribution to the LLL studies. (A complete list of Lawrence Livermore Laboratory publications resulting from Enewetak studies appears in the bibliography.)

The continuing surveillance of Bikini, commencing with the cleanup of that atoll in 1969, provided additional insight and experience pertinent to the Enewetak task. Although the radiological conditions of the two atolls differed in detail, there was enough similarity to make knowledge gained and lessons learned at one highly useful at the other.

2.1.3 Engineering Study, 1972

In October 1972, Holmes & Narver, Inc., (H&N) was awarded a contract by the Defense Nuclear Agency, Washington, D.C., to make an engineering study and estimate of the work involved in making the islands of Enewetak Atoll safe for human habitation. Field work under this contract commenced on 12 October 1972, and was completed on 21 December 1972.

The objectives of the mobilization, demobilization, and cleanup plans were:

1. To conduct the cleanup work safely and efficiently.

2. To use, to the maximum extent possible, the existing facilities for the support of the work force.

3. To remove the existing impediments to the use of the islands for food production and for habitation within the limits of practicality and economy.

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. (Holmes & Narver, 1973.)

Radiological support was provided to the engineering survey by a team composed of AEC staff and personnel on loan from EPA. The purpose of the radiological effort was twofold:

1. To provide radiological safety support to the engineering team on those islands which had known or suspected radiological hazards.

2. To survey, evaluate, and report the radiological conditions of the structures and scrap on these islands.

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.

Radiological survey measurements of structures and scrap metal were recorded directly on as-built drawings provided by H&N. These drawings were also used by the engineering team to locate the structures they were examining.

Contaminated structures and activated/contaminated scrap were found on a number of islands. The locations of this scrap and the contact exposure rates measured were indicated on the as-built drawings. Area exposure rates and approximate isopleths were also shown on the drawings so that a simple comparison could be made between scrap radiation levels and the surrounding "background".

The report to DNA was compiled into a three-volume document to provide an engineering study of the condition of Enewetak Atoll. It also includes recommendations, schedules, and cost estimates for mobilizing and demobilizing construction and base forces, logistics, and cleanup procedures.

The structures, facilities, and debris found on the atoll in 1972 were the result of World War II activities, nuclear testing, missile testing, and other programs conducted by governmental agencies. The H&N report outlined as follows the work necessary "to make the atoll safe for occupation":

1. Demolishing and disposing of all structures that, by their presence, constitute safety hazards.

2. Disposing of all debris deemed to be a safety hazard.

3. Disposing of radioactive materials and reducing the radiation emitted from soils that exceed permissible residual radiation levels.

Volume I contains an island-by-island survey consisting of aerial photographs of each island and a listing of all structures and other construction on each. The condition of each item was indicated as well as a recommendation for it to be removed, left as is, or that some modification or rehabilitation be done. Each decision was based primarily on potential use to the Enewetak people, present or future, which the item represented.

Volume II is an oversize assembly of individual maps of all the islands. Each map shows the location of each structure, item of construction, junk pile, concrete strip, and bomb test station, as well as of stands of vegetation and other natural features. Also shown are such items of radiological interest as contaminated burial areas, contaminated scrap heaps, and other radioactive debris.

Volume III contains detail and summary cost estimates. The estimate at that time (April 1973) for cleanup alone was approximately $28.85 million. However, the cleanup actions to which this estimate applied differed considerably from actions actually taken during the 1977-80 cleanup.

2.1.4 AEC Surveys, 1971-1973

Survey of July 1971. When the Air Force was planning to conduct the PACE programs at Enewetak, the AEC/NV was requested to perform a radiological reconnaissance as part of the site selection phase. In July of 1971, a two-man team (one of the members was borrowed from EPA Las Vegas) made radiation measurements on six islands of interest to the pending Air Force program. Islands

surveyed were Irene, Janet, Sally, Tilda, Ursula, and Yvonne. Exposure rate measurements showed that Yvonne had the highest reading of the islands visited. The survey report stated that the contaminated metal scrap on Janet probably constituted the major radiological hazard on that island. A tabulated summary of radiological conditions indicates that the highest exposure rates on Yvonne were in the order of 1 mR/h at 1 meter while the highest on Janet was one-tenth as high. Exposure rates on Irene were twice those on Janet, while on Sally the readings averaged 15 uR/h. Alpha contamination was observed only on Yvonne in the vicinity of the Fig/Quince GZ. (Costa and Lynch, 1971.)

The original Air Force plan for the PACE programs called for high explosives detonations to be conducted on Janet and Yvonne. Resulting craters were to remain for undetermined future study. In response to requests by the Enewetak Marine Biological Laboratory of the University of Hawaii, the AEC, and EPA, islands other than Janet were considered for PACE test sites, as Janet was a potentially valuable land asset. Island Sally was finally selected instead of Janet, based partially on the results of the radiological reconnaissance.

Program of September 1971. Based upon findings of the July 1971 reconnaissance survey, a comprehensive radiological program was initiated for PACE on 27 September 1971. AEC and EPA personnel assisted in the establishment of the program conducted by the Air Force which included surface surveys and soil and water sampling of the islands of interest. Extensive radiological surveys were conducted on Irene, Sally, Tilda, Ursula, and Yvonne with the readings confirming those recorded in July 1971. An alpha contamination area on Yvonne was defined in detail and fenced off. Two sites on Sally known to contain plutonium contamination were surveyed for leakage. No leakage was found but the areas were fenced off anyway.* (PACE, 1971.)

Survey of May 1972. When it became apparent, early in 1972, that Ambassador Williams planned to commit the United States to relinquish control of Enewetak to the Trust Territory administration, NV recommended and AEC/HQ approved an extension of the Spring 1972 survey of Bikini to include Enewetak.

In the Enewetak portion of the survey, an attempt was made to cover as many islands as possible, with 18 of the 43 islands actually visited, thus bringing to 21 the number of islands for which recent data had been collected. The results of this survey showed the same pattern of atoll-wide contamination suggested by the 1971 survey, namely, that the northern islands contained significantly high levels of contamination while the southern islands had low levels of radiation. Data from the survey were used to guide the planning and execution of the much larger survey begun in October 1972.

Survey of 1972-73. Extensive planning preceded the start of the Enewetak Atoll pre-cleanup radiological survey, authorized 7 September 1972, which had the following specific objectives:

1. To locate and identify contaminated and activated debris.

2. To locate and evaluate any significant radiological hazards which could complicate cleanup activities.

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

The Nevada Operations Office distributed a planning directive on 4 October 1972 which outlined the purpose, objectives, and plan for the 1972 Enewetak Atoll Radiological Survey, established authorities, responsibilities, and procedures for its execution, and set forth program policy, definition, coordination, and authorization for funding. (NVO-121, 1972.)

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*In 1957, the Kickapoo and Yuma tower bases were each covered with a 3-inch layer of clean concrete and a bronze plaque attached which stated, "This three inch thick slab covers plutonium contaminated concrete debris." These two remains were erroneously identified as "crypts" by PACE personnel and the misnomer persisted into the cleanup project.

Field work for this survey was conducted between October 1972 and February 1973. Laboratory analysis of the samples collected continued into July 1973 and the final report, about 2,200 pages in three volumes, was published in October 1973 and distributed early in 1974 with the title "Enewetak Radiological Survey." (NVO-140, 1973.) Actual cleanup at Enewetak during 1977-79 relied heavily on the large quantity of data and maps found in NVO-140 for guidance in planning the overall field effort and the day-to-day details of project operation.

No attempt will be made here to summarize the results of NVO-140. Instead, the three-page Abstract has been reproduced and is included as Figure 2-1 to illustrate the primary thrust of the project. In accordance with objective 3 stated above, the Abstract deals primarily with the data required for judgments as to whether or not all or any part of the atoll can be safely reinhabited.

2.1.5 AEC Task Group Report

On 7 September 1972, the AEC agreed to provide radiological criteria for cleanup and rehabilitation of Enewetak Atoll to DOD and to the Department of the Interior (DOI). AEC also agreed to conduct a comprehensive radiological survey, as discussed in Section 2.1.4. In July 1973, a Task Group was established to review the survey findings and to prepare cleanup and rehabilitation recommendations for consideration by the Commission. Two members of the Task Group were from the AEC, and two were from Lawrence Livermore Laboratory (LLL). The Task Group utilized seven advisors and consultants, six of whom were from various divisions within the AEC. Representatives from DNA, EPA, and DOI attended Task Group meetings.

The job of the Task Group was to recommend for consideration by the Commission, radiological criteria for cleanup and rehabilitation of Enewetak Atoll and to recommend those remedial measures and actions needed to reduce exposures of the Enewetak people to levels within these criteria; the underlying objective was to keep exposures as low as practicable. At the time the Task Group was established, there were no criteria applicable to remedial action for soil contaminated with plutonium. However, an interim standard was proposed (Healy, 1974) during the period the Task Group was in deliberation, ano this proposal was utilized in formulating final recommendations. The Task Group, advisors, and consultants reviewed the AEC Radiological Survey results (NVO-140); then-current information on the life style, diet, and rehabilitation preferences of the Enewetak people; applicable radiation protection guidance established by various national and international radiation standards-setting bodies; and then-current laws and regulations pertaining to disposal of radioactive waste materials. In its final report the Task Group notes that "...experts are not in agreement as to the critical organ for inhaled plutonium, whether to use an average dose for this organ, or the model to be used to predict dose." (Task Group, 1974, App. IIL)

The objective for cleanup at Enewetak was stated by the Task Group in the following passage:

> "For contaminated soil, other than plutonium, the Task Group has not included removal of such soil in its recommendations and therefore there would be no requirement to select a method of disposal. If such disposal were required, the objective would be to assure that there would be no pathway for any exposure of the Enewetak people to this radioactivity and a minimal follow-up requirement to insure that this situation continues after disposal.
>
> "The Task Group view is that because of its extremely long half-life, disposal of plutonium in the form of contaminated soil and scrap is a problem of greater magnitude than for fission products and induced activity. In its deliberations, the Task Group has assumed that the disposition of such material will be such that there is no potential for exposure of the residents of the Atoll once cleanup has been completed. This is then the objective for cleanup." (Task Group, 1974, p.15.)

Recommendations developed were considered by the Task Group most appropriate for the U.S. Government to translate into actions to provide a radiologically acceptable environment for the Enewetak people. The complete text of the recommendations is reproduced in Figure 2-2 for reference. The final report of the Task Group was released in June 1974, whereupon the group was disbanded.

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}Sr, ^{137}Cs, ^{60}Co, and ^{239}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 levels 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.

	30-year integral dose, rem Unmodified conditions									
Living	Inhalation			External Bone,	Terrestrial		Marine		Total	
pattern	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	6.4	75.	0.053	0.84	11.	80.
IV	0.47	0.59	0.24	10.	21.0	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 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 ^{90}Sr- and ^{137}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.

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

Food	^{90}Sr dose to bone, %	^{137}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.

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 can 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^3 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^3 of material.

FIGURE 2-1. ABSTRACT FROM ENEWETAK RADIOLOGICAL SURVEY REPORT, NVO-140.

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

Location	30-yr integral dose, rems			
	Unmodified soil case		Modified soil case[b]	
	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[c]	3.0	3.0	3.0	3.0

[a]Sum of all pathways for the Enewetak living patterns (i.e., external, inhalation, marine, and terrestrial).

[b]Soil modified by placing 2 in. of clean gravel in the village area and plowing the agricultural area.

[c]Based upon background of 100 mrem/yr at sea level.

FIGURE 2-1. ABSTRACT FROM ENEWETAK RADIOLOGICAL SURVEY REPORT, NVO-140 (CONTINUED).

RECOMMENDATIONS

After careful review of all available radiological data the Task Group members' specific recommendations are as follows:

1. The people of Enewetak Atoll may be safety returned to their homeland provided certain actions are taken and precautions observed.

2. In the interest of achieving a minimum practicable radiation dose for the Enewetak people the Task Group recommends that:

   a. The first villages and residences be constructed on ELMER, FRED, DAVID, or on any of the southern islands (ALVIN-KEITH) that the Enewetak people choose.

   b. Growth of all subsistence crops such as pandanus, breadfruit, tacca, pigs, chickens, and all other terrestrial food stuffs except coconut be limited to islands ALVIN-KEITH.

   c. Subsistence and commercial coconut may be grown without remedial measures on any island in the Atoll except ALICE, BELLE, CLARA, DAISY, IRENE, JANET, and YVONNE.

   d. Fishing be permitted anywhere.

   e. Travel be unrestricted to all islands except YVONNE. When the Pu contamination on YVONNE is removed, the restriction of travel to that island can be lifted.

   f. Wild birds and bird's eggs be collected anywhere.

   g. Coconut crabs be collected only on the southern islands (ALVIN-KEITH).

   h. Wells which are intended to provide fens water for human consumption or for agricultural use be drilled only on the southern islands (ALVIN-KEITH). When drilled, water from each well should be checked for bacteria, salinity, and radioactivity content before the well is approved for use.

3. It is recognized that the people of Enjebi have a strong desire to return to live on that island. The island contains three ground zero locations from nuclear tests and was within about 3 miles of the Mike event that had a total yield of about 10 Megatons. According to the survey results presented in NV-140, Enjebi was the most heavily contaminated of the larger islands in the Atoll. The Task Group has been unable to determine any way in which radiation exposures can be brought within the acceptable criteria, that is both reliable and feasible, in order to resettle Enjebi at the same time as islands in the south of the Atoll. It is reasonable to expect that one day the island can be resettled. There appear to be two possible approaches:

   a. Soil removal followed by studies using test plantings to determine when exposure for Enjebi residents would be within acceptable criteria.

   b. Conduct of studies using test plantings to determine when exposures would be within acceptable criteria but no soil removed.

   In either case, housing construction and planting of subsistence and commercial crops would be deferred until research with test plantings showed acceptably low levels of radioactivity. The Task Group recommends the second approach as one having minimal adverse impact on the island environment.

4. The research program in 3 above should also include a determination of radioactivity levels in coconut and other food crops produced on PEARL, CLARA, ALICE, and BELLE. YVONNE should also be included after removal of plutonium contaminated soil.

5. All radioactive scrap metal and contaminated debris identified during the Holmes and Narver Engineering Survey should be removed. If additional contaminated debris is discovered in the course of cleanup and rehabilitation operations, it too should be removed. Specifically included in this recommendation are the three locations on SALLY and one on ELMER where contaminated debris is known to be buried. This debris should be exhumed and removed.

6. The quarantine of YVONNE, put into effect by the Air Force on May 26, 1972, should be continued in effect until the cleanup of plutonium contamination on that island has been completed. Should any Enewetak people return to the Atoll before cleanup is begun or before completion, an authority responsible for enforcement of the quarantine should be identified and should be in residence in the Atoll when people return.

7. The distribution of plutonium contamination on YVONNE is sufficiently complex that specific recommendations for cleanup cannot be presented. It is expected that the true picture of this contamination will unfold as the decontamination effort proceeds. The area observed to have pieces of plutonium and the highest soil concentrations is the interior and shoreline of the island beginning at a line drawn from the ocean reef to lagoon 60 meters north of the tower (hardtack Station 1310) to CACTUS Crater. See Fig. 152, page II-17, Appendix II. Presented are some of the requirements and objectives that will establish a background from which plans can be made for recovery of plutonium on YVONNE.

   a. A team of experts should be assembled who can make and interpret field radiation and radioactivity measurements, advise on cleanup actions envolving plutonium and other radionuclides, and provide necessary health physics support including protection of workers, decontamination of workers and equipment, and packaging and handling of collected contaminated materials. A Public Health Service group, which is now part of the Environmental Protection Agency, EPA, provided radiological assistance for cleanup of Bikini Atoll. Similar support should be sought from EPA for Enewetak Cleanup.

   b. Decontamination of YVONNE is seen as an interactive process, namely, removal of soil, monitoring of radioactivity levels, and removal of more soil. This amounts to a search for the higher plutonium levels in soil with removal according to the guidance provided.

   c. The objectives of the cleanup are two:

      (1) Recovery of the pieces of plutonium that have been observed on or near the island surface. Some contain milligram quantities of plutonium metal and are easily detected with field survey instruments such as the FIDLER.

      (2) Recovery of plutonium contaminated soil. To a first approximation, the location of the zones of higher Pu concentrations are shown in the survey profile samples.

FIGURE 2-2. RECOMMENDATIONS FROM THE REPORT BY THE AEC TASK GROUP ON RECOMMENDATIONS FOR CLEANUP AND REHABILITATION OF ENEWETAK ATOLL, JUNE 19, 1974.

d. Recovery of plutonium in soil at concentrations greater than 400 pCi/g $^{239,240}Pu$ at any depth these levels are found. The justification is that plutonium at some depth may one day be at the surface. Also, recovery of contaminated soil sufficient to reduce surface levels to a value well below 40 pCi/g $^{239,240}Pu$. The justification is to keep air concentrations of resuspended plutonium to levels well within national and international standards. After soil removal, all areas should be resurveyed to ensure no pieces or hot spots of plutonium remain.

8. Plutonium contaminated soil on IRENE should be handled the same as on YVONNE and using the same general criteria for removal except it is not expected that pieces of plutonium metal will be found.

9. Since it is recommended that replanting of food crops be limited to certain islands, test plantings of pandanus, breadfruit, coconut, and arrowroot should be made, as soon as growth can be assured, on each of the islands indicated for such crops by the Enewetak people. As edible parts of these plants become available, their concentrations of ^{90}Sr, ^{137}Cs, $^{239,240}Pu$ and any other significant radionuclides should be measured and compared with the radiological survey predictions. These studies will provide for a determination to be made of the earliest time at which planting of food and commercial crops can be made on islands other than those listed in 2b. and 2c. above.

10. An underground lens water sampling and analysis program should be conducted in which samples are taken over a period of at least 12 calendar months. Bacterial content, salinity, and radionuclide content should be measured, but primary emphasis of the program should be placed on development of an understanding of processes which are operating - or which can be made to operate - to reduce the ecological half-life of ^{90}Sr and ^{137}Cs below the radioactive half-life on the northern islands, especially JANET.

11. A comprehensive air sampling program should be conducted over a period of 12 consecutive months under conditions closely approximating human habitation and expected soil disturbance. This would add to the body of available information on radioactivity levels in air. This program could be conducted coincident with and in support of cleanup operations.

12. Base-line surveys of body burdens and urine content of ^{137}Cs and ^{90}Sr should be made for the Enewetak people prior to return to Enewetak Atoll, after the first year of residence, and as appropriate thereafter. Resurveys of the environmental radiation and radioactivity levels should be made starting in the first year of return and repeated every other year. To be determined is the adequacy of the diet and the actual average daily dietary intake of radioactivity for various age groups for comparison with estimated levels and how radioactivity levels in water, air, soil, plants, and animals are changing with time. (Included should be measurements of radionuclide content of air and collection of information on the chemical and physical form and size distribution of particles in the air containing ^{239}Pu.) Information from such surveys will provide a continuing check of the radiological status of the people and the environment and will assure that the exposure criteria is not being approached or exceeded.

13. Considering that the method of disposal of plutonium contaminated soil and scrap has not yet been decided, that not enough information is available to determine whether it is feasible to remove plutonium from the soil to reduce the amount of material requiring disposal, and not wanting such problems to delay cleanup and rehabilitation of the Atoll, the Task Group recommends the following:

a. As a minimum, cleanup should accomplish the recovery of plutonium contaminated soil and scrap into storage on YVONNE.

b. The YVONNE quarantine should remain in effect with access controlled and all visitors and workers monitored as for a radiation control zone.

c. If disposal is deferred for further study, such study should be planned and conducted promptly.

14. The cleanup phase of rehabitation, i.e., removal and disposal of contaminated scrap, debris, and soil, should be carefully documented in a comprehensive final report from those conducting the cleanup operation.

15. The planning and conduct of cleanup, including radiological support for cleanup, should be similar to cleanup of Bikini Atoll and advantage taken of that experience. As Bikini people were given opportunity for employment during cleanup, an equal opportunity should be given Enewetak people if they desire.

FIGURE 2-2. RECOMMENDATIONS FROM THE REPORT BY THE AEC TASK GROUP ON RECOMMENDATIONS FOR CLEANUP AND REHABILITATION OF ENEWETAK ATOLL, JUNE 19, 1974 (CONTINUED).

2.1.6 Meeting of September 1974

The first draft of the Master Plan (see Section 2.1.7) for resettlement of the Enewetak people on their home atoll included plans for residential development on Janet (Enjebi). However, the AEC Task Group Report stated that the group "has been unable to determine any way in which radiation exposures can be brought within the acceptable criteria, that is both reliable and feasible, in order to resettle Enjebi at the same time as islands in the south of the Atoll." A Draft Environmental Impact Statement (DEIS) for the proposed cleanup of Enewetak was in preparation at the time the Task Group Report was released in June 1974. The plan outlined in the DEIS was based on postponement of the resettlement of Janet. In recognition of the impact this development would have on the people of Enewetak, the decision was made to release the Draft Statement to the public at the same time that the Statement was presented to the people of Enewetak. The presentation was made to the leaders of the Enewetak people at Enewetak in meetings held on 6 and 7 September 1974.

Lieutenant General Warren D. Johnson, Director, DNA, summarized for the people of Enewetak events and actions that had occurred to that time. Following descriptions of early surveys and planning efforts, a movie was shown depicting the radiological survey, in order that the people might appreciate the extensive work upon which the AEC recommendations were based. AEC representatives presented a discussion of radiological conditions at Enewetak using slides which ERDA, successor to AEC, later produced as a pamphlet for distribution to the Enewetak people (ERDA, 1975). The Director, DNA, continued with explanations of the Engineering Survey, planning for construction of residences, the Master Plan, and finally the DEIS. He explained that cleanup and rehabilitation would be in accord with the Case 3 recommendations which precluded living, and growing of certain foods, on the northern islands.

A number of issues were raised during the course of the meeting, including:

1. Some of the U.S. officials questioned whether it was "safe" to permit the return of a token group to Japtan; whether the people could be relied upon to stay off Yvonne and the Northern Islands. When the Enewetak Council learned of this they immediately convened and that very night passed an ordinance, relevant portions of which are quoted below:

   "WHEREAS the conditions existing on Enewetak Atoll require that certain safety precautions be taken with respect to the movements and activities of the members of the settlement and the Trust Territory of the Pacific Islands, the Department of Interior and the Atomic Energy Commission have suggested certain precautions and limitations in a memorandum to the Council on September 9, 1974, and

   "WHEREAS the Council is in full agreement with those precautions and limitations,

   "NOW THEREFORE THE FOLLOWING ORDINANCE IS ADOPTED:

   "Section 1. This ordinance shall apply to all persons residing or visiting on Japtan Island, Enewetak Atoll, in connection with the temporary settlement there.

   "Section 2. No person shall visit or enter into that area in the northern or western part of Enewetak Atoll bounded by Runit Island in the east and Biken Island in the west and including all the intervening beach, island and reef areas."

   "Section 6. This ordinance shall be enforceable by the District Administration and violation thereof shall be punishable by a fine of One Hundred Dollars ($100.00) and the Council pledges its full assistance in enforcement."

   (Council, 1974.)

2. AEC officials were asked by the representatives of the Enjebi people what could be done about Enjebi and how soon. The AEC promised to continue studies.

3. Enjebi people asked when Enjebi might be resettled. The AEC answer was, "We don't know, but we will undertake studies to try to be able to answer the question within about five years."

Among the commitments made by AEC: an experimental farm would be established on Enjebi in order to better understand the food chain problem.

4. A major theme of all of the discussions at Enewetak in September 1974 was the people's expressed desire to actively participate in planning of the rehabilitation and resettlement and, to the extent that opportunities might exist, to be employed in support and construction efforts. They were assured that all effort would be made to accommodate these wishes.

In the months that followed, the people of Enewetak worked with project planners to revamp the entire schedule of residence locations to eliminate from the Master Plan any construction on Janet. The community facilities and residences originally planned for Janet were, for the most part, rescheduled for Elmer.

2.1.7 Master Plans

Authority for preparation of the Enewetak Atoll Master Plan for Island Rehabilitation and Resettlement of the Enewetak people was granted by the Government of the Trust Territory of the Pacific Islands to H&N through an agreement dated June 13, 1973.

The purpose of the Master Plan was to provide an in-depth study to be used as a basis for developing both immediate and long range programs for the rehabilitation and resettlement of Enewetak Atoll. The plan involved the Enewetak people, through their planning council, in the various decision-making processes to the maximum extent possible. It provided cost estimates for use by the Department of Interior and the Trust Territory of the Pacific Islands in budgeting for the programs. The plan also contained a preliminary study of long range market areas that might be developed to broaden the economic base of the Enewetak people.

The scope of work in preparation of the Master Plan included the following items of work:

- Master Land Use Plans
- Conceptual Plans and Models for Residences and Community Buildings
- Agricultural Plans
- Utilities Plan
- Industrial Facilities Plan
- Preliminary Study of Potential Market Areas for Commercial Development
- In-Depth Review of Existing Facilities and Assets
- Budget Estimates

The Master Plan was first released in November, 1973, and was based on several assumptions which were negated by later developments. Following the publication of the first Master Plan, the results of the AEC's radiological survey were published. In addition, the report of the Task Group was distributed in June, 1974, wherein it was recommended that resettlement of Janet be delayed. Also, the DNA's Draft Environmental Impact Statement (DEIS) for the Cleanup, Rehabilitation, and Resettlement of Enewetak Atoll was distributed to the public in September, 1974. The DEIS Case 3 followed the recommendations of the AEC Task Group Report relative to radiological cleanup of the atoll, the living patterns of the people and local food sources.

The introduction to the revised Master Plan (1975) stated:

> "The people of Enewetak among themselves have determined on which islands they wish to reside. Land has been reallocated and both the driEnjebi and the driEnewetak will live on Enewetak, Medren, and Japtan islands. These determinations were made known to the TTPI during the Ujelang field trip in December, 1974.

"Other developments subsequent to the dissemination of the 1973 Master Plan include the projected early return of approximately 50 of the Enewetak people to Japtan at their request. They will be accompanied by a Marshalls District representative and a health aid. This is expected to take place during the first half of 1975. This event was agreed upon at an inter-agency planning meeting held in January, 1975. In addition, a ground water survey of selected islands in the atoll and a test planting program on Enjebi have been initiated. The latter is for the purpose of evaluating the uptake and redistribution of radionuclides from the soil by plants under various conditions.

"Assumptions upon which the Master Plan is based are:

- Prior to atoll rehabilitation, the condition of the islands will reflect the degree of cleanup depicted by Case 3 of the Environmental Impact Statement.
- Development of Enewetak Island for use as an inhabited island is the basic plan.
- Japtan also will become an inhabited island (4 families).

"The plan presents all necessary elements required for the orderly development of Enewetak Atoll and encompasses the desires of the Ujelang people as discussed with them during a field trip in December, 1974. It covers all aspects of residential, island community, and agricultural requirements and presents a review of potentials for economic development of Enewetak Atoll. Recommendations for implementation of the plan, along with a preliminary construction schedule for rehabilitation, and a budget estimate are included." (Master Plan, 1975.)

The Master Plan was published in four volumes. Volume I describes plans for land use and the development of island communities, and includes a review of potentials for economic development. Volume II is a collection of some of the documents upon which the plan is based. Volume III summarizes the costs of providing the housing, community facilities, coconut trees, and other resettlement requirements. Detailed cost estimates appear in Volume IV.

2.1.8 The DEIS and EIS

A Draft Environmental Impact Statement (DEIS) was prepared under supervision of DNA for the cleanup, rehabilitation, and resettlement of Enewetak Atoll. The proposed project was to remove and dispose of debris, structures, and soils which could be physical or radiation hazards or be obstructions to human habitation. The statement was made available to the Council on Environmental Quality (CEQ), concerned federal agencies, and the public on 6 September 1974. Substantive comments on the DEIS were received from federal agencies and the public, all of which were considered and are included in the final Environmental Impact Statement (EIS) filed with the CEQ on 15 April 1975. Several comments on the DEIS raised controversial issues concerning the degree of risk associated with the levels of plutonium which should be permitted to remain in the soil of the atoll. The DNA view was that resolution of such issues was outside the scope of the EIS and rested with agencies charged with the establishment of standards for radiation protection; therefore, guidelines recommended by the AEC would be observed during project execution.

Source documents considered in compilation of the DEIS—all discussed earlier in this chapter—included the H&N Engineering Study, the Enewetak Radiological Survey (NVO-140), the AEC Task Group Report, and the Master Plan for resettlement. Utilizing the materials in these documents it was possible to develop many alternatives in the evaluation of the many human, physical, and cost variables which were present. The EIS states:

"In order to obtain an overview of the possible solutions, a tabulation of twelve illustrative solutions has been made. These involve three separate cleanup procedures for each of four different habitation control plans. The consequences of all these combinations are tabulated. Factors involved in structuring these solutions are radiological conditions, living patterns, physical hazards, and the disposal of hazardous and radioactive materials and scrap. The tabulation analyses presented for these twelve

particular solutions include possible radiation doses and cost-benefit comparisons. Based on this orientation, five solutions hereafter referred to as Cases 1 through 5, are selected for detailed discussion. Of these, two--Cases 1 and 5--are considered to be outside of reasonable limits. Case 1 permits radiological doses greater than the protective guides and Case 5 results in unacceptable ecological damage to the land. The remaining three solutions are considered to illustrate the reasonable means to accomplish the objectives of the program.

"Case 3 is considered to be the most responsive to the established goals and is a balance of the human, physical, and cost parameters which must be considered. It is planned to conduct the proposed cleanup, resettlement, and rehabilitation project as outlined by Case 3. The estimated radiological dose is well below the radiation protection guides recommended by the AEC Task Group; all physical hazards resulting from past construction and testing will be removed and the cost is well below the mid point between other viable solutions.

"Under the conditions of Case 3, the Enjebi People could not expect to return to their ancestral residence island of Enjebi at an early time. This would require both the Enjebi and the Enewetak People to live on land formerly owned and occupied by only the Enewetak People. Thus, until natural decay processes reduce the exposure rates on the northern islands, there would be less land available for agriculture and some supplement to the people's diet may be needed. The people will be subjected to acceptable low levels of ionizing radiation with a relatively low risk." (EIS, 1975)

Case 2 was dropped from consideration because it did not provide a plan of action that would eventually result in the people being able to use the northern islands. Case 4 was not considered further because the uncertainty in the effectiveness of the corrective actions proposed to bring the exposures within the AEC guidelines were so great that the gamble was not justified. (EIS, 1975, p.6-1.)

Since the cleanup project was to be conducted in accordance with the Case 3 objectives, details for only that case are reproduced in Figure 2-3.

The EIS was published in five volumes. Volume I contains a brief history of Enewetak Atoll and its people, followed by discussion of cleanup and habitation alternatives, then detail of the environmental impacts. Volumes II and IIA reproduce a variety of source documents pertaining to the proposed cleanup project. Volume III presents a summary of the EIS in both Marshallese and English. Volume IV contains comments on the DEIS from interested parties and replies thereto.

2.1.9 Work Toward Project Approval

With the filing of the EIS in April 1975, one major hurdle remained before the cleanup project could start: congressional authorization. The DNA provided cleanup plans, testimony and supporting witnesses to House and Senate subcommittees in the late spring of 1975. The Senate Armed Services Committee agreed to a one-time authorization of $20 million but recognized that the lowest estimate presented was $25 million.

The following paragraph, of interest to ERDA/DOE, was included in the authorizing legislation:

> "The Committee agreed to a one time authorization of $20 million to accomplish the cleanup. The Department is charged to accomplish the cleanup within that amount using every possible economy measure. The committee insists that radiation standards established by the Energy Research and Development Agency be met before any resettlement is accomplished. Although the moral obligation to permit the Enewetak people to return to their atoll was a major consideration, the Committee's decision was based primarily on the premise that the United States cannot walk away from a testing program that cost several billion dollars without making a responsible effort to restore the atoll to the degree that it can be made habitable." (SR 94-157, 1975.)

on interisland visitations and the growing of commercial crops. With respect to the latter, it provides for the clearance of obstructions which would deny use of some of the land. Case 3 also provides for the removal of contaminated scrap to negate the possibility of any radioactive material reaching the world's markets. Although Case 3 is composed of all actions described in Case 2, it also provides for further actions in establishing and maintaining radiological safeguards, such as the quarantine of Runit.

In addition to this quarantine, (Paragraph 5.5.3.1), Case 3 recommends that studies be conducted as follows:

- A test planting program on Lujebi to determine when exposure would be within acceptable criteria without the removal of soil. This program has been initiated.
- A program to determine radioactivity levels in coconut and other food crops produced on Lujor, Kirunu, Bokoluo, Bokombako, and Runit (after plutonium cleanup).
- As an alternate to the preceding program, soil removal on Lujebi, followed by a test planting series to determine whether exposure for Lujebi residents would be within acceptable criteria.
- The assembly of a team of experts to make and interpret field radiation and activity measurements, advise on cleanup actions involving plutonium and other radionuclides, and advise on necessary health physics support for protection of workers, decontamination of workers and equipment, and handling of collected contaminated materials.
- A comprehensive underground water lens sampling and analysis program for a minimum period of 1 year. Bacterial content, salinity, and radionuclide content would be measured every twelve months. However, the primary emphasis would be on the development of understanding those processes which are operating or can be made to operate to reduce the ecological half-life of ^{90}Sr and ^{137}Cs below the radioactive half-life on the northern islands. This program has been initiated.
- An air sampling program, conducted during cleanup, which would obtain samples representative of those that might be expected from the activities of the returned population.

Further, the controlling criteria for radiation exposure developed by the AEC Task Group can be best met by this particular alternative. This is most likely to provide the lowest possible exposure in accordance with accepted guidelines.

5.5.3 Case 3 - Living on Southern Islands, Food from Southern Islands plus Coconuts from 12 Northern Islands. Travel Unrestricted. Material and Some Plutonium Cleanup

Case 3 permits partial use of areas of the atoll having low radioactive levels, greatly reduces radioactive hazards for the indefinite future, and permits living patterns which, with high confidence, are expected to result in population doses well below the ERDA guidelines. This case does restrict habitation to the southern islands, Jinedrol through Kidrenen, and does not recommend specific action against radioactivity in the soils of Bokoluo, Bokombako, and Kirunu (Figure 5-3).

5.5.3.1 Habitation Plan. In Case 3, the Enewetak people would live and obtain food as follows:

- Residence would be restricted to southern islands, Jinedrol through Kidrenen.
- Runit would be quarantined until Pu cleanup is effected and crater containment has been completed. Other travel would be unrestricted.
- Pandanus, breadfruit, arrowroot and other subsistence food would be cultivated on the southern islands only.
- Coconuts would be grown on the southern islands and in the northern islands of Aijikadrek through Billae only. No cultivation would be permitted on the northwest islands of Bokoluo through Lujebi and on Runit.
- Domestic meat would be raised on the southern islands only (Jinedrol-Kidrenen).
- Coconut crabs would be taken from the southern islands only.
- Lagoon fishing and wild bird and bird egg gathering would be unrestricted (except on Runit).

5.5.3.2 Cleanup Actions. The following actions would be taken to clean up the atoll:

- Physical hazards would be removed from all islands.
- Obstructions to development of habitations and agriculture would be removed.
- Radioactive scrap would be removed from all islands in the atoll.
- Nokon, Lujor, and Runit plutonium concentrations greater than 400 pCi/g would be excised and all other concentrations between 400 and 40 pCi/g would be dealt with on an individual basis as described in AEC Task Group Report. Concentrations of less than 40 pCi/g would not be disturbed. Cleanup of Pu is expected to be performed iteratively until a sufficiently low concentration level well below 40 pCi/g is attained. Some 79,000 cu yds of soil are estimated to be in this removal.
- Plutonium would be removed from the three burial crypts on Aomon.
- Unsalvable nonradioactive and noncombustible material would be disposed of by dumping in the lagoon at selected locations for forming artificial reefs.
- Radioactive materials would be disposed of as discussed in Section 5.4.3.2.3, namely by containment in Lucrosse mud, if necessary Cactus craters on Runit.

5.5.3.3 Conclusions. Case 3 reasonably insures a safe habitation plan for the proposed return of the islanders and provides a means of eventual improvement of the environment for the benefit of all of the Enewetak people. By virtue of the fact that it requires removal of only the most seriously contaminated materials, it is less expensive than succeeding Cases 4 and 5. Although this case recommends that Lujebi not be utilized for habitation, it does impose far less stringent limitations

FIGURE 2-3. CASE 3 HABITATION PLAN AND CLEANUP ACTIONS FROM THE ENVIRONMENTAL IMPACT STATEMENT, APRIL, 1975.

The House Armed Services Committee authorized $14.1 million (HR 94-293, 1975) as requested as the first of three increments of a $39.9 million cleanup project. In conference, the House acceded to the Senate position and a one-time authorization of $20 million was passed (PL 94-107, 1975). The House Appropriations Committee denied funding for the project, emphasizing the high per person cost, and stated its belief that the minimum cost had not been presented to the Congress (HR 94-530, 1975). The Senate Appropriations Committee recommended full funding of the $20 million authorization, recognizing the figure as a target (SR 94-442, 1975). In the Committee of Conference, the Senate conferees agreed to defer funding for the project and the committee expressed the belief that other alternatives should be explored by the DOD and DOI to determine the best and most economical means of returning the Enewetak people (CR, 1975).

Efforts to gain funding approval continued into the spring of 1976. These efforts included making arrangements for a visit to Enewetak in February 1976 for on-site inspection by a staff assistant to the House Appropriations Subcommittee on Military Construction and a staff assistant to the Senate Military Construction Appropriations Subcommittee. Crucial hearings were held by the House Committee on Appropriations on 29 March 1976. The Director, DNA, presented revised cleanup plans reflecting diligent effort to achieve the minimum cost as requested at hearings the year before. In addition, several high-level supporting witnesses provided testimony to emphasize the awkward position the U.S. Government would face if the problems created in the Pacific by nuclear testing were not remedied before the U.S. terminated the Trust in 1981. Following extensive questioning of witnesses, including an ERDA representative who reported on radiological conditions at Enewetak and on protection of future residents, the committee approved $15 million of the $20 million requested by DNA. On 22 June 1976, the Senate Committee on Appropriations recommended approval of the full $20 million appropriation. In the conference to resolve Senate and House differences, the conferees approved the $20 million request. Subsequently, an appropriations bill was passed by both the House and the Senate and signed into law. The act provided:

> ". . .that none of the funds appropriated under this paragraph may be expended for the cleanup of Enewetak Atoll until such time as the Secretary of Defense receives certification from appropriate administering authorities of the Trust Territory of the Pacific Islands that an agreement has been reached with the owners of the land of Enewetak Atoll or their duly constituted representatives that this appropriation shall constitute the total commitment of the Government of the United States for the cleanup of Enewetak Atoll.
>
> "All feasible economies should be realized in the accomplishment of this project, through the use of military services' construction and support forces, their subsistence, equipment, material, supplies and transportation, which have been funded to support ongoing operations of the military services and would be required for normal operations of these forces. Further, such support should be furnished without reimbursement from military construction funds." (PL 94-367, 1976.)

With funding authorized, the cleanup project was scheduled for implementation during fiscal year 1977, and execution to occur over a period of about 30 months.

There were a number of other activities of note between April 1975, when the EIS was filed, and July 1976, when funding was authorized. The cleanup plan that formed the basis of the EIS involved disposal of contaminated debris and soil in the Lacrosse and Cactus craters on island Yvonne. The EIS discussed and dismissed several alternative disposal methods including ocean dumping. The DNA concluded from discussions with the EPA that ocean dumping would not be permitted, or at best, several years could be consumed in seeking a permit which would not be assured in advance and might not be issued in any case. DNA held that to delay the cleanup project while seeking a permit to dispose of contaminated soil and debris in the deep ocean might well mean the project could not be done within the time, money and political constraints surrounding the cleanup. The AEC position was that the cleanup of Enewetak might total about 10 Curies of plutonium, an insignificant amount compared to that which was already in the water and sediments of the lagoon

and nearby ocean. In addition, both the total inventory and the average concentration level of soil and debris to be disposed of were well below the limits set by international agreement to which the U.S. was signatory.

An agreement between DNA and AEC/ERDA negotiated and signed during the summer of 1975 became an important center of controversy in the years that followed. The purpose of the agreement was ". . . to define the technical support ERDA is to provide DNA and likewise to define the support DNA is to provide ERDA and its contractors during the time DNA is actively engaged in cleanup operations at Enewetak Atoll. The determination as to when the DOD cleanup activities have been successfully completed will be a joint DNA/ERDA decision." The majority of the agreement, reproduced on the microfiche (AGREE, 1975), was understood and acceptable to both sides as written; however, two points were later subject to differing interpretations and became issues which were not resolved for several years. Specifically these points stated:

In 2.a. ERDA agrees to:

> "(3) Providing an official ERDA representative(s), without reimbursement by DNA, who will be present on the atoll during the cleanup. The ERDA representative will advise the DNA Enewetak Atoll Commander (Cleanup Project Coordinator) on schedules and procedures and recommend changes thereto as needed, and provide certification when radiological cleanup meeting the guidelines established by the AEC (ERDA) in their Task Group Report has been accomplished." (Underlining added.)

> "(4) Performing, with full reimbursement from DNA, radiological support for the cleanup operation to include (but not limited to): ...(c) Certification, on an island-by-island basis, when radiological cleanup meeting the guidelines established by the AEC/ERDA in their Task Group Report has been accomplished." (Underlining added)

Resolution of the two issues, reimbursement and certification, will be presented in Sections 2.2.2 and 2.2.6, respectively.

Other activities occurring during the wait for project funding were accomplished without controversy but not necessarily without disagreement. These activities included generation by DNA and review by ERDA of a radiological plan for cleanup, development by DNA of a concept plan (CONPLAN, 1976) for the entire cleanup project, and later an operations plan (OPLAN). AEC/ERDA input to these plans, and review of sections involving ERDA, required numerous plan drafts and discussion conferences. The controlling document on hand when the mobilization phase of the cleanup project started was OPLAN 600-77. (OPLAN, 1977.)

2.1.10 Operations Plan (OPLAN 600-77)

Planning for the cleanup and rehabilitation of Enewetak Atoll began in the fall of 1972 and was allotted a significant effort by DNA during the next four years. Congressional resistance to the funding requests was not overcome until July 1976, when Congress authorized a one time expenditure of $20 million to complete the cleanup task. Estimates of actual costs were several times the funded amount, but the DOD was expected to make up the balance with resources already programmed for other purposes.

A basic concept plan for cleanup and rehabilitation was developed, then modified through a series of revisions to adjust to the funding stipulations mandated by the Congress. When cleanup funds were authorized, the concept plan was expanded and refined in a series of planning meetings with the operations plan, OPLAN 600-77, as the end result; portions relevant to ERDA aspects of the cleanup are presented in Appendix E.

2.1.11 The In-Situ System

During the time awaiting funding of the Enewetak Atoll cleanup, ERDA was conducting a radionuclide characterization and survey program of the old aboveground nuclear test areas at its Nevada Test Site (NTS). ERDA was aware from this program that the sole use of soil sampling to characterize the radionuclide concentrations (particularly Pu) is time consuming, extremely expensive, and produces large uncertainties. Therefore, ERDA began investigation of other methods to characterize surface contamination. One highly promising method was the use of a high-resolution gamma ray spectroscopy system in place in the field (in-situ). During October 1973, Lawrence Livermore Laboratory (LLL) conducted tests at the NTS to determine feasibility of the in-situ system. Early in 1976, they returned with a new Germanium-Lithium (GeLi) detector optimized for ^{241}Am detection. (With isotopic ratios, Pu can be inferred from ^{241}Am). The results were sufficiently promising that ERDA developed a concept for a dedicated, self-contained, vehicle-mounted production type in-situ system later to be known as the "In-situ van." Construction of the in-situ van was begun during the summer of 1976 by EG&G, one of ERDA's contractors. By the end of the year construction and testing had been completed.

On 24 June 1976, a briefing on in-situ technology was given to ERDA/HQ staff in Germantown, MD. The briefing included the recommendation that this in-situ technology be used on the Enewetak cleanup in order to improve confidence in the required survey measurements and to drastically reduce the amount of expensive radiochemistry that would be needed. However, the final decision to use in-situ technology to support the Enewetak cleanup was not made until much later in the year.

EG&G was later tasked by ERDA to design and construct in-situ van systems specifically for the Enewetak cleanup. The first of these systems, later to be known as the IMP (named after the vehicle they were mounted in), was completed and deployed to Enewetak in June of 1977. Two additional IMPs were also constructed and subsequently shipped to Enewetak to support the cleanup effort.

2.2 RESOLUTION OF ISSUES

Phase I, Mobilization, of the Cleanup of Enewetak Atoll (most commonly referred to as the Enewetak Cleanup Project, or ECP) began officially, by DOD reckoning, on 14 March 1977. Advance preparations by a limited crew were designed to accommodate the large group scheduled to arrive at Enewetak on 15 June 1977; this was "D-day", when mobilization began in earnest. ERDA was scheduled to complete many preparatory actions prior to 15 June so that operational aspects of field and laboratory work could proceed on schedule. However, there were still a number of unresolved policy issues requiring the attention of top-level DNA and ERDA management. The issues, stated in the approximate order of resolution, were:

1. Ocean dumping vs. crater entombment.

2. Funding responsibilities.

4. Cleanup criteria and standards.

5. Priority of island cleanup.

6. Island certification.

Two additional issues arose later (after 15 June 1977) and were resolved in due course; they are numbered here in the order of resolution and will be so presented in following sections. Specifically, the two additional issues were:

3. Plutonium vs. total transuranics.

7. Planting of coconuts on northern islands.

Figure 2-4 lists the issues and shows the approximate period each was unresolved. There is no intent here, or in the following sections, to draw attention to the fact that controversy existed, nor

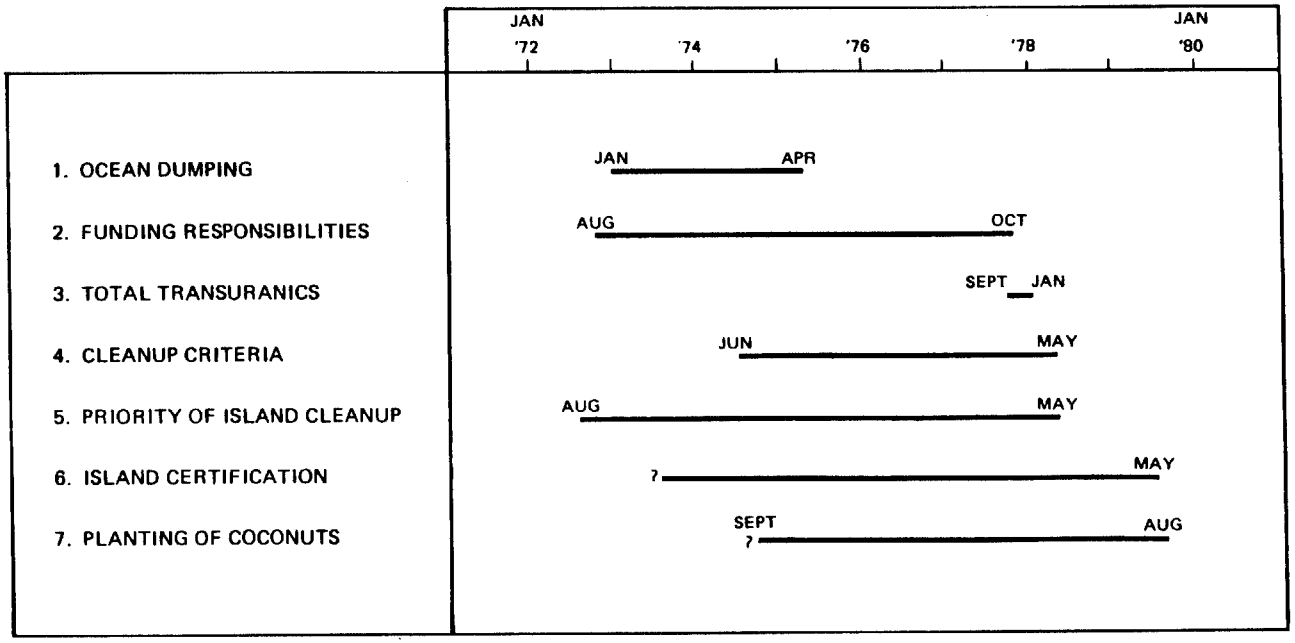

FIGURE 2-4. CLEANUP ISSUES AND THE PERIOD EACH WAS UNRESOLVED

is it intended to show one point of view as superior to another, or to illuminate a "victor" at the expense of a "loser" in any issue. Controversy can, and did, exist for a number of reasons, such as misinterpretation of intent, honest difference of opinion, uncertain interpretation of a poorly defined problem, reluctance to commit to an action with long-term and unclear consequences, to name a few. In the sections that follow, the seven issues will be presented first with background as necessary, then from the viewpoint of each side, then final resolution along with justification for the decisions made. This procedure is intended to document, as well as illuminate, the issues, and to steer readers to more detailed supporting documents, some of which may be found in the microfiche.

2.2.1 Ocean Dumping Versus Crater Entombment

The question of the proper method to be used to dispose of plutonium contaminated soil and debris was not resolved with issuance of the EIS in 1975. As actual soil characterization and removal became imminent the issue was again raised, this time at the ERDA - Marshall Islands Workshop held at LLL on 27-29 June 1977. A large group of ERDA and ERDA contractor personnel had gathered to review ERDA programs in the Marshall Islands, including the decontamination program for Enewetak Atoll. At an informal "rump session" the second evening of this workshop, a group of participants drafted a statement expressing their concerns regarding soil removal and crater containment. On the following day, in open session, their statement was offered to the Chairman for possible workshop discussion. Instead, however, the Chairman chose to accept the memorandum unsigned, and bring it to the attention of Dr. Liverman, Assistant Administrator for Environment of ERDA. The statement included the following:

> "The placement of contaminated concrete slurry into Cactus Crater does not remove this material from environmental interaction, since direct ocean water connections into the crater exist; and present knowledge indicates breakdown and remobilization of Pu will occur. We therefore recommend that the projected soil removal aspect of the Enewetak cleanup should immediately be re-evaluated. We recommend that you re-evaluate specifically the basis for soil removal and the disposition of that which is removed." (Gates, 1977.)

The statement received very limited distribution outside of ERDA but produced two almost immediate results. The first was a flurry of correspondence enumerating the arguments for or against the subjects of the statement. The second was a call by ERDA to assemble a select group of scientists familiar with biological, health and environmental aspects of plutonium to participate in a review of:

1. AEC recommendations for cleanup and rehabilitation of Enewetak Atoll and specifically the criteria for plutonium-239 in soil.

2. Environmental and health implications and long-term monitoring requirements for crater disposal of contaminated debris and soil on Runit Island.

The group of scientists met in Las Vagas, Nevada, on 15-18 August 1977. The chairman of the group was Dr. William J. Bair, Manager, Biomedical and Environmental Research Program, Battelle-Pacific Northwest Laboratory. The group became known as the Bair Committee. The committee heard presentations from several staff members from both ERDA and DNA, and reviewed supporting documents distributed prior to the meeting. In reporting to ERDA, the committee stated:

> "In examining the question of disposal of contaminated soil and debris, the reviewers considered potential human health effects, future maintenance and monitoring requirements, retrievability, potential restrictions on access to Runit Island, implications and risk of reopening the Environmental Impact Statement, costs, quantities of debris, and engineering problems. Weighed against these considerations the reviewers agreed that the planned emplacement of concrete-encased plutonium-contaminated soil and debris in the Cactus Crater would not in itself impose unacceptable human health risks. The method could result in the gradual

release of this plutonium to the marine environment; this would be in addition to the 1500 Ci already in the lagoon sediment. However, for the worst case in which 10 Ci Pu is added to the Crater below the water level, the local lagoon water plutonium concentration would not increase more than by a factor of two. This could lead to an increased dose of a few mrem per year to a person who obtained all of his food from the local marine environment.

"Several alternate disposal schemes, while not significantly influencing the health risk prospects, might be preferable. While it may be inadvisable to change disposal plans at this late date, the reviewers believe you should be aware of the possible advantages of other methods." (Bair, 8/1977.)

Alternate disposal schemes discussed included ocean dumping, lagoon dumping and several methods of terrestrial disposal on Yvonne (Runit) Island. Following distribution of the Bair Committee recommendations, the issue of ocean dumping versus crater entombment was not again raised.

2.2.2 Funding Responsibility

In the first interagency meeting to discuss cleanup of Enewetak, held on 17 August 1972, it was agreed that the source of funding would not be discussed at that meeting. By the end of the 7 September 1972 interagency meeting, the general outline of funding responsibilities had been arranged. It was agreed that AEC would fund the radiological aspects of the 1972 precleanup survey, the conduct of any other radiological survey activity that might be required to understand conditions in the environment as they relate to exposures of people and development of standards, and the conduct of periodic followup radiological surveys that take place after cleanup. If later field and/or laboratory work was to be done by AEC in support of cleanup, AEC should be reimbursed by DOD. DOD would be responsible for funding the engineering portions of the precleanup survey and those monitoring and survey activities that were required to support cleanup operations and to insure safety of personnel involved in cleanup activities. DOD also would fund the later cleanup of both radiological and nonradiological material. DOI would be responsible for funding rehabilitation costs once cleanup was completed. The EPA suggested that if DOD was going to fund the major part of the cleanup, then DOD should prepare the environmental impact statement, and it was so agreed.

At this time it was generally believed that the pending radiological survey would provide detailed information sufficient for making cleanup decisions. However, even with the tremendous amount of data gathered during the 1972-73 survey, without which the cleanup could never have been planned, the cleanup required extensive radiological support. This requirement was not readily apparent to the early planners.

In 1973, while preparing its budget estimates, DNA requested a cost estimate from the AEC for the establishment of a radiochemistry laboratory at Enewetak. The estimate furnished was $1.5 million and that number remained in DNA's planning from 1973 on. No funds were identified in those plans for the acquisition of other radiological support equipment or for AEC/ERDA field operations. The $1.5 million was included in DNA's $39.9 million request to the Congress. When Congress in July 1976 authorized only $20 million, the Director, DNA, wrote in a letter to ERDA:

". . . it is essential that we either accomplish the radiological monitoring within the estimated costs or that any new or additional funding for those tasks outlined in paragraph 2a(4) of our agreement be borne by ERDA." (Johnson, 1976.)

This was in direct conflict with the ERDA-DNA agreement of the previous year wherein it was provided that ERDA would perform radiological support for the cleanup "...with full reimbursement from DNA..." However, the July 1976 letter was not challenged at this time. (AGREE, 1975.)

By November 1976 the scope and duration of ERDA support was becoming more clear and on 2 February 1977 ERDA HQ requested from DNA the release of the $1.5 million and advised that that sum would support ERDA's field participation for only 15 months.

The Office of the Assistant Secretary of Defense informed the Director, DNA, (Queisch, 1977.) that "The $1.5 million programmed under military construction (as a convenience) represents a firm limit on obligations for this purpose against military construction funds," and noted further that additional funding requirements should be incorporated in ERDA's fiscal year 1979 budget request. (The $1.5 million was considered sufficient to support ERDA functions through fiscal year 1978.)

Initial DNA cost estimates for the Enewetak cleanup were based on a contractor supplying the work force on a reimbursable basis, with reimbursement to come from Military Construction (MILCON) funds appropriated by the Congress. When Congress balked at the level of funding requested by DNA, and indicated the maximum appropriation would be about $20 million, the DNA planners were forced to develop alternatives which would not depend on MILCON funding. One alternative was to have troops perform all possible labor, thus to transfer substantial manpower costs to the military services and out of the MILCON account. During the course of DNA-DOE negotiations and planning, DNA agreed to provide military service personnel to support operation of the radiation laboratory, and to perform day-to-day field monitoring, dosimetry and recordkeeping pertaining to health and safety of cleanup personnel. The effects of this arrangement were twofold: about 40 labor positions were transferred from MILCON funding to military service payrolls, and health physics responsibilities for monitoring and dosimetry were transferred from DOE to DNA. The DOE/ERSP Technical Advisor assumed an advisory role to the JTG RADCON office on health physics matters. This change in responsibilities reduced DOE funding requirements over the life of the cleanup project by several million dollars.

On 7 April 1977, FCDNA noted in a letter to ERDA/NV that ". . . an agreement has been reached whereby ERDA Headquarters would provide any additional funds required" (beyond the $1.5 million already allocated). This would seem to end the funding issue—but not so. ERDA advised DNA on 13 September 1977 that ERDA had sought the Office of Management and Budget (OMB) approval for a reprogramming action, but the action had not yet been approved; efforts at resolution were continuing. In the meantime, ERDA was providing $300,000 on an interim basis rather than recall personnel already deployed and would continue to provide, on a reimbursable basis, resources needed for radiological support to the DOD cleanup. The total project cost was now estimated by ERDA to be $5.194 million through fiscal year 1980.

DNA responded to the ERDA letter on 16 September, reiterating the history of the issue and pointing explicitly to the OPLAN, signed by two ERDA representatives, which stated:

> "ERDA will budget for, and fund, complete radiological effort over and above the $1,500,000 provided from MILCON funds."

It was also noted that ERDA's $1.5 million was not reduced pro rata when Congress reduced the MILCON request from $39.9 million to $20 million.

ERDA/HQ assembled a notebook of 23 memoranda and letters exchanged among Interior, DNA, OMB, and AEC/ERDA between 7 September 1972 and 16 September 1977 and submitted the notebook to OMB on 27 September 1977. The transmittal letter stated the ERDA position in these words:

> ". . . the only conclusion permissible from all of this is that ERDA will do the radiological monitoring and certification on a reimbursable basis. On the basis of the understandings in these memoranda, ERDA has not budgeted for these activities. I recommend that OMB determine, in the most expeditious manner, who is going to accommodate the cost and how it should be done so as not to slow down the cleanup activities." (Liverman, 1977.)

On 25 October 1977, DOE representatives met with DOI, DNA and OMB in an attempt to finally resolve the funding problem. Having reviewed the above-mentioned notebook, the group heard additional arguments from both DOE and DNA, the most telling of which was the reading by the Director, DNA, of a telegram from the former Director stating categorically that Dr. Liverman had acknowledged DOE (then AEC) responsibility for funding radiological support (Hollister, 1977). On the same day, subsequent to the meeting, OMB representatives advised by telephone that DOE would be expected to fund the program by reprogramming in FY 78 and should budget for it in FY 79. Thus the $1.5 million ceiling on DNA funding became a firm limitation, and DOE became committed to a total obligation of over $3.5 million over the life of the project.

Tabulated below are the actual costs, exclusive of salary, travel and office costs of DOE/NV staff participants.

	DNA FUNDING (000)		
	FY 77	FY 78	TOTAL
EG&G	$ 417	$ 83	$ 500
H&N-PTD	173	63	236
Eberline	598	97	695
DRI	27	0	27
LLL	8	2	10
REECo	0	10	10
Sandia	0	22	22
Total	$1,223	$ 277	$1,500

	DOE FUNDING (000)				
	FY 77	FY 78	FY 79	FY 80	TOTAL
EG&G	$ 300	$ 319	$ 386	$ 220	$1,225
H&N/PTD	0	284	525	(160)	649
Eberline	0	327	609	52	988
DRI	0	104	154	52	310
H&N/OCTD	0	0	5	151	156
LASL	0	22	20	0	42
LLL	0	24	1	10	35
Sandia	0	4	30	0	34
EPA	0	2	9	0	11
Battelle/PNL	0	0	17	0	17
REECo	0	3	3	50	56
Total	$ 300	$1,089	$1,759	$ 375	$3,523

Total funding for the Enewetak Radiological Support Project is summarized below in thousands:

	DNA	DOE	TOTAL
EG&G	$ 500	$1,225	$1,695
H&N/PTD	236	649	885
Eberline	695	988	1,683
DRI	27	310	337
H&N/OCTD	0	156	156
LASL	0	42	42
LLL	10	35	45
Sandia	22	34	56
EPA	0	11	11
PNL	0	17	17
REECo	10	56	66
Total	$1,500	$3,523	$5,023

The incremental costs for the Fission Product Data Base Program were, in thousands:

Eberline	-	$230
H&N/PTD	-	$ 90
Total	-	$320

These costs were incurred in FY 79 and are included in the overall ERSP totals stated above.

2.2.3 Plutonium Versus Total Transuranics

Presentation of sampling results following the 1972-73 Enewetak Radiological Survey (NVO-140) usually referred to plutonium as ^{239}Pu or $^{239,240}Pu$.

The AEC Task Group Report and the EIS followed the pattern of NVO-140 and continued to refer primarily to ^{239}Pu or $^{239,240}Pu$. There was a tendency to shorten the reference to just "Pu" as may be seen in the discussion of OPLAN 600-77 presented in Appendix E. By the summer of 1977, ERDA staff members were making occasional reference to "transuranics" instead of "plutonium". Two developments in late 1977 brought the question of plutonium vs. transuranics to the forefront. The first was the release by EPA of new dose guidelines for transuranic elements in the environment. The second was discovery that ^{238}Pu concentrations found in the soil of Island Pearl made a significant difference in the volume of soil that might have to be removed to meet the criterion anticipated for this island.

DNA obtained oral assurance from EPA that the new draft guidelines, which were more stringent than earlier guides with regard to transuranics, would not apply to Enewetak, then or in the future. Nevertheless, DNA was concerned that ERDA might adopt and implement the new guidelines independently, creating a much larger requirement for soil removal than had been previously planned. Several DNA staff members attempted to independently evaluate the impact that including total transuranics would have on soil removal volumes. A mathematical/statistical approach indicated the potential volume could increase from about 87,000 yd^3 to about 147,000 yd^3, excluding soil cleanup from Yvonne, and assuming cleanup of all soil indicated to bear total transuranic concentrations greater than 40 pCi/g of soil. (Bramlitt, 12/1977.) Another study compared the response, in terms of soil volume, to changing the intended use of selected islands as compared to including ^{238}Pu and ^{241}Am in the cleanup criteria. The conclusion of this study was that DNA should not object to inclusion of ^{238}Pu and ^{241}Am in calculating soil contamination levels for cleanup, since the impact of inclusion would be considerably less than changing the intended use. (Treat, 12/29/1977.) Both studies utilized data reported in NVO-140, and qualified their conclusions to the effect that ongoing characterization activities could lead to different conclusions.

The ERDA/HQ (DOE as of 1 October 1977) staff, although saying Pu for many years, stated that they had intended to mean transuranics all along. (McCraw, 11/1977.) From September 1977, when DNA began to develop concern over the transuranics question, to late December 1977, when the question had become acute for DNA, DOE/HQ remained silent, except to say that transuranics was always intended rather than just "Pu". (Treat, 12/8/1977; McCraw, 12/1977.)

By late December 1977, several issues requiring attention had developed. A resolution conference was held at DOE/HQ on 6 January 1978. Because DNA had already reached internal agreement not to object to expansion, in their view, to include total transuranics in the cleanup calculations, the conferees were able to report:

> "Consequently, the conference made a tentative agreement subject to confirmation or change, once the full scope is known, that the soil cleanup criteria would be considered to apply to all transuranic isotopes. . . .Since cleanup planning was based on removal of soil contaminated with $^{239,240}Pu$, this change in definition of cleanup criteria might mean the degree of cleanup of certain islands may be more or less than planned in view of the fixed level of funding." (Deal, 2/1978.)

Once the full scope of the cleanup problem was known, there was no change to the inclusion of all transuranic isotopes. Other developments, reported in the next section, overshadowed any questions that remained concerning the "change" from plutonium to transuranics.

2.2.4 Cleanup Criteria

In the interagency meeting of August 1972 (discussed in Sec. 2.1.1), the suggestion was made that it probably would not be difficult to establish criteria for the cleanup of the so-called "clean" islands because in large measure cleanup would simply be removal of debris. For the so-called "dirty" islands, the potentially enormous quantity of debris and soil for removal suggested a requirement for policy determination as to the final disposition of contaminated soil. The alternatives appeared to be in situ burial, lagoon or crater disposal or engineered storage in the continental U.S. The only alternatives to cleanup appeared to be fixation of the contaminants, a permanent quarantine or denial of access to areas of concern.

As part of the 1972-73 engineering survey, it was necessary to make certain assumptions regarding the maximum level of contamination below which no cleanup would be required and to propose disposal methods for soil failing the criteria. The engineering criteria for estimating the magnitude of cleanup, with respect to residual plutonium, were stated as follows:

"1. Residual plutonium will be limited to 500 pCi/g (500 pico Curies of plutonium radioactivity per gram of soil) which is equivalent to 500 micrograms of plutonium - 239 per square meter of soil through the top 5 cm (2 inches) of soil.

"2. For site Yvonne (Runit Island) regions exceeding 500 pCi/g of soil will be removed to a depth of 24 inches.

"3. Any soils with surface contamination exceeding 50 pCi/g not already diffused to a depth of 10 inches or more will be plowed to this depth."

Areas with soil above the residual level limitations were to be reduced to the limits by either removal of soil or covering with soil having negligible radioactivity. Removed soil was to be transported to only one of three alternate areas:

"1. Soil shall be removed to an island with minimal uses for other purposes, such as Runit Island, and used as intermediate "land fill" over contaminated metal and debris.

"2. Soil shall be removed to an underwater disposal area (either at sea or in the lagoon) and dumped.

"3. Soil shall be encased in containers and returned to Conus (continental United States) for burial at a designated location to be determined."

The above criteria were used solely as the basis for constructing scope-of-effort estimates of the cleanup project and had little bearing on final cleanup criteria, although the alternatives mentioned were each evaluated extensively in later deliberations.

The AEC Task Group was assembled in 1973 to develop judgements and recommendations on cleanup and rehabilitation of Enewetak Atoll. The Task Group effort was to arrive at a thorough understanding of the extent and character of the radioactive contamination in the atoll and, more importantly, to examine the implication of this contamination for continuous and long term human habitation. The Task Group based its recommendations on an extensive review of federal and international radiation exposure guidelines and the results of the 1972-73 radiological survey of the atoll. The first draft of Task Group recommendations was distributed to selected agencies for review and comment on 1 February 1974. On 6 March, an interagency meeting was held to discuss the draft report. Summary notes of this meeting by an AEC representative enumerate the different agency views and differences of opinion and are quoted at length below:

"EPA Hold position that current radiation standards are 'upper limits'. EPA will likely look only at risk of exposures rather than at the benefit-risk area. Expressed concern that restrictions for control of exposures may not be effective over the long term. Stated that use of 100% of the genetic criteria is not justifiable. Urged use of Federal standards (FRC) instead of ICRP guidance. Expressed concern that soil removal criteria for ^{239}Pu may not be stringent enough. Cited need for more specific requirement for obtaining additional information on Pu levels in air. Had concern for verification of predicted doses and followup studies. Rejected use of DNA radiation criteria developed from consideration of past cleanup experience (the 'precedent' approach). Support Task Group's approach to development of recommendations.

"DNA Stated a strong preference for their own criteria and need for no other guidance. Feel that they are too far along in their planning and it is too late to change the approach taken last year. Support radiation criteria based upon a review they have conducted of past AEC cleanup experience. Have selected numerical criteria taken primarily from Grand Junction uranium mill tailings experience. Reject Task Group criteria based upon current radiation standards as being too low and too conservative. Support view that the cleanup objective must be to reduce external gamma level with no other cleanup or restrictions required. Support the concept of 'fallback positions' to be used if all necessary cleanup funds are not available. Hold that availability of money will determine extent of cleanup. Reject the 'as low as practicable' requirement.

"DOI Have concern that Janet may not be returned. Support the Task Group's approach to development of recommendations. Are hopeful of actions leading to return of people to Janet. Question when Janet can be returned if not now. Hold position that people will eventually return to Janet.

"HEW See need for more air sampling and investigation of exposure from inhaled Pu. Cited need for information on ^{129}I exposure of the thyroid. Found the Task Group draft a very satisfactory report.

"TASK GROUP Supports use of current radiation standards and philosophy recommended by FRC and ICRP. Cannot support DNA approach to criteria development using cleanup experience such as current effort for removal of mill tailings under and near structures in Grand Junction. Cannot support recommendation of cleanup alternatives wherein basic Federal radiation exposure standards would not be met. Supports position that both internal and external exposures must be evaluated in considering cleanup alternatives. Cannot support concept of fall-back positions to be used if necessary funds for cleanup to acceptable criteria are not available. Hold to position that recommended actions are only those known to be feasible and effective. Cannot support DNA recommendation of use of 'clean beds' of soil for growing food on a contaminated island since this action involves many uncertainties and is unproven as to effectiveness. View of remedial (cleanup) action is that once it is taken, the objective is to make substantial reduction in radioactivity levels, not to reduce levels to some specified value. Support approach of studying all alternatives for cleanup, but to recommend only a preferred set of actions that in the judgement of the Task Group will comply with the 'as low as practicable' requirement. Believe that DNA has misinterpreted and is misusing AEC cleanup experience in citing this as a basis for choosing radiation exposure criteria. Observes that DNA uses a 'worst case' approach to cleanup based upon AEC exposure estimates that are actually average exposures. Believe that DNA recommendations cannot be successfully defended against criticism from those who are familiar with current Federal regulations and standards."

In a cover letter to which the above notes were attached the AEC representative further stated,

> "The differences between the Task Group approach and the DNA approach involve issues that are so fundamental that to try to change the approach and adopt their position would bring us into conflict with both the spirit and letter of regulations that govern Federal agency radiation protection activities. It is not possible to conform to their wishes by merely putting forth a wider spectrum of cleanup alternatives." (McCraw, 1974.)

Viewpoints of the various concerned agencies were exchanged during the next several months. The Task Group continued to work on its recommendations, incorporating many suggestions submitted by reviewers, and responding to critical comments with detailed rationale for positions taken. The final report on recommendations was issued on 9 July 1974 (see Section 2.1.5). The Director, DNA, informed the Chairman, AEC, by letter dated 7 August 1974, that DNA had accepted the AEC staff position on the radiological criteria and the advisory controls necessary for return of the people to Enewetak. Planning began immediately for a meeting to be held at Enewetak to present the DEIS and the results of the radiological survey to the people of Enewetak (as discussed in Section 2.1.6).

Reviewer comments on the DEIS were received by DNA and in one instance ERDA prepared a response. Commenting on the comments supplied by the Micronesian Legal Services Corporation (MLSC), ERDA staff noted:

> "Numerical values of radiation exposure and concentrations of plutonium in soil were recommended by the Task Group as guides for use in evaluating radiological conditions at Enewetak Atoll only. Such guides are not to be considered as standards. These guides were used as limits in evaluating remedial action options in order to recommend actions and restrictions that will insure that exposures of people when they return will not exceed the basic FRC, ICRP, and NCRP standards. These considerations are the basis for actions and restrictions recommended in the DEIS. While there is no National or International standard for plutonium expressed as a concentration in soil, the guides recommended, 40 and 400 pCi/g, were derived using the best current information relating such soil concentrations to possible exposures to man. The guidance for cleanup of contaminated soil was selected such that exposures of people are expected to be well within the basic standard. This guidance has been approved by EPA for use at Enewetak." (Biles, 1975.)

Guidance provided by the Task Group was quite clear with respect to soil with Pu concentration below 40 pCi/g or above 400 pCi/g, but the case-by-case treatment of concentrations between 40 and 400 pCi/g became an obstacle in cleanup planning. There were numerous meetings and exchanges of correspondence during the next two years on this subject with no real progress toward a solution; planners could not identify beforehand specific actions appropriate for treatment of Pu concentrations in soil between 40 and 400 pCi/g.

In the memorandum prepared following the ERDA - Marshall Islands Workshop on 27-29 June 1977, it was noted that:

> "The rationale for removing plutonium-contaminated soil is based on assumptions regarding resuspension of Pu that are not validated by empirical data. Additionally, we question whether the guidelines which have been established for soil removal are supportable.
>
> "The present total inventory of plutonium in the terrestrial environment at Enewetak available for resuspension and resultant dose commitment cannot be significantly altered by the proposed course of action." (Gates, 1977.)

The Bair Committee reviewed criteria for removal of contaminated soil at the meeting of 15-18 August 1977 and concluded: "There was unanimous agreement that the criteria for cleanup of the islands contaminated with plutonium are reasonable in light of present knowledge and their

application does not pose an unacceptable health risk." Elaborating on this conclusion, the Committee stated:

> "The reviewers considered the criteria for the relocation of approximately 10 Ci of plutonium from dispersed locations in the terrestrial environment to a central location in the Cactus Crater on Runit Island.
>
> "The reviewers concurred with the 40 pCi Pu/g soil value adopted in the Environmental Impact Statement as a minimal action level and with 400 pCi/g as the mandatory cleanup level. Using the assumptions in the EIS the reviewers estimated that the lung dose resulting from lifetime inhalation of air containing an equivalent concentration (100 μg soil/m^3 air or 4 fCi Pu/m^3) would be approximately 0.01 rem/year, or 1 mrad/year, assuming a quality factor of 10. This compares with the proposed EPA federal guidance value of 1 mrad/year to the lung from transuranic elements in the environment. The reviewers believe that lung doses from inhaled plutonium will be considerably less than this for persons living and working on the Atoll because of the small land area which minimizes buildup of plutonium concentrations in the air and because of the conservative assumptions used in estimating dose; e.g., all contaminated soil was considered respirable, the concentration of soil in air was maintained constantly at the 100 $\mu g/m^3$ level, etc.
>
> "The reviewers recommend that more specific guidance for application of the criteria at plutonium levels between 40 and 400 pCi/g be developed for the Task Group Commander.
>
> "The Environmental Impact Statement indicates that ^{90}Sr and ^{137}Cs in the soil and the uptake by plants is the major problem which will limit the occupancy and utilization of certain islands of the Atoll. Certain soil amendments that have been shown to significantly decrease the uptake of these radionuclides may be useful for hastening the rehabilitation of the Atoll." (Bair, 8/1977.)

The Bair Committee recognized that the Commander Joint Task Group (CJTG) was in need of more specific guidance for application of criteria. At the time of this meeting, the only explicit guidance appeared in OPLAN 600-77 which said, in essence, excise all areas exceeding 400 pCi/g, whether surface or subterranean, excise to some lower level of activity any area where the one-half hectare average exceeds 100 pCi/g, excise to some lower level of activity any area where the one-quarter hectare average exceeds 40 pCi/g.

Seeking additional guidance consumed many man-hours between August 1977, and January 1978, with no recorded progress. At the 6 January 1978 meeting, where the transuranics question was resolved, the question of field application of criteria was also addressed. The conferees agreed that DOE would develop dose estimates for islands designated for agricultural use. Minutes of the meeting state: "Of special interest are dose contributions resulting from use of certain islands for agricultural purposes at or near 100 pCi/g."

The need arose for the Advisory Group to review application of cleanup criteria for transuranic concentrations in the range 40 to 400 pCi/g when measurements on the northern islands showed many areas to be in this range. The Task Group Report (issued as guidance) had recommended case-by-case treatment for areas with TRU concentrations in the 40-400 range, but did not suggest either a methodology or a case-by-case rationale. Ultimately, the question became one of cost vs. benefit, that is, to achieve the maximum overall improvement in the TRU situation given the availability of a finite cleanup resource. ERSP staff, although technically qualified to submit sound recommendations based on interpretation of Task Group guidance, were too close to the operational problems of cleanup to make unbiased recommendations that would be acceptable to both DOE/HQ and DNA.

On 4 April 1978, DOE/HQ again called upon a group of experts not directly engaged in the cleanup project to review and evaluate operations and advise DOE. This group was officially titled the Advisory Group on Cleanup of Enewetak Atoll; however, since Dr. William Bair was designated the chairman and many of the members were also on the August 1977, Bair Committee, this name was

again used by many observers. (For the remainder of this report, the group assembled in April 1978, will be called the Advisory Group to be consistent with what the group called itself.) The Charter for the Advisory Group listed these review topics:

1. Cleanup criteria and recommendations.

2. Field operations:

   a. Monitoring and sampling
   b. Sample analysis
   c. Data handling and analysis including statistics
   d. Advisory activities in support of cleanup commander
   e. Application of cleanup criteria and recommendations
   f. Certification
   g. Post cleanup conditions including disposal of contaminated debris and soil

3. Dose estimates and applicable standards.

For clarity, it should be emphasized that the Advisory Group was advisory only to DOE/HQ. Conclusions and recommendations of the group would be considered by DOE in formulating policy regarding cleanup; they were not automatically binding on DNA.

The first meeting of the Advisory Group was held 26-27 April 1978, timed to precede an issue resolution conference scheduled by DNA for 3-4 May. Four questions were submitted to the Advisory Group prior to their meeting; all four are presented in the quotation below but responses to only the first two are reproduced here. The third question, while bearing on significant topics, was not the center of a controversial issue in need of immediate resolution; however, the dose estimate question later became critical as discussed in Section 2.2.7. Question 4, and the Advisory Group response, is presented in Chapter 6, Section 6.7. The questions and responses, with the revised wording to response number 2 as distributed on May 3, were:

"1. Is it possible to develop dose-related cleanup guidance that would assure that doses to future residents of Enewetak Atoll would not significantly exceed proposed EPA guidelines for transuranics?

"2. What advice can be given to the Defense Nuclear Agency on May 3, 1978, to facilitate planning for cleanup of transuranics on Enewetak?

"3. What additional information can be obtained that could improve the confidence of the dose estimates and cleanup criteria for transuranics?

"4. Can plowing be used as an effective cleanup measure for transuranics in soils?

"The Advisory Group reviewed information and data provided by DOE-Division of Occupational and Environmental Safety, Lawrence Livermore Laboratory, DOE-Nevada Operations Office and Defense Nuclear Agency and offers the following response to the above questions. (This pertains only to transuranic elements and does not consider radiation doses from other radionuclides which, the Advisory Group understands, will delay the resettlement of some of the islands for many years.)

"1. The Enewetak Advisory Group does not find it possible to develop reasonable cleanup guidance that would assure that radiation doses from transuranics to future residents would not significantly exceed proposed EPA guidelines. Obviously, the more stringent the cleanup criteria, the greater the degree of assurance; but uncertainties inherent in our present understanding of the problem preclude absolute assurance. One cannot predict with certainty the contamination levels that will exist in the islands after cleanup—this must be determined at a future time. One cannot predict the lifestyle and dietary habits of every individual who returns to the islands. Perhaps most important,

many of the factors that are involved in movement of transuranics in the environment and the deposition and retention of transuranics in human beings are not well established.

"The Advisory Group is of the opinion that the recommended cleanup criteria as discussed in Item 2 below will result in average transuranic radiation doses to subsequently exposed populations that will be commensurate with proposed EPA guidelines. The EPA considers its guidance levels to be equivalent to a lifetime risk of about 14 premature cancer deaths per 100,000 persons exposed and to perhaps an equal number of genetic effects, although these estimates are based on many uncertain assumptions and are generally considered to be quite conservative. An estimate of 14 cancers per 100,000 people would correspond to a .3% chance of one cancer appearing in a population of 200 people exposed to EPA guidance levels for their lifetime; or expressed differently, to a probability of one cancer in every 2,100 years (assuming a constant population size).

"2. Considering the physical and ecological limitations to removal of transuranics from the Enewetak Atoll, the Advisory Group recommends the following:

All one-quarter or one-half* hectare areas on village islands should be cleaned unless (with 70% confidence) the average concentration in surface (0-3 cm) soil does not exceed 40 pCi/g. That is, each one-quarter or one-half hectare area should be cleaned if the average concentration plus one-half sigma (for the unit area) exceeds 40 pCi/g. From the information currently available and used for dose assessment, we believe this procedure will provide a reasonable expectation that doses in the bone and lung will be commensurate with the EPA guidance. In terms of radiation dose-sparing benefit to future inhabitants, cleanup of a standard area on a village island is worth about 4 times as much as cleanup to a given level on an agricultural island and 12 times as much as cleanup of the same area to the same level on a picnic island. However, in the light of existing contamination levels and available cleanup resources, it would appear that cleanup of all one-quarter or one-half hectare areas on village islands according to the above criteria should receive first priority. Because the other islands may have increased use over that currently assumed, a second priority should be the cleanup of agricultural island half-hectare areas unless (with 70% confidence) the average concentration for the unit does not exceed 80 pCi/g. A third priority should be the cleanup of picnic island half-hectare areas unless (with 70% confidence) the average concentration for the unit does not exceed 160 pCi/g. If resources are exhausted, some islands may not be cleaned up; final dose assessment may indicate that these islands will have to be permanently quarantined. We note that the soil profile on Pearl is anomalous since the concentration of transuranics appears to be uniform with depth. We believe that the possibility of effective cleanup for use as a village or agriculture island is remote. However, the possibility of covering Pearl with the less contaminated soil from the village islands and, perhaps, from the agricultural islands should be considered for lowering the average surface contamination levels and reducing the logistics problems of transporting the soil from the other islands to Runit.

*1/4 hectare if IMP readings are taken on a 25 meter grid; 1/2 hectare if a 50-meter grid is used." (Bair, 4/1978.)

Information and data provided to the Advisory Group for review included a draft dose assessment by LLL as agreed in the 6 January meeting. The new assessment indicated that the controlling dose may be ingested through the food chain rather than through inhalation of transuranics as had earlier been believed.

DOE informed DNA by teletype on 2 May 1978 that it was DOE's firm intention to follow the Advisory Group guidance (stated above) and that final certification decisions would be based on this guidance. On 3 May, DNA convened a conference of representatives from agencies participating in the Enewetak Cleanup Project to resolve selected issues so that contaminated soil cleanup operations could begin. Detailed review and discussion were held on the critical issues and the operational impacts that various alternatives would have on the overall success of the cleanup effort. The Director, DNA, made several key decisions at the end of the conference. (See conference report in the microfiche.) With regard to cleanup criteria and standards, a summary of the conference states:

> "The soil cleanup criteria provided by the Bair Committee report . . . were tentatively accepted by the Director, DNA, as the criteria to be followed for cleanup operations. This acceptance is contingent upon the DOE/Bair Committee developing more precisely the status of islands (e.g., Boken (Irene) or Lujor (Pearl)) which may end up being cleaned to below 400 pCi/gm, but not down to the 160 pCi/gm criteria established by the Bair Committee for food gathering islands." (Monroe, 1978)

The final criteria for surface soil cleanup, summarized from the Advisory Group report, were:

1. Condition A. Clean all 0.5 hectare areas on food gathering islands that exceed 160 pci/g.

2. Condition B. Clean all 0.5 hectare areas on agricultural islands that exceed 80 pCi/g.

3. Condition C. Clean all 0.25 hectare areas on village islands that exceed 40 pCi/g.

Priority of cleanup actions was the reverse of the above sequence, that is, first priority was assigned to Condition C, 2nd to Condition B, 3rd to Condition A. Criteria and priorities presented above remained in effect for the duration of cleanup.

Criteria applicable to subsurface contamination (Condition D) were also specified at this time, but required additional clarification prior to unambiguous implementation. The original Condition D (see Appendix E) specified excision of Pu concentrations exceeding 400 pCi/g. The action value was reduced from 400 to 160 pCi/g as a result of DNA's acceptance of Bair Committee recommendations; however, additional wordsmithing was still required. Part of the problem of interpretation in the field centered on the criteria statement regarding "An assay area", which was defined (see Appendix E) as the field of view of the in situ detector, and that this area was to be "measured" rather than estimated. The in situ detector could not measure subsurface concentrations of Pu.

The DOE/ERSP Deputy Manager and the Commander, JTG, sent a coordinated appeal for help in interpretation to FCDNA and DOE/NV, and suggested some new wording for Condition D. The key element of the new wording introduced definition of an assay area as a "defined area of interest not less than 1/16 hectare". There followed an exchange of correspondence between DNA, DOE/NV and elements on Enewetak, and a request that the Advisory Group resolve the problem. The Advisory Group was reluctant to do so (Bair, 9/1978 and 10/1978), but found the definition of an assay area applicable to subsurface contamination to be acceptable.

With no further guidance forthcoming, the final criteria for Condition D, as applied in the field was:

4. Condition D. TRU activity in any 5 cm depth interval below the surface shall not exceed 160 pCi/g when averaged over 1/16 hectare.

Tech Notes 18 and 19 demonstrate field sampling and implementation procedures required to abide by the final criteria.

2.2.5 Priority of Island Cleanup

Radiological reconnaissance of Enewetak Atoll in 1971, confirmed by later detailed surveys, indicated that, for convenience, the southern islands could be classified as "clean" and the northern islands as "dirty." However, the groupings were reversed in terms of effort required to accomplish debris removal and preparation for rehabilitation. Most of the uncontaminated debris was located on the southern islands of Elmer and Enewetak, as these two islands had been extensively developed during the testing period; unwanted facilities would have to be removed to accommodate rehabilitation. Initial proposals in 1972 envisioned cleanup of radiologically "clean" islands first, then progressing to increasingly "dirty" islands. It was suggested that this approach might produce the greatest benefit with the least effort and the experience gained on the easier tasks could later be applied to the harder jobs.

The DNA position on the priority of island cleanup was clearly stated in question and answer worksheets prepared for use in congressional committee hearings held in March 1976. The following answer was prepared in anticipation of a question:

> "The plan of operation provides that the soil on Runit will be the last soil to be excised for encapsulation into the crater(s). The plutonium-contaminated soils on all other islands would be removed first. If, during the procedures, it became apparent that fiscal constraints would preclude encapsulating plutonium-contaminated Runit soils, we would request additional funds to complete all soil work. If this request was not favorably received, the soils on Runit would be left in situ." (FCDNA, 1979.)

During testimony, the Director, DNA, deviated from the prepared answer and stated:

> "If funding limits prevent the cleanup of Runit, which everyone considers the major hazard on the atoll, we have only three choices:
>
> - Cancel or postpone the project until such time as we can meet our commitment to the people.
> - Continue to retain control indefinitely over the atoll to prevent innocent people from inadvertent exposure to the hazards that will exist on Runit.
> - Quarantine Runit forever, but this would not be in accordance with standards established.
>
> "The cost of mobilizing and maintaining the work force on Enewetak Atoll is the major cost. If, after having made this costly effort and then not completing the cleanup, it would really not be a very cost effective method of operation. The most significant hazard, the plutonium-contamination on Runit, still remains and must be controlled or resolved some time in the future. The mobilization costs will again be required when it is decided to resolve the plutonium problem.
>
> "Incidentally, we cannot expect to be absolute in our cleanup of Runit. We can only make our best effort to reduce the concentration of plutonium as low as feasible within the established guidelines set by ERDA." (CR, 1976.)

Following the Senate committee hearings, the DNA staff was faced with the problem of resolving the differences between what had been planned to that point and the commitments that the Director had introduced in his testimony.

Northern island cleanup priorities were enumerated by FCDNA staff on 17 February 1977. A staff paper included consideration of such factors as boat access to islands, the volume of debris and contaminated soil present on each island, density of vegetation to be cleared, intended post-cleanup island use, starting more complex (i.e., ground zero) islands as soon as methods had been perfected on "easy" islands, and work on several islands at the same time. The suggested priority list was: Daisy, Belle, Ursula, Alice, Clara, Edna, Pearl, Irene, Kate, Yvonne, Janet, Olive, Sally; small northeast islands; Wilma, Vera. (Bramlitt, 2/1977.)

The DNA staff (DNA/HQ and DNA/FC) did not all agree with the priority list suggested in the February 1977, MFR. Based upon the testimony of General Johnson in March 1976, and supported by statements in the EIS and OPLAN 600-77 (to which no earlier objections had been raised), but counter to the Task Group Report, DNA staff developed the philosophy that plutonium concentrations greater than 400 pCi/g on Irene, Pearl, and Yvonne (and the Aomon Crypt(s)) were categorized as "mandatory" cleanup. The Bair Committee report of the 15-18 August 1977 meeting, quoted in Section 2.2.4, included the words, "The reviewers concurred . . . with 400 pCi/g as the mandatory cleanup level. . ." FCDNA interpretations equated "mandatory" with "top priority" and expressed this position in August 1977. (Tate/Ray, 1977.) While signatory to this MFR, the ERSP Manager expressed concern over the DNA position that cleanup of Yvonne might receive top priority of the entire atoll (Ray, 1977). FCDNA responded by referencing the Task Group report, the EIS, the OPLAN and NVO-140 in support of the statement that ". . . corrective action be taken on all areas with contamination exceeding 400 pCi/g."

The FCDNA letter went on to state:

> ". . . definitization of the scope of work involved in meeting the specified requirements of the EIS. . . is absolutely essential in order for us to know whether sufficient resources will remain to permit us to consider radiological cleanup on other, possibly more desirable, islands such as Enjebi." (Tate, 1977.)

An interagency meeting, held 4 and 5 October 1977 to discuss cleanup of Yvonne (Runit), was attended by the DOE/HQ representative who had chaired the AEC Task Group. The DOE position was spelled out in the following terms:

> "After two or three more instances where DNA staff used the term 'mandatory cleanup of 400 pCi/g'. . . I felt compelled to state that this approach to cleanup had been generated by DNA and was not the intent of the AEC Task Group. I pointed out that the distinction DNA was making between '>400' as mandatory cleanup and 'case-by-case' as budget limited cleanup, was incorrect and that the Task Group had seen Runit cleanup as requiring a 'case-by-case' determination. In fact, the Task Group had made a specific recommendation that the approach to Runit cleanup be devised by a committee such as this one . . . . I stated that even though a case-by-case determination was required for some islands to determine the extent of cleanup to be performed cleanup of such islands was no less a requirement and no lower priority than >400 cleanup on other islands." (McCraw, 10/1977.)

Positions having been clearly stated, dialogue continued between DNA and DOE with measurable progress toward resolution of the issue. Citing extensively the available guidance, FCDNA recommended on 8 November 1977 (Treat, 11/1977) the following:

a. Highest priority - Islands of size (greater than 50 acres) to be potential residential islands, specifically Janet, Sally/Tilda, and Pearl. Resources permitting, clean to Condition C (less than 40).

b. Second priority - Islands of planned intensive agricultural use. In addition to the islands of highest priority, they include Vera, Ursula, and Olive. Resources permitting, clean to Condition B (less than 100, later changed to less than 80).

c. Third priority - Islands of planned food gathering use but whose size (20 to 50 acres) provides a potential for agricultural use, specifically Alice, Belle, Daisy, Irene and Lucy. Resources permitting, clean to Condition B.

d. Lowest priority - Islands whose planned use is food gathering and whose size (less than 20 acres) does not provide good potential for residence or agriculture. Cleanup of contamination levels below 400 pCi/g $^{239,240}Pu$ is not warranted. This priority also applies to Yvonne with regard to areas already below 400 pCi/g.

   In all cases, Condition A or D must be applied to concentrations shown to exceed 400 pCi/g (later changed to 160 pCi/g).

Though promulgated by FCDNA, the above recommendations were not immediately accepted as official DNA policy; that acceptance was delayed until the 6 January 1978 DNA/DOE issue resolution conference. As of the date the conference was in session, initial characterization was completed, or nearly so, for the most important and most complex islands, namely Pearl, Sally, Irene, and Janet. The conferees agreed that to some lesser degree of urgency, characterization of Alice, Belle, and Daisy must be accomplished. To present a complete characterization of the scope of northern island soil cleanup, Yvonne and the other northern islands not mentioned should be characterized with a completion target date of 1 April 1978.

Before priorities could be set for the lesser islands, an important question, whose answer could have a long term impact, had to be asked and a decision made: Should the limited cleanup resources available be used for cleanup of Janet or Yvonne? DOE had long argued that Janet was of greater import than Yvonne to the people of Enewetak because of its past use, and potential future use, as a residence island. Supporting considerations included the fact that if Janet was not now cleaned to the residence criteria for transuranics then it would never qualify even after sufficient decay of the fission products, whereas Yvonne was of little, if any, interest for future residential use and would never qualify for any intended use because the heterogeneous distribution of transuranics made cleanup to criteria highly improbable. The DNA view had recently been that cleanup was mandated for islands with $^{239,240}Pu$ concentrations exceeding 400 pCi/g, and the largest volume of soil falling in this category was located on Yvonne; therefore, cleanup of Yvonne was mandated, with resource expenditure for cleanup of Janet limited to removal of hazardous debris. Rationale presented at the 6 January meeting, and decisions that followed, were prepared as a joint DNA/DOE meeting report and these important conclusions are noted:

- Realizing the value of Janet as a residence island and the likely permanent restriction of Yvonne for any use, the consensus was that consideration be given to cleaning Janet, and other islands, in lieu of cleanup of Yvonne.

- It was agreed that priority would be put on the thorough characterization of the radiological environment of all the northern islands, excluding Yvonne, and that DOE would make dose assessments for a range of contamination levels and uses of islands.

  (The full report may be seen in the microfiche under Deal, 2/1978.)

Radiological characterization of the northern islands continued from 6 January toward the 1 April target date, by which time results for 11 of the most important islands had been transmitted from DOE/ERSP to JTG. This effort continued and, by the time of the 3-4 May conference, results for four additional islands, plus the south half of Yvonne, had been transmitted. Results for the six smallest northern islands were being accumulated but were not considered critical to future planning decisions. Necessary planning factors were, therefore, available prior to the 3-4 May decision conference. In a draft report of the conference the Director, DNA stated cleanup priorities to be:

1. First Priority - Removal and disposal of the contaminated waste from the Aomon Crypt.

2. Second Priority - Cleanup of Sally and Janet to 80 pCi/g with the objective of reducing contamination to 40 pCi/g, if resources permit. Since current estimates indicate resources will not be available to clean Janet to the level of residential use, it is planned to lower the soil concentrations to a level as low as practical within the time and resources available.

3. Third Priority - As resources permit, clean up Irene and Pearl to some level which will permit restricted use of the land short of quarantine.

4. Concurrent - With resources available on Yvonne for crater operation and which are not otherwise fully employed, excavate known highly contaminated soil and deposit it in the crater.

With cleanup targets and priorities established, work began in earnest to remove contaminated soil from designated areas on Janet and Sally. The Director, DNA elected to approach cleanup targets incrementally, first removing soil bearing the highest concentrations of TRU, and working toward lower and lower levels. As each target level was approached, DNA would evaluate the entire status cleanup and available resources, then approve work toward the next lower target. Authority to clean Janet down to 50 pCi/g was issued 20 June 1978; down to 45 pCi/g on 17 August 1978; to continue toward 40 pCi/g on 12 Sept 1978. The decision to remove surface soil from Pearl was not made until late spring 1979.

Priority decisions made during the remainder of the cleanup project were primarily of an operational nature. By the end of cleanup, soil had been removed from Irene, Janet, Pearl, Sally, the Aomon Crypt, and Yvonne. Table 7-5 summarizes soil excision data, and the final status of each island is presented in Chapter 7.

2.2.6 Certification

Certification by AEC/ERDA/DOE that DNA had accomplished cleanup to AEC guidelines became an issue during 1975-76, although the basis for disagreement was expressed as early as January 1974. In his report of a multiagency coordination visit to Enewetak in January 1974, a DNA representative notes:

> "Commander Wolf (AEC/HQ) indicated that an element of AEC favored no participation (in the cleanup) by AEC until the cleanup is 100 percent complete and then an AEC party would inspect to certify satisfactory accomplishment. This position was labeled entirely unacceptable by Maj. Gen. McEnery and Mr. Eagles (both from DNA). Mr. Ray (AEC/NV) indicated that he considers an on-site rep with authority to make decisions for AEC as a must." (Esser, 1974.)

DNA and ERDA representatives met in August 1975, to discuss an interagency agreement then in draft form, to attempt to reach a clear and mutually agreeable interpretation of the draft, and to identify details which might require clarification. Reporting on this meeting, the DNA representative noted that ERDA/NV would be willing to certify that cleanup operations had achieved certain specified goals but would not be willing to certify that it was now safe for personnel to inhabit an island. It was also noted that certifying that guidelines have been met implies that numerical guidelines exist against which cleanup can be measured. Numerical guidelines should be low enough that, with imposition of certain lifestyle restrictions, future exposures would not exceed the guidelines. This in turn implies evaluation of potential dose based on post-cleanup radiological conditions and possibly monitoring of the returning population. Since these steps could extend over a period of years," . . . certification based on such data would clearly not be acceptable to DNA. The point was made that the Certifier needs specific rules upon which to base his guarantee, and those rules have not yet been established. . ." (Esser, 1975.)

The interagency agreement was signed by Major General W. E. Shedd, Deputy Director, Operations and Administration, DNA, on 28 August 1975, and by J. L. Liverman, Assistant Administrator for Environment and Safety, ERDA, 10 September 1975 (The Shedd-Liverman Agreement). Although neither agency had a clear, acceptable definition of what was meant by certification, the agreement stated that ERDA would provide DNA "certification, on an island-by-island basis, when radiological cleanup meeting the guidelines established by the AEC/ERDA in their Task Group Report has been accomplished." Certification was discussed at numerous interagency meetings held during the following year. ERDA held to the position stated in August 1975. DNA disagreed with the ERDA position, and, while not suggesting an alternative definition, repeatedly sought clarification from ERDA. The DNA position was clearly stated in a meeting at ERDA/HQ on 24 June 1976, when a DNA representative ". . . quoted both the draft and final Impact Statement as explicitly using the phrase 'certified as safe' and since ERDA (AEC) did not object to this phrase, they tacitly gave their approval to cleanup leaving the atoll safe within constraints to be imposed." (An ERDA representative disagreed) "and rebutted that the AEC did not approve of many aspects to the Impact Statement, and claimed they were pressured to 'agree not to disagree'." (Schaefer, 1976.)

DNA was at this time in the process of developing a Radiological Cleanup Plan and sought ERDA assistance and guidance with respect to debris classification, soil sampling recommendations, locations of in situ detector measurements and other details that would help define the scope of work and allow overall project planning. DNA felt that "We must be given the rules of the game before the game begins," and wanted to be sure that data accumulated during the course of cleanup would be useful toward certification. Several additional exchanges of views occurred during the next year and by October 1977, draft certificate formats were in review circulation. However, review comments and suggested changes to key phrases tended to clarify the disagreement rather than to approach agreement. A few insistent and sharply worded exchanges in November and December were followed by a new tone as expressed in this summary from the 6 January 1978 meeting:

> "The conferees agreed that it was not desirable for the DOE representatives on the Atoll to certify to the reasonableness of the resource expenditure by the JTG Commander as this was a DOD responsibility. It was further agreed that when DOE provides additional planning guidance for cleanup of islands intended for agricultural use, the DOE on-island representative will be able to certify on an island-by-island basis as the individual cleanup actions are completed. In fact it was agreed that some certifications could be accomplished at this time; i.e., for those islands not needing cleanup actions for their intended use. The exact wording of the certification will be provided by DNA for DOE approval no later than January 11, 1978." (Deal, 2/1978.)

The proposed certificate provided by DNA did not resolve the problem, however, as is clear in this summary from the 3-4 May 1978 meeting:

1. It became clear during the discussion that DNA and DOE are still far apart concerning the island-by-island certification required of DOE. DNA's position basically is that each certificate should contain two parts: a statement concerning the actual radiological conditions remaining on a given island following cleanup; and a statement concerning the use that the Enewetak people can make of the island (residence, agriculture, or food gathering) based upon established criteria (Bair Committee, etc.). This would be done on an island-by-island basis as the cleanup is completed for a specific island. DOE does not disagree with the need for the first statement but believes that the second statement must be measured against the total atoll living pattern and against the total cleanup plan, as opposed to an island-by-island determination.

2. DOE pointed out that they felt the end result, whether stated in a certificate or not, has to be that the expenditure of resources and time had provided a significant dose reduction for certain patterns of living. DOE also pointed out that they had a longer term responsibility than the one to DOD in certifying the cleanup. DNA did not disagree with this longer term responsibility but reiterated its position that the island-by-island certification had to be complete with respect to both statements indicated above, and that if the DOE wanted to make a total assessment of the entire atoll as separate documentation, there was no objection to this.

   DECISION: DNA will submit for DOE concurrence a sample certificate, with proposed wording to cover the two statements desired. (Monroe, 1978.)

Many significant changes were made to the cleanup plan between the signing of the Shedd-Liverman Agreement and implementation of the plan, some as a result of funding limitations mandated by the Congress, others by mutual agreement when alternative means or methods were identified and determined to be superior to originally-planned means or methods.

Throughout the planning period, and most of the cleanup period, FC/DNA continued to believe that ERDA/DOE should certify that cleanup actions had made the islands "safe" for resettlement by the people of Enewetak. DOE held to the position that an island certificate

would describe the radiological condition at the end of the cleanup, but would not state that an island was "safe," nor would the DOE/ERSP presume to judge DNA's allocation of resources by certifying the adequacy of island-by-island cleanup.

Except for the removal of contaminated and activated debris (cable, steel beams and the like), the radiological cleanup was concerned exclusively with the transuranium elements as an inhalation hazard. Thus, most attention was given to the soil within a few centimeters of the surface, although in a few locations relatively high transuranic concentrations dictated subsurface soil removal also. However, the cleanup did not significantly diminish or alter the availability of the inventory of fission product nuclides, two of which, ^{137}Cs and ^{90}Sr, are substantial contributors to dose, especially in the short term (a human life span). And so it was that an island might meet the cleanup guidelines (e.g., have acceptably low transuranic concentrations) and yet not be suitable for unrestricted rehabitation because of food chain implications of the fission product nuclides. One could not write a "seal of approval" regarding an individual island, much as this might be desired by the cleanup forces.

Informal agreement in principle was reached between the ERSP Manager and the Director, DNA early in 1979, as by this time a cost-benefit methodology had evolved. Wording of the certificates was not finalized until cleanup actions were substantially complete late in 1979 and the collection of certificates was issued in March of 1980. The following paragraph was included in that issuance.

> "Because the DNA cleanup actions were not directed at fission products (except in the removal of debris), fission product concentrations and inventory are not addressed in the certification. The certification document is therefore not a sufficient basis for resettlement decisions. It is emphasized that the classifications Residence, Agricultural, and Food Gathering are simply convenient terms pertaining only to surface concentrations of the transuranic elements. Guidance for consideration of resettlement patterns should be taken from current dose assessment documents."

Additional discussion, and reproductions of two certificates as issued, may be reviewed in Chapter 7.

2.2.7 Planting of Coconuts

When replanting of coconut trees was initially mentioned in 1972, there was no controversy since the discussions at that time were quite general. The November 1973 version of the Master Plan included new coconut planting on Janet (14,735 trees) and Yvonne (2,517 trees) among the total of 60,776 trees to be planted. When the AEC Task Group recommended deferral of new habitation and coconut planting on Janet and indefinite quarantine of Yvonne, the Enewetak people assisted in the revision of the Master Plan to accommodate these recommendations. Accordingly, the March 1975 Master Plan indicated new planting of 58,259 trees, with the Janet trees to be planted at some later date. The islands of Enewetak, Elmer (Medren), and David (Japtan) were scheduled to receive a total of 26,689 new trees. (Final 1980 planting data for these three islands show 19,643 new trees planted. The difference is due primarily to an agreed-upon change in tree spacing.) New planting on northeast islands Olive, Pearl, Sally, Tilda, Ursula, and Vera was scheduled in 1975 to total 13,389 trees. It was the planting on these six northeast islands that became a controversial issue in 1978.

A note of background is necessary to the understanding of how planting of about 13,000 coconut trees could become controversial.

Commencing in 1970, individual Bikinians and Bikini families returned to resettle Bikini Atoll and to prepare for the return of others. Initially, and for several years, these Bikinians subsisted almost entirely upon imported foods, the newly planted trees being not yet mature. By 1977-78, however, coconuts were available in abundance—available as a staple in the people's diet and available also for radiochemical analysis. The concentrations of ^{137}Cs and ^{90}Sr were found to be unexpectedly high, and led to three actions: 1) a recommendation was made to the High Commissioner that an imported food supplement be made available to the Bikini community; 2) a recommendation was made to the Bikini people that they reduce their consumption of locally grown terrestrial foods; and, 3) a bio-assay program was established at Bikini.

By April 1978, however, in spite of the above actions, it was clear that the body burdens of ^{137}Cs and ^{90}Sr of the people resident on Bikini were still on the increase, and a decision was made by the Department of the Interior to move all of the people off Bikini. This was done in August 1978. Approximately 140 people were moved, and most were resettled either at Kili (whence they had come) or at Ejit Island in Majuro Atoll.

DOE/HQ reviewed data available from islands of Enewetak and made a preliminary determination that the northeast islands had soil concentrations of ^{90}Sr and ^{137}Cs in the range of values observed at Bikini. On the basis of these findings, DOE/HQ recommended on 18 August 1978 a delay in planting coconuts in any islands beyond the southern islands until a major review of the matter had been conducted. DNA was immediately concerned that a delay in planting according to the planned schedule would have an adverse impact which might be difficult to overcome later, and that alternatives should be promptly evaluated so that the 13,000 coconut seedlings scheduled for the northeast islands could be planted elsewhere if the major review concluded the northeast islands should not be planted at all. By 29 September 1978, DOE/HQ had completed an island-by-island comparison of the ^{137}Cs concentration in Enewetak soil with values found at Bikini, and concluded that all the northern Islands at Enewetak Atoll exceeded the Bikini Island levels. Because copra from Enewetak was expected to be important to the long term economic base of the Atoll, DOE/HQ was also concerned that radiologically-contaminated copra would be unacceptable for commercial purposes. In view of these concerns, DOE/HQ recommended not planting coconuts on the Northern Islands during the 1978-79 planting season. The DOE Advisory Group met on 3-4 October 1978 to consider the issue of planting coconuts on Enewetak Atoll, along with consideration of several other topics, and offered the following comment:

> "A final decision concerning the permissible degree of occupancy of the northern islands can be made only after conclusion of the present cleanup effort and after acquisition of additional information on applicable living habits and food chains and the movement of radionuclides such as ^{90}Sr, ^{137}Cs, ^{239}Pu and ^{241}Am through these food chains. Pending this evaluation it would be unfortunate if steps were taken that would encourage the Enewetak people to believe that a decision had already been made. (We assume that it has not been stated or implied to the people that they can expect to return to the Northern Islands at the completion of the cleanup effort.) This is particularly cogent in view of the unfortunate experience at Bikini. That experience suggests that coconuts grown on the northern islands might not be suitable for human consumption and might not be suitable for copra production. To plant coconut trees on the northern islands at this time might, therefore, require their early future destruction, which would have unfortunate repercussions. Alternatively it might require restricting their consumption, which the Bikini experience would indicate to be ineffective. Therefore, the Advisory Group recommends that coconuts not be planted now and that decisions to plant in the future be delayed until dose assessments and evaluations are completed." (Bair, 10/1978.)

DNA expressed concern that important decisions were being made based on old, pre-cleanup data (NVO-140), and that no effort was given to utilizing soil samples collected during cleanup to more accurately describe the current situation. DOE responded that cleanup project soil samples were not representative of the coconut tree root zone because cleanup was aimed at the transuranics and not at the more soluble fission products which tend to become more evenly distributed to greater depths in the soil than is true of the transuranics. (These exchanges occurred in the fall of 1978 and became the basis for the Fission Product Data Base Program, which commenced 28 February 1979, as described in Chapters 4 and 6.)

By early November 1978, a study of alternatives for coconut planting had been prepared and distributed for review, with the intent of presenting the alternatives to the Enewetak Planning Council at their quarterly meeting in late November-early December. All agencies but DOE favored presentation of alternatives to the Enewetak Council to allow them consideration of options and to provide time for a considered response. The DOE view prevailed, however, and no alternatives were presented at the 2 December 1978 meeting. In the DOE view, it was premature to discuss alternatives for several reasons: a post cleanup radiological assessment remained to be done, the impact of the research program remained to be measured, and hard lessons from the

Bi xperience had to be considered. DOE offered to do a thorough reassessment of the radiation do fore the end of May 1979. DNA was concerned that a delay in planting beyond the planned schedule might mean that logistics and facilities support would not be available, and consequently, the trees might not be planted at all. One DNA report stated that the success of the overall project would be at least partially judged by the U.S. Government's fulfillment of its commitment to provide the people of Enewetak with adequate subsistence and commercial cash crops.

Concern over funding problems that could develop if the six northeast islands were not planted prior to departure of cleanup and rehabilitation forces, led to the suggestion in May 1979, that planting be done immediately. If it was later determined that the fruit bore excessive levels of radiation the trees could be destroyed. In the 8- to 10-year interim, the trees could harm no one, but would contribute substantially to the ecological restoration of the islands. (Mitchell, 1979.)

On 13 September 1979, Interior informed DNA that after considering all of the factors involved, it had been decided that planting of the six islands should proceed. Planting of 10,690 coconut seedlings on Olive, Pearl, Sally, Tilda, Ursula and Vera was completed 28 February 1980. Because these trees were planted during the Enewetak dry season, some additional expense was encountered in watering the seedlings until the 1980 wet season was well underway.

2.3 CLEANUP PHASE (by E. D Campbell, DOE/NV)

2.3.1 Scope of DOE Responsibility

The Shedd-Liverman Agreement between DNA and ERDA outlined the basic responsibilities assigned to ERDA in the cleanup project. The specific features of ERDA's (DOE's) role were modified somewhat during subsequent planning and execution of the field work. In summary, DOE provided personnel and resources to do the following:

a. Perform radiological surveys of the atoll to ascertain the areal distribution of transuranic nuclides in the soils of the various islands.

b. Provide technical advice to DNA and JTG in the planning and conduct of cleanup operations.

c. Establish and operate a radiation laboratory at Enewetak. (The laboratory was used to analyze samples, primarily soils, as part of the radiation survey effort, and to support the JTG radiological safety program by counting air filter papers, nose swipes, and other health physics samples. The RADLAB included an instrument calibration and maintenance shop for servicing all radiation instruments on-Atoll.)

d. Certify to the CJTG, on an island-by-island basis, the radiological conditions on each island at the conclusion of the cleanup project.

2.3.2 ERSP Concept and Staffing

To carry out the responsibilities described above, an "Enewetak Radiological Support Project" (ERSP) was established by the ERDA Nevada Operations Office in Las Vegas, Nevada. The project organization was staffed with personnel from ERDA and ERDA contractors experienced in nuclear test programs, augmented at Enewetak with military personnel detailed from the Navy and Air Force (see Figure 2-5).

The Manager of ERSP was a senior management official of the ERDA (DOE) Nevada Operations Office (NV). Either he, or one of his six Deputy Project Managers (technical staff from NV), was on Enewetak at all times to lead the field team. Other components of the ERSP field team, when at full strength, consisted of the following:

a. Technical Advisor. A physical scientist, usually a health physicist. This position was filled by rotating personnel on loan from: DOE/NV, Environmental Protection Agency, Los Alamos Scientific Laboratory, Lawrence Livermore Laboratory, Sandia Laboratory, Battelle-Pacific Northwest Laboratory, Desert Research Institute, and Reynolds Electrical & Engineering Co., Inc.

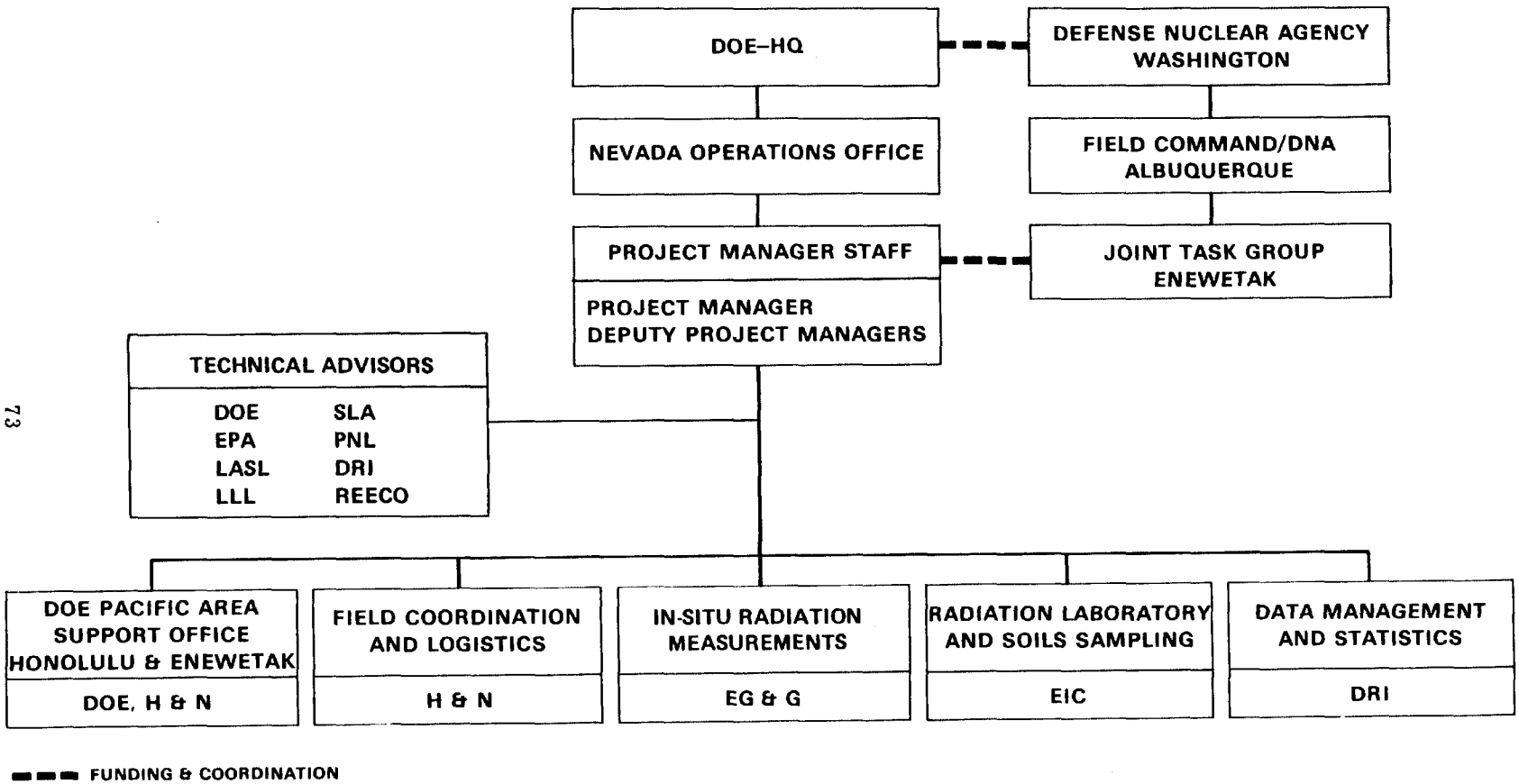

FIGURE 2-5
ENEWETAK RADIOLOGICAL SUPPORT PROJECT (ERSP)

b. In Situ Radiation Measurement. A physical scientist or engineer and two technicians from EG&G, Las Vegas; plus two U.S. Air Force driver/mechanics.

c. Radiation Laboratory and Soils Sampling. A four-person group from Eberline Instruments Co., Santa Fe, NM: laboratory manager, chemist, electronics engineer, and soils sampling/processing team leader. Seven U.S. Navy personnel were assigned to the soils team. One USAF Precision Measurements and Electronics Laboratory (PMEL) electronics technician was assigned to the instrument calibration/maintenance shop; two USAF chemical technicians and two physical science technicians were assigned to the chemical lab and counting lab, respectively.

d. Data Management and Statistics. The Desert Research Institute of the University of Nevada provided a statistician for this function who was assisted by a data processor/computer programmer from the Navy.

e. Field Coordination and Logistics. A staff assistant from Holmes & Narver, Inc., acted as field coordinator and provided administrative and clerical assistance to the Project Manager; he also arranged on-island logistic support for all ERSP needs.

f. DOE Pacific Area Support Office (PASO). This office, located at Hickam AFB in Honolulu, is an element of the parent DOE Nevada Operations Office in Las Vegas. PASO and its support contractor, Holmes & Narver, Inc., provided administrative and procurement assistance, shipping and personnel transportation arrangements, and helped in innumerable ways in solving field problems. A PASO site representative was normally in residence at Enewetak to assist JTG, ERSP, and MPRL (see Section 1.5.3).

2.3.3 Chronology

During the spring of 1977, ERSP staffing, operational planning and preparations proceeded with accelerating intensity. Equipment and supplies for the RADLAB were procured and stockpiled. Development of the mobile in situ field radiation detector systems (IMPs) had begun earlier but was proceeding slowly because of limited funding until the principal project funds were released. An intensive effort then ensued to complete development, fabrication and field checkout of the IMPs so they could be placed into service during the summer of 1977.

ERSP personnel buildup at Enewetak began in June 1977. The project organization, radiation lab and other facilities were completed and occupied during the summer. By 2 August, all staff positions had been filled, the RADLAB and IMPs were operating, and ERSP was functioning.

The project work continued at a fairly constant level of effort until the spring of 1979. From late February until April of that year, an increment of eight personnel was added to the soil sampling crew to collect and prepare additional soil samples required for the Fission Product Data Base Program (see Sections 4.2.2 and 6.11).

By late June 1979, most of the ERSP field work was nearing completion; personnel were released accordingly. By the end of September, the work was complete, the RADLAB was deactivated, backshipping of high value equipment and supplies was arranged, and the last of ERSP personnel withdrew from Enewetak.

2.3.4 ERSP Management and Planning Philosophies

Experience gained in past ERDA (and AEC) field projects in remote locations had strong influence on planning and management of the Enewetak Radiological Support Project and its staff.

Personnel sought for both the ERDA (DOE) and contractor positions were those who were experienced, resourceful, adaptable, field-oriented individuals known to be good team workers. Personnel were rotated between Enewetak and their home bases periodically to minimize stress and hardship on the individuals and their families due to periods of separation. The length of each tour usually ranged from one to two months except for individuals who volunteered for longer tours.

A very important factor in the structure of the ERSP operations was "the home team." At the home base of each participating organization were one or more persons acting as a point of contact on ERSP matters (usually these were individuals who, in the rotational cycle, had served or would serve tours on Enewetak). These home teams were responsible for taking actions on technical questions from the field, obtaining urgently needed supplies or repair parts, and dealing with personal needs of their counterparts on Enewetak. This home team concept was vital to maintaining smooth and efficient operations in the field.

Another policy, adopted by management very deliberately, concerned the acquisition and maintenance of technical and mechanical equipment. Because Enewetak was approximately 4,500 miles from mainland U.S., obtaining repair parts or services of factory representatives would be both slow and costly. Also, because of the tropical climate with its persistent high humidity and corrosive salty air, the environment was inherently conducive to rapid deterioration of equipment. Therefore, at the outset, a policy was adopted and passed on to the supporting contractors that whenever possible new equipment should be acquired for use on Enewetak, and it should receive scrupulous preventive maintenance.

A related policy was that of carefully selecting a large reserve of spare parts, keeping them immediately at hand on Enewetak, and reordering spares promptly when standby units were placed into use. This was particularly important for those components that were susceptible to malfunction, had long lead times to replace, or were otherwise hard to obtain.

The most elaborate example of these policies may be illustrated by the approach taken for the IMPs. Three complete systems were fabricated and sent to Enewetak, even though there were only two teams of IMP personnel. The intention was that the third system would be available either as a complete spare unit, or as a source of 100 percent of the spare parts, any of which could be transferred to another IMP requiring a replacement component (meanwhile, new replacement parts would be procured). Since a complete IMP system cost approximately $100,000, this was expensive insurance; but it allayed concern that if the IMPS could not be kept operational, they would cause the overall cleanup project to fall off schedule.

These policies repeatedly demonstrated their wisdom, as it was very rare for any key capability of ERSP to be out of operation because of component failure. The significance of this can be fully appreciated only by those able to observe the astonishingly high attrition of other equipment experiencing the working and climatic environments on Enewetak.

2.3.5 Typical Sequence of ERSP Radiological Surveys

To assess the concentration of transuranic radionuclides in the soil of a given island, and to provide this information to JTG, the following sequence was generally employed by ERSP.

a. Background information, primarily from NVO-140, the The Enewetak Fact Book (NVO-214), and from the 1977 aerial survey, was studied to determine from the history of the island and from recent investigations what its radiological characteristics might be, especially whether there was reason to suspect subsurface contamination in any given location.

b. Then ERSP personnel made a reconnaissance visit to the island to become familiar with its current physical condition (both the perimeter geometry and the vegetation can change with time). Plans were made to clear vegetation, lay out a survey grid, devise the soil sampling scheme and the approach for in situ measurements with an IMP.

c. Following this, the Army element cleared the island prior to the radiological survey.

   Explosive Ordnance Disposal (EOD) personnel searched the island to locate and remove (or destroy in place) any unexploded ammunition or other hazardous ordnance remaining from combat during World War II. Heavy vegetation (trees, dense shrubs, etc.) was either removed or access lanes were cut through thickets. The vegetation thus removed was piled to dry and then burned. Metal debris and concrete structures were present to varying degrees on many islands. The Army removed and disposed of those which might prove a hazard or interfere with cleanup and future use of the area.

d. On all islands (except the very small ones) that were radiologically surveyed, an orthogonal grid was established. Grid nodes were marked with wooden stakes bearing the coordinates of the location. Maximum spacing of the grid lines was 100 meters. In many places, closer spacing eventually became desirable--50, 25, 12-1/2 and even 6-1/4 meters where TRU concentration gradients were found to vary significantly over small distances.

e. An IMP was taken to the island to perform an in situ survey of ^{241}Am in the surface soil. Analyzer printouts and recording tapes from each day's measurements were sent daily to the EG&G scientist for review and forwarding to the DRI statistician for entry into the data base.

f. A soil sampling crew from the Radiation Lab visited the island to collect a suite of samples following a sampling plan devised by the Tech Advisor and the DRI statistician. These samples were returned to the RADLAB for analysis. The soil sampling sometimes preceded, and sometimes followed, the IMP measurements.

g. After the data were critically evaluated by the statistician, the TRU results were plotted on a map or diagram (with elaborating text) and forwarded to JTG. This information was used by JTG to determine which areas did not meet the cleanup criteria and therefore required additional soil removal to bring them into compliance.

   The Army element was tasked by JTG to remove soil from those areas needing cleanup. Bulldozers and front-end loaders were used to remove surface soil. A clamshell was also used in excavating the Aomon Crypt (cf.). Contaminated soil (and any other contaminated debris) that was excavated was stockpiled and then hauled by landing craft to Runit for disposal in the Cactus Crater.

h. After removal of soil from a given area was complete (a six-inch "lift" was the layer usually removed), a follow-up in situ ^{241}Am survey by the IMP was performed and the new results forwarded to JTG as described in Item g above. If the "new" surface met cleanup criteria, no further cleanup was needed. If the new surface was still above criteria, further cleanup, followed by further IMP measurements, continued. This cycle was repeated until cleanup criteria were met.

i. In some locations, primarily those where deeper excavation was needed because of subsurface contamination, restoration work was necessary to leave the surface in a condition that was topographically similar to the adjacent area. Clean soil was hauled in to fill such areas. The IMP surveyed borrowed soil before it was brought in to be sure it, in turn, was within the cleanup criteria.

j. After all cleanup, excavation and restoration had been completed on a given island, the ERSP Project Manager provided JTG with a certifying letter stating the TRU condition of the island and which of the cleanup criteria had been met.

Workweek

The official workweek in the Enewetak Cleanup Project was 60 hours—10 hours per day, Monday through Saturday. Because much of the field work required travel by boat from the camps to the work islands, the 10-hour workday was adopted in hope that approximately eight hours of productive worktime could be accomplished.

2.3.6 Operational Planning and Coordination

With over 900 persons from three military services and a number of civilian organizations in the Joint Task Group, all of whom were engaged in diverse, interlocking activities involving more than 40 islands of the atoll, coordinated planning quickly emerged as a vital factor in the project. No single military element or civilian component could operate independently. There was much interdependence among the organizations. Thus a matrix of planning and coordinating committees and other entities evolved to facilitate communication and solve problems among the groups. Those that were of the greatest importance to ERSP are summarized here.

Daily

Standup. The Commander, JTG, held a "standup" meeting each workday at 0800. The leader of each project organization attended to state what had been done the previous day and what was planned for the present day. The ERSP Manager participated in these meetings which usually lasted only 15 minutes.

Boat Meetings. At 1500 each workday, the JTG, Operations Section (J-3) held a boat meeting. All project participants requiring boat (or helicopter) support the following day presented their requirements for coordination. The ERSP field coordinator usually attended these meetings.

SATCOM. As described in Section 2.3.7, several days each week a short radio conference by satellite relay radio was held between the ERSP principals on Enewetak and their home teams.

Weekly

ERSP Planning Meetings. Once a week, usually at 1400 on Thursday, the ERSP Manager and group leaders gathered to review the status of the field work. The sequence of activities for the following week would be developed.

JTG Operations Planning. Each Friday morning the JTG Operations Officer led a meeting of all project groups conducting field work to coordinate major activities and intermesh efforts wherever possible for the following week. The ERSP Manager and field coordinator normally participated in these meetings.

SitRep. Each Saturday at noon, all major elements of the project provided the JTG with a brief written Situation Report (SitRep). The ERSP SitRep was simultaneously sent by teletype to the DOE home base in Las Vegas and DOE/HQ so they were kept similarly informed.

JTG consolidated SitReps from the individual project elements into an overall project SitRep that was sent to DNA by teletype. Copies were also distributed to the contributers as another means of coordination and communication.

Other

ERSP, along with other concerned project elements, participated in periodic meetings of special committees formed to deal with specific topics or needs. Among those of particular interest to ERSP were the Safety Committee and the Radiation Control Committee (RCC). The latter group reviewed programs and procedures dealing with radiation protection and related matters.

2.3.7 ERSP Facilities and Logistic Support

The Enewetak Radiological Support Project had bases on both Enewetak and Ursula Islands. The main base was the Radiation Laboratory (RADLAB) located near the center of Enewetak Island.

The RADLAB was a cluster of trailers and other structures consisting of the following:

- an office trailer
- a soils preparation trailer
- a chemistry laboratory trailer
- a counting trailer
- an instrument maintenance trailer
- a liquid nitrogen plant

- a perchloric acid fume hood building
- a bunker (remaining from the nuclear test era) used for storing radioactive check sources and hazardous chemicals
- an open shed--originally built for IMP maintenance but later converted to archiving soil samples

Approximately two miles away at the southwest end of the island, other chemicals, supplies and materials were stored in an old sheet metal building.

The ERSP Project Manager also had an office in the JTG Operations Section in the JTG office building.

On Ursula ERSP had two structures—an enclosed steel shed for IMP maintenance and a living trailer occupied by IMP technicians.

ERSP had a unique, essential requirement for liquid nitrogen (LN), utilized in the operation of the intrinsic germanium radiation detectors in the RADLAB and on the IMPs. Shipping this "hazardous" cryogenic material from Honolulu via MAC aircraft was impractical on a continuing basis, so an old USAF transportable liquid oxygen plant was obtained and placed in operation at Enewetak. The LN needed by ERSP was produced in this plant which was operated by H&N.

H&N, as the overall Enewetak Support contractor, provided general craft support as needed. Their Supply Department handled many of the routine procurements of materials and supplies that were needed during the course of the project. H&N also coordinated the shipping of articles to and from Enewetak. This was a very important service as shipments often went astray or were delayed in the complicated shipping channels. The assistance of H&N expediters was frequently needed to ensure shipments met project schedules. In addition to a terminal at Enewetak, H&N had staging areas at Honolulu, Hawaii, and Oakland, California, to receive, process, and forward cargo to or from Enewetak.

Camps

There were two camps on Enewetak Atoll during the cleanup operations. The main camp was on Enewetak Island (the largest island) at the southeast side of the atoll. Here were located the headquarters of the Joint Task Group (JTG): the U.S. Army element; the U.S. Navy element; the U.S. Air Force element; Holmes & Narver, Inc.; the Mid-Pacific Research Laboratory; and ERSP. Population of this camp was usually 500 or more. The Radiation Laboratory and most ERSP personnel were based here.

Twenty miles NNE on the island of Ursula was the other camp, with an average population of about 400. The majority of military personnel actually doing the cleanup work were based here. The two ERSP IMP teams, consisting of two EG&G technicians and two USAF driver/mechanics, were also based at Ursula.

Housing. Project personnel were quartered in a variety of accommodations ranging from private rooms to open barracks. Cooling for comfort against the tropical heat was either by refrigerated air conditioning or by wide open windows allowing the (almost) continual trade winds to blow through. These accommodations ranged from very comfortable to not very comfortable.

Many of the ERSP civilian personnel were lodged in house trailers which were very satisfactory. Some of the military personnel, especially those on Ursula, were in more primitive quarters, e.g., the trade wind ventilated barracks.

All fresh water used for drinking, cooking and bathing was produced by distilling seawater. An adequate supply was usually available to meet all needs. A positive water conservation program helped achieve this.

Messing. All project personnel were fed in mess halls operated by the base support contractor, H&N. The reputation H&N had earned during the thirty previous years for serving excellent, morale-building meals in their Pacific operations was sustained and appreciated by all.

Recreation. In an isolated location like Enewetak, recreation and other activities to occupy spare time are very important to the morale of personnel. This was, of course, recognized by JTG. Considerable effort and resources were devoted to providing varied recreational opportunities for all hands. The following were available to all without charge:

- Movies
- Television (recorded network shows)
- Radio (music, news, sports)
- Library
- Photographic darkroom
- Softball
- Volleyball
- Basketball
- Tennis
- Ping Pong
- Weight lifting, exercise room
- Swimming - snorkeling and scuba
- Pool
- Running (mini-marathons)
- Fishing
- Boating - motor and sailing
- Horseshoes
- Recorded music; musical instruments
- Bicycling

Approximately quarterly, a travelling show of USO entertainers visited Enewetak and gave live performances that were always greeted enthusiastically by project personnel.

Medical. The USAF element operated infirmaries on both Enewetak Island and at Ursula. A physician and medical technicians were located at each site. Medical care was provided to all project personnel. An Army helicopter was used to transport emergency cases from accident sites to the main infirmary. Cases of injury or sickness that were beyond the capabilities of the facilities at Enewetak were evacuated to military hospitals by aircraft from the Military Airlift Command (MAC).

PO and BX. The USAF element operated post offices at both the Enewetak and Ursula camps, handling official and personal mail. Mail usually arrived on-atoll each Tuesday and Friday by scheduled MAC flights. Outgoing mail was dispatched on flights returning to Honolulu, usually Wednesday and Friday.

The Air Force also operated an Armed Forces Base Exchange (BX) open to all project personnel. Personal articles, reading materials, radios, TVs, clothing, photo supplies, etc., were available for purchase.

Church

There were chapels on both Enewetak Island and at Ursula. An Army chaplain conducted services in both locations each week and was available to counsel any military or civilian member of the project needing advice on personal problems.

Transportation-On-Atoll

Boat. The U.S. Navy element operated and maintained a fleet of about 25 boats that provided transportation for people, supplies and equipment between Enewetak, Ursula, and the work islands. Certain of these craft were devoted to hauling contaminated soil and debris to the disposal sites.

ERSP personnel, equipment and soil samples were transported by:

- LCU (Landing Craft Utility) and LCM (Landing Craft Medium, two sizes). These boats had droppable front-end ramps. IMPs and other motor vehicles were moved between islands on these crafts.

- J-Boat. An enclosed water taxi that carried passengers between Enewetak and Ursula Travel time: 1-1/4 hours.

- Boston Whaler. High-speed outboard motor boats used to ferry up to eight persons between islands.

The availability of boat transportation and the travel time between islands were frequently the pacing factors in accomplishing a given task. All boats required a great deal of maintenance and frequently work schedules had to be revised because of boat problems. The Navy crews worked hard, but the dilapidated condition of many of the landing craft was difficult to overcome.

During a few brief periods, the DOE Research Vessel Liktanur (based at Kwajalein) was used at Enewetak as a dormitory ship for staging small ERSP work parties at remote islands. The improvement in operational efficiency was significant--most of the day could be devoted to work on the islands.

Vehicle. During most of the project, ERSP had the following complement of vehicles to support its activities:

On Enewetak Island:
- Two Carryalls
- Four Bicycles
- Plus occasional use of a pickup truck and forklift.

On Ursula:
- Two four-wheel drive weapons carriers to support the three IMPs which were based there.

Helicopters. The U.S. Army element had four UH-1H turbine powered helicopters at Enewetak. Their primary assignment was search and rescue (medical evacuation). Secondary uses were for command and control, reconnaissance and inspection, and twice-weekly mail runs to Ursula. Occasionally, ERSP obtained helicopter support for transporting small numbers of personnel and/or critical radiation survey equipment to locations where they were urgently needed. Dramatic savings in time resulted when this was possible, especially when working at the difficult-to-reach northwestern islands.

LARC. The Army element had four remarkable conveyances known as "LARCs." These were amphibious vehicles capable of travel across land on tires about 10 feet in diameter and travel in the water powered by propellers. A droppable front-end ramp enabled vehicles as large as 20-ton dumptrucks to be driven aboard and be transported nearly anywhere. Use of the LARC was vital in taking heavy equipment to islands surrounded by shallow water such as in the northwestern quadrant of the Atoll which could not be reached by the LCUs or LCMs. The ERSP IMPs traveled by LARC to such places.

Transportation-Off-Atoll

Personnel traveled to and from Enewetak on MAC C-141 cargo aircraft operated by the USAF. The C-141 is jet powered with four engines and can carry a load of about 36 tons. The cargo hold can be fitted with passenger seats. In the configuration usually flown to Enewetak, the aircraft carried sixty seats, a comfort pallet (galley and latrines), and 20 tons of cargo and mail.

Usually, there was one combination passenger/cargo flight each week to and from Enewetak. It would originate at Hickam AFB in Honolulu, fly 4-1/2 hours, stop at Wake Island for an hour, and reach Enewetak after another hour's flight. The aircraft would continue on to Kwajalein for crew rest and refueling. The following day, the aircraft would reverse the above route, carrying passengers, mail and retrograde cargo to Honolulu.

In addition, there was at least one cargo flight from Hickam to Enewetak each week. Frequently, these "all" cargo flights could and did carry a few passengers in web seats along the wall.

Urgently needed cargo was hauled by air to Enewetak as described above. However, most equipment, supplies and materials traveled by surface, either in ships of the Military Sealift Command or by barge. Shipping by surface obviously required considerable time, even more so because of the lead time required to deliver the cargo to the staging area well in advance of the loading time.

Hazardous cargo (acids, flammable liquids, compressed gases, radiation sources, etc.) required special handling. In many cases, it could not be shipped on passenger aircraft. When possible, such cargo was sent by ship or barge. Supplies urgently needed were sent by air, but with difficulty if there was need to avoid passenger-carrying flights.

Communications

On-Atoll. A dial telephone system was the principal means of communication on Enewetak Island. During a part of the operation, it was possible also to dial Ursula over a radiotelephone link.

A network of five Very High Frequency (VHF) radio nets received great use and was immensely important to all project activities. These nets were the only means of communicating with boats underway between islands, work parties on islands other than Enewetak and Ursula, and with the helicopters. A great deal of traffic was also passed over these nets between individuals and offices on Enewetak and Ursula. It is probably safe to say the project could not have been completed on schedule had it not been for the timely coordination that the radio nets made possible.

Off-Atoll. A communications center, operated by the USAF element, was the main link with the outside world. There were several High Frequency (HF) radioteletype and three radiotelephone circuits between Enewetak and Hawaii (about 2,000 miles distant) where they connected with military and commercial circuits to mainland U.S. The quality of the voice circuits varied considerably due to vagaries of HF propagation and ranged from very good to impossible. Competition for use of the voice circuits was keen during business hours. However, personal calls were permitted during off hours if no official traffic was waiting.

A secondary, quasi-official capability existed in the Military Affiliate Radio System (MARS) stations. Personnel were able to contact their families by HF radio link from Enewetak to some amateur radio operator in the mainland who would complete the call over commercial telephone, i.e., a phone-patch. The only cost was for any tolls between the receiving station and the caller's destination. Although each atoll occupant was limited to one three-minute call per week, this service was of incalculable value to morale and helped solve or avert many personal problems. The MARS stations were augmented by ham radios on both Enewetak Island and Ursula. Operators of these ham stations generously donated their time in setting up phone patches to families back home.

The more conventional form of routine communication was, of course, through the mail. Though not fast, it generally functioned reasonably well, even though Enewetak was, literally, outside the U.S. Occasionally, delays were encountered in customs when shipping articles to the U.S. from Enewetak.

SATCOM.

The ATS-1 satellite was used as a special ERSP programmatic communication link. Three days each week, key ERSP personnel converged at a radio terminal in the ERSP office trailer to exchange information with their home team counterparts. This was done by means of a radio satellite that enabled a direct link between the home DOE office in Las Vegas and the ERSP office trailer at Enewetak via the satellite relay station.

A telephone bridge network from Las Vegas to DRI, EG&G, EIC and other laboratories allowed the home teams in those locations to listen and participate in discussion with personnel on Enewetak.

This "SATCOM" was limited to one-half or one hour time periods, at a fixed time, on certain days of the week that were rigidly scheduled by the satellite controller. In spite of this lack of flexibility in use, the satellite radio system was immensely valuable for obtaining prompt guidance on policy or technical matters, ordering urgently needed replacement parts or supplies, making logistic arrangements, etc. When the reception signals were strong enough, data and written text could be transmitted in either direction by telecopier.

Hazards and Safety

Being located at 11°N latitude (only 660 nautical miles north of the equator), Enewetak Atoll confronted project workers with a number of environmental factors requiring due recognition and precaution. Intense sunlight could cause severe sunburn or even heatstroke to the unwary. The high humidity (normally about 80 percent RH), combined with daytime temperatures of 90°F or higher, was debilitating, and personnel were required to pace themselves during physical activity.

Daily tasks frequently required travel by boat between islands. The smaller boats, e.g., Boston Whalers, usually traveled at high speed across choppy water. This mode of travel was physically abusive and tiring because the boats continually slammed down hard as they dropped into troughs between waves.

The lagoon was shallow near some of the islands—especially to the northwest. Unless the tide was high in such locations, the boats sometimes could not land on the beach, making it necessary for passengers to wade ashore from perhaps as much as 100 meters out. This was not a pleasant task in waters inhabited by sharks, although there were no incidents of shark attack during such landing or pickup operations.

Travel by small boat also had other hazards. The small boat dock at Enewetak was stationary, i.e., it did not have a floating landing stage. When the tide was low, the difference in height from boat deck to dock required a sizable step or leap which was frequently hazardous due to swell and surge moving the boat. Conversely, at Ursula, there was a floating landing stage, but much of the time there was no gangway to the shore and a leap to or from wet, slippery, slanted rocks was required. A number of ERSP personnel suffered injuries during small boat landings, but fortunately none of the injuries was very serious.

An unusual hazard encountered on a few islands was colonies of wasps. Several times work had to be suspended because of the wasps menacing workers.

The most severe hazards were posed by the fierce tropical storms and typhoons that visited the area occasionally in fall and winter. Violent winds and ocean waves flooding low areas during some of the storms did considerable damage to buildings, power lines and other facilities. Two hazards on these occasions merit special mention: coconuts blown from palm trees and airborne sheet metal roofing and siding torn from buildings were very hazardous to personnel. During these storms all persons were ordered to remain indoors, preferably in substantial, well-anchored buildings, on high ground, away from the shoreline. (This was theoretically the best kind of shelter to seek, but there were almost no locations on the Atoll meeting all of these criteria!) A checklist of precautions to be taken to protect personnel, equipment, facilities and data was developed by ERSP for use when typhoon alerts occurred.

Radiological safety for all cleanup project participants was managed by the JTG. An elaborate radiation protection program was conducted as a matter of policy even though the radiological hazards to personnel were very small. In addition, the ERSP undertook a number of radiation safety measures pertaining to the radiation laboratory operations, e.g., see ERSP procedures in Appendix A.

CHAPTER THREE

A critical feature of the Enewetak Radiological Support Project was timeliness. Early in the planning stages it became clear that traditional techniques and methods of radiological survey would simply not be applicable in this remote location and under these operational circumstances. DNA expected to have as many as a thousand people conducting and supporting the cleanup, and the most critical elements of their task would require daily and detailed technical guidance from the ERSP. Thus, we could not afford the time which would normally be required to acquire, package, ship (to home laboratories), analyze, interpret and report upon the many thousands of soil samples necessary to characterize the atoll's islands. The new approach to soil characterization, evolved during 1976, was to make the measurements on the islands, in-situ, supported by only limited soil sampling to assist with interpretation. Data were thus made available almost in real time, and the data flow and resulting technical guidance were consistently able to keep pace with the operational progress. This chapter describes the in-situ system and its use. As a new application of technology under remote and difficult circumstances, its success is a credit to those responsible for its design, construction and operation.

Project Manager's Note

ON-SITE RADIOLOGICAL MEASUREMENTS

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3.1 AERIAL SURVEYS

Two aerial radiation surveys were conducted at Enewetak Atoll prior to actual initiation of cleanup activities. These surveys were performed by the U.S. Department of Energy's Remote Sensing Laboratory, operated for the DOE (and earlier for the AEC and ERDA) by the Energy Measurements Group of EG&G.

The first survey was conducted in the fall of 1972 as part of a comprehensive effort to assess the radiological condition of the atoll prior to developing a cleanup plan. Two large arrays of sodium iodide (NaI) scintillation detectors were used, each containing twenty 12.7-cm diameter by 5.1-cm thick thallium activated sodium iodide (NaI (Tl)) scintillation detectors, mounted inside a CH-53 helicopter. Spectral data were acquired continuously in a 300 channel pulse-height analyzer and stored on magnetic tape in 3-second data blocks. Position information was obtained with an inertial navigation system and recorded each second on magnetic tape. All islands within the atoll were surveyed at an altitude of 30 meters, with 45-meter line spacing. The radiation data obtained from the aerial survey were processed to provide total terrestrial gamma ray exposure rate values extrapolated to microroentgen per hour (μR/h) at the 1 meter level, as well as the individual exposure rate contributions due to ^{137}Cs and ^{60}Co. A special low energy survey for ^{241}Am was also conducted over Yvonne. These results, presented in the form of radiation contours superimposed on island photographs, formed an integral part of the data base used for developing the Enewetak cleanup plan. Complete results for the entire reconnaissance survey are given in NVO-140.

Although the 1972 aerial survey helped to provide a comprehensive overview of the radiological conditions at Enewetak, only limited data were obtained for ^{241}Am, which was to become the indicator isotope for the cleanup project. For this reason, a second aerial survey was conducted in July 1977. This survey concentrated on measuring the 60 kiloelectron volt (keV) gamma ray from ^{241}Am and only covered the northern islands from Alice down through Yvonne. The 1977 survey employed the same sodium iodide detector array as utilized in the 1972 survey. However, the

detectors were mounted externally on an Army UH-1H helicopter rather than inside the helicopter as in the 1972 survey. The data acquisition system employed was an improved second generation version of the system used in the 1972 survey. Position information was obtained using a microwave ranging system rather than the inertial navigation system used in the first survey. Flight lines were flown at an altitude of 30 meters, with 45-meter line spacing. The radiation data were processed to provide the average ^{241}Am concentration (in pCi/g) within the top 3 cm of soil. Minimum ^{241}Am detectability for the aerial survey was 7 pCi/g over islands containing low to moderate contamination from other isotopes (mainly ^{137}Cs and ^{60}Co). The actual minimum detectability varied as a function of the background radiation present. The worst case was over Belle where the minimum ^{241}Am detectability was 35 pCi/g. Although the results of the 1977 survey were never formally published, they were used quite extensively during the early stages of the cleanup project as an aid in the determination of island priority for the ground-based in situ measurements.

3.2 FIELD MEASUREMENTS

3.2.1 Introduction

Under contract to the United States Department of Energy, EG&G operated an in situ gamma ray spectrometer system at Enewetak Atoll from July 1977 to December 1979 in support of the Enewetak cleanup project. This system was used to determine surface (0-3 cm) concentration values of ^{241}Am as one step in the effort to characterize total transuranic surface contamination at Enewetak arising from the nuclear testing program.

A high purity germanium (HPGe) planar detector, suspended 7.4 m above the ground, was used to measure the 60 keV gamma ray from ^{241}Am (a daughter of ^{241}Pu). Conversion factors were established to relate the measured photopeak count rate data to average ^{241}Am concentration in the soil. Using the ratio of total transuranics (TRU) to ^{241}Am established from soil sample data (see Section 4.2.1), a statistical interpolation routine was then used to convert the individual ^{241}Am measurements into area-averaged transuranic surface concentration values (see Section 5.2). These results formed the data base used in deciding whether removal of contaminated soil was required. Final measurements made after soil removal had been completed were used to document remaining transuranic surface contamination.

Guidelines for the removal of contaminated soil existed for both surface and subsurface contamination (see Section 2.2.4). Since the attenuation mean free path for 60 keV gamma rays in Enewetak soil is approximately 2.0 cm, the sensitivity of the in situ system to subsurface ^{241}Am contamination decreases rapidly with depth. For a distribution uniform with depth, approximately 95 percent of the unscattered 60 keV gamma rays reaching the detector would originate within the top 6 cm of soil and approximately 99 percent would originate within the top 9 cm. For this reason, the in situ measurements were used to obtain only "surface" concentration values (defined for the Enewetak cleanup as the average concentration in the top 3 cm). Subsurface soil samples were used to evaluate and quantify subsurface contamination.

3.2.2 Instrumentation

The in situ gamma ray spectrometer utilized an HPGe planar detector having a surface area of 19 cm^2 and a thickness of 1.6 cm. The detector was mounted inside a canister suspended at the end of a 9 m retractable pneumatic boom. This boom was mounted at the rear of a small, lightweight, tracked vehicle (the IMP*, Figure 3-1) specifically selected for its ability to operate in soft sand. The IMP was modified and equipped as a fully self-contained mobile data acquisition and reduction system. Power was supplied by a 4 kW Onan generator mounted on the front of the IMP. A roof-mounted air conditioner provided the necessary humidity and temperature environment for the electronic equipment mounted in the rear section of the vehicle. Signals from the preamplifier (mounted on the detector) were fed inside the IMP to a microprocessor-based 4096 channel pulse height analyzer. At the completion of a measurement, data were transferred from the analyzer to a

* The word IMP and its variations as used in this report were derived from a trademark of the DeLorean Manufacturing Company.

FIGURE 3-1. TWO IMPs SET UP IN A TYPICAL COUNTING MODE. The HPGe detector is housed inside the canister at the end of the retractable boom.

Hewlett-Packard (HP) 9831 calculator for initial field processing. The results were printed out on an HP printer, and the data then stored on cassette tape.

A Pb-Cd collimator was used to limit the detector field-of-view for 60 keV gamma rays to a finite area on the ground (see Section 3.2.8). The collimator consisted of 1.6 mm (1/16") thick soft lead backed by 0.8 mm (1/32") thick cadmium. Both the lead and cadmium were supported on a 1.6 mm thick aluminum cone. The collimator slipped around the detector housing cap and then extended down 12 cm at an angle of 50° from the vertical. A 1.27 cm thick soft lead collar, 2.54 cm long, was placed around the detector housing cap to further reduce background counts in the ^{241}Am photopeak window due to air scatter.

In order to adequately support the Enewetak cleanup project, it was necessary to fabricate three complete in situ systems, i.e., three IMPs. All three systems were identical. Two systems were routinely deployed in the field while the third system provided a complete backup.

3.2.3 Data Reduction Procedures

Field Processing. The initial stage of the data reduction was performed in the field immediately following each measurement. The main advantage of this procedure was that the operator could perform quality control checks on the system after each measurement, which shortened the data turnaround time. In addition, the program allowed the operator to input certain bookkeeping information through the HP 9831 calculator; usually, this consisted of island name, stake number, percent of brush cover, date, time, weather conditions, and the detector serial number. This information and the spectral data were then stored on magnetic tape.

The field program was restricted to analyzing five specific narrow regions of the spectrum to yield data for ^{241}Am, ^{155}Eu, ^{137}Cs, and ^{60}Co (^{60}Co in two regions). This restriction, and the technique used to extract the photopeak data, enabled the field processing to be completed during the time it took to move between locations.

Photopeak shapes for the four isotopes (five photopeaks) were determined empirically on Janet for the first two HPGe detectors to arrive at Enewetak. Resolution of both units was 1 keV to 1.2 keV full width at half maximum (FWHM) at 59.5 keV under normal field operation conditions. Detailed manual (graphical) analysis was performed on each of the five photopeaks for count rates ranging from background to those of the calibration sources--tens to hundreds of times background. Peak shapes were constant over the count rate ranges within the limits of recognition imposed by statisitics at lower count rates. Careful measurements were then made, using the high count rate data, to determine the points at which the peak rises out of the background. Each region so delineated was used in the program to determine the centroid and net photopeak counts. Symmetrical windows adjacent to the peak region were used to determine (by straight line interpolation) the background under the peak.

To find a peak, a narrow predetermined segment of the spectrum was examined. This method, which contributed greatly to the quickness of the program, was viable because each measurement was analyzed immediately, so the IMP operator could adjust the gain and zero of the analyzer system, when necessary, to keep the peaks where they belonged. For peak finding, the raw data were first smoothed by a sliding interval filter of near-optimum width. The filtered data were searched for the channel with the most counts. This channel was the "peak" channel. No further use was made of smoothed data. The central peak region and background windows were positioned with respect to the peak channel as described in the previous paragraph. Then the peak centroid, background counts, and net peak counts were determined. The one sigma standard deviation was calculated from the total counts (peak plus background) and a statistical counting error was assigned (sigma/net counts). The centroid (in channel number) was converted to energy. Net counts were converted to equivalent soil concentration using a conversion coefficient stored in the library array and the live time measured by the analyzer during spectrum acquisition. The coefficient stored in the library had units of (pCi/g)/cps. Determination of that number is described in Section 3.2.5. The error assigned to the soil concentration result was the statistical counting error, plus a 10 percent error to account for uncertainties in the conversion coefficient (see Section 3.2.6). It should be pointed

out that any bump in the spectral region assigned to a photopeak was analyzed and printed out. The net/sigma value and a spectral plot were used to determine if the result was significant.

Below are numbers used for the 59.5 keV (^{241}Am) and 86.5 keV (^{155}Eu) analyses. Slightly wider windows were used for higher energy peaks.

Sliding interval filter:	rectangular, 3 channels wide
Region examined for americium-241:	ch 155 to 162 (58.1 keV to 60.75 keV)
Region examined for europium-155:	ch 227 to 234 (85.1 keV to 87.75 keV)
Low energy background window:	peak -8 to peak -5 channels
Photopeak:	peak -4 to peak +3 channels
High energy background window:	peak +4 to peak +7 channels
Analyzer gain:	0.375 keV/channel

Laboratory Processing. Several correction factors had to be applied to the ^{241}Am data prior to its use in determining the area-averaged total transuranic surface concentration values. These were all made in the laboratory. The conversion factor used in the field program was the same for all systems. This conversion factor assumed a detector height of 740 cm and a detector efficiency of 19.0 cps per ($\gamma/cm^2 \cdot sec$). It did not include the possibility of any additional attenuating material between the detector and the ground. Corrections had to be made if any of these assumptions were not valid. Correction factors were routinely applied to correct for attenuation due to vegetation (a maximum 15 percent correction) and to correct for the different efficiencies of the various detectors used at Enewetak (see Table 3-1). (The derivation of the brush attenuation correction factor is described in Technical Notes 1.0 and 1.1.)

TABLE 3-1. INITIAL DETECTOR EFFICIENCY CALIBRATION RESULTS FOR ^{241}Am

Detector Serial Number	Operating Voltage (kV)	Detector Efficiency cps/(γ/cm^2 sec)
386	-2.0	19.1
393	-2.0	19.3
483	-3.0	17.2
496	-3.0	18.1
513	-2.5	18.7
635	-2.0	17.2

3.2.4 Operational Procedures

Prior to making any measurements, the detector system was calibrated to 0.375 keV per channel (approximately 1500 keV full scale) using a combination ^{60}Co, ^{137}Cs, and ^{241}Am calibration source. The calibration was checked periodically and any gain shift was corrected. (Maintaining power to the preamplifier and amplifier on a 24-hour-a-day basis minimized gain shift problems.) The IMP was moved from location to location with the boom fully retracted and the detector securely fastened. At a measurement point the boom was extended to its full length and then inclined at an angle of 20° away from the IMP. After completing the measurement (a typical acquisition time was 900 seconds), the boom was retracted and the detector secured for movement to the next measurement location. The total time required for each measurement sequence was typically 20 to 25 minutes.

A five minute calibration run was made every morning, noon, and afternoon when a system was in the field. This data was processed in the same way that a typical measurement was processed and was also stored on magnetic tape for permanent retention. Although the sources used were not calibrated, the relative response as a function of time provided a means of monitoring for any changes in the detector efficiency.

3.2.5 System Calibration

Flux Calculation. The unscattered flux of gamma rays of energy E at a height h above a smooth air-ground interface due to an emitter distributed in the soil is given by (see Figure 3-2):

$$\phi = \int_0^\infty \int_0^\infty \frac{S_v}{4\pi r^2} \exp\left[-(\mu/\rho)_a \rho_a r_a\right] \exp\left[-(\mu/\rho)_s \rho_s r_s\right] \cdot 2\pi x \, dx \, dz \qquad (1)$$

where

S_v = the activity per unit volume $\left(\frac{\gamma/\text{sec}}{\text{cm}^3}\right)$,

$r = r_a + r_s$ (cm),

$(\mu/\rho)_a$, $(\mu/\rho)_s$ = the air and soil mass attenuation coefficients $\left(\frac{\text{cm}^2}{\text{g}}\right)$ and

ρ_a, ρ_s = the air and soil density (g/cm^3).

z = depth in soil below the surface

This expression assumes a source distribution which varies only with depth. A uniform distribution in the horizontal plane is assumed, which leads to results expressed in terms of an area average over the field-of-view of the detector. For fallout activity subject only to environmental weathering, the distribution after a period of time can be reasonably approximated by an exponential distribution given by:

$$S_v = S_v^o e^{-\alpha z} \qquad (2)$$

where

S_v^o = the activity per unit volume at the surface $\left(\frac{\gamma/\text{sec}}{\text{cm}^3}\right)$ and

α = the reciprocal of the relaxation length (cm^{-1}).

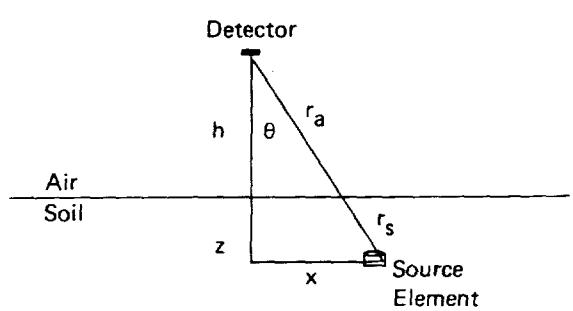


FIGURE 3-2. GEOMETRY USED IN THE DERIVATION OF CONVERSION FACTORS RELATING IN SITU PHOTOPEAK COUNT RATE DATA TO SOURCE CONCENTRATION IN THE GROUND

Rewriting Equation (1) in terms of θ and z, combining with Equation (2) and integrating over z leads to:

$$\phi = \frac{S_v^o}{2} \int_o^{\pi/2} \frac{\tan\theta \exp[-(\mu/\rho)_a \rho_a h \sec\theta]}{\alpha + (\mu/\rho)_s \rho_s \sec\theta} d\theta \tag{3}$$

Detector Calibration. The detector response to a given flux, ϕ, of gamma rays of energy E incident at an angle θ can be given in terms of an effective detector area, A, defined by:

$$A = \frac{N_p}{\phi} \tag{4}$$

where N_p is the net photopeak count rate (sec^{-1}).

The effective area, in general, varies as a function of the gamma ray angle of incidence and is normally written as:

$$A = A_o R(\theta) \tag{5}$$

where

A_o = the detector photopeak count rate for a unit flux incident perpendicular to the detector face $\left(\frac{cps}{\gamma/cm^2 \cdot sec}\right)$ and

$R(\theta)$ = the ratio of the detector response at an angle θ to that at $\theta = 0^o$.

Both A_o and $R(\theta)$ can be determined experimentally.

Conversion Factor. Combining Equations (4) and (5) with Equation (3) leads to an expression which relates the measured photopeak count rate to source activity at the surface. This is given by:

$$\frac{N_p}{S_v^o} = \left[\frac{A_o}{2} \int_o^{\pi/2} \frac{R(\theta) \tan\theta \exp[-(\mu/\rho)_a \rho_a h \sec\theta]}{\alpha + (\mu/\rho)_s \rho_s \sec\theta} d\theta \right] \tag{6}$$

The conversion factor N_p/S_v^o given by Equation (6) is in units of $\frac{cps}{\gamma/cm^3 \cdot sec}$.

For a specific isotope the conversion factor is normally changed to units of $\frac{cps}{pCi/cm^3}$.

Multiplying the expression in the brackets in Equation (6) by the soil density (in g/cm^3) leads to the conversion factor $N_p/(S_v^o/\rho)$ normally given in units of $\frac{cps}{pCi/g}$.

For the Enewetak cleanup, surface contamination was defined as the average concentration within the top 3 cm of soil. In general, the average concentration in the top z cm, S_v^z, for a source distributed exponentially with depth is given by:

$$S_v^z = \frac{1}{z} \int_0^z S_v^o \, e^{-\alpha z} \, dz = \frac{S_v^o}{\alpha z} (1-e^{-\alpha z}) \tag{7}$$

Combining Equations (6) and (7) leads to the final expression for the conversion factor used at Enewetak:

$$\frac{(S_v^z/\rho)}{N_p} = \frac{(1-e^{-\alpha z})}{\alpha z} \, B \left[\frac{A_o \rho_s}{2} \int_0^{\pi/2} \frac{R(\theta) \tan\theta \exp[-(\mu/\rho)_a \rho_a h \sec\theta]}{\alpha + (\mu/\rho)_s \rho_s \sec\theta} d\theta \right]^{-1} \tag{8}$$

in units of $\frac{pCi/g}{cps}$, where B converts γ/sec to pCi for a specific isotope.

Results. In order to evaluate Equation 8, it was necessary first to determine A_o and R (θ) for each detector which was used, in its normal field configuration. A_o was determined by placing a known source directly below the detector at a distance great enough to simulate a parallel beam of photons at the detector face. In determining A_o it is important to utilize the same method for determining the net counts in the photopeak as that used in the field. A total of six detectors were calibrated for the Enewetak program. Although two of these detectors were purchased for another program, all six were used at one time or another during the course of the cleanup project. Table 3-1 summarized the initial ^{241}Am results for these detectors. The detectors were periodically recalibrated at Enewetak to correct for efficiency changes which occurred during the course of the cleanup project.

R (θ) was measured in detail for gamma ray energies between 60 keV and 2600 keV using detector #386. The detector was mounted inside the container used at Enewetak. Measurements were made with and without the Pb-Cd collimator. Calibrated sources were placed at a fixed distance of 1 m from the detector face at angles from 0° to 90° (0° being directly below the detector). Measurements were made at 10° intervals except between 50° and 65° when the collimator was in place, where 2° intervals were used. In order to account for any azimuthal asymmetries which might exist in the detector, the source was rotated about the detector at a rate of 4 rpm during each measurement. Figure 3-3 shows the results for ^{241}Am. The R (θ) data were fitted with a Fourier series to the 10th order and folded into Equation (8) for derivation of the conversion factors. Although these measurements were made in detail only for detector #386, the results were checked for ^{241}Am using several other detectors: no significant difference was observed.

To evaluate Equation (8), it is necessary to obtain experimentally or make some assumptions on the source depth distribution and certain properties of the soil. Table 3-2 gives results for ^{241}Am with the following parameters:

Photons per disintegration	=	0.359
Effective area (A_o)	=	19.0 cps/(γ/cm^2 · sec)
Detector height (h)	=	800, 450, 100 cm
Depth distribution (α)	=	0.33, 0.10, 0.05 cm^{-1}
Soil density (ρ_s)	=	2.0, 1.5, 1.0 g/cm^3
Air density (ρ_a)	=	1.30 (10^{-3}), 1.15 (10^{-3}), 1.0 (10^{-3}) g/cm^3
Soil mass attenuation coefficient, $(\mu/\rho)_s$	=	0.333 cm^2/g (for 60 keV gamma rays)
Air mass attenuation coefficient, $(\mu/\rho)_a$	=	0.188 cm^2/g (for 60 keV gamma rays)

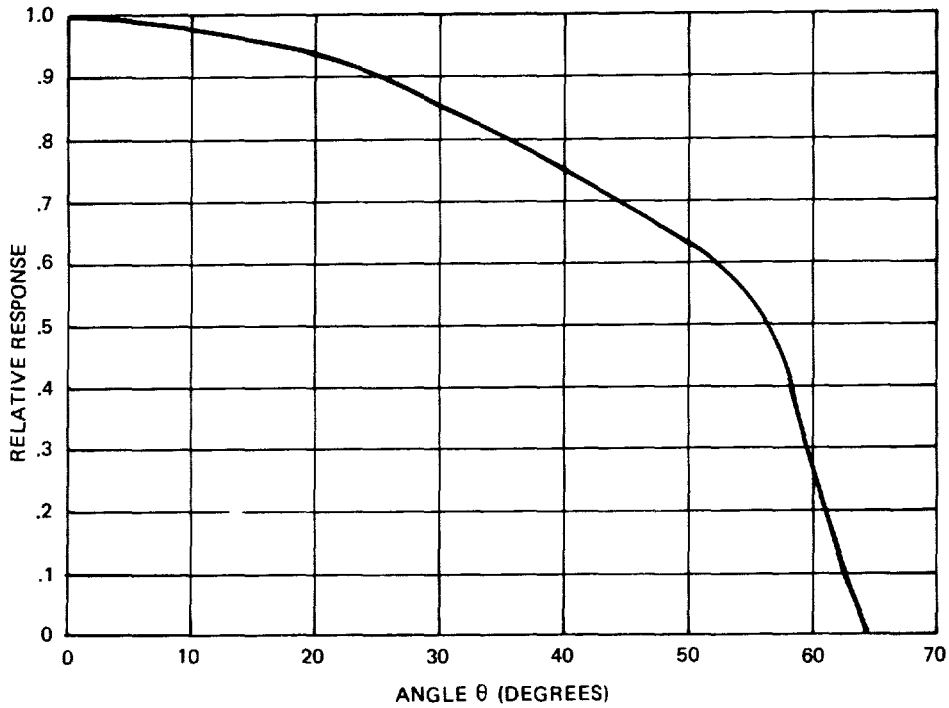


FIGURE 3-3. RELATIVE RESPONSE OF THE HPGe DETECTOR MOUNTED IN ITS NORMAL FIELD CONFIGURATION (WITH COLLIMATOR) FOR 60 keV GAMMA RAYS AS A FUNCTION OF INCIDENT ANGLE (ZERO DEGREES BEING DIRECTLY BELOW THE DETECTOR).

Conversion factors are given for the average ^{241}Am concentration in the top 3 cm. The detector angular response, R (θ), was obtained with the Pb-Cd collimator in place from the data shown in Figure 3-3.

The final ^{241}Am conversion factor (8.95 $\frac{\text{pCi/g}}{\text{cps}}$) was obtained for a detector height of 7.4 m, a soil density of 1.5 g/cm^3 and an air density of 1.15 (10^{-3}) g/cm^3. A weighted average was used to account for observed variations in the depth distribution. The actual ^{241}Am conversion factor used in the Enewetak field program was 7.7 $\frac{\text{pCi/g}}{\text{cps}}$. This value was based on a soil mass attenuation coefficient of 0.248 cm^2/g, which is typical for many soils, and a soil density of 1.2 g/cm^3. A detailed study of the soil composition and soil density at Enewetak conducted in December 1979, however, led to a revised value for the soil mass attenuation coefficient and soil density. All final data based on the IMP results given in this report have been corrected for this error. (See Tech Notes 22 and 23 for more detail.) In the following section, each of the input parameters to Equation (8) is discussed in detail. Errors in the conversion factor associated with variations in each of these parameters are also discussed.

3.2.6 Variables Affecting the ^{241}Am Conversion Factor

Air Density and Composition

As may be inferred from Table 3-2, the conversion factor for ^{241}Am at a detector height of 7.4 meters is relatively insensitive to large changes in the air density. The IMP conversion factor assumes an air density of 1.15 (10^{-3}) g/cm^3, which corresponds to air at a temperature of 85°F (30° C) and a pressure of 750 mm Hg. There is only a ±2.5 percent change in the conversion factor by going to the density extremes given in Table 3-2. (A density of 1.30 (10^{-3}) g/cm^3 corresponds to air at a temperature of 41°F (5°C) and a pressure of 780 mm Hg and a density of 1.00 (10^{-3}) g/cm^3 corresponds to air at a temperature of 125°F (52°C) and pressure of 700 mm Hg.) Changes in air density over the ranges of temperature and pressure which actually occur at Enewetak should not contribute more than a 1 percent error to the conversion factor.

The mass attenuation coefficient for 60 keV gamma rays in air (0.188 cm^2/g) was derived from standard air composition tables and elemental mass attenuation coefficient tables. Since the corresponding mass attenuation coefficient for water is 0.20, moisture in the air should not significantly affect the air attenuation factor.

Soil Density and Composition

The in situ or wet soil density and soil composition are both required to determine the attenuation factor for gamma rays of a given energy in soil. Soil composition is required to determine the mass attenuation coefficient. The product of the mass attenuation coefficient and the soil density then gives the linear attenuation coefficient, which is the inverse of the attenuation mean free path. (On the average, 63 percent of the gamma rays traversing a distance of one mean free path in a given medium undergo an interaction which attenuates, i.e., reduces, their energy.) The soil density is also required to convert concentration per unit volume to concentration per unit mass.

Soil density and soil composition data used for the final Enewetak conversion factor were obtained in December 1979 (see Tech Note 22). Up to that time the data available for in situ density was somewhat limited. In addition, a question arose in the fall of 1979 about the mass attenuation coefficient which was used in the original conversion factor. (These problems are discussed in detail in Tech Note 23.)

Soil density and percent soil moisture were obtained using a Troxler Model 3411 nuclear density/moisture gauge. Density is determined by measuring the attenuation of 662 keV gamma rays from a ^{137}Cs source through a given depth of soil. The moisture content of soil is determined by measuring the moderation or slowing of fast neutrons from an Am-Be neutron source. Dry density is obtained by subtracting the moisture content from the wet density. The percent moisture is obtained by dividing the moisture content by the dry density. In the Troxler gauge, both the ^{137}Cs and the Am-Be sources are located in a probe which can be inserted to a given depth in the soil. The gamma ray and neutron detectors are placed on the surface at a fixed lateral displacement of 25 cm from the sources. After placing the sources at a given depth, gamma ray and neutron counts are accumulated for a period of one minute. The resulting counts are converted to wet density and moisture content using calibration curves supplied by the manufacturer.

Measurements were made at 182 locations within 73 different areas over 9 islands. At each location the average wet density and percent moisture were obtained for the top 15 cm, the top 10 cm and the top 5 cm. The 5 cm measurements were repeated after rotating the detectors through an angle of 90°. Based on the 364 independent readings taken at the 5 cm depth, the mean wet density obtained was 1.53 g/cm^3, with a standard deviation of 0.14 g/cm^3. The mean value for the percent moisture was 16 percent, with a standard deviation of 5 percent.

A wet density of 1.50 g/cm^3 was used for the final conversion factor. This corresponds to an average percent moisture of 14 percent, which is probably closer to the average yearly percent moisture.

TABLE 3-2. THE CONVERSION FACTOR (S_v^3/ρ) / N_p IN (pCi/g)/cps FOR ^{241}Am AS A FUNCTION OF DETECTOR HEIGHT, AIR DENSITY, SOIL DENSITY AND DEPTH DISTRIBUTION

Detector Height, h (cm)	Depth Distribution, α (cm^{-1})	Air Density, ρa (g/cm^3)	Soil Density, ρs (g/cm^3) 2.0	1.5	1.0
800	0.33	1.30	8.33	9.10	10.61
800	0.33	1.15	8.10	8.85	10.33
800	0.33	1.00	7.89	8.63	10.06
800	0.10	1.30	9.17	9.49	9.60
800	0.10	1.15	8.94	9.24	9.35
800	0.10	1.00	8.71	9.01	9.11
800	0.05	1.30	9.35	9.52	9.86
800	0.05	1.15	9.11	9.28	9.60
800	0.05	1.00	8.88	9.04	9.36
450	0.33	1.30	7.45	8.14	9.49
450	0.33	1.15	7.35	8.03	9.36
450	0.33	1.00	7.25	7.92	9.23
450	0.10	1.30	8.22	8.50	8.60
450	0.10	1.15	8.11	8.39	8.48
450	0.10	1.00	8.00	8.27	8.37
450	0.05	1.30	8.38	8.53	8.84
450	0.05	1.15	8.26	8.42	8.71
450	0.05	1.00	8.16	8.31	8.60
100	0.33	1.30	6.67	7.29	8.49
100	0.33	1.15	6.67	7.28	8.48
100	0.33	1.00	6.66	7.27	8.47
100	0.10	1.30	7.36	7.61	7.70
100	0.10	1.15	7.35	7.61	7.70
100	0.10	1.00	7.35	7.60	7.69
100	0.05	1.30	7.50	7.63	7.91
100	0.05	1.15	7.50	7.63	7.91
100	0.05	1.00	7.49	7.63	7.90

The mass attenuation coefficient for Enewetak soil was based on chemical analysis of 124 soil samples obtained from 9 islands during December 1979. These samples were analyzed for organic content as well as elemental composition. Results of the analysis showed that the primary component of Enewetak soil is calcium carbonate. A number of trace elements were also identified. The most significant trace element was magnesium, which contributed approximately 1-2 percent by weight. Although the organic content varied from 0.5 percent to 25 percent by weight, most samples were in the range of 1 percent to 8 percent, with an average of approximately 4 percent for all samples. The in situ mass attenuation coefficient for each sample was obtained from a weighted average of the water, organic and appropriate elemental mass attenuation coefficients. The water content, by weight, for each sample was based on the in situ soil moisture measured with the nuclear density/moisture gauge just prior to collecting the sample. (All samples were dried prior to the chemical analysis.) The mass attenuation coefficient for organic material was estimated by using the value derived for cellulose. Based on these 124 soil samples, an average value of 0.333 ± 0.012 cm^2/g was obtained for the in situ Enewetak soil mass attenuation coefficient. The average value for the dry, organic-free component was 0.365 cm^2/g compared to 0.37 cm^2/g for pure calcium carbonate. (Complete details and results for the soil density and mass attenuation coefficient determination are given in Tech Note 22.)

Table 3-3 shows the effect on the ^{241}Am conversion factor due to variations (at the 1 and 2 σ level) in the soil density and the soil mass attenuation coefficient. For a fixed mass attenuation coefficient of 0.333 cm^2/g, a $\pm 2\sigma$ variation in the soil density leads to approximately a ±2 percent change in the conversion factor. For a fixed soil density of 1.5 g/cm^3, a $\pm 2\ \sigma$ variation in the mass

TABLE 3-3. VARIATION IN THE ^{241}Am CONVERSION FACTOR* WITH DIFFERENT VALUES FOR SOIL DENSITY AND THE MASS ATTENUATION COEFFICIENT

Mass Attenuation Coefficient $(\mu/\rho)_s$ (cm^2/g)		Soil Density ρ (g/cm^3)				
		1.22 (-2σ)	1.36 (-1σ)	1.5 (mean)	1.64 ($+1\sigma$)	1.78 ($+2\sigma$)
0.309	(-2σ)	8.61	8.49	8.38	8.29	8.22
0.321	(-1σ)	8.89	8.77	8.66	8.57	8.56
0.333	(mean)	9.18	9.06	8.95	8.86	8.79
0.345	($+1\sigma$)	9.47	9.35	9.24	9.15	9.08
0.357	($+2\sigma$)	9.75	9.63	9.52	9.43	9.36

*$(S^3_v/\rho)/N_p$ (pCi/g)/cps) with detector height of 7.4 m.

attenuation coefficient leads to a ±6.5 percent change in the conversion factor. Since the soil density and the in situ soil mass attenuation coefficient, in general, both vary from location to location, it is more appropriate to examine their combined effect on the conversion factor. As seen in Table 3-3, the maximum effect occurs with a low soil density combined with a high mass attenuation coefficient or a high density combined with a low mass attenuation coefficient. For the appropriate 2σ limits this case would lead to a ±9 percent change in the conversion factor. In reality, however, low density areas were generally found to be those areas having higher organic and/or soil moisture content, which would lead to a lower mass attenuation coefficient. Similarly, high density areas generally had a higher mass attenuation coefficient. For this combination the appropriate 2σ limits lead to a ±5 percent change in the conversion factor. This is more typical of the actual range of uncertainty in the data due to observed variations in the wet soil density and in situ soil composition.

Depth Distribution

One of the most critical factors in relating an in situ measurement to radionuclide concentration in the ground is a knowledge of the source distribution with depth. This is especially true when attempting to determine the total activity per unit area. For the Enewetak ^{241}Am conversion factor, depth distribution data were obtained from profile measurements made during the 1972 reconnaissance survey (NVO-140). A total of 108 profile measurements were made on 20 islands from Alice to Wilma. The data for each profile, most taken to a depth of 30 cm, were fit to an exponential distribution, as given in Equation (2), and a value computed for the relaxation length. Of the 108 profiles, 11 had a relaxation length between 3 and 5 cm, 45 had a relaxation length between 5 and 10 cm, 15 had a relaxation length between 10 and 20 cm, and the remaining 37 were best represented by a uniform distribution. The last group included those distributions which were slowly decreasing with depth, slowly increasing with depth, or oscillating up and down with depth. Based on these data, the actual conversion factor was computed from a weighted average of the values obtained for relaxation lengths of 4 cm, 7.5 cm, 15 cm, and 1000 cm (i.e., a uniform distribution).

Figure 3-4 shows the variation in the ^{241}Am conversion factor for average concentration in the top z cm, with z varying between 0 and 10 cm, for several different depth distributions. As can be seen, the conversion factor can vary significantly with variation in the depth distribution. This variation, however, is minimized when determining the average concentration in the top 2-3 cm. In particular, for the 3 cm average specified in the Enewetak cleanup criteria, the conversion factor varies from a value of 8.63 pCi/g per cps for a relaxation length of 3 cm to a value of 9.00 pCi/g per cps for a uniform distribution, compared to a value of 8.95 pCi/g per cps obtained from the weighted average. Thus, even for the extreme case of the measured depth distributions, there is only a 4 percent error in the conversion factor. For 90 percent of the distributions measured, the uncertainty in the conversion factor due to variations in the depth distribution is on the order of ±1 percent. For this reason, no effort was made to obtain additional depth profiles during the cleanup project.

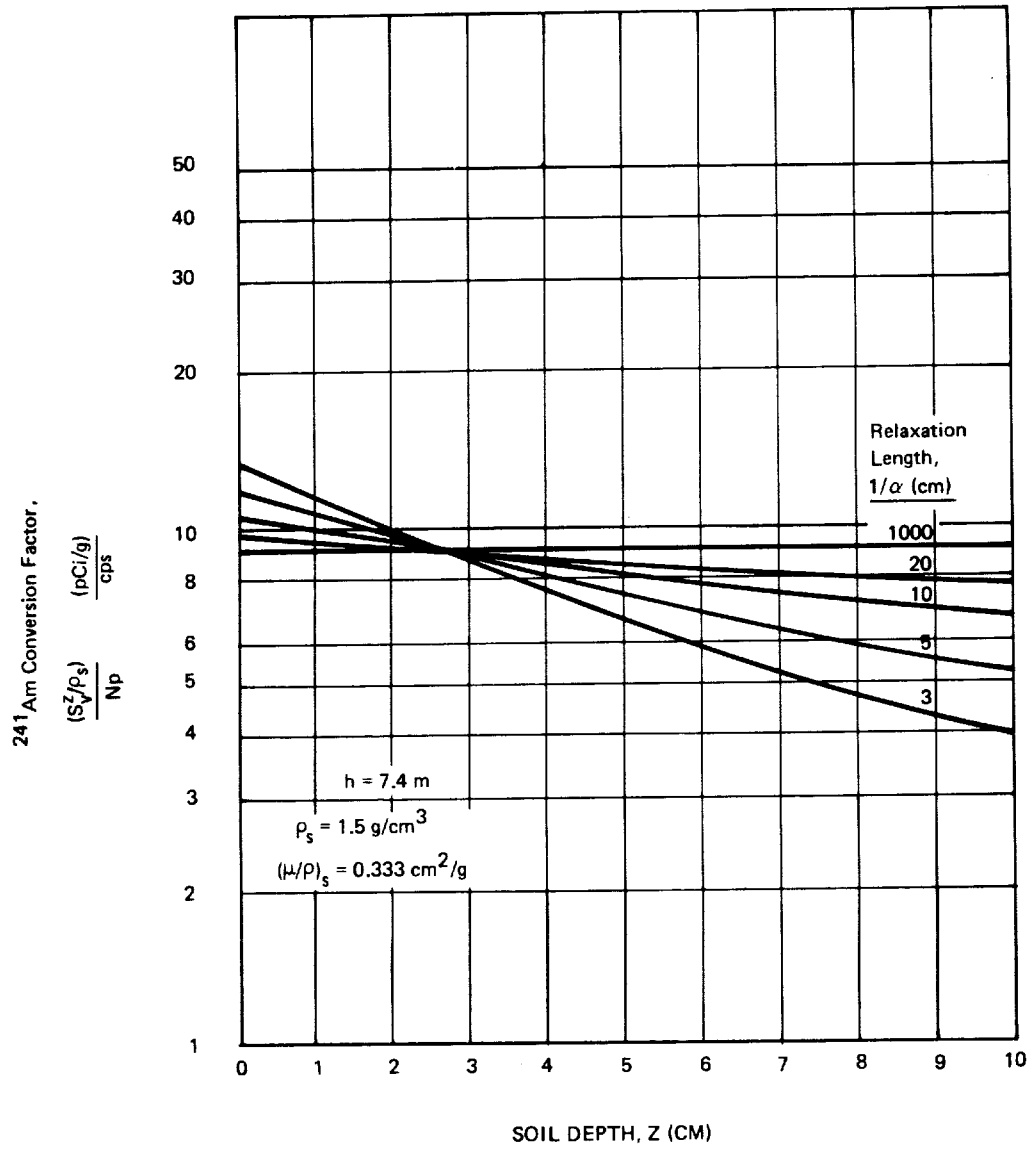


FIGURE 3-4. CONVERSION FACTORS FOR ^{241}Am GIVING AVERAGE CONCENTRATION IN THE TOP Z CM AS A FUNCTION OF DEPTH DISTRIBUTION.

Detector Efficiency

The in situ conversion factor is directly proportional to the detector efficiency, as shown in Equation (8). Since the conversion factor used in the field program for ^{241}Am assumed a detector efficiency of 19.0 cps/(γ/cm^2 · sec) , it was mandatory to correct the data for detectors whose efficiency differed from this value. Table 3-1 shows the original values obtained for the detector efficiency for each of the six detectors which were used at Enewetak.

Several of these detectors showed a significant change in efficiency after the original measurement. One detector suffered a 15 percent decrease in efficiency over a single weekend. The daily calibration measurements made in the field were monitored closely in order to detect any sudden change in efficiency. In addition, starting in July 1978 a remeasurement of detector efficiency (using an NBS cross-calibrated ^{241}Am source) was made every three to four weeks. A new correction factor was applied whenever the efficiency changed by 5 percent or more from the efficiency at the time the last correction factor was determined.

Detector Height

As can be seen from Table 3-2, variations in detector height do not significantly affect the ^{241}Am conversion factor. This is primarily due to the assumption made in the derivation that the activity is distributed uniformly in the horizontal plane (see Section 3.2.5). (It is because of this assumption that an in situ measurement provides a direct method for obtaining an area-averaged value for the activity over the field-of-view of the detector.) As the detector height increases, the $1/r^2$ decrease in the gamma-ray flux at the detector due to a given source element is compensated for by the r^2 increase in area, or source elements, within the detector field of view. The rather minor variations observed are due to slight additional attenuation for gamma rays incident at a given angle due to an increased path length through the soil and air. For the Enewetak ^{241}Am conversion factor, a variation in the normal detector height (7.4 m) of ± 0.5 m leads to a 1 percent change in the conversion factor.

For some areas, measurements were taken on a 12.5 m grid pattern with the detector at a height of 4.6 m. For this height there is a 7 percent change in the conversion factor. Corrections were made to account for this difference on all measurements taken at 4.6 m (see Tech Note 12).

3.2.7 Other Sources of Error

Shielding by the IMP

A portion of the ground area which is within the detector's field-of-view is shielded from the detector by the IMP. This reduces the flux arriving at the detector by approximately 4 percent. The original ^{241}Am conversion factor used during the cleanup did not correct for this effect. All final ^{241}Am data, however, were corrected to account for this 4 percent shielding factor (see Tech Note 23).

For measurements taken at a detector height of 4.6 m, the IMP shielding factor is approximately 13 percent. All data obtained at the 4.6 m detector height were corrected for this factor throughout the cleanup (see Tech Note 12).

Contributions Due to ^{155}Eu

One of the residual fission products found at Enewetak, ^{155}Eu, emits a 60 keV gamma ray which interferes with the 59.5 keV gamma ray from ^{241}Am. It is possible to correct for this interference by monitoring one of the two other gamma rays emitted by ^{155}Eu: one at 86.5 keV and one at 105.3 keV. The ratio of 86.5 keV to 60.0 keV gamma rays from ^{155}Eu is 24.3 to 1. For an in situ measurement, the ratio of these two gamma rays at the detector is somewhat dependent on the depth distribution of the europium; this is due to differences in soil attenuation at 60 keV ($\mu/\rho = 0.333$ cm^2/g) and at 86.5 keV ($\mu/\rho = 0.22$ cm^2/g). A reasonable compromise for field measurements is to assume a ratio at the detector of 30:1. As discussed in Section 3.2.3, the field program processed the spectral data for the 86.5 keV photopeak. The contribution of ^{155}Eu to the 60 keV photopeak was obtained by dividing the net counts at 86.5 keV by 30 and subtracting this from the net counts at 60 keV. This correction factor was never more than 3 percent (at a few locations on Pearl) and generally ran between 1 percent and 2 percent. For this reason, although the ^{155}Eu was always monitored, no significant correction was required for the ^{241}Am data.

Effects of Detector Distortion

The typical symptom of detector degradation (due to icing, vacuum leak, lowered bias, etc.) was reduced resolution, i.e., wider photopeaks. The simple analysis program used in the field could not accommodate such an effect. Photopeak counts would be spread into the background windows resulting in an erroneously low value for net counts and, therefore, soil concentration. Window limits in the program could have been changed in the field if one cared to analyze peak shapes for a detector that was degraded but stable. The philosophy at Enewetak, however, was to correct the problem rather than attempt to correct the data.

Brush Correction Factor

Most of the islands surveyed were covered with a dense growth of Messerschmidia and Scaevola scrub vegetation, ranging in height from 1 to approximately 4 meters. A series of measurements were performed in October - November 1977 on Pearl to determine the effect of this vegetation on the 60 keV gamma ray from ^{241}Am. Ten representative areas with brush covering 70-80 percent of the IMP field-of-view were measured. (The access road cut through the brush accounted for most of the open area.) Brush in each area was then carefully cleared by hand to prevent any soil disturbance and the measurements repeated. The results of this experiment gave a brush correction factor of 15 percent for 100 percent brush cover (see Tech Notes 1.0 and 1.1 for details). No correlation was observed between the brush height and the brush attenuation factor. This was attributed to the fact that the vegetation normally encountered on the northern islands typically grew in the form of a canopy rather than solid cover.

At each measurement location, an estimate of the percent brush cover within the detector field-of-view was made by the operator. This value was then used to provide a correction factor for brush attenuation. The estimate of brush cover was somewhat subjective and could have been in error by as much as 20 percent for some locations. Even a 20 percent error in the brush cover estimate, however, would only introduce a 3 percent error in the ^{241}Am concentration value. Thus, although some uncertainty was inherent in the method used to determine a brush attenuation correction factor, the uncertainty was less than would result from neglecting brush attenuation effects completely.

Measurement Reproducibility

A repeatability experiment was conducted on Pearl at location 3-N-0.5 in May 1979 to determine if any systematic variation could be observed in the IMP measurements over the course of a typical day. A total of 17 measurements were made, each for the standard 900-sec measurement time, with the detector fixed in position. The sample standard deviation for the series of measurements was 5 percent of the mean value. For the same set of measurements, the average one sigma error due to counting statistics was 6.7 percent. No systematic variation was observed between the early morning measurements, made when the ground was damp due to an early morning rain, and the afternoon measurements made during the hottest part of the day.

One location on Janet was remeasured five times over a two-month period in the fall of 1977. The standard deviation for this set of measurements was 7.8 percent of the mean value. During the same period of time, two locations on Pearl were remeasured three times over a period of one month. The standard deviation was 4.4 percent of the mean for one location and 6.6 percent of the mean for the other location.

These data indicate that the primary source of error in measurement reproducibility was associated with counting statistics, which generally ran from 5-7 percent. Additional details on measurement reproducibility can be found in Tech Note 21.

3.2.8 Detector Field-of-View

The detector field-of-view is of some practical concern for an in situ measurement. However, as shown in Figure 3-3, even with a collimator the detector response does not drop abruptly to zero. Thus the "field-of-view" has an edge which is somewhat fuzzy. The field-of-view can only be

defined in a practical sense by investigating the fraction of the flux reaching the detector which originates from a given area on the ground. This can be obtained using Equation (3) combined with the relative angular response of the detector given in Figure 3-3. The results for 60 keV gamma rays are shown in Figure 3-5. It can be seen that 95 percent of the total flux originates from a circle with a diameter of approximately 21 m, while 99 percent of the total originates from a circle having a diameter of approximately 25 m. Thus a 30 percent increase in area at the edge of the field-of-view only contributes an additional 4 percent to the total flux. In going from a circle 21 m in diameter to a circle 30 m in diameter, the total area is doubled. However, the flux arriving at the detector from this additional area represents only 5 percent of the total. Due to the collimator, all 60 keV gamma rays originating beyond a circle of approximately 30 m in diameter are cut off. It can also be seen that minor variations in the detector angular response from system to system would not significantly affect the results of the in situ measurement.

On most islands at Enewetak it was necessary to cut roads through the brush to survey in a grid and to allow the IMP access between locations. In many cases the method used to clear away the brush led to significant soil disturbance within the approximately 3 to 4-m wide area of the road. Figure 3-5 can be used to estimate the fraction of the total flux which originates from this disturbed area. The detector was routinely suspended directly over the center of the road. From Figure 3-5 it is seen that approximately 10 percent of the total flux originates from a circle with a diameter of 3.5 m directly under the detector. This entire area was normally within the road. The road also occupies approximately 15 percent of the remaining area which contributes the other 90 percent of the total flux. Thus the disturbed area within the road contributed about 25 percent of the total flux reaching the detector.

3.2.9 Comparison with Soil Sample Data

In order to obtain an independent measurement which could be used as a quality control check on the in situ measurements, a soil sampling program was established which attempted to obtain a sample which was representative of the average concentration within the area sampled by the IMP. A total of 109 locations on 17 different islands were compared using both techniques. Two soil sample composites, each comprised of 6 samples, were analyzed for each measurement location. (See Section 4.2 for details on the soil sampling program.) Results of the comparisons are summarized in Tech Note 8. Based on final IMP data (see Tech Note 23), the ratio of the mean of the soil sample results to the mean of the IMP results was 1.05. A difference of approximately 10 percent (based on laboratory soil moisture measurements) was expected since the soil sample results were expressed in terms of dry weight rather than in situ or wet weight as given by the IMP. After correcting for this difference in reporting methodology, the IMP mean value was approximately 5 percent greater than that given by the soil sample data.

There are a number of factors which could account for the measurement difference. Probably the most important is the fact that the soil sample results, for each location, were based on a measurement of several thousand cm^3 of soil compared to approximately 10 to 15 million cm^3 of soil for the IMP measurement. This fact becomes more important when combined with data obtained on Tilda (see Tech Note 8) which showed that there could be a high degree of variability in ^{241}Am activity in both the horizontal and vertical directions within a single IMP measurement location. For many of the locations sampled, the two soil sample composites obtained within the same area gave significantly different results, in some cases by as much as a factor of 2 or 3. This again indicated that there could be a high degree of variability within a given measurement location. Because of this, one would not necessarily expect to achieve agreement at any given measurement location between soil sample analysis and an IMP measurement. This was indeed found to be the case. However, based on a large number of comparisons, the overall agreement was considered excellent.

3.2.10 Results for ^{137}Cs and ^{60}Co

Although the primary function of the in situ measurement system at Enewetak was to obtain surface (0-3 cm) concentration values for ^{241}Am, complete spectral data were obtained at each measurement location for gamma-ray energies up to approximately 1500 keV. The rather simple data reduction program used in the field, however, only processed these data for ^{241}Am, ^{155}Eu, ^{137}Cs and ^{60}Co. The ^{155}Eu data were used to correct the ^{241}Am data due to interference from

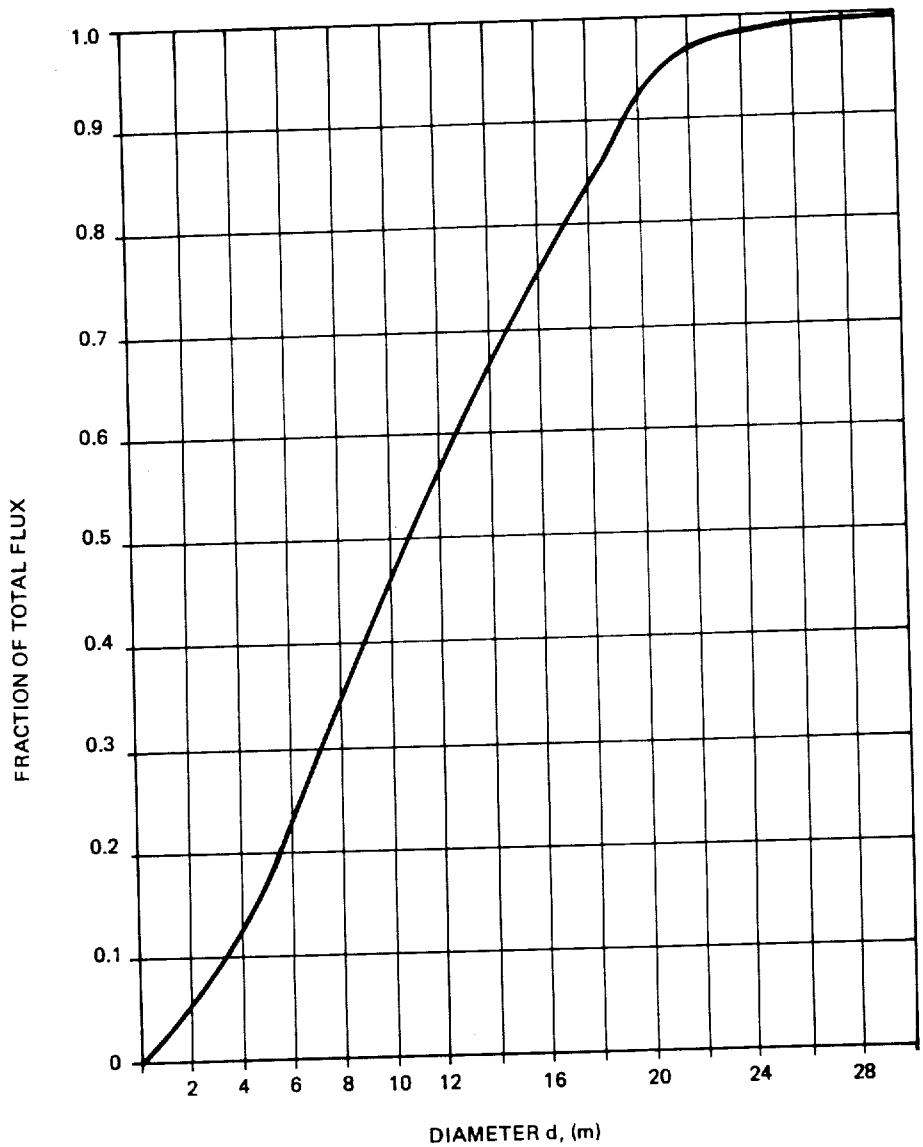


FIGURE 3-5. FRACTION OF THE TOTAL FLUX REACHING THE COLLIMATED DETECTOR ORIGINATING FROM A CIRCLE OF DIAMETER d DIRECTLY BELOW THE DETECTOR FOR A DETECTOR HEIGHT OF 7.4 m.

the 60 keV gamma ray of ^{155}Eu, as discussed in Section 3.2.7. Data for ^{137}Cs and ^{60}Co were used to obtain external exposure rate values for use in the post-cleanup dose assessment. The selection of these particular isotopes for detailed analysis was based on previous data (see, for example, NVO-140) which indicated that the primary gamma-ray-emitting radionuclides at Enewetak were ^{241}Am, ^{137}Cs and ^{60}Co. Random visual inspection of the complete spectrum tended to support this assumption with the exception of Pearl, where measurable levels of barium-133 were detected.

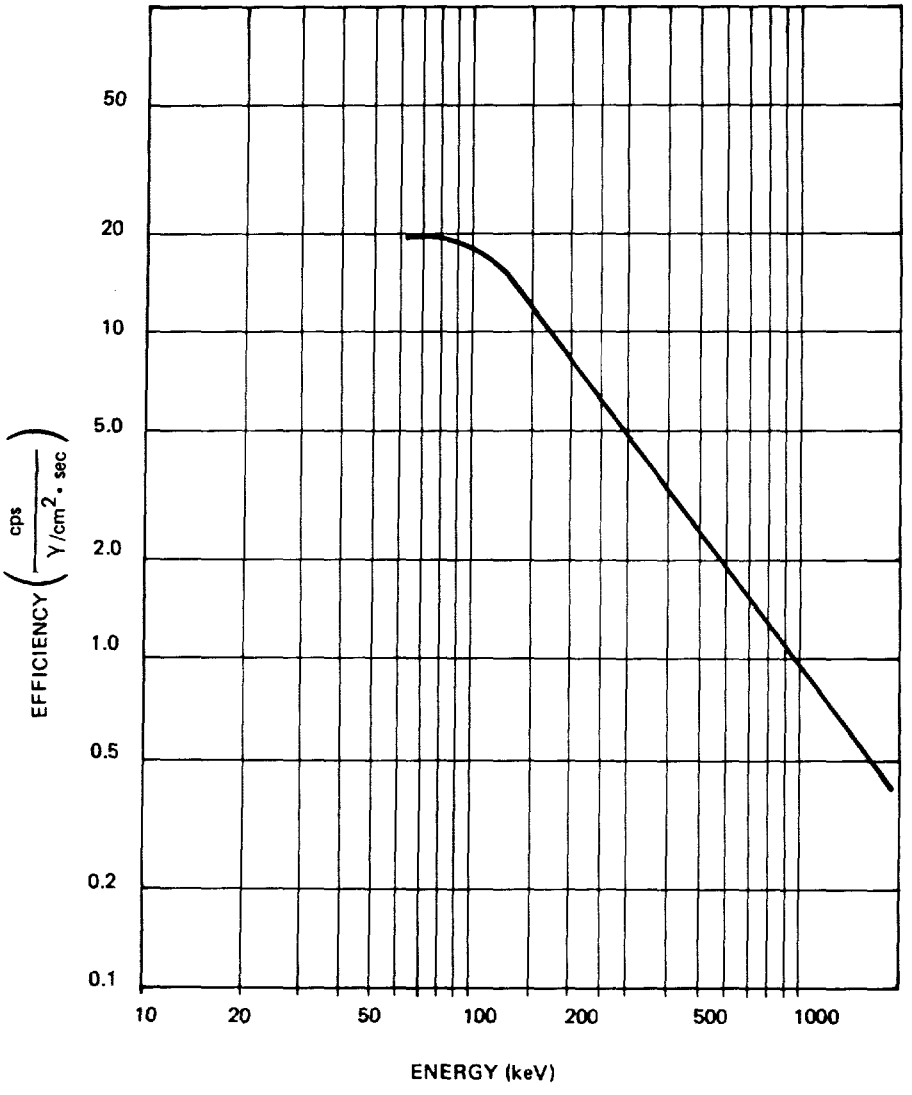


FIGURE 3-6. A TYPICAL DETECTOR EFFICIENCY VERSUS ENERGY CURVE FOR THE HPGe PLANAR DETECTORS USED AT ENEWETAK.

Conversion factors, in units of pCi/g per cps, can be obtained for these radionuclides, as well as any others which might be present in detectable quantities, by using Equation (8) in Section 3.2.5 with the appropriate input parameters. Figure 3-6 shows a typical detector efficiency (A_O) curve for the HPGe planar detectors which were used at Enewetak. Angular response data, R (θ), were also obtained for a number of gamma ray energies. Figure 3-7 shows the results for 662 keV gamma rays from ^{137}Cs with and without the collimator. Although the collimator does have a significant effect on the angular response, it was not thick enough to provide complete cutoff at the higher energies as it did for the 60 keV gamma rays from ^{241}Am (see Figure 3-3).

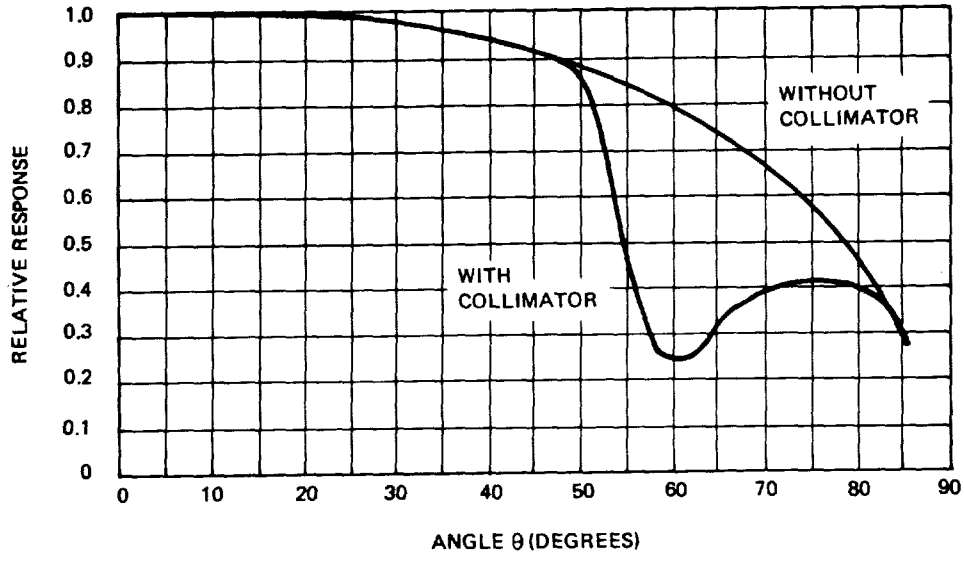


FIGURE 3-7. RELATIVE RESPONSE OF THE HPGe DETECTOR FOR 662 keV GAMMA RAYS AS A FUNCTION OF INCIDENT ANGLE (ZERO DEGREES BEING DIRECTLY BELOW THE DETECTOR).

Conversion factors are given in Table 3-4 for ^{137}Cs as a function of source depth distribution. Also shown in Table 3-4 are conversion factors relating external exposure rate (in μR/h at 1 meter) to photopeak count rate. The exposure rate conversion factors were obtained from data (Beck, et al 1968, 1972) which relate exposure rate at 1 meter to source distribution in the ground for a variety of radionuclides. It can be seen that, although a knowledge of the source depth distribution can be very critical in determining concentration values, it is not nearly so critical for determining exposure rate values.

For the post-cleanup dose assessment, external exposure rate values for ^{137}Cs were obtained using a conversion factor of 3.6 μR/h per cps. Conversion factors used for ^{60}Co were 20.5 μR/h per cps for the 1173 keV peak and 22.3 μR/h per cps for the 1333 keV peak. In principle, either peak could be used to determine the total external exposure rate due to ^{60}Co. Both should lead to the same result. In practice, however, some measurements showed a slight difference in the two results. In these cases the average value was used.

Table 3-5 shows the post-cleanup island average values for ^{137}Cs and ^{60}Co exposure rate from the IMP data. Also shown for comparison are the values obtained in November 1972 from the aerial survey (see Section 3-1). For comparison, the aerial data have been corrected for radioactive decay to November 1978. The two sets of data agree fairly well except in the obvious cases where cleanup activities have reduced the levels. It should be noted that the island average values for the aerial survey data were estimated from exposure rate contours while those for the IMP were obtained by numerically averaging discrete data points.

The island average values for ^{137}Cs exposure rate given in Table 3-5 can be converted to island average concentration values using the data given in Table 3-4. Although the depth distribution for ^{137}Cs can vary significantly from point to point, the profile data obtained in 1972 showed that a reasonable compromise for all the northern islands would be to take an average of the values given for a 10 cm and a 15 cm relaxation length. Table 3-6 gives the results for the 0-15 cm average concentration based on a conversion factor of 5.4 pCi/g per cps. Shown for comparison are the results obtained from the 1979 Fission Product Data Base sampling program. The results, in general, agree quite well.

TABLE 3-4. CONVERSION FACTORS RELATING THE NET PHOTOPEAK COUNT RATE (CPS) FOR ^{137}Cs TO SOURCE ACTIVITY IN THE SOIL AND TO EXTERNAL EXPOSURE RATE, AS A FUNCTION OF SOURCE DISTRIBUTION, FOR A DETECTOR HEIGHT OF 7.4 METERS.

Relaxation Length		^{137}Cs Conversion Factors	
		Average Activity in the Top z cm $\frac{S_v^z/\rho}{N_p}$	External Exposure Rate at the 1 Meter Level
$1/\alpha$ (cm)	z (cm)	$\frac{(pCi/g)}{cps}$	$\frac{(\mu R/h)}{cps}$
5	0	13	3.6
	5	8.2	
	10	5.6	
	15	4.1	
	25	2.6	
	40	1.6	
	60	1.1	
10	0	10	3.7
	5	7.9	
	10	6.3	
	15	5.2	
	25	3.7	
	40	2.5	
	60	1.7	
15	0	8.8	3.4
	5	7.5	
	10	6.4	
	15	5.6	
	25	4.3	
	40	3.1	
	60	2.2	

3.3 SOIL SAMPLE MEASUREMENTS

In April 1978, a method was devised to use the IMP for gamma counting soil samples. It was designed as a screening technique to classify samples with ^{241}Am above or below 1.5 pCi/g. Samples above that level were transferred to the Radiation Counting Laboratory for accurate measurement. As the majority of soil samples were below the screening level, the IMP soil sample measurement technique greatly reduced the workload on the Radiation Lab, shortening the lag time in obtaining data. As confidence in IMP measurements grew, the technique was used with increasing frequency. The philosophy of DOE/ERSP Procedure No. 21 was maintained. Samples above a certain activity level were counted by the Radiation Lab and an additional 10 percent of the samples measured were counted by the Radiation Lab as a quality control check. About 1,000 samples were screened for the Aomon Crypt excision project, and about 1,100 for the northern islands subsurface sampling and excision program. For the latter project, having data available within hours after sample collection was invaluable, and allowed an iterative boundary definition method to be utilized. IMP sample screening also was effectively used for a number of special investigations such as: Kickapoo beach debris samples; Cactus crater lip soil sampling; and occasional samples suspected of being too high in activity to be allowed in the Radiation Lab soil preparation - counting facilities. Occasionally, debris was measured upon request of JTG to determine relative content of ^{241}Am, ^{137}Cs, and ^{60}Co.

TABLE 3-5. ISLAND AVERAGE EXPOSURE RATE VALUES FOR ^{137}Cs AND ^{60}Co OBTAINED FROM THE FINAL POST CLEANUP IMP DATA AND FROM THE 1972 AERIAL SURVEY.

	Average Exposure Rate (μR/h at 1 m)					
	^{137}Cs			^{60}Co		
Island	Aerial* (Nov 72)	Aerial** (Nov 78)	IMP	Aerial* (Nov 72)	Aerial** (Nov 78)	IMP
Alice	42	37	29.3	36	16	17.4
Belle	61	53	35.8	50	23	15.2
Clara	20	17	18.3	19	8.6	9.2
Daisy	6.8	5.9	4.4	14.4	6.5	7.0
Irene+	14	12	3.3	63	29	13.0
Janet+	25	22	10.2	13	5.9	3.3
Kate	11	9.6	5.0	7	3.2	1.8
Lucy	6	5.2	6.1	7	3.2	2.6
Mary	5.5	4.8	3.1	4	1.8	1.4
Nancy	6	5.2	6.8	5	2.3	2.2
Olive	6.5	5.7	5.1	4.5	2.0	1.9
Pearl+	12	10	4.0	45	20	7.0
Ruby	2	1.7	0.6	12	5.4	3.8
Sally+	3.5	3.0	2.0	3	1.4	1.5
Tilda	4	3.5	2.3	2	0.9	0.7
Ursula	3	2.6	0.9	1.8	0.8	0.3
Vera	2.8	2.4	1.7	2	0.9	0.5
Wilma	1	0.9	0.8	1	0.5	0.3
Yvonne+	5.6	4.9	1.9	22.4	10	4.1

* From NVO-140, Table 9, p. 80
** Nov. 72 data corrected for radioactive decay to Nov. 78
+ Islands where soil was removed during the cleanup

TABLE 3-6. AVERAGE ^{137}Cs ACTIVITY IN THE TOP 15 cm OBTAINED FROM THE IMP DATA (WITH $1/\alpha$ = 12.5 cm) AND THE 1979 FISSION PRODUCT DATA BASE RESULTS.

Island	Final IMP Results (pCi/g)	Fission Product Data Base Results (pCi/g)
Alice	44	40
Belle	54	61
Clara	27	22
Daisy	6.6	6.8
Irene+	5.0	6
Janet	15	16
Kate	7.5	7.8
Lucy	9.2	12
Mary	4.7	6
Nancy	10	11
Olive	7.7	7.5
Pearl	6.0	7.2
Ruby	0.9	2.0
Sally	3.0	3.5
Tilda	3.5	3.2
Ursula	1.2	1.2
Vera	2.6	3.0
Wilma	1.2	1.3

+Additional cleanup was performed on this island after the fission product data base samples were obtained.

A detailed description of the soil sample screening procedures is given in Tech Note 6. Briefly, the soil sample was placed in a petri dish, and the dish placed in a holder which maintained a distance of about 3 cm from the top of the dish to the detector entrance plane. (In the counting laboratory the same distance was maintained.) The sample was counted for five minutes. An initial calibration was performed using two samples previously measured in the Raditation Counting Lab. A calibration factor of approximately 10 pCi per count/5 minutes, or 3,000 pCi/cps was obtained. A screening level of 20 counts per 5 minutes was adopted, corresponding to approximately 1.5 to 2 pCi/g of soil (typical samples were around 100 g). Counts due to ^{137}Cs and ^{60}Co were noted, but no attempt made to quantify them.

Tech Note 6.1 presents a statistical analysis comparing the IMP soil sample screening results to Radiation Lab gamma counting. The mean ratio of IMP/LAB is 1.05 $\pm$ 0.35. Linear regression gives the equation IMP = 0.92 · LAB + 2.72, with a coefficient of determination (r^2) of 0.88. This comparison was based on measurements made of the same petri dish samples. The good agreement is not surprising, as the same type detector was used for both IMP and LAB counting.

To prepare for the Aomon Crypt excision project, further calibration was performed using a series of petri dishes standardized by the Radiation Counting Lab, and the Radiation Lab standards. To account for the effective area factor of various detectors, the technique finally adopted was to input to the soil sample measurement program the average pCi/g measured using a standard petri dish calibration source. The final program also allowed the input of sample percent moisture, so that pCi/g dry soil could be calculated (corresponding to the value determined by Radiation Lab analysis). Approximate calibration factors were also determined for ^{155}Eu, ^{137}Cs, and ^{60}Co.

For the Aomon Crypt core drill samples, an analysis similar to that of Tech Note 6.1 was conducted. The IMP sample was a filtered aliquot from a sample can, with an assigned 23 percent by weight moisture content. If the IMP screening gave a value for ^{241}Am greater than 25 pCi/g, the Radiation Lab dried the entire core drill sample and then prepared an aliquot for laboratory gamma counting. For 95 pairs of data (each pair taken from the same core sample) the mean ratio of IMP/LAB is 1.23 $\pm$ 0.54. Linear regression gives the equation IMP = 0.95 · LAB - 3.8, with a coefficient of determination (r^2) of 0.96. The greater standard deviation in the ratio of IMP/Lab result is probably a reflection of the different aliquots counted and the difference between the assumed constant moisture content of 23 percent and the actual moisture content, which varied from 14 to 49 percent.

3.4 OPERATIONAL EXPERIENCE

3.4.1 IMP Operations

The IMP performs in situ gamma ray spectroscopy to measure ^{241}Am and other gamma emitters and thus functions as a mobile laboratory. Experience in operation of a sophisticated system such as the IMP under remote tropical conditions is limited. Thus this section has been included to discuss the operational problems and their solutions. It was desired to have two IMPs operational at all times. To achieve this, three complete IMPs were provided. It was also desired to have two operating detectors for two of these IMPs, and a third available on-atoll in the Radiation Laboratory for soil sample spectroscopy. Four detectors were procured to satisfy these requirements. The desired mode of operation was not always achieved, however, because of detector repair requirements.

Operating conditions for the IMPs included high temperature, high humidity, and salt spray. Depending on the season, tropical rain storms and high winds were often encountered. During the project, several tropical storms caused major damage to the atoll. During these times, the IMPs were secured inside the IMP shed and the detectors lashed inside the IMP cab.

Transportation between islands was by military landing craft or amphibious LARCs. The landing craft ramp angle was usually about 30 degrees. The LARC ramp angle ranged up to 60 degrees. Considerable shock and vibration was inherent in any boat operation, and sea conditions sometimes made a fast, rough embarkation mandatory.

Several design measures were taken to minimize the effects of these conditions. The detector was mounted inside a canister packed with an annulus of foam cushioning (polyurethane). The detector rested on a 1/4-inch, foam-rubber-cushioned, metal support ring. The ring itself was spring suspended inside the canister. The top of the detector dewar was tightly packed using foam cushioning against the top lid of the canister. The collimator cone was suspended from the bottom of the dewar, so that the collimator and dewar (with protruding detector) moved as a unit. The canister was hung from a yoke, hinged to allow the canister to remain vertical as the boom was pushed out to its 20-degrees-from-vertical position. A latch-plate locking pin arrangement was used to secure the canister to the boom at all times other than while the canister was elevated to take a measurement.

The IMP data acquisition portion of the cab was air conditioned, using a roof-mounted unit. The air conditioner was operated at full cool continuously. The IMP electronics, computer and printer were mounted in a standard instrument rack which was shock-mounted inside the IMP. The scheme was successful in allowing use of laboratory equipment for the field operation. Maintenance experience was similar for the IMP computers and the laboratory computers. The pulse height analyzer (PHA) was designed for field use and had a satisfactory maintenance record.

Rain storms initially caused problems because of water penetration at cable connectors. These were solved by providing a flexible rubber boot over the cables at the canister entrance and at the feedthrough in the rear of the cab. In addition, the feedthrough was recessed inside the cab wall and partially protected by a door. It was also necessary to put thermal insulation around the cab side of the feedthrough plate to avoid condensation problems. The dew point at Enewetak is usually greater than 80°F, so a cold connector (i.e., less than 80°F) caused condensation.

The Onan electrical generator was modified to increase its reliability. The fuel pump was changed to an electrical fuel pump. An oil bath air cleaner was installed. A water separator and an improved filter were installed in the gasoline feed line. One of the Onans operated for about 4,400 hours, which is a factor of two longer than the normal lifetime.

Rust prevention was also a design concern. The inner and outer surfaces of the sheet metal forming the IMP body were coated with zinc chromate primer. Outer surfaces then received a coat of white acrylic enamel. Inside surfaces were coated either with Glyptal varnish or commercial undercoating material, depending on the location. These initial measures were combined with a maintenance "grind and repaint" program. There was considerably less deterioration on the IMPs than on other equipment on-atoll that did not receive this sort of attention.

3.4.2 Maintenance Scheme

Critical spare parts and replacement components were maintained on-atoll. These included an Onan electrical generator, air conditioners, air compressors, the extendable mast, and spare parts for the IMP engine and Onan engine. Electrical spares included the cable harness and detector power supplies. Mechanical and electronic maintenance was performed by the two-man IMP technician crew, assisted by the two Air Force mechanic-drivers assigned to the IMP. Occasionally the base operating contractor's vehicle maintenance shop provided a special service, such as welding. The required spare parts and components were selected based on general experience, modified by on-atoll history. Replacements were ordered as parts were used from the spares inventory, or as failure required a part.

A regular maintenance schedule was established and usually adhered to. One day per six day work week was usually devoted to maintenance for each operating IMP. This was modified based on urgency of survey schedules, and further modified depending upon transportation needs; that is, if an IMP were working a remote island not served by a military work boat, and required one or two days to complete the survey, the survey would be completed and maintenance delayed until the third day.

On the average, two IMPs were available about 80 percent of the time. At least one IMP was available about 95 percent of the time.

3.4.3 Liquid Nitrogen

The HPGe detectors used in the IMPs operated with liquid nitrogen at a temperature of -196°C. In the early months of the program the liquid nitrogen was air lifted from Honolulu on scheduled MAC cargo flights. Two military surplus 500-gallon containers were used. Shipping regulations required that the pressurized containers be vented outside the aircraft cabin. The condition of the containers, combined with these regulations, resulted in excessive nitrogen loss before reaching Enewetak. The on-atoll transfer containers were military surplus, wheeled, horizontal 50-gallon liquid oxygen carts, all of which had a high liquid nitrogen loss rate. This system was rather expensive and inconvenient.

An improved system was devised, and better containers purchased. A military surplus, trailer-mounted liquid oxygen/liquid nitrogen plant was obtained, and the base operating contractor had people trained to operate it. About every two weeks, the plant was activated and two of the three on-atoll liquid nitrogen containers were filled. The containers were Linde LS-160B models, each holding 160 liters. This scheme successfully supplied the IMP and Radiation Lab with liquid nitrogen.

3.4.4 Detector Performance

Three detectors were purchased for use in the project and a fourth was ordered a few months later, when the effects of Enewetak conditions on the detectors were confirmed. Two other detectors had been procured for a similar measurement program at the Nevada Test Site (NTS). Detectors were assigned by DOE to Enewetak or NTS, based on priority and scheduling of the two projects. Detectors were transferred informally and expeditiously, in response to DOE direction. All six detectors were used at Enewetak at various times.

All detectors used at Enewetak were initially calibrated in Las Vegas, as discussed in Section 3.2.3. Starting in July 1978, a calibrated ^{241}Am source was available on-atoll and periodic remeasurements of effective detector area were made. These were used to provide an effective area correction factor for data handling. Field calibration sources, consisting of ^{241}Am, ^{137}Cs, and ^{60}Co, were used for three-times-daily detector performance monitoring. Field calibration was performed to set the gain of the detector electronics, and to generally track detector behavior. Tech Notes 5.2 and 11 discuss effective area factor and field calibration. For the field calibration measurements, the percentage standard deviation for the ^{241}Am value was 2 to 5 percent. The mean error in a series of effective area measurements was 1.1 ± 0.8 percent.

In the first months of the project, gradual loss of detector resolution with usage was noted. This was traced to water vapor entering the liquid nitrogen dewar during refilling in the field, causing an ice layer to form at the bottom of the dewar. This in turn partially insulated the detector, causing higher than design operating temperature. The problem was solved by the following maintenance procedure. About once each month, the detector was brought to room temperature, and ethanol used to remove water from the detector dewar. The dewar interior was then dried using a stream of air. The dewar was then refilled with liquid nitrogen.

Operational history of the detectors is summarized in Appendix D. The average detector life span when installed in an IMP was about four months, with a range of less than a month to over seven months. Causes or symptoms of failure were: preamp corrosion, vibration sensitivity, no signal transmission, wide peaks and noise at low energy, and the dewar failure. The last three items listed can probably all be classed as dewar failure, and were ultimately traced near the end of the project to corrosion of the 22 mil beryllium entrance window, or the beryllium-aluminum epoxy seal. An all-aluminum window was ordered on repaired detectors, but was not available in time to be used on the Enewetak project.

CHAPTER FOUR

Although the basic source of field data for the Enewetak Radiological Support Project was the in-situ system described in Chapter 3, a field radiochemistry capability was required for verification and interpretation of the in-situ measurements and to establish localized ratios for the conversion of ^{241}Am concentrations to concentration of total transuranics. These requirements led to the establishment of a laboratory complex on Enewetak Island with a 24-hour capability. The laboratory was in continuous operation from mid-1977 until September 1979. More than 11,000 soil samples were processed (and later archived), and extensive support was provided to DNA's radiological safety program. Despite the cost of establishing and operating a laboratory far from sources of supply and technical management, its ready availability and rapid turnaround for data were indispensable. At no time in two and a half years of the cleanup were operations stymied for lack of radiochemistry data. The laboratory and its operation are described in this chapter.

Project Manager's Note

RADIOLOGICAL LABORATORY OPERATIONS

by Richard Powell and Ernest Sanchez
Eberline Instrument Corporation

4.1 DESCRIPTION OF FACILITIES

On 16 February 1977, the Nevada Operations Office of the Department of Energy (DOE-NV) contracted with Eberline Instrument Corporation (EIC) to design, install and supervise the operation of a low-level radiological laboratory and instrument maintenance facility for the Enewetak Radiological Support Project (ERSP). The specific responsibilities included providing routine laboratory analyses of environmental samples for transuranic radionuclides (Pu and Am), gamma isotopic analyses of many media, air filter and nose swipe analyses for the Field Radiation Support Team (FRST), and any non-routine specialized analytical requests.

EIC provided a laboratory manager, a radiochemist, an electronics engineer and an electronics/soil sampling technician to supervise the radiological-chemical complex utilizing military technicians assigned by the Air Force and the Navy. EIC also provided other technicians to expedite soil sampling and analyses during the Fission Product Data Base (FPDB) program.

The radiological laboratory complex, which was set up and in operation in less than six months, consisted of five trailers which were placed on concrete pads that had been left over from the 1958 test series. The complex included sample preparation, chemistry, and counting laboratories, an instrument maintenance trailer, a combined office and data processing trailer, and a shed open on the leeward side (see Figure 4-1). A bunker adjacent to the complex and a warehouse on the south end of the Island of Enewetak were utilized for bulk storage of chemicals and other laboratory supplies.

4.1.1 Sample Preparation Laboratory

The Sample Preparation Laboratory provided the capability to perform gross analysis screening of the radioactive content of soil samples taken from the field and to prepare the samples for radiochemistry and gamma analyses. The trailer was an aluminum shell wood frame instrument maintenance unit which was refurbished on site to accommodate the laboratory equipment. Reconstruction included the following major projects: stabilizing the structure, weatherproofing, reworking the electrical system, and installing hoods, louvres, ducts, fan and high efficiency particulate air (HEPA) filter units. The laboratory consisted of two sections separated by a

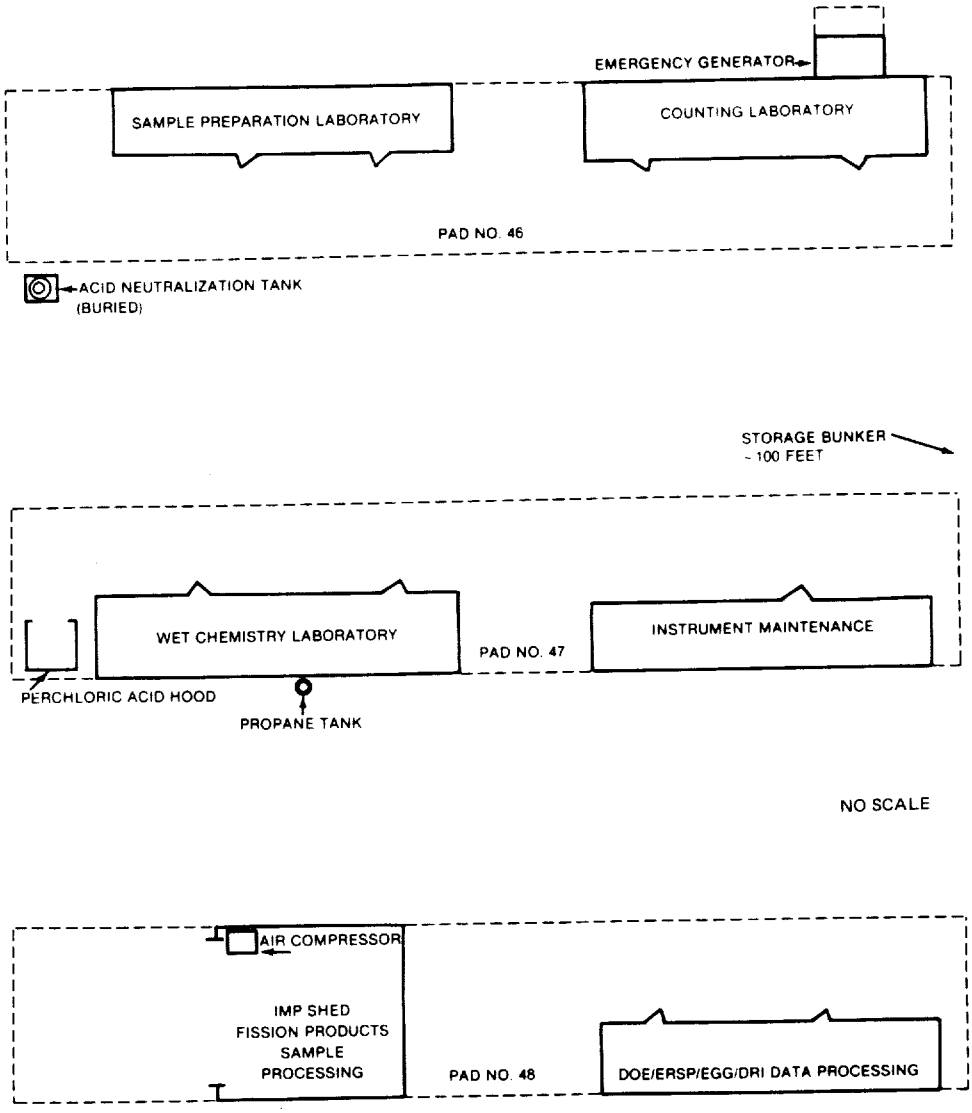


FIGURE 4-1. ENEWETAK RADIOLOGICAL SUPPORT COMPLEX

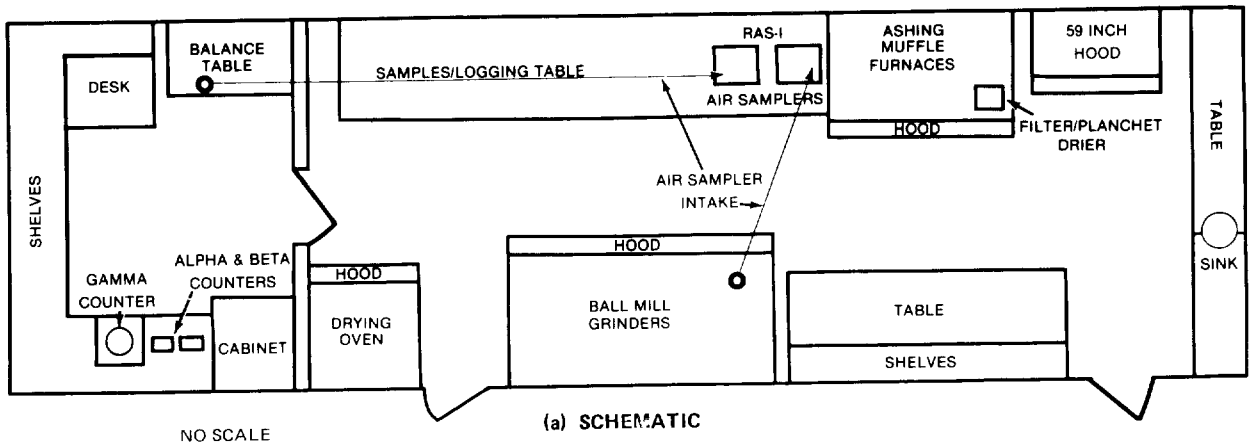
partition. The larger work area contained hoods, grinders, furnaces and tables and was not air-conditioned due to the large air flow requirements of the hoods. The smaller section was set up with air-conditioning to provide humidity and temperature control for the electronic instruments and sensitive balances. The Sample Preparation Laboratory is shown in Figure 4-2.

The work tables, hoods, and related equipment in the large work area were arranged for maximum effective use during production. A large sample logging table was used to check the field samples for proper identification and to log them into record books. Two other tables were used for sample processing and storage. The majority of space in this section was occupied by four fume hoods. One hood (70 x 36-inch) was installed to house two convection drying ovens used to dry the soil samples. The ovens were placed on an Equipto metal bench and had maximum temperature capabilities of 200°C.

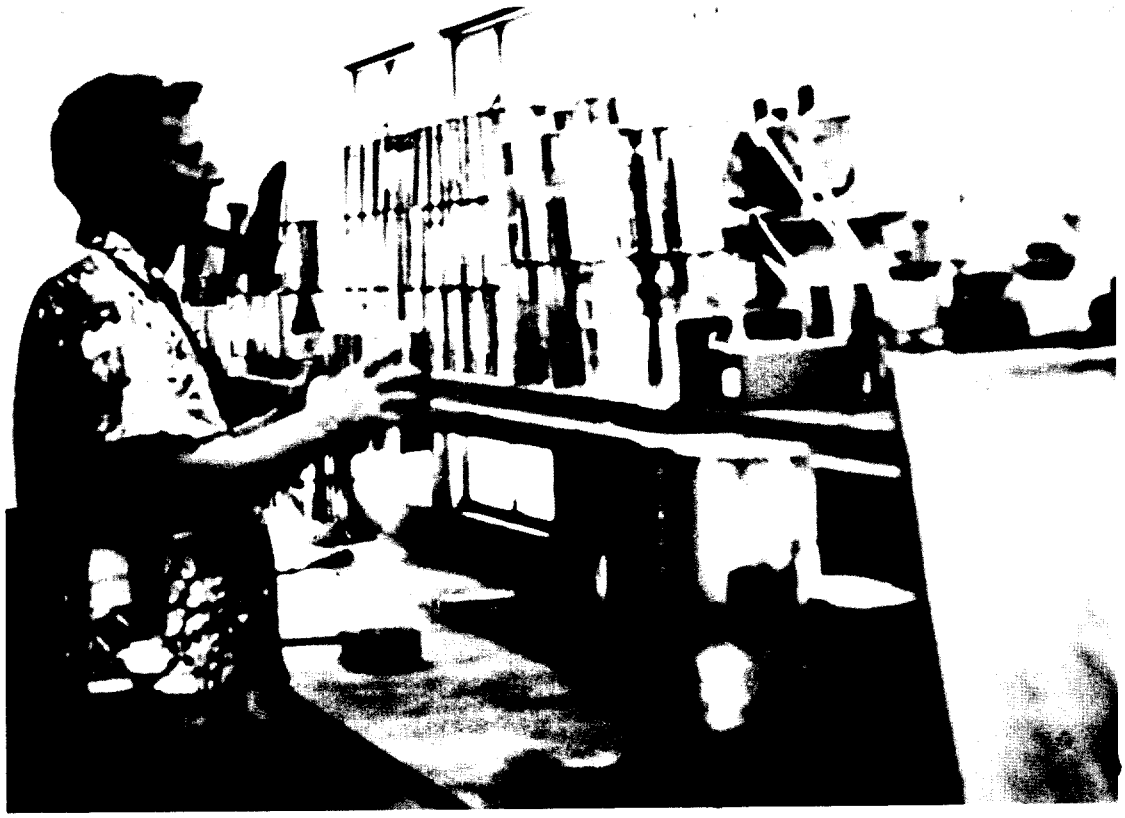
A second hood (84 x 48-inch) covered a work area for three ball mills and a small coral grinder used to pulverize dried soil samples. The hood was surrounded by a plastic enclosure and curtain shroud for noise abatement and air flow control. A third hood (88 x 48-inch) contained two high temperature muffle furnaces and was set up on a heavy duty steel support table. Firebricks lined the table and back wall for heat protection. Each furnace had temperature capabilities of 700°C and was used to burn organic material from the soil samples. A small planchet drying oven was placed on top of the muffle furnace and inside the hood. This oven was a sheet metal box enclosure that used infrared lamps to dry air filter papers and plancheted samples. The fourth hood was a standard (59 x 29-inch) Labconco laboratory hood used to handle dry sample material and to remove contaminated balls from the milling cans. It had a higher air flow rate than the other hoods and was principally used to transfer materials and contain soil particulates within the hood.

The air-conditioned section of the laboratory had a balance table, gross alpha and beta counters, a gamma screening probe, work desk and shelf storage. The balance table was decoupled from the trailer body by installing the table legs through holes cut in the floor and setting it directly on the concrete pad underlying the trailer. Two laboratory balances were used for measuring sample weights. A Metler analytical balance, sensitive to 0.1 mg, was used to measure aliquots for wet chemistry analyses. A Metler top loader balance, sensitive to 0.1 g, measured the total bulk weight of wet and dry samples and petri dish aliquots for the counting laboratory. The screening probe used was an Eberline Model RD-21 (FIDLER) which detected gross amounts of ^{241}Am gamma activity in unopened sample cans. The probe functioned to screen out high activity samples (greater than 60 pCi/g) that might have contaminated the laboratory. The FIDLER was encased in a two-inch lead shield with an open top, set with the sensitive area up and covered with a 0.125-inch plastic sheet for can support and dust protection. A field alpha scintillation detector (AC-3) was set up and calibrated to detect gross alpha particles in the soil samples, and a thin window beta detector (HP-210) was used for gross beta counting. All three counting instruments used the standard Eberline scaler-timer model PRS-1 or MS-2 for electronic readouts. Both scaler-timer models were field portable and provided single-channel Pulse Height Analyzer (PHA) capability.

Several safety-monitoring instruments were installed throughout the Sample Preparation Laboratory to check air quality control and insure personnel protection. All fume hoods were exhausted through HEPA filters to eliminate the possibility of air contamination on Enewetak Island from the soil samples being processed. The HEPA filter units required changing only once, about halfway through the project, due to dust loading. Manometers were placed in the work areas to indicate pressure drop across the filter boxes. Two air samplers (RAS-1) were used to monitor air particulate concentrations inside the trailer; one sample head was placed in the grinding hood and the other above the balance table. Dust respirators and glove protection were required while working at the Labconco hood. Dust respirators and ear protection were required while working in the grinding hood. The decontamination facility was located in the rear of the trailer and included a double sink and bench area which provided hot water for cleaning hands, equipment, and milling balls. A solution of Dekasol in a five gallon open-top container was used to decontaminate the mill balls for reuse. Water was drained into the RADLAB complex acid neutralizing tank for processing. Both air quality and contamination control were integral in laboratory procedures to insure personnel safety. Detailed soil sample procedures are discussed in Section 4.3.2.



(a) SCHEMATIC



(b) INTERIOR VIEW

FIGURE 4-2. SAMPLE PREPARATION LABORATORY

4.1.2 Wet Chemistry Laboratory

The Wet Chemistry Laboratory provided a facility for the quantitative and qualitative wet chemistry separation and purification of radioelements in the soil samples. The ashed and aliquoted soil samples from the Sample Preparation Laboratory, after separation and purification, were electrodeposited on stainless steel discs for subsequent alpha spectrometry counting by the Counting Laboratory. Although the Wet Chemistry Laboratory was established primarily for the analytical determination of plutonium, some chemical separations were performed on a limited number of samples for americium, strontium, and uranium.

The Wet Chemistry Laboratory was a 12-foot by 53-foot modular mobile office unit bought in the United States. EIC assembled the basic laboratory environment in Albuquerque, New Mexico, and shipped it to Enewetak prior to personnel arrival. Cabinets, benches, plumbing, electrical wiring and air conditioning were constructed in the United States with exhaust outlets prepared for immediate hood installation on the island. An air conditioner was installed on each end of the trailer and connected through a common duct system to provide a backup system in case one unit failed. The Wet Chemistry Laboratory is shown in Figure 4-3.

Wet chemistry procedures involved the dissolution of sample aliquots, chemical separation and purification of the desired nuclides, tracer yielding and quantification. For these purposes the laboratory contained two 59-inch hoods, a 72-inch hood, air intake and exhaust stacks for each, benches, cabinets, work table, centrifuge, Burrell shaker, sinks, dishwasher, and the essential chemicals, tools and small equipment required for wet chemistry procedures.

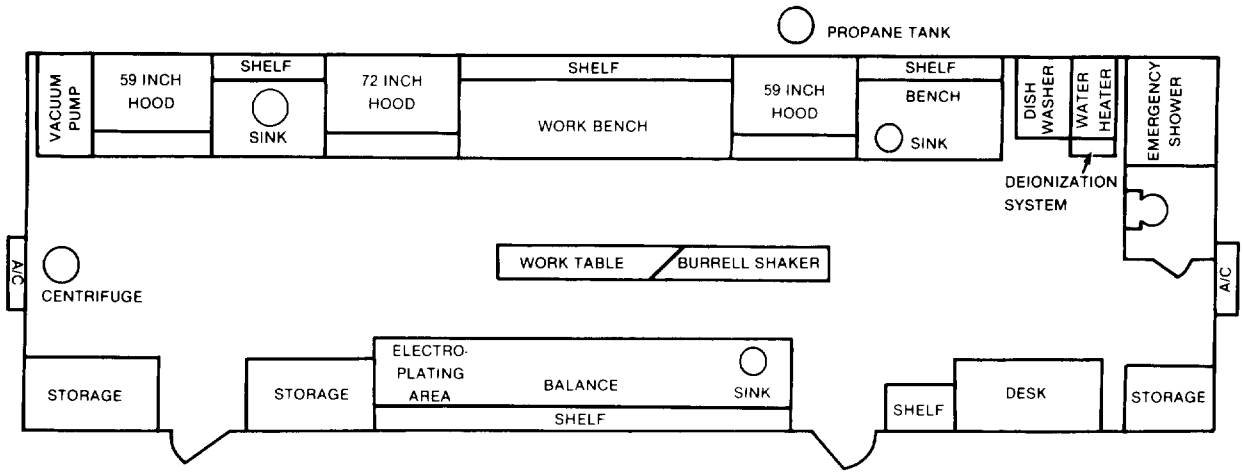
One 59-inch hood was used mainly for wet-ashing the sample aliquots brought over from the Sample Preparation Laboratory. The wet ashing process oxidized all organic matter to a white residue, thus facilitating the sample dissolution prior to chemical processing. The large 72-inch hood contained 25 ion exchange columns used for the purification process of the sample, a step that functioned to isolate plutonium and americium and separate them from interfering elements. The second 59-inch hood was used to draw off toxic fumes during solvent extractions. All three hoods were standard Labconco add-air hoods and had intake and exhaust stacks installed through the roof. Fresh outside air was supplied to the hood through the short air intake units, then exhausted while simultaneously pulling air from the trailer. Since the fumes exhausted to the atmosphere were free of radioactivity, no HEPA filters were required on the hoods.

Base cabinets with acid resistant table tops were installed under each hood for supply storage and work counters. A radioactive solution storage with 2-inch lead shielding was located under the 72-inch hood. Standard Equipto benches were placed between the two hoods and installed away from the wall, approximately 4 to 6 inches, to allow space for a laboratory pipe chase. The chase and benches were covered with a stainless steel sheet for protection from corrosion and for ease of decontamination. The benches were also painted with green epoxy paint to inhibit rust and deterioration.

A Burrell shaker, designed to accommodate twelve separatory funnels, was set up over the center table. A special flat plate was installed into the trailer ceiling, and a three-inch pipe column was dropped from the ceiling to secure the top of the shaker. Lead weights were added to the column to increase mass and cut down the amplitude of vibration.

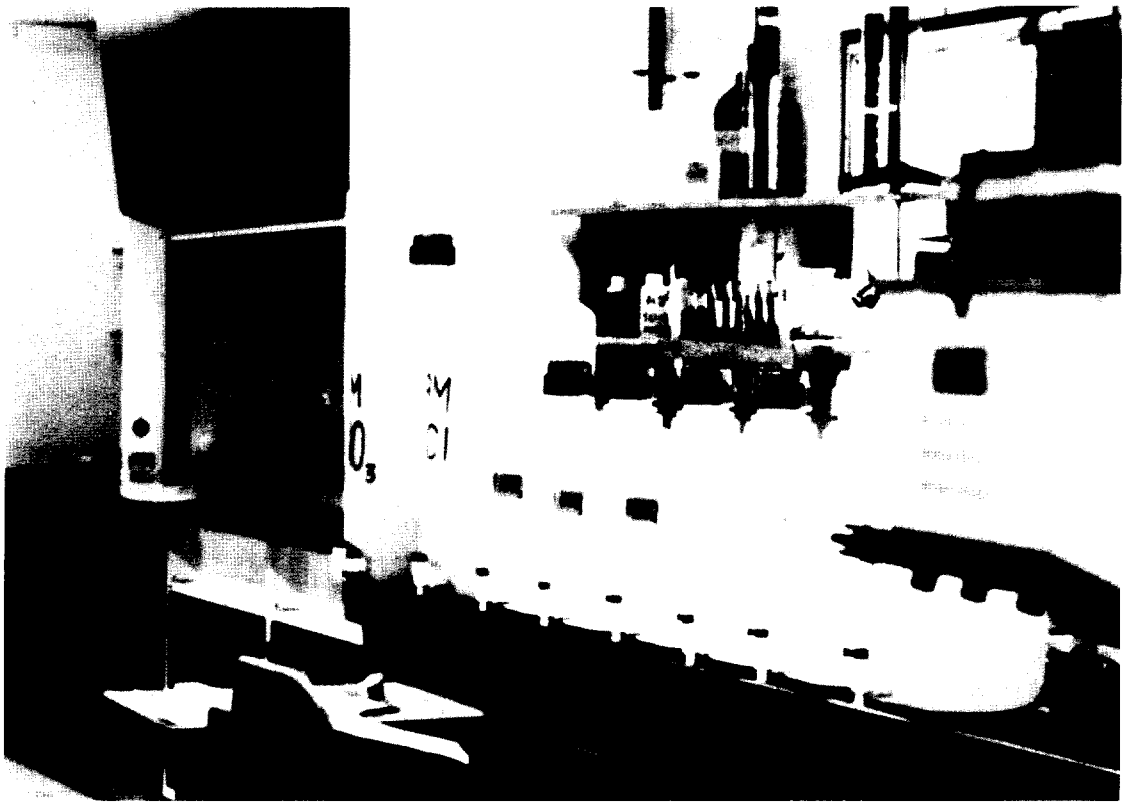
4.1.3 Counting Laboratory

The Counting Laboratory was used to assess the radiological content of soil samples, nose swipes, air filter papers, and other samples as required in support of DOE operations on Enewetak. The capabilities of the laboratory included alpha and gamma spectrometry, gross alpha and beta, and gas flow proportional alpha and beta counting. These facilities provided the basis for determining the TRU to ^{241}Am ratio of soil samples to be used with the in-situ IMP results. Although the majority of samples counted by the laboratory were for Pu and Am analysis by alpha and gamma spectrometry, a small number of samples was processed for Sr and U. The Counting Laboratory is shown in Figure 4-4.



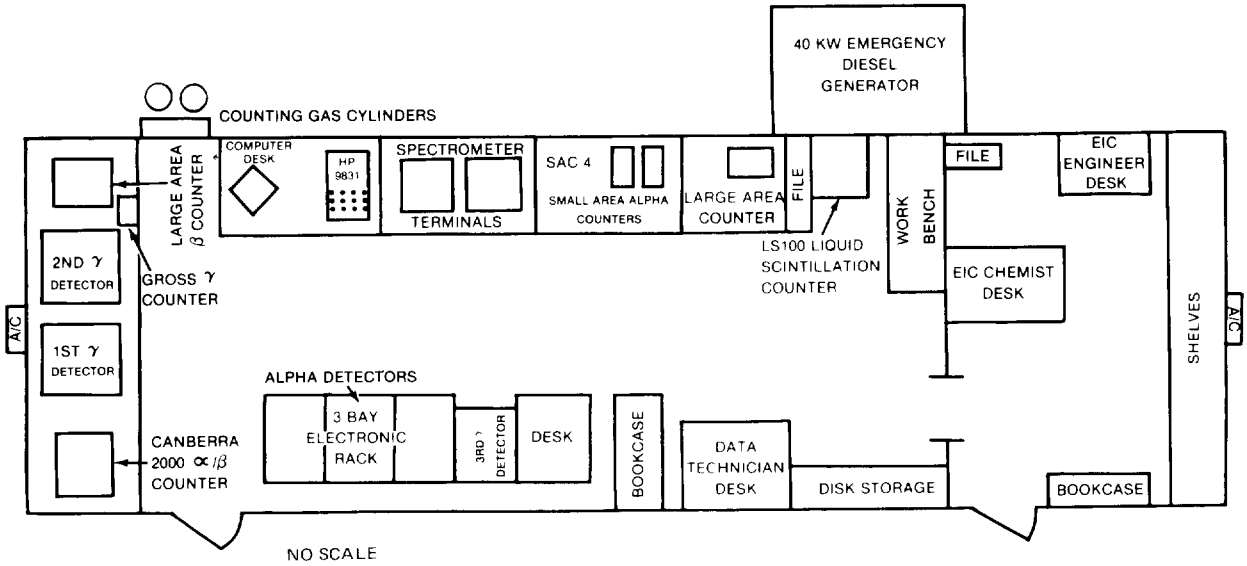
NO SCALE

(a) SCHEMATIC

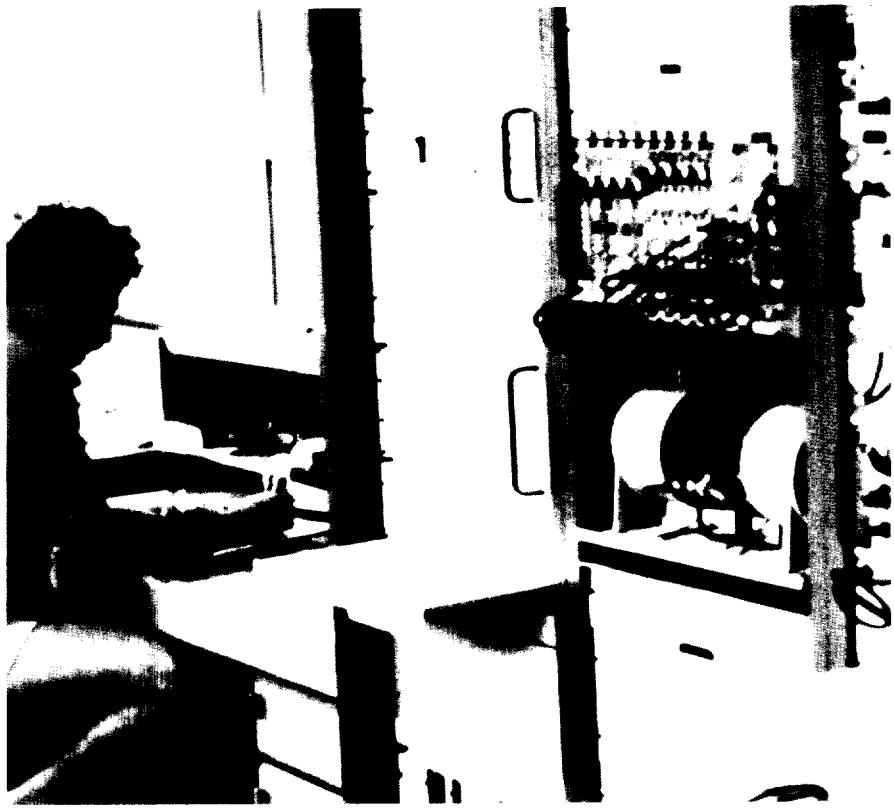


(b) INTERIOR VIEW

FIGURE 4-3. WET CHEMISTRY LABORATORY



(a) SCHEMATIC



(b) INTERIOR VIEW

FIGURE 4-4. COUNTING LABORATORY

The alpha spectrometer system for Pu analyses included four alpha detectors and the related equipment necessary for counting and data printout or storage. The alpha system was located entirely within the electronics rack. Each alpha unit had a solid state silicon detector that was sensitive to alpha particles when under a vacuum. The actual counting electronics were contained in a nuclear instrument module or NIM Bin, with attached power supply providing the necessary voltage. The alpha pulses were directed through a pre-amplifier and amplifier to shape and increase the output signal for analyses. The pulses were then put into a gated analogue router (GAR) which routed the signal to an analogue digital converter (ADC) for spectrometry. The GAR eliminated the need for four ADC units and thereby directed the appropriate alpha pulses into a selected portion of the PHA memory. Spectrum results were displayed on cathode ray tube (CRT) terminals for manipulation and control. Information was then printed out through the HP9831 computer printer for final data reduction.

The gamma spectrometer system for isotopic analyses included three built-in shields to enclose intrinsic germanium (IG) detectors plus their related electronic hardware. Two permanently installed shields were constructed of low-background, two-inch steel plate and placed at one end of the trailer. One shield contained a large-area upright IG coaxial detector referred to as IG-1 and its companion shield was used for the spare IMP planar detectors (IG-2 through IG-7). Both shields were designed to accommodate either uplooking or downlooking detector models. When the FPDB program began in 1979, EIC was authorized to construct a third shield to supplement the laboratory capabilities for gamma counting. This shield was made of two-inch lead brick and placed by the electronics rack. A planar detector was then transferred to the new shield and an uplooking coaxial detector was installed into the vacant permanent shield. The shields were equipped with plexiglass liners, sample support shelves adjustable to 1 cm increments, and had interchangeable circular cutouts and rings to hold the samples for the various counting geometries used. An additional four-inch lead brick shield was also installed to hold a 2 x 2-inch sodium iodide detector for any required gross gamma counting.

The IG gamma detector electronics consisted of a pre-amplifier mounted on each individual unit, a high voltage bias supply in the rack, plus two NIM Bins that contained the amplifiers, ADC, and Multiplex (MUX) modules necessary to combine and channel the signals to the PHA. Spectrum results were displayed on CRT terminals and the final data were stored on magnetic tape cartridges in the HP9831 computer. Electronic readouts for the sodium iodide detector were provided through a single-channel analyzer and scaler also mounted on the electronics rack.

The gross alpha and beta counting systems consisted of two standard EIC scintillation alpha counters (SAC-4), and two EIC Model A-23 large-area gas proportional counters. The SAC-4 units measured gross alpha on two-inch filter papers and planchet samples for detecting contamination levels in the RADLAB complex. Both of the large-area alpha and beta counters used chemically pure (CP) grade methane gas for counting. The beta unit also had a two-inch lead shield to reduce background interference from cosmic sources. Electronic readouts for the units were channeled through mini MS-2 scalers.

Additional low-level counting of alpha and beta was provided by two other instruments. A Beckman LS-100C Liquid Scintillation Counter was set up to detect gross alpha on nose swipes collected in the FRST personnel monitoring program. However, it was also calibrated to count low energy betas. A low background Canberra 2000 simultaneous alpha-beta counter was set up for beta determinations. The counter electronics consisted of a high voltage power supply, amplifier/timing single-channel analyzers, anticoincidence gate-delay, and manual readout scaler/timers mounted in the rack. The beta unit was a 4π methane gas proportional counter with an 80 $\mu g/cm^2$ window and integral anticoincidence guard.

The three-bay electronics rack provided the power sources, NIM Bin mounting and analyzer/processor space for the alpha detectors and gamma electronics modules. Additional electronic equipment included troubleshooting multimeters, sliding pulsers, cable patch panels and other digital instruments. All counters and terminal units in the laboratory were cabled to the electronics rack through an under-floor conduit system. These cables supplied interconnections for high voltage power supply, preamplified power, signal and data output. Interconnection coaxial cables used for high voltage and signals were RG-59/U and RG-62/U, respectively.

The electronics rack also contained an uninterruptible power supply (UPS) system which had two internal battery packs with charger, inverter system and static transfer switch. The UPS system was sized to supply alternating current (AC) power to the critical busses feeding the major counting instruments for as long as 45 minutes when the main power system was interrupted. This allowed time to start the emergency diesel generator to meet the counting trailer requirements. An autotransformer type regulator was installed to supply power for any noncritical buss requirements in the electronics rack.

Each of the two PHA units had a 4096-channel memory which could be divided into subgroups for data acquisition of multiple alpha and gamma signals. One PHA unit was used as the alpha spectrometer and contained groups of 512 channels for each of the four alpha detectors. The other 2048 channels were kept as a spare until the FPDB project began and were then utilized for the third gamma detector output. The second PHA memory was grouped into two 2048-channel areas and sectioned to accommodate each IG detector. Signal multiplexers were installed into the system to tie all signals into one analyzer if required. The two PHA systems were identical so that not only could both alpha and gamma radiations be analyzed simultaneously on one PHA, but parts could be interchanged if one system broke down. The dual PHA system resulted in full operation and zero time loss during the entire project for alpha and gamma counting capabilities.

4.1.4 Instrument Maintenance Facility (IMF)

The IMF was utilized to calibrate and repair laboratory and field instruments used in support of DOE and FRST operations and to store the tools, spare parts and equipment esential to perform such calibration/repair operations. The IMF was vital to the radiological operations on Enewetak because of the isolated geographical location and adverse field conditions. It was staffed by an AF Precision Measurements Electronics Laboratory (PMEL) technician and contained office space for the EIC laboratory manager and Navy storekeeper. The majority of space in the work section was occupied by an extended bench with shelving to hold repair equipment which included a drill press, vise, grinder, drying oven, nickel-cadmium battery charger, and voltage regulator.

The efficiency of the IMF enabled both the FRST and the RADLAB complex to function continuously without time loss due to electronic or mechanical equipment failures. Specific information on the inventory of the maintenance instruments is in Appendix C-3.

4.2 MAJOR PROGRAMS

The RADLAB support of the Enewetak Cleanup Project was principally concerned with the collection, analysis and archiving of surface and subsurface soil samples for the transuranics program, fission product data base program, and suspected burial site investigations.

During the project, EIC assigned laboratory control sample numbers to 22,534 samples, processed 8,400 TRU samples, processed 6,003 FPDB samples, and processed 11,455 soil samples for shipment to, and long term storage at, the Nevada Test Site for DOE. Table 4-1 shows the specific sample breakdown by type of analysis.

4.2.1 Transuranics (TRU) Program

The purpose of the TRU Program was to determine the concentration of TRU in the soil and then to take measures to reduce the concentrations to acceptable levels. Surface soil samples were taken as directed by DRI and the ERSP Tech Advisor and analyzed in support of the in-situ IMP operations to provide ^{241}Am concentrations and ratios of TRU to ^{241}Am for on-island estimation of the transuranic contamination. Subsurface samples were taken at locations as directed by the ERSP Tech Advisor and DRI statistician to investigate locations that were suspected of exceeding the limit for subsurface soil.

TABLE 4-1. NUMBER OF SAMPLES PROCESSED, BY TYPE OF ANALYSIS

Type of Analysis	Number of Samples
Gross Alpha & Beta	
JTG/FRST & DOE/ERSP Swipes	4,027
JTG/FRST & DOE/ERSP Air Filters	3,589
JTG/FRST Nose Swipes	808
Soils (Alpha only)	8,394
Water	27
Gamma Spectrometry	
Soil	5,429
Concrete	12
Soil for FPDB	6,003
Urine Samples	3
Animal Samples (Rattus exulans)	77
Water	22
IMP Calibration Samples	7
Radiochemistry and Alpha Spectrometry	
Soil ^{238}Pu, $^{239, 240}Pu$	2,453
Soil ^{241}Am	1,162
Soil ^{234}U, ^{235}U, ^{238}U	22
Soil ^{230}Th	3
Water ^{238}Pu, $^{239, 240}Pu$	6
Water ^{241}Am	6
Urine ^{238}Pu, $^{239, 240}Pu$	3
JTG/FRST Filter Composites ^{238}Pu, $^{239, 240}Pu$	37
QC Samples	248
Other Analysis	
Soil ^{90}Sr-^{90}Y	172
FPDB ^{90}Sr-^{90}Y (sent to Albuquerque)	645
Water ^{3}H	4
Soil pH	26
Soil Solubility	36
Soil Archiving	11,455

Sampling teams were dispatched from Enewetak Island as required using an EIC team leader and Navy personnel assigned to the RADLAB. Daily transportation to the work islands was via Navy Boston Whaler or Landing Craft service. Samples were taken and referenced to the island grid system stakes placed by the 84th Army Engineer teams, or by H&N surveyors, for the in situ IMP measurements program.

Soil Sample Pattern Design. A standardized soil sampling procedure was designed and documented in the DOE/ERSP Procedure No. 4 (see Appendix A) by the EIC laboratory manager and the DRI statistician at the start of the project. The objective of the sampling procedure was to collect a sample which was reasonably representative of the surface being sampled and to provide a measure of the nonhomogeneity of the sample. The sampled spots were randomized through the use of a game-board-type spinner to set the initial sampling direction. The compass direction of the initial spinner angle was recorded on all sample can labels for inclusion later into the data base. Then the spinner heading was considered as 0° and samples were taken at the clockwise angles and distances indicated in Table 4-2. Six aliquots were taken for each composite sample. (See also Figures 4-5 and A-4-1). Only composites A and B were taken until 20 April 1978, after which the composites C and D were also taken at the discretion of the DOE Tech Advisor.

Surface Soil. Surface soil aliquots were taken at the distances detailed in Table 4-2 using a custom made "cookie-cutter" tool to excise 300 cm^3 from a square 10 cm on a side to a depth of 3 cm. Samples were taken at 0 cm, 10 cm and 20 cm depths to provide both surface and shallow depth distribution data. DOE/ERSP Procedure No. 4 provides details on specific steps used during sampling. All field surface samples were collected in one-gallon paint cans and sample data were written on an adhesive aluminum (3 x 6-inch) label with a ballpoint pen used as a stylus to emboss the label. The environmental conditions precluded use of paper labels or conventional writing pens.

TABLE 4-2. SOIL SAMPLING PATTERN

Clockwise Angle from Spinner Heading* (Degrees)	Composite A	B	C	D
	(Meters from a spinner)			
0	1.8			
15				8.8
30		5.3		
45			1.8	
60	8.8			
75				5.3
90		1.8		
105			8.8	
120	5.3			
135				1.8
150		8.8		
165			5.3	
180	1.8			
195				8.8
210		5.3		
225			1.8	
240	8.8			
255				5.3
270		1.8		
285			8.8	
300	5.3			
315				1.8
330		8.8		
345			5.3	

*Actual spinner heading, a geographical compass direction recorded on each sampling can for each sampling point, was used as zero degrees for the sampling pattern.

FIGURE 4-5. SAMPLING PATTERN SPINNER BOARD

Sampling locations were referenced to grid nodes. The area around the grid nodes generally was disturbed during lane clearing for the in situ measurements. The actual undisturbed areas were generally less than 50 percent of the total area of the sampling pattern which was occasionally shifted to maximize the undisturbed points.

Subsurface Soil. Subsurface soil samples were taken to evaluate areas where burial may have occurred or where actual surface samples or in situ gamma readings indicated elevated levels of transuranic nuclides. Soil augers, taken to Enewetak to be used as one method of sampling, failed to provide good samples due to the large rocky chunks of coral always present and sandy soil caved back into the hole. Profile pits were provided by ditching with a backhoe to a depth of approximately 180 cm. A clean sidewall was obtained by removing loose material with a spade. Samples of 1000 cm^3 were taken at the surface and centered on vertical depths of 20, 40, 60, 80, 100 and 120 cm using a standard 2-inch-high by 4-inch-wide closed-top sidewall sampler (See Figure 4-6). No specific procedure was written for the sidewall sampling, but care was exercised in the field to eliminate depth cross-contamination. One-half-gallon paint cans were used with aluminum labels similar to those used in the surface soil sampling procedure. Some logging of profiles using a gamma detector was done but not on all early profile sampling locations due to gamma background levels that were high enough to interfere with the in situ profiling effort. Profile investigations were performed on the islands of Irene, Janet, Pearl, Sally and Yvonne.

4.2.2 Fission Product Data Base (FPDB) Program

The Fission Product Data Base Program was initiated to expand the data base for the LLL dose assessment work to be reported in the summer of 1979. Eberline was requested by DOE in January 1979 to provide the additional equipment and manning necessary to sample an estimated 1200 profile locations from the northern islands, and to provide ^{137}Cs and ^{90}Sr analysis data to LLL. Four additional technicians were sent to Enewetak in March to assist field sampling teams in collecting and processing samples to meet the LLL deadline. Personnel levels were back to normal by July.

FIGURE 4-6. SOIL PROFILE SAMPLING

The specific sampling and analysis techniques are detailed in DOE/ERSP Procedure 28 in Appendix A. Additional gamma counting capability was provided through the purchase of a medium-volume intrinsic germanium detector (IG-8) which was installed in the count trailer shield used with the spare EG&G planar detector. Another counting shield was built using lead brick to house the EG&G planar detector which provided the third gamma counting system as described in Section 4.1.3.

Table 4-3 lists the islands sampled, the number of grid locations sampled, sample dates, and minimum and maximum gamma readings (gamma scintillation probe) taken during sampling. Trenches were excavated to a depth of 100 cm using a tractor-mounted backhoe and samples were taken using the LLL standard profile sampling technique.

DOE/ERSP provided the DOE vessel Liktanur II, which was anchored adjacent to each island, to be used as an operations base and living quarters for the FPDB sampling teams. Without the dedicated use of this vessel, the sampling program could not have been executed in time to meet the May 1979 deadline. The vessel was used because it made possible an 8-hour sampling day on the island, gaining 1 to 4 hours on-site compared to using military transportation and operating out of Ursula or Enewetak camps. The sampling program was started on Wilma on 26 February. Janet was started on 6 March and completed 15 March 1979. The other northern islands were finished on 2 April 1979, at which time the Liktanur II was released for return to normal duty.

All samples taken from 100-meter grid nodes were gamma scanned, processed, and shipped to the Eberline Albuquerque Laboratory for expeditious ^{90}Sr analysis. The gamma data were forwarded to DRI for transmittal to LLL. The ^{90}Sr analysis data from the Albuquerque laboratory were forwarded directly to DRI at Las Vegas, Nevada for transmittal to LLL. A total of 36 boxes containing 645 samples from the 100-meter grids were shipped to Albuquerque for analysis through 5 June 1979.

TABLE 4-3. SAMPLING FOR THE FISSION PRODUCT DATA BASE PROGRAM

Island	Grid Locations Sampled	Sample Date	Sidewall Gamma Scan μR/h*
Alice	26	3/19/79	6-92
Belle	40	3/19/79	20-113
Clara	8	3/21/79	6-58
Daisy	26	3/22/79	3-50
Edna	5	3/22/79	9-26
Irene	53	3/23 & 3/24/79	6-970**
Janet	364	3/7 & 3/15/79	6-91
Kate	18	3/30/79	3-25
Lucy	22	3/30/79	4-43
Percy	2	3/30/79	1-6
Mary	12	3/29/79	3-17
Mary's Daughter	3	3/29/79	2-49
Nancy	14	3/29/79	3-19
Olive	50	3/5-3/6/79	2-17
Pearl	72	3/27,5/30 & 6/13/79	2-60
Pearl's Daughter	2	3/31/79	3-29
Ruby	3	3/25/79	8-22
Sally	137	3/20-3/27/79	1-72
Sally's Child	4	4/3/79	3-13
Tilda	48	3/9, 3/10 & 3/15/79	1-10
Ursula	15	3/14/79	1-5
Vera	48	2/28/79	1-8
Wilma	17	2/26/79	1-5
Yvonne	14	4/2/79	7-132
Leroy	8	4/9, 4/17/79	1-9
TOTAL	1,011		

*Gamma readings were made with Eberline PRS-1 with SPA-2 1"x1" NaI(Tl) Probe with threshold set for 60 keV gamma energy. The Enewetak background was typically 4-5 μR/h.

**High gamma levels occurred at locations 14-N-1 and 11-N-1 and were subsequently excavated. The next highest reading of 270 μR/h occurred at 9-S-1.

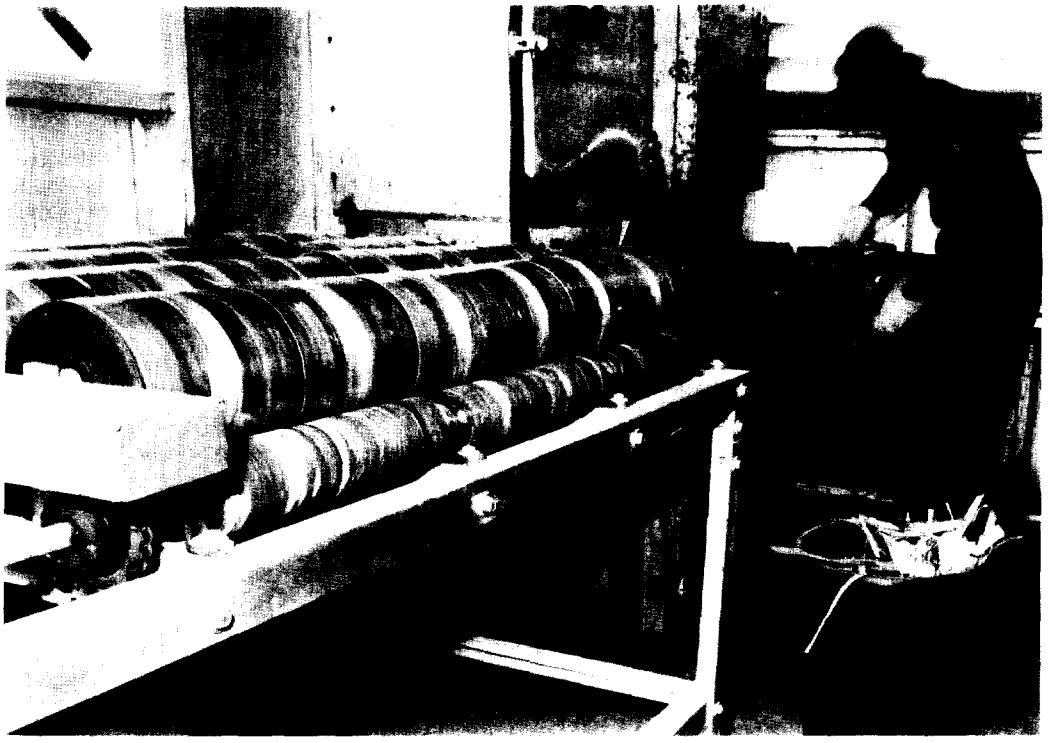


FIGURE 4-7. BALL MILL FOR FPDB PROGRAM SAMPLES

After completing the 100-meter grid samples, the 50-meter samples were gamma scanned at Enewetak and all the 100-meter and 50-meter samples were prepared for archiving. The ball mill constructed for processing FPDB program samples is shown in Figure 4-7; up to 24 samples in 1-gallon cans could be processed simultaneously. The FPDB program, including the analyses of all 50-meter samples, was completed during the week of 7 July 1979.

4.2.3 Aomon Crypt Sampling

Pre-Excavation Sampling and Coring. Initial test holes were excavated by JTG teams before September 1978 to test the soil sidewall stability. Holes were dug to depths of 5 feet in the area around the center monument. Soil and debris removed from the holes were monitored for radioactivity with a PG-2 (small FIDLER). Detectable readings were obtained from the visible traces of grey-colored clay silt found in the predominantly coral material. Metal debris removed from the hole near the monument had very high levels of ^{241}Am activity. A 5-meter by 5-meter grid system was established as a reference system for future sampling. A small drilling rig with a split-spoon sampler was brought in by JTG in November 1978 to map the extent of contamination in the crypt area. A plywood building for sample preparation was constructed on Tilda 50 meters east of the crypt, within the crypt hot line, to provide a semi-dry working facility during IMP gamma scanning of the core samples and to protect the sample preparation equipment. During the coring operation, starting 26 November 1978 and ending 13 January 1979, approximately 1,000 soil samples were collected from 125 grid locations and processed by IMP scanning. Each sample with a ^{241}Am activity greater than 25 pCi/g of soil was sent to the RADLAB to be dried and gamma scanned. Ten percent of all samples with activity levels less than 25 pCi/g were also sent to the RADLAB to be processed as quality assurance samples.

Using an 18-inch core shoe, core samples were taken at each 2-foot depth. The core shoe was scanned with a PG-2 detector for gamma activity and sample material was collected in a 1-gallon can. Samples were allowed to sit for a short time, then surface water was decanted before the can was sealed and moved to the sample preparation building. Cans were marked with the grid

coordinates, depth, and gamma activity reading. Each sample was prepared for counting by removing the moisture through a vacuum filter and transferring the soil to a standard petri dish. Each sample was weighed on a gram scale and the weight and EIC sample number were recorded. All samples were scanned using the IMP gamma detector and the data transferred to DRI for analysis. Samples were saved for archiving or disposal as directed by DOE/ERSP.

Excavation and Bottom Sediment Sampling. Excavation of the Aomon Crypt was started by JTG on 15 January 1979 using a clamshell. Operational samples of the dirt pile and bottom sediments were collected as requested by DOE/ERSP. The EIC sampling crews were staged out of the Ursula camp until 26 January 1979, and thereafter sampling missions were staged from the RADLAB at Enewetak. On 5 April 1979 a complete set of bottom sediment samples was collected from the pond created by the excavation using a sediment sampler borrowed from MPRL. A military pontoon footbridge was used to provide a walkway for sampling personnel. Position reference was provided by grid marks on the sheetpile or stakes located on the crypt perimeter. Bottom sediments were prepared by vacuum filtration and aliquoted into petri dishes for gamma scanning by the IMP at the EG&G facility on Ursula, or returned to Enewetak for counting at the RADLAB. Water samples were also collected and the suspended material filtered out. The bottom sediment material consisted of a gray and black clay-like material which contained measurable gamma activity. Additional samples of the bottom sediments were collected during the final cleaning of the crypt bottom with a clamshell at the end of May 1979.

Post Backfill Sampling. A barrel-type impact core sampling tool mounted on a truck was used to sample 26 locations to 120 cm in the Aomon Crypt area after it had been backfilled with radiologically clean beach sand. Samples were returned to the RADLAB at Enewetak for processing. The Aomon Crypt project was completed on 28 July 1979 with final core sampling. All Aomon Crypt certification samples were archived along with representative samples of the bottom sediments.

4.2.4 Soil Archiving

The soil archiving program was initiated by DOE/ERSP to provide a library of samples that were representative of the "as left" conditions of the Enewetak Islands at the end of the project. The archived samples consist principally of surface soil taken in support of the transuranics program and the FPDB samples. Future researchers may recheck the earlier data or may run new analyses with more sophisticated procedures to check on elements for which analysis was not done during the clean-up.

Samples were prepared in accord with DOE/ERSP Procedure 20 in Appendix A. The preparation started in late 1978, after discovering that the soil sample cans stored in the warehouse on the south end of Enewetak were rapidly corroding due to the high moisture and salt content of the air. Mother Nature, in the form of Typhoon Alice in January 1979, had a substantial influence in hastening the archiving project by destroying the warehouse and about 5 percent of the stored soil samples. After sterilizing to meet Department of Agriculture importation requirements (DOA Permit S-2044), samples were placed in Army Mil Van units, as shown in Figure 4-8, for shipment to the Nevada Test Site. A total of 11,455 samples were shipped at the close of the project.

4.2.5 Soil Sample Data Base

A soil sample data base was compiled from data contained in field notes, RADLAB analysis sample control records and final chemistry reports. See Section 4.3.5 for a discussion of this information and procedures used during the Enewetak project. RADLAB soil sample handling is described in DOE/ERSP Procedure No. 8. All field sample notes and log books were kept by island and sent to DOE/NV for archiving at the close of the project in 1980.

4.2.6 Additional Support Programs

In addition to the program support described above, Eberline provided support to the FRST, off-site counting, and instrument repair and maintenance programs.

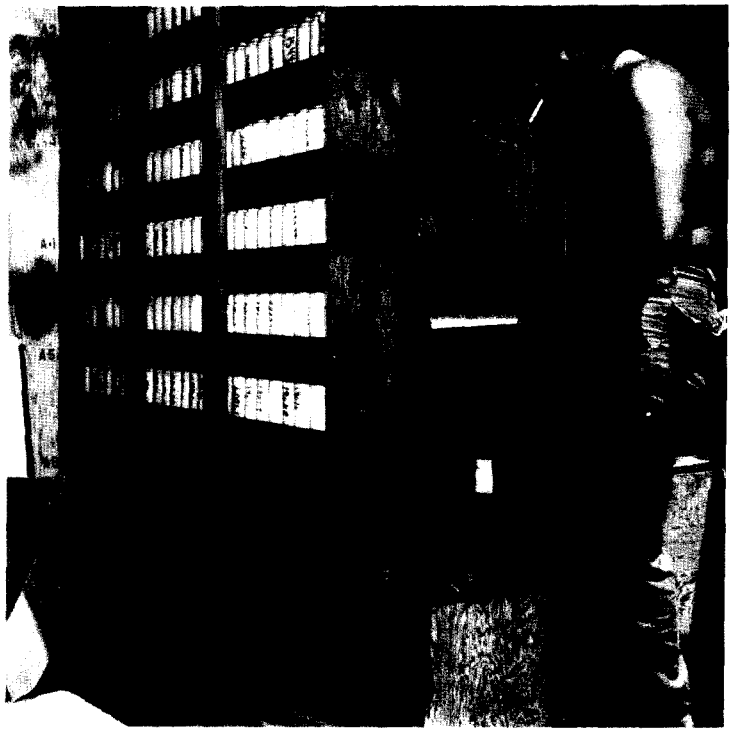


FIGURE 4-8. PACKING ARCHIVE SAMPLES FOR SHIPMENT TO THE NTS

FRST Support. The RADLAB provided counting support for the FRST health physics operations by analyzing air filters, nose swipes, and equipment swipes. The actual count of various sample types is listed in Table 4-1. All counting performed for the FRST was reported directly to the FRST and was not included in the DOE/ERSP data base. FRST samples that required gamma analysis are recorded on the LLL archive tapes but all other data exist only in the RADLAB analysis sheets sent to DOE/NV for storage and in the FRST data system. DOE/ERSP Procedure No. 13 describes the method for processing nose swipes. Eberline health physicists provided consultation on the first drafts of the radiological operations, plans, and standard operating procedures during early 1977 and at other times during the project operations.

Off-Site Counting Support. The Eberline analytical laboratory in Albuquerque, New Mexico, provided the analytical procedures used during the operation and additional technical support during problem periods with on-site counting techniques. The Albuquerque laboratory performed the ^{90}Sr analysis of the 100-meter-grid FPDB samples and analyzed FRST-expedited urine samples for military personnel who extended their on-island assignments.

The urine analysis procedure used is described by DOE/ERSP Procedure No. 14. The off-site analysis of coral soil for ^{90}Sr followed DOE/ERSP Procedure No. 15. Approximately 10 percent of all samples recorded were processed for isotopic plutonium and americium as detailed in DOE/ERSP Procedures No. 10 and No. 11.1.

Instrument Support. Instrument support consisted of calibrating and maintaining both FRST and DOE field portables, in addition to the RADLAB counting equipment. Calibration procedures for all field instruments are described in DOE/ERSP Procedure No. 29. DOE/ERSP Procedure No. 18 describes use of the 100 mCi and 1 mCi ^{137}Cs gamma source ranges as used on Enewetak Island.

The Eberline engineer provided direct work supervision of the USAF PMEL staff assigned to the RADLAB and provided technical training and problem consultation for the FRST/PMEL instrument repair technicians working out of Ursula.

EIC maintained an inventory of repair parts and instruments necessary to keep the 35 Eberline field portables and 100 probe systems operational during the project for the FRST and DOE.

Additional instrument support was provided to repair the EG&G IMP pulse height analyzer, the HP 9831A computer systems, and spare planar detectors.

4.3 ANALYTICAL PROCEDURES

Routine analytical procedures are documented in the DOE/ERSP procedures in Appendix A. Procedures conform to those specified by the USEPA, USDOE and USNRC. Internal tracer techniques were used when feasible for analyses of ^{234}U, ^{235}U, ^{238}U, ^{238}Pu, $^{239,240}Pu$, ^{228}Th, ^{230}Th, ^{232}Th, ^{241}Am, $^{243,244}Cm$ and ^{90}Sr. Chemical yields for alpha emitters were determined by electrodeposition with an NBS or USEPA solution standard of another isotope of the element. It was followed by alpha spectrometry and was verified by internal proportional counting with corrections for impurities based on alpha spectrometry. The value of the ^{85}Sr tracer used in the ^{90}Sr determination was measured by gamma counting. Amersham-Searle, NBS, and International Atomic Energy Agency (IAEA) standards were used to calibrate the high resolution gamma spectrometer system for various counting geometries.

4.3.1 Field Soil Sampling

Soil sampling was accomplished using DOE/ERSP Procedures 4 and 28, as described in Section 4.2.1 in the preceding section, and sampling procedures were similar to those established by DOE and LLL during similar projects in other Marshall Islands.

4.3.2 Sample Preparation

Following field collection, samples were transferred to the Enewetak DOE laboratory in 1/2- or 1-gallon paint cans with tightly fitting lids. Each container had a label affixed to the outside with all pertinent information recorded thereon.

The general sample preparation procedure was as follows:

A. The sample was logged in, screened for gamma activity, and assigned a lab number.
B. Wet weight and estimated volume were recorded.
C. Sample was transferred to a drying pan and dried at 110°C to constant weight.
D. Dry weight was recorded.
E. Sample was transferred to a paint can containing 5 to 10 one-inch stainless steel balls and ballmilled for four hours.

Aliquots were taken from the A, B, C, and D composites at 0 cm, 10 cm and 20 cm depths. The A and B composite samples were prepared for gross alpha, plutonium and gamma scan analysis. The A and C composite samples from 0 cm depth were prepared for ^{241}Am analyses. Aliquots of the ballmilled material were weighed, placed in a muffle furnace and ashed at 700°C for 12 hours prior to chemical separation of plutonium, strontium, or americium. Samples for alpha, beta and gamma analyses were placed in their appropriate counting geometries and taken to the counting laboratory.

All ERSP subsurface samples were dried and prepared for gross alpha and gamma scans. Thirty percent of the samples were selected to go through the general sample preparation procedure described above. The analysis included gross alpha, ^{238}Pu, $^{239,240}Pu$, and gamma scan with one out of every 10 samples analyzed for ^{241}Am. Aliquoting and preparation of each sample was the same as for surface samples.

FRST samples were dried and prepared for gross alpha counting. The specific sample preparation procedure was as follows:

A. Samples were received at the sample preparation laboratory. These samples were first checked to assure that each can had a label affixed and that field collection data were legible and complete.
B. Samples were then gamma scanned to obtain an estimated activity range (^{241}Am measured with Eberline FIDLER).

C. If the sample read less than 60 pCi/g in ^{241}Am activity it was logged in and processed according to the general sample preparation procedure.

For gross alpha measurement the sample was stirred with a disposable spoon and an arbitrary portion of soil was removed and dried. About 50 g of the dried soil, representing an infinite thickness, was spread evenly in an AC-3 plastic holder; then a spacer was emplaced and the sample was counted for gross alpha activity using an Eberline AC-3 Probe.

A. If the gross alpha activity read above 400 pCi/g the sample was handled as a "high" level sample.
B. If gross alpha activity read below 400 pCi/g the sample was processed according to general sample preparation procedures.

After completing the general sample preparation, another 50 g aliquot was spread on an AC-3 plastic holder and an alpha measurement made as a double check prior to processing the sample through the wet chemistry lab.

Sample preparation for plutonium, americium, strontium, and uranium chemistry required the aliquot to be ashed in a muffle furnace at 700°C for 12 hours. Aliquoting samples for chemistry analysis followed these criteria: a) 5 g aliquots were taken if gross alpha activity was less than 100 pCi/g; b) 1 g aliquots were taken if gross alpha activity was greater than 100 pCi/g but less than 400 pCi/g.

Aliquots of 100 g were taken for gamma scan, sealed in a petri dish (100x20mm) and the lid secured with tape. This sample geometry was used for beta counting using an HP-210 Beta Probe with a thin screen of plastic between the sample and the detector.

After all analyses were completed the samples were placed in the original cans and taken to the sample storage area.

4.3.3 Radioisotope Counting and Calculation

Counting

Radioisotope counting at the RADLAB was designed for specific and gross measurements techniques. Counting for ^{238}Pu, $^{239,240}Pu$, ^{241}Am, and ^{234}U, ^{235}U and ^{238}U was completed using an ND 600 pulse height analyzer with four ORTEC silicon surface barrier detectors. The average performance rating for the semi-conductor detectors gave a FWHM resolution of about 45 keV with efficiencies of about 25 percent using a ^{239}Pu electroplated alpha standard. (See alpha efficiency records in the microfiche.) This alpha spectrometer covered a range of about 3.8 to 6 meV with 500 channels devoted to each detector.

The ^{90}Sr concentration was determined by the measurement of its yttrium-90 (^{90}Y) daughter. The ^{90}Y was counted in a Canberra low background beta counter. The Canberra counter had a beta efficiency of about 40 percent based on a ^{90}Sr source and a background of less than 1.0 cpm. The ^{85}Sr internal tracer was determined by measuring the gamma energy on an ND 600 PHA with a coaxial intrinsic germanium detector.

Swipes and air particulate samples were counted in one of several units depending on the size of the sample. Swipes and air particulate filters smaller than a two-inch diameter were counted in an Eberline scintillation alpha counter; samples larger than a two-inch diameter were counted in an Eberline large-area alpha counter and/or in the large-area beta counter. Plots of the background and efficiency data for the alpha and beta detectors appear in Figures 4-9, 4-10, 4-11 and 4-12.

Calculation

The radioactive concentration of the specific radionuclide was determined by use of the appropriate equation as presented below. The 2σ error term, at the 95 percent confidence level, associated with each of the results was included in the final calculation. The specific calculations were programmed on magnetic cards for use in an HP-97 desktop calculator. The final analytical results were reviewed and approved by the EIC laboratory manager prior to submittal to DOE/ERSP and DRI.

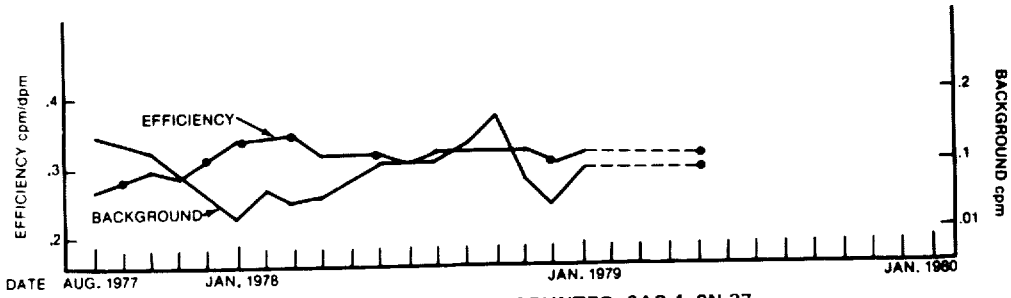


FIGURE 4-9. ALPHA SWIPE COUNTER, SAC 4, SN 37

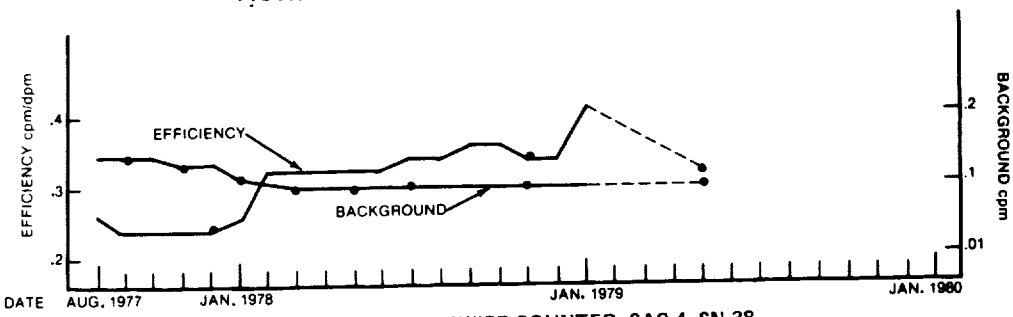


FIGURE 4-10. ALPHA SWIPE COUNTER, SAC 4, SN 38

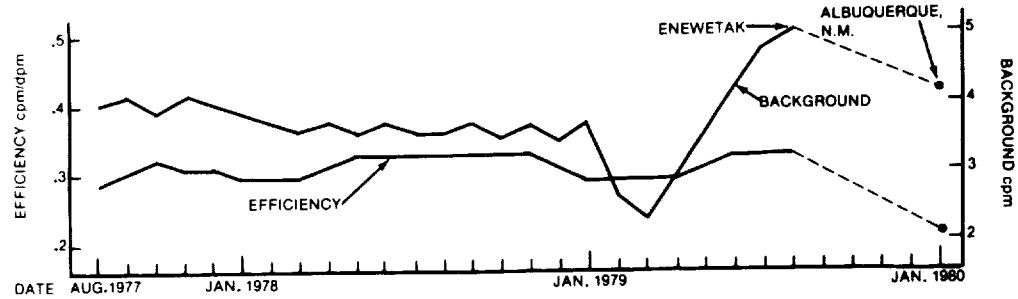


FIGURE 4-11. LARGE AREA ALPHA COUNTER, AC-23-.5/MS-2, SN 636

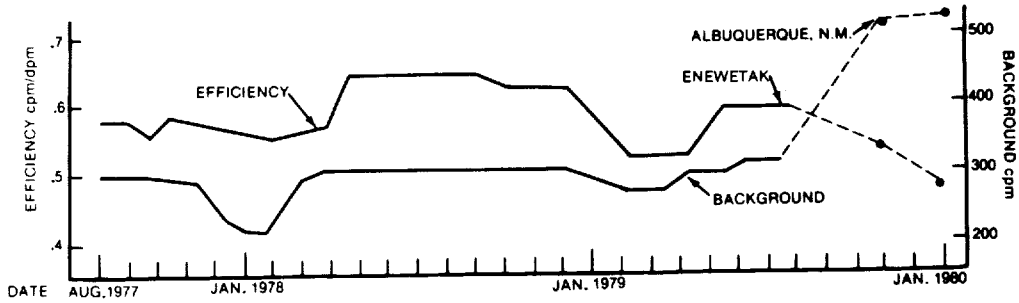


FIGURE 4-12. LARGE AREA BETA COUNTER, AC-23-.5/MS-2, SN 570

Strontium – 90

Result:

$$\frac{\left(\frac{C}{T} - B\right)}{Y \cdot E \cdot D \cdot R_1 \cdot R_2 \cdot U \cdot 2.22} = \text{pCi/unit} \qquad (4\text{-}1)$$

Error Term:

$$\pm\ 2\ \frac{\sqrt{C + T \cdot B}}{C - T \cdot B} \qquad (4\text{-}2)$$

where,

C	=	gross counts	D	=	decay of ^{90}Y
T	=	count time, minutes	R_1	=	^{85}Sr recovery
B	=	background, cpm	R_2	=	yttrium gravimetric recovery
E	=	efficiency, cpm/dpm	U	=	units (volume or weight)
Y	=	ingrowth ^{90}Y	2.22	=	conversion factor, dpm/pCi

Gross Alpha and Beta

Result:

$$\frac{F\ \left(\frac{C}{T} - B\right)}{U} \qquad (4\text{-}3)$$

Error Term:

$$\pm\ 2\ \frac{\sqrt{C + T \cdot B}}{C - T \cdot B} \qquad (4\text{-}4)$$

The counting factor:

$$\frac{1}{E \cdot 2.22} = F$$

Liquid Scintillation for Alpha and Beta

Result:

$$\frac{\left(\frac{C}{T} - B\right)}{E \cdot U \cdot 2.22} = \text{pCi/unit} \qquad (4\text{-}5)$$

Error Term:

$$\pm\ 2\ \sqrt{\frac{C}{T} + B} \qquad (4\text{-}6)$$

Alpha Spectrometry

Result:

$$\left(\frac{N_1}{N_2}\right)(P) = A_1; \qquad \left(\frac{V_1}{V_2}\right)(A_1) = A_2 \qquad (4\text{-}7)$$

Error Term:

$$\pm\ 2\ (A_1 \text{ or } A_2)\ \sqrt{\frac{1}{N_1} + \frac{1}{N_2}} \qquad (4\text{-}8)$$

N_1 = net counts of isotope
N_2 = net counts of tracer isotope
P = amount of tracer isotope added, dpm
A_1 = activity of isotope per aliquot
A_2 = activity per sample
V_1 = total sample volume
V_2 = aliquot size used for the analyses

Gross Alpha and Beta (large area AC-23 probes and small area SAC-4)

Result:
$$\frac{\left(\frac{C}{T} - B\right) F}{U} = \text{pCi/unit} \tag{4-9}$$

Error Term:
$$\pm 2 \frac{\sqrt{C + B \cdot T}}{C - B \cdot T} \tag{4-10}$$

$$F = \frac{1}{E \cdot 2.22} \tag{4-11}$$

Liquid Scintillation (Gross Alpha, Gross Beta Nasal Swipes)

Result:
$$\frac{\left(\frac{C}{T} - B\right)}{E \cdot 2.22} = \text{pCi/swipe} \tag{4-12}$$

Error Term:
$$\pm 2 \sqrt{\frac{C}{T} + B} \tag{4-13}$$

Radioactive Standard Sources. Radioactive standard sources were used to calibrate instrumentation on a weekly basis. An electroplated ^{90}Sr-^{90}Y standard was used for the calibration of beta counters. An electroplated ^{239}Pu standard was used for calibration of alpha counters and the alpha spectrometer. A mixed standard containing ^{238}Pu, ^{239}Pu, ^{237}Np was used for energy calibration of the alpha spectrometer. Parameters describing these sources are listed in Table 4-4.

Radioactive Standard Solutions. The radiochemical procedures utilized calibrated solution standards as internal tracers to quantify the radionuclides of interest.

Other standard radionuclide solutions were used to make up spike samples for the quality assurance program, as well as for calibration of the gamma and liquid scintillation counting systems. (See Table 4-4 for specific parameters.)

TABLE 4-4. RADIOACTIVE STANDARD SOURCES

Source Isotope(s)	Serial Number	Reference Date	Base Material	Decay (dpm)	Calibration Purpose
Electroplated Discs (SS = stainless steel; Ni = nickel)					
^{60}Co	S-1447	5-5-77	SS	0.0049 ± 0.0002[1]	Gamma spectrometer
^{90}Sr-^{90}Y	S-7668	5-9-77	Ni	16,420 ± 490	Beta counter
^{90}Sr-^{90}Y	S-1510	6-10-77	Ni	3,060 ± 90	Beta counter
^{90}Sr-^{90}Y	S-1914	11-9-78	Ni	1,320 ± 40	Beta counter
^{90}Sr-^{90}Y	S-1915	11-9-78	Ni	1,700 ± 90	Beta counter
^{230}Th	S-10764	6-10-77	SS	1,630 ± 30	Alpha counter
^{235}U	S-1508	6-10-77	SS	1,250 ± 25	Alpha spectrometer
^{236}Pu	S-1513	6-10-77	SS	820 ± 20	Alpha spectrometer
Mixed[2]	S-1511	6-10-77	SS	3,760 ± 80	Gamma spectrometer
^{239}Pu	S-1509	6-10-77	Ni	4,040 ± 80	Alpha spectrometer
^{241}Am	S-7680	6-10-77	Ni	1,260 ± 25	Alpha spectrometer
^{241}Am	S-7669	5-9-79	Ni	4,150 ± 80	Alpha spectrometer
Solutions					
^{60}Co		7-1-76		2,904/ml	Gamma systems
^{133}Ba		7-1-76		13,928/ml	Gamma systems
^{137}Cs		5-1-76		13,159/ml	Gamma systems
^{152}Eu		4-16-77		444,000/ml	Gamma systems
^{236}Pu		7-2-78		5.17/ml	Internal tracer[3]
^{239}Pu	1281	10-1-76		99.42 ± 1%[4]	Prepare spikes
Mixed[5]	4332	Sept. 74		134.5 ± 1.4%[6]	Internal tracer
^{241}Am		6-1-74		2,434/ml	Gamma and spikes
Petri Dishes (coral base)					
^{133}Ba		9-19-78		12,079/ml	Gamma systems
^{241}Am		9-19-78		2,417/ml	Gamma systems

1 Unit is μCi rather than dpm.
2 Source included ^{237}Np, ^{238}Pu, and ^{239}Pu.
3 Used NBS ^{239}Pu standard 1281 to cross-calibrate ^{236}Pu.
4 Alpha emissions per second per gram of solution. From NBS.
5 Source included ^{239}Np and ^{243}Am. Activity ratio of ^{241}Am to ^{243}Am was 0.002.
6 Nuclear transformations per second per gram. From NBS.

4.3.4 Chemistry

^{238}Pu, $^{239,240}Pu$ Analysis in Coral Samples

Coral samples analyzed for plutonium were processed as described in DOE/ERSP Procedure No. 8. This procedure assured that a representative aliquot of the sample could be taken for the analysis. The separation of plutonium was completed by solvent extraction followed by anion exchange purification and electrodeposition on a stainless steel disc. The sample was then counted in an alpha spectrometer. Refer to detailed descriptions of the preparation procedure in DOE/ERSP Procedure No. 8 and of the chemistry procedure in DOE/ERSP Procedure No. 10.

^{241}Am Analysis in Coral Samples

Coral samples analyzed for americium were prepared following DOE/ERSP Procedure No. 8. This procedure assured that a representative aliquot of the sample could be taken for the analysis. The analysis required the isolation of the americium by the co-precipitation technique followed by purification through anion and cation exchange resin columns. The purified americium was then prepared for alpha counting by electrodeposition on a stainless steel disc. Refer to DOE/ERSP Procedure No. 11 for detailed information.

^{234}U, ^{235}U, ^{238}U Analysis in Coral Samples

Coral samples analyzed for isotopic uranium were prepared following DOE/ERSP Procedure No. 8. This procedure assured that a representative aliquot of the sample could be taken for the analysis. The uranium was separated from the sample matrix using a solvent extraction technique, followed by an anion exchange resin purification. The purified uranium was then electrodeposited on a stainless steel disc and counted in an alpha spectrometer. The details appear in DOE/ERSP Procedure No. 12.

^{90}Sr Analysis in Coral Samples

The analysis for ^{90}Sr in coral samples was based on the assumption that secular equilibrium between ^{90}Sr and ^{90}Y existed. The ^{90}Y daughter was separated from the ^{90}Sr parent and counted in a low beta background counter. Refer to DOE/ERSP Procedures 8 and 15, for details.

Treatment of High Level Samples

High level samples with gross alpha activity greater than 400 pCi/g were processed in order to determine the TRU to ^{241}Am ratio. Samples were not required to be ballmilled but had to be homogenized. A 100 g aliquot was sealed in a petri dish for gamma analysis. A small aliquot of the sample was analyzed by chemistry to determine the concentration of plutonium and americium. The chemical yields were based on the values obtained on the ^{236}Pu and ^{243}Am internal tracers.

4.3.5 Data Handling

Early in the cleanup project, a requirement was recognized for a permanent, accessible data storage system to allow future access to the sample date and location, spectral data, and chemistry results for each sample. To satisfy this requirement, EIC, EG&G and DRI were provided with identical HP9831A programmable desktop computers, with peripheral attachments varying according to functional requirements. The EIC computer system included a drive for flexible discs which were used to store programs and later the data obtained in the counting laboratory. Having identical computer components allowed sharing of the equipment between EIC, EG&G and DRI when equipment failures occurred and reduced programming and data transfer problems.

All samples entering the RADLAB were given a controlled identification number from a preprinted roll of labels and were recorded in a sample preparation record book as well as on laboratory analysis sheets. The record book was kept by EIC laboratory number sequence and the analysis sheets were ordered by island and EIC laboratory number. The laboratory sheets reflected the

specific analysis requested and all pertinent information such as: sample weights, raw counting data, sample aliquots, analytical and gamma activity results. All laboratory analysis sheets were filed by island after final reports were submitted to DRI and DOE/ERSP for on-island operational decisions. All raw data sheets, notebooks, and work sheets were sent to DOE/NV for archiving at the close of the project in 1980.

Gamma data reports were computed from spectrum channel printouts and an HP-97 desktop calculator during the early phase of the program as only the ^{241}Am photopeak data were required for the transuranics program. Efficiency data tables were computed and stored on the HP-97 magnetic cards and used during data computation. Detector histories in the microfiche list detectors used and efficiencies calculated for each geometry during the cleanup project. Starting in December 1978, after learning that the FPDB program would greatly increase the gamma sample volume, the gamma photopeak data reduction was programmed for calculation on the HP9831A with printouts of the photopeaks for ^{241}Am, ^{155}Eu, ^{152}Eu, ^{137}Cs, ^{60}Co, and ^{40}K. No efficiency calculation at photopeak energies other than the above were used or provided. The series of specific gamma geometry standards used to calibrate for energy and efficiency are listed in Table 4-5 and Table 4-6. These tables also list the standard solutions used to prepare the various geometry standards. Sample counting geometries are presented in Table 4-7.

All gamma spectrum data were transferred directly to the HP9831A program files from the ND-600 PHA LS1-11 using a 1200-baud serial interface. Sample headers were manually entered on the keyboard and then output with the spectra to the cartridge tape files for storage.

Samples not analyzed by gamma spectrometry such as FRST nose swipes, other FRST swipes, FRST air filters, EIC RADLAB internal air filters and swipes were reported to the organization requesting the data and were not included in the data base. All raw reports on these data were later sent to DOE/NV for archiving. Sample data, gamma spectra, and chemistry results were stored on high-speed magnetic tape cartridges in the HP9831A on-island and subsequently transferred to 8-inch floppy discs for transfer to DRI to be put on magnetic tape. Data were added to each sample record where appropriate as the data fields were set up for all possible types of samples. The data records for each sample were set up in three blocks: header, spectrum data and results.

4.4 QUALITY ASSURANCE PROCEDURES

A continuous quality control program was implemented for assuring the quality of results reported by the Enewetak Radiological Laboratory. The program consisted of internal quality control checks for precision and accuracy plus external quality control crosscheck programs with various laboratories.

The quality assurance program covered the following specific applications: the radioanalytical laboratory performing the analyses, quality control of counting equipment, analytical performance, data handling and reporting.

The following information will give a breakdown, details, and tabulation of results for the quality assurance program.

4.4.1 Internal Quality Control - Precision and Accuracy

The RADLAB quality control (QC) program had to ensure the accuracy of its analytical results within acceptable limits; this was accomplished by the following steps. The first step was to establish standards which could be used and processed through the laboratory along with samples being analyzed in order to verify the accuracy of the laboratory's analytical results. A sample physically similar to the sample being analyzed but which had very little radioactivity was collected from Enewetak Island and used as a background sample. The Enewetak soil was sieved, homogenized and ballmilled. Several aliquots of the Enewetak soil were analyzed numerous times to determine the concentrations of ^{238}Pu, $^{239,240}Pu$ and ^{241}Am. This Enewetak soil was processed with each group of samples to determine the sensitivity of the procedure at the lower limit of detection.

TABLE 4-5. GAMMA GEOMETRY STANDARDS

Standard Number	Standard Isotope	Geometry Type	Standard Solution Quantity (ml* or dpm)
1	^{241}Am	CCC	9 ml
2	^{152}Eu	LPD	0.5 ml
3	^{137}Cs	LPD	3 ml
3	^{60}Co	LPD	9 ml
4	^{241}Am	LPD	6 ml
5	^{241}Am	SPD	13 ml
6	^{133}Ba	SPD	9 ml
7	137Cs	LPD	1 ml
8	^{60}Co	LPD	1 ml
9	^{60}Co	LPD	5 ml
10	^{54}Mn	LPD	1 ml
11	^{241}Am	LPD	10 ml
11	^{133}Ba	LPD	2 ml
12	^{22}Na	LPD	1 ml
13	^{88}Y	LPD	1 ml
14	^{137}Cs	LPD	3 ml
14	^{60}Co	LPD	9 ml
15	^{241}Am	LPD	5 ml
17	^{152}Eu	SPD	0.5 ml
21	^{241}Am	LPD	40 ml
21	^{133}Ba	LPD	6 ml
24	^{241}Am	LPD	17 ml
24	^{133}Ba	LPD	6 ml
30**	^{241}Am	CCC(708g)	51,271 dpm @ 31 Dec 78
30**	^{155}Eu	CCC(708g)	11,851 dpm @ 31 Dec 78
30**	^{152}Eu	CCC(708g)	943 dpm @ 31 Dec 78
30**	^{137}Cs	CCC(708g)	170,206 dpm @ 31 Dec 78
30**	^{60}Co	CCC(708g)	9,698 dpm @ 31 Dec 78
40	^{40}K	CCC(593g)	0.5 ml
Rat Standard #1	^{137}Cs	CCC(138g H_2O)	1 ml
	^{60}Co	CCC(138g H_2O)	5 ml
Rat Standard #2	^{137}Cs	CCC(243g H_2O)	1 ml
	^{60}Co	CCC(243g H_2O)	5 ml

*See Table 4-6 for solution activity of standards.
**Soil from Janet FJNW 12-4 sample used for QA interlab comparison #1.
CCC = Cottage Cheese Container, one-pint
LPD = Large, Petri Dish, 100 cc
SPD = Small, Petri Dish, 10 cc

TABLE 4-6. GAMMA STANDARD SOLUTIONS

Isotope	keV	Solution Activity dpm/ml	@ Date	Decay Constant (1/Day)
^{241}Am	60	2,434	5/31/74	4.38×10^{-6}
^{133}Ba	81, 161, 273	13,928	7/1/76	1.76×10^{-4}
^{133}Ba	303, 356	13,928	7/1/76	1.76×10^{-4}
^{152}Eu	122	430,000	4/15/77	1.355×10^{-4}
^{137}Cs	662	13,159	5/1/76	6.324×10^{-5}
^{60}Co	1173, 1332	2,904	7/1/76	3.621×10^{-4}
^{40}K	1461	144,200	2/19/79	5.414×10^{-10}
^{88}Y	898, 1836	35,520	5/18/77	6.418×10^{-3}
^{22}Na	511	14,481	9/1/76	7.30×10^{-4}

TABLE 4-7. SAMPLE COUNTING GEOMETRIES

	Sample Geometry	Distance from Detector to Center of Sample
1	Large Petri Dish, 100 cc, (LPD)	1 cm
2	Large Petri Dish, 100 cc, (LPD)	2 cm
3	Large Petri Dish, 100 cc, (LPD)	3 cm
4	Double Bagged Bulk Sample	Contact
5	Small Petri Dish, 10 cc, (SPD) With Planchet	Contact
6	Cottage Cheese Container, 473 cc, (CCC)	6 cm
7	Marinelli Beaker 1000 cc	Contact
8	Marinelli Beaker 500 cc	Contact
9	Large Petri Dish, 100 cc, (LPD)	Contact
10	Large Petri Dish, 100 cc, (LPD)	1.5 cm
11	Large Petri Dish, 100 cc, (LPD)	2.5 cm
12	Small Petri Dish, 10 cc, (SPD)	2.0 cm
13	Small Petri Dish, 10 cc, (SPD)	1.5 cm
14	Small Petri Dish, 10 cc, (SPD)	2.5 cm
15	Small Petri Dish, 10 cc, (SPD)	3.0 cm

Actual photo peak computation methods used by the RADLAB are an adaptation of computer routines originally written by Dr. Frank Markwell of DOE, Dr. John Tipton and Mr. Al Villaire of EG&G and were modified for the specific RADLAB hardware by EIC personnel.

The Enewetak soil was the best natural matrix standard for processing along with the samples analyzed at the Enewetak RADLAB.

The Enewetak soil sample was analyzed and determined to contain very low concentrations of the radionuclides of interest and was, therefore, used as a control sample. This soil sample was "spiked" with known amounts of the radionuclides routinely analyzed at the RADLAB. This served as part of the internal quality control program to check the accuracy of the laboratory analyses. Reagent spikes and blanks were processed with routine samples at the RADLAB as another check for accuracy and specifically to check cross-contamination. Calcium carbonate was also used to prepare blank and spike samples with a known concentration of radionuclides to be analyzed.

Another aspect of the internal QC program was processing of 5 percent of all samples through the RADLAB as duplicates. The duplicate analyses were reported as part of the quality control program. Another check on precision was based on the results obtained on the Enewetak soil which was processed with each set of samples analyzed in the laboratory.

Other precision checks were based on the results obtained on the Janet standard soil processed with each group of samples analyzed in the laboratory. The precision measurements were based on the analysis of duplicates and standard soil.

4.4.2 External Quality Control - Precision and Accuracy

The determination and comparison of crosscheck sample results analyzed by the Enewetak laboratory and other laboratories served to satisfy the external quality control program requirements and to establish the quality of the on-site analyses.

A large soil sample was collected from the island of Janet for the external quality control program. This soil was prepared in the same manner as the Enewetak soil. The Janet soil, from the vicinity of location NW12-4, was sent to various laboratories for analysis in order to establish the concentration of the various nuclides of interest. The Janet soil was the natural matrix standard used to check RADLAB accuracy based on results obtained from the other laboratories. A comparison of laboratory results is presented in Table 4-8, with the RADLAB shown as Lab A.

TABLE 4-8. EXTERNAL QUALITY CONTROL

	dpm/gm $\pm 2\sigma$				
Lab	^{241}Am	^{238}Pu	$^{239,240}Pu$	^{137}Cs	^{90}Sr
A	31.7 ± 0.6 32.9 ± 0.4 32.4 ± 0.4	1.30 ± 0.06	64.0 ± 0.6	108 ± 1.0 110 ± 1.0	177 ± 3
B	23.0 ± 2.3		77.2 ± 4.6	119 ± 8	102 ± 19
C	30.0 ± 1.0	1.20 ± 0.10	66.0 ± 6.0	120 ± 2	
D	33.0 ± 1.4		71.0 ± 10.0	114 ± 2	106 ± 5

4.5 LOGISTICS AND MAINTENANCE

4.5.1 Liquid Nitrogen

Liquid Nitrogen (LN) was required for the operation of the intrinsic germanium gamma detectors in the RADLAB. Initially, LN was flown to Enewetak. Later, an LN plant was installed next to the RADLAB complex. (See 3.4.3.) No recorded down-time of the RADLAB operations was due to a shortage of LN.

4.5.2 Bottled Methane Gas

Methane gas was used as a counting medium in three RADLAB gas proportional detector systems. A two-bottle manifold was installed on the counting trailer to allow cylinder change-out without disruption of gas flow. An initial supply of methane gas was shipped to the island at the start of the project and was followed by resupply from H&N in San Francisco on normally scheduled sea lifts. Empty methane gas cylinders were returned to Airco Industries in California for refill and return. On two occasions, it was necessary to transport methane gas by MAC to avoid shutting down the counting systems. Considerable effort was required to retard corrosion and maintain threads on stored cylinders so the caps could be removed.

4.5.3 Replacement Supplies

All supplies and materials furnished for the project were purchased and shipped through the Eberline Albuquerque, New Mexico facility by personnel directly responsible to the Enewetak project. In April 1977, materials, supplies and equipment were brought into Albuquerque, inventoried, and reshipped via Holmes & Narver (H&N) in San Francisco, for export to Enewetak by available sealift or MAC flights. All expendable hazardous acids, and laboratory materials were ordered in quantities that would allow completion of the full project without resupply, to avoid reshipment of items that could only go by slow surface transportation.

A military storekeeper was assigned to inventory, issue and order supplies at the RADLAB on Enewetak. On-island storage of materials utilized a bunker adjacent to the RADLAB complex (see Figure 4-1), and a warehouse located on the south end of the island. Both areas were without lights and were subject to many leaks during rainstorms. The bunker was used to store organic materials and the warehouse was used to store separately the oxidizer materials (to minimize the fire hazard). Most reorders of supplies and materials to be expedited were shipped directly to Honolulu by commercial air freight and then on to Enewetak by MAC. Normal orders were shipped by truck to H&N in San Francisco, and then to the island by MAC. A total of 183 resupply shipments of minor nonhazardous items was made after the initial deployment.

4.5.4 Disposal of Radioactive Wastes

Radioactive wastes generated in the RADLAB operations were disposed of by packing and delivering to the FRST for movement to the Cactus crater on Yvonne. The requirements set by the FRST were used in the preparation and transfer.

Solid Waste. The RADLAB produced solid wastes totalling approximately 4000 cubic feet. This volume consisted of 36 55-gallon drums of soil, 59 wooden crates, and 12 filter boxes from the following sources:

1. Soil from field samples that remained after the analysis and archiving aliquots were removed.

2. Metal cans used to collect the samples in the field which were damaged in transit to the RADLAB.

3. Laboratory drying pans and glassware.

4. Paper and rubber goods contaminated during the laboratory process.

5. One damaged ^{137}Cs 10 mCi calibration source.

Liquid Wastes. The small amount of contaminated liquid waste produced during the project and laboratory operation was disposed of by mixing with the soil in the 55-gallon drums. All radioactive laboratory and counting standard solutions were mixed with soil and shipped with the last few soil drums.

Non-radioactive organic wastes which had been stripped by ion-exchange resins were taken to the Enewetak dump site at the south end of the island and burned under the direction of the island Fire Department.

4.6 PROJECT DISCUSSION

The RADLAB support for the Enewetak Cleanup Project was unique because it was the first time that a complete radiological laboratory had been attempted for on-site support at a site as remote as Enewetak Atoll where supplies were not readily available from commercial suppliers. This facility had its disadvantages as well as benefits. The major problem was the rapid deterioration of some equipment exposed to the adverse and corrosive atmosphere encountered at Enewetak Atoll. In the final months of the project, equipment failure was more frequent for items such as fume hoods, drying ovens, grinders, sampling material, plumbing, electrical connections, etc.

Although the Atoll experienced several typhoon warnings during the project, it was not until January, 1979, that Typhoon Alice unleashed her destructive power on the Enewetak Atoll. The major force of the storm was concentrated on Enewetak with little damage experienced by the RADLAB complex except for the IMP shed and the warehouse facilities.

Due to the high salt content of seawater, a water softener was installed next to the chemistry trailer to pretreat the water prior to passing it through the deionization system. The backup power system, a 40kW diesel generator, was used on several occasions to provide uninterrupted power service to the counting trailer during times when on-island power was not available.

Since most sampling missions were dependent on boat support, many man-hours were lost due to lack of timely and dependable boat transportation. Boat support was often provided with less than adequate attention to safety. Unsecured floating ramps, side-by-side docking and inadequate walkways for embarking and disembarking were among the objectionable conditions. On several occasions the RADLAB Manager felt obliged to abort or delay missions when in his judgment the safety conditions were unacceptable. Helicopter transport for several sampling missions emphasized the contrast in the effectiveness and time utilization.

The military personnel assigned to the RADLAB, with few exceptions, carried out their tasks with professionalism and personal dedication. This support was instrumental in generating the analytical data which, along with field information, permitted the DOE/ERSP evaluation of the radiological condition of the individual islands.

The instrument maintenance facility was vital to the radiological operations at Enewetak because of the isolation and adverse field conditions. This facility maintained all the instruments and counting equipment without time loss due to electronic or mechanical failures.

A well planned and stocked warehouse and a current inventory of supplies and materials were essential to the success of this project. At no time during the project were the RADLAB operations delayed due to lack of this support.

CHAPTER FIVE

The nerve center of the ERSP team was the field data management center. Staffed continuously throughout the cleanup by one statistician and one data technician, the data center literally provided overnight data reduction and enabled the resident project manager to give real time advice and technical direction to the cleanup effort. Although the statistical methods were for the most part classical, their application to a massive "brute force" engineering project presented a distinctly non-classical challenge. As decision making rationale and cleanup method evolved, the statisticians regularly visited the field engineering sites to develop an appreciation for the needed format and detail of their advice. Mentioned only briefly at the end of this chapter is the matter of education--but it must be acknowledged as one of the more important contributions of the resident statisticians. The entire ERSP staff and the command and staff of the Task Group as well as members of the DNA command chain gained their insight into the scientific basis for the cleanup from the data management staff. The technical integrity of the process was largely in their hands.

Project Manager's Note

STATISTICS AND DATA HANDLING

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5.1 INTRODUCTION

The Desert Research Institute (DRI), under contract with the Department of Energy, was assigned the responsibility for statistical design and analysis in the Enewetak Cleanup Project, as well as for related data management functions. Because timely information and rapid turnaround on data analyses were critical for keeping the project on schedule, the statistical effort was concentrated in the data processing office on Enewetak Atoll. From July 1977 through September 1979 (except for two weeks immediately after Typhoon Alice struck the Atoll), a DRI statistician was present on-island. One Navy data processing technician was assigned to assist the statistician.

Although some preliminary computer programming was done and data procedures were established before the project began, most decisions about methods and procedures were made onsite, based on the experience gained as the cleanup progressed. The presence of a statistician on-island facilitated the timeliness of these decisions and also meant that existing procedures could be modified as necessary without delays.

In order to allow statistical analyses to be performed using the equipment on-island, a number of simplifications were made in the computer programs. One of the functions of DRI in Las Vegas was to use the first set of data collected on Enewetak to check the accuracy of the simplified routines. Other tasks for which DRI - Las Vegas was responsible included maintaining up-to-date information, transferring IMP spectra to magnetic tape for long-term storage, and performing statistical analyses that were too complex for the computer on-island.

5.2 STATISTICAL METHODS

Most of the statistical techniques used for data on various aspects of the cleanup were from classical statistics. The major exception was the use of the estimation technique, kriging, to perform the initial surface TRU characterizations. The method, which is discussed more fully in Section 5.2.1, was chosen because the assumptions made are reasonable in light of the physical processes at work, and because it had already proven to yield useful results with radiological data. The kriging approach is also useful because it provides an estimate of the standard deviation of the difference between the true, unknown value at a point and the estimated value at that point. This standard deviation can then be used to give an upper bound on the true value at a specified probability level, thus allowing cleanup criteria to explicitly incorporate a set probability level.

For example, if a criterion required cleanup of any region with TRU activity greater than 80 pCi/g, averaged over 0.5 hectare (ha), the criterion could be applied to the 0.5 s (s is the standard deviation) upper bound on the estimated average. That is, if the estimate plus 0.5 s exceeded 80 pCi/g, soil might be removed. If soil was not removed because the estimate plus 0.5 s was less than 80 pCi/g, probability is .69 that the true average was in fact less than 80 pCi/g, under the assumption of normality. On the other hand, this approach results in some soil being removed that really has lower TRU activity than 80 pCi/g.

The other estimates that were required for surface and subsurface characterization and cleanup were almost all made using standard techniques. Some of these, for example the method used to estimate the ratio of TRU to ^{241}Am, were changed based on experience with actual data, but they were changed to other standard methods. Classical approaches were also used for analyzing data from other programs such as the plowing experiment on Janet (see Section 6.7). In all cases, however, both with kriging and more classical methods, consideration was taken and adjustments made for unique aspects of the Enewetak situation. Some of the considerations and alterations are discussed in Section 5.2.6.

The greatest adjustments were required in experimental and sampling design. For example, the subsurface sampling methodology underwent considerable alteration before a satisfactory approach was found. In some cases, such as the plowing experiment and in sampling the Aomon Crypt, special sampling methods were designed to fit the situation. Even the collection of the soil samples for determining the ratio of TRU to ^{241}Am was specifically designed to allow valid comparison with the IMP ^{241}Am data from the same locations.

The general approach used for the surface cleanup was to obtain preliminary estimates using kriging and data from a 50 meter (m) grid, then collect additional data on a small grid in and around areas that did not meet the applicable criterion. Arithmetic means of adjacent IMP measurement values were then used to provide estimates of activity and boundaries for cleanup areas. After a soil lift, the area would be remeasured at the closer spacing so arithmetic means could again be used for determining if the lifted area met the criterion, and the process was repeated if necessary.

A similar approach was used for subsurface cleanup. Once the excision boundaries were determined from soil samples and the soil had been removed, additional soil samples and IMP measurements were taken to check if another iteration would be required.

By using an iterative approach, less data were needed and the initial data collection for both surface and subsurface characterization could be speeded up. Yet, the cleanup was still done conservatively, because contamination above the cleanup criterion would be detected and removed on the next lift. This iterative process along with the kriging technique used for the initial characterization was quite effective during the cleanup.

5.2.1 Surface Characterization

Kriging. The kriging technique, originally developed at the School of Mines in Paris, France, (Matheron, 1967), was inspired by certain estimation problems in mining. It was named by Matheron in honor of D. G. Krige, a South African mining engineer who pioneered the use of weighted averages in ore reserve estimation. Many of the terms defined below, such as "nugget effect" and "zones of influence," reflect the mining heritage of kriging. However, the method has been successfully applied to petroleum exploration, meteorological variables, seafloor mapping, water table mapping, and other geoscience applications.

The kriging estimator is a weighted moving average of the data with the weights determined using a function called the variogram. The variogram mathematically relates the variability of the difference between the values at two points to the distance between the points. The variogram is estimated from a set of data values, but the task is simplified because most variograms fit one of a few common patterns.

It is not necessary to have data on a regular grid to use the kriging method, but a grid pattern was used because it has several advantages. First, the kriging theory shows that for a fixed number of data values and any of the common variogram forms, a regular grid pattern will result in smaller standard deviation of the kriging error than other patterns. A regular grid is also easier to set up in the field, and it is easier to find the same location again than with a pattern such as random sampling. Finally, by using a regular grid and limiting the total number of data values used in each weighted average, the computations were simplified enough to be within the capability of the microprocessor on-island. The validity of the results from the simpler program was verified by using the same data in a general-purpose kriging program on a large computer. There were no significant differences between the results of the two programs, so the results from the on-island program were used throughout the project.

The mathematical assumption made in deriving the kriging estimator is that the observed data values are samples from a realization of a random function Z(x) with the following properties:

a) $E(Z(x)) = m$
b) $Var\,(Z(x+h) - Z(x)) = 2\gamma(h)$,

where m is a constant, x is a two-dimensional location vector, and h is a vector distance. The function $\gamma(h)$ is the variogram function mentioned previously. In practice, these assumptions need hold only locally, where "local" means for h less than or equal to the maximum radius of the neighborhood of points used in making an estimate. In the case of the Enewetak cleanup, the maximum radius was about 70 m. Thus if the expected TRU activity did not change much in a 70 m distance, and a reasonably good estimate of $\gamma(h)$ could be made for $h < 70$, then the kriging estimate could be considered valid. Both these conditions were sufficiently fulfilled by the surface TRU data.

Under the assumptions above, the kriging estimator is the best linear unbiased estimator where "best" is the sense of minimum variance. The linear condition means the estimator, Z*, is of the form:

$$Z^*(x) = \sum_{i=1}^{n} \lambda_i Z(x_i),$$

where λ_i are weights and $Z(x_i)$ is the observed data value at location x_i. The unbiasedness condition

$$E(Z^*(x)) = Z(x) = m,$$

leads to the constraint that,

$$\sum_{i=1}^{n} \lambda_i = 1.$$

Then minimizing $Var(Z^*(x) - Z(x))$ under this constraint leads to the system of linear equations:

$$\sum_{j=1}^{n} \lambda_j \gamma(|x_i - x_j|) + \mu = \gamma(|x_i - x|),\ i = 1, 2, \ldots n$$

$$\sum_{j=1}^{n} \lambda_j = 1$$

where $|x_i - x_j|$ is the Euclidean distance between x_i and x_j and μ is the Lagrange multiplier used to satisfy the constraint on the sum of the λ_j.

Solving this system of equations gives the weights λ_i, and the resulting variance of the kriging error $(Z^*(x) - Z(x))$, called the "kriging variance," is:

$$\sum_{i=1}^{n} \lambda_i \; \gamma(|x_i - x|) + \mu$$

For details on the derivation of these equations, and extensions to estimating area averages and to the case where $E(Z(x))$ is not constant, see Delfiner, 1975.

Because the $Var(Z^*(x) - Z(x))$ is expressed in terms of the variogram $\gamma(h)$, the weights λ_i do not depend on the data values $Z(x_i)$, but only on $\gamma(h)$ and the relative geometry of the x_i. One advantage of this is that, for a given island, the same set of weights is applicable to every complete square array of data points used in estimating an area average. In other words, the set of weights could be calculated once, and would apply to most of the island area, with individual computations required only for estimates on the island edges. This resulted in a substantial saving in computer memory and time required to make the calculations.

Although the weights do not depend on the $Z(x_i)$, they do depend on the variogram, which must be estimated from the data. Most of the variograms encountered in practice, including those observed in Enewetak, fit one of several common models. Figure 5-1 shows a few of these models.

As shown by the spherical model in Figure 5-1, the variogram may be bounded, that is, may attain a maximum value for $\gamma(h)$. The bound is called the "sill," and this value represents the general underlying variance of the population of sample points. The distance at which $\gamma(h)$ reaches its sill is called the "range" and this corresponds to the concept of the zone of influence of a data point.

By definition $\gamma(0) = 0$, but $\gamma(h)$ may not be approaching zero as h gets small. Such a discontinuity is called a "nugget effect," so named because the presence of a nugget of gold in a mine will cause a discontinuity in the variogram. A nugget effect can be caused by changes in the variogram structure at distances smaller than the smallest distance between observed data values, as in the gold nugget example. It can also be caused by uncertainty in the data measurements themselves. Most of the variograms on Enewetak data were linear and all had a nugget effect which was probably due to a combination of the two causes.

Ratio Estimation. The cleanup criteria for Enewetak were expressed in terms of average TRU activity, but the data from the IMP were ^{241}Am activities. The TRU activity was calculated using an estimated ratio of TRU to ^{241}Am. This ratio should theoretically be constant at a given time for fallout from a particular nuclear event. Many of the northern islands received fallout from several events, however, so the measured ratio represented composites from several fallout incidents. If an island was not the site of a nuclear event, the ratio was usually found to be fairly constant for that island. On ground zero islands, the effects from the various events appeared to influence the ratio for different parts of the island, so several ratio populations were present. However, these islands could usually be divided into several areas each having a single ratio population. The divisions were based on prior information such as known soil recontouring activities or on cluster analysis of data collected during the cleanup.

The data for estimating ratios came from alpha- and gamma-spectrometric analyses of soil samples. Soil sample locations were chosen in an attempt to get a representative sample of an island and the samples were collected in a consistent manner (see Section 4.2.1). A sample consisted of two composites of six subsamples each, with the subsample taken in a specific pattern. (See Procedure No. 4.) This was designed to roughly reflect the angular efficiency characteristics of the in situ detector, thereby increasing the comparability of IMP data and laboratory data from soil samples.

In the early stages of the cleanup, the ratio of TRU to ^{241}Am was estimated using the sample mean of the ratios from individual soil samples. The sample standard deviation was used to estimate the error in the ratio estimate. Use of these estimators assumes that the variance of the TRU value is proportional to the square of the corresponding ^{241}Am value. As more soil data became available, they showed that it was more accurate to assume that the variance of the TRU was

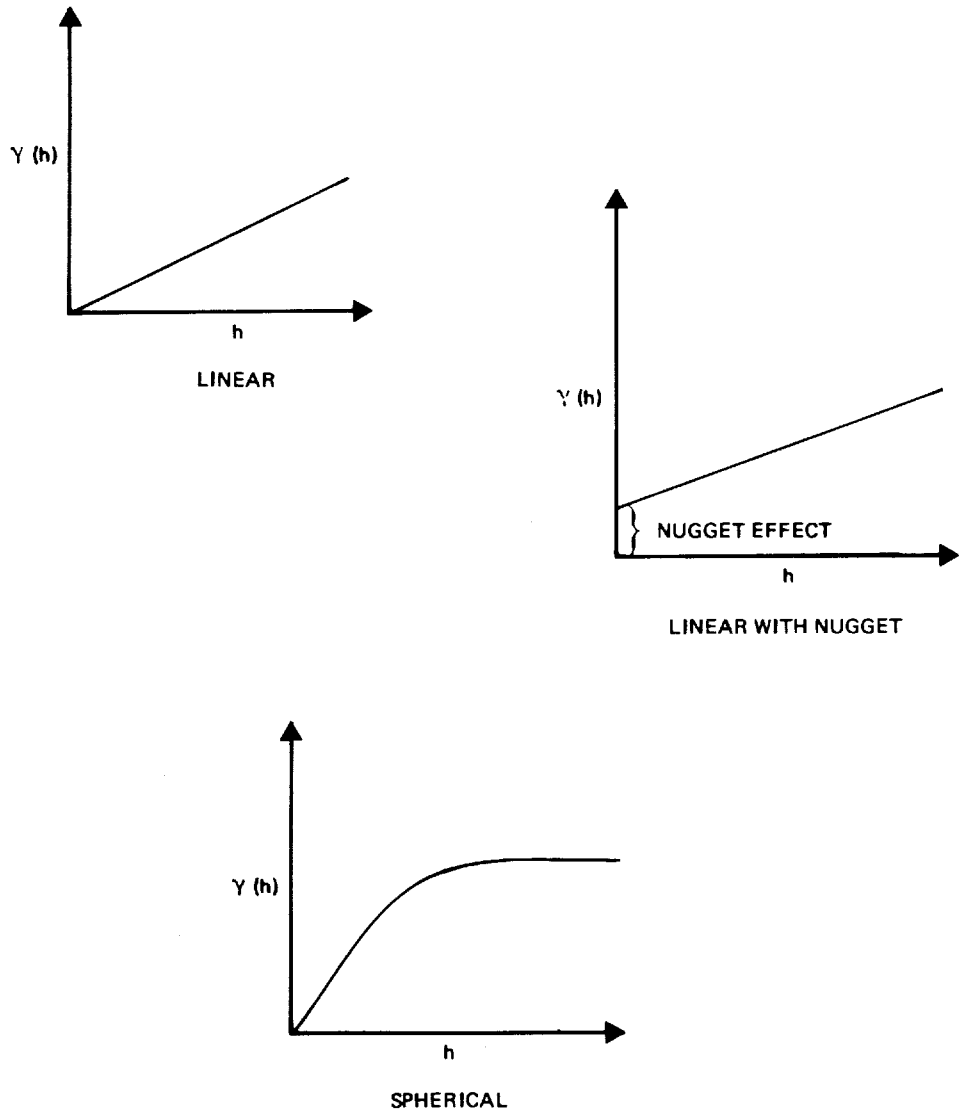


FIGURE 5-1. SOME COMMON VARIOGRAM SHAPES

proportional to the ^{241}Am value. Therefore, the ratio and error estimators were changed to reflect this approach (Doctor and Gilbert, 1978).

TRU Activity Estimation. Before the TRU activity calculation from ^{241}Am data could be performed, several corrections had to be made to the raw ^{241}Am data. The first correction was for detector effective area (detector efficiency), which was required because the program which computed ^{241}Am activity from the gamma spectrum peak area assumed all the detector crystals were 19 cm^2 in area. However, some of the crystals were actually smaller in area, and the effective area of the crystals tended to change while the detectors were in the field. The crystal effective areas were checked routinely by the EG&G scientist and any changes were reported to DRI so that the data could be corrected appropriately. For results of these calibration procedures, see Appendix C. No estimate of the variance of this correction factor was available.

Another correction was for signal attenuation due to the presence of vegetation in the detector field of view. The correction factor, called the Brush Correction Factor (BCF), was estimated using the data from an experiment on Pearl and corroborated by later experiments. The experiments and results are described in Tech Notes 1 and 1.1. (All Tech Notes can be found in Appendix B.) The standard deviation of the BCF estimate was included in the error propagation. The proportion of the detector field of view that was covered by brush was estimated by the IMP technician in the field.

In some cases, corrections were made for efficiency losses caused by operating the detector at an incorrect bias voltage. The necessary correction factors and corresponding standard deviations were estimated from remeasurements using the correct voltage, as described in Tech Notes 5.0 and 5.1. These standard deviations were included in the error propagation. Finally, there was one instance when a detector suffered a step-function loss in efficiency as a result of mechanical damage, but the loss was not noted until some time later. A detector efficiency check was performed to estimate the correction but no variance estimate was made (see Tech Note 5.2). The correction was applied to all data taken with this detector after the date of mechanical damage.

After all the necessary corrections to the ^{241}Am data had been made, these values were multiplied by the estimated TRU to ^{241}Am ratio to arrive at the estimated TRU activity. The estimated variance of the ratio was propagated into the estimate of the variance of the TRU activity. Details on the corrections, TRU computations, and propagation of error are given in Tech Note 20.

The computed TRU activity and propagated error values were used as input to the kriging programs for initial surface characterization. The kriging routines on-island could be used to estimate the average over a square area of side d, where d is the grid spacing, using a 3 x 3 array of data points. It was also possible to use a 4 x 4 array of data points to estimate the average over a square area of side 2 d or side $\sqrt{2}$ d centered on the center four data points. For example, with data taken at the usual 50 m grid spacing, average TRU activity could be estimated over 0.25 ha, 1.0 ha or 0.5 ha. The programs were set up to estimate the average activity over the square area even when some data were missing, such as when a sampling location coincided with a large bunker and no data could be taken. On the island edges, the programs would check which points in the standard 3 x 3 or 4 x 4 array were missing, to determine how much of the square area actually lay on the island rather than over water. Then the average activity would be estimated only on the region of the square actually on the island.

The results of the area estimates were output in several forms. The computer printed a data map with the averages centered in the square they represented. A similar printout showed the 0.5 s upper bounds, where s is the standard deviation of the kriging error, on the area-average estimates. Another set of printouts consisted of maps with the sections of the island having estimates or upper bounds less than a criterion shaded one intensity and the sections above the criterion shaded a different intensity. These printouts could be done several times using different criteria or different multipliers on s, thus making comparisons of various alternatives easier for the project managers.

5.2.2 Surface Cleanup

Once it was established that an area of an island would require cleanup, additional data would be collected to try to get complete coverage of an area. Prior to cleanup, the entire boundary of the area (as determined from the kriging estimates), plus a row of points on either side of the

boundary, would be measured with the IMP at 25 m spacing. These data were used to draw a revised, more accurate boundary of the area to be excavated. In most cases, the new boundary enclosed less area than the original estimate, but in any event it enclosed the smallest area that would require soil removal to meet the applicable criterion. Measurements were not made at spacing smaller than 25 m after the initial cleanup efforts on Sally because the boundaries based on 12.5 m measurements there were essentially the same as for 25 m data.

Estimates of the total volume of soil to be removed were based on the refined cleanup boundary and the results of soil sampling. The soil data were used to determine the maximum depth of the contamination above cleanup criterion in the soil. If there were insufficient subsurface data in the cleanup area from previous sampling, additional locations were sampled using the subsurface procedure (see Section 6.9).

The total volume of soil to be removed was estimated by multiplying the surface area by the depth to which soil was to be excavated. When appropriate, the cleanup area was subdivided into smaller sections, each having a different depth. In these cases, the boundaries of the small sections and the excavation depth for each and the volume estimates were transmitted to the Joint Task Group (JTG).

After a soil lift had been completed, the entire lifted area and a row of points outside the boundary were surveyed by the IMP at 25 m spacing. Average activity over 0.25 or 0.5 ha was estimated by using arithmetic means of adjacent data values. If the mean for any section still exceeded the criterion, the lift-remeasure process would be repeated until the applicable criterion was met. In a few instances, additional lifts were required in an area where no elevated subsurface contamination had been expected. In those cases subsurface soil data were collected before any more lifts were taken, to provide a better estimate of the maximum depth of the soil requiring removal.

When the soil removal was complete for an area, an estimate was made of the total TRU activity contained in the excavated soil. The estimate was based on the depth gradient of the TRU activity determined from subsurface soil data, before and after average activity from IMP data, and JTG's report of the total volume of soil removed. Details of how the parameters describing the depth gradient were determined and the assumptions used in making total activity estimates are in Tech Note 10.0.

The final set of measurements after cleanup included the lifted area that had been used for stockpiling contaminated soil. Measurements on the stockpile areas confirmed that no contaminated soils remained after the stockpile had been transported to Yvonne for disposal. These measurements were used in determining the final surface TRU isopleths in Section 7.5.

5.2.3 Subsurface Characterization and Cleanup

The approach used for subsurface characterization in the beginning of the project was to take samples on a 25 m or 12.5 m grid in the vicinity of each area of suspected subsurface contamination. Then, if any subsurface TRU activity above acceptable levels was discovered, samples were taken on a finer spacing around the location with elevated activity to determine the boundary of unacceptable contamination. Each iteration of sampling was always on a finer mesh of the initial regular grid, and was intended to cover the region of interest.

The first few sets of samples, from Irene and Pearl, were auger core samples. This method proved unsatisfactory, so a sidewall sampling method was used for the rest of the project. The data from the samples early in the project consisted of gross alpha counts, with some laboratory analyses for ^{241}Am and ^{239,240}Pu. The ^{241}Am data were more useful in practice, so eventually all the samples were analyzed for ^{241}Am and some were analyzed for ^{239,240}Pu. These results were also used to determine a TRU to ^{241}Am ratio for subsurface soil.

The sampling design changed as the cleanup project progressed. Various grid spacings and layouts of the samples were tried, but all tended to be inefficient because of the large number of sampling locations and iterations required to adequately define a cleanup boundary. Eventually the approach described in Tech Note 18 was incorporated and proved to be efficient with respect to samples and iterations, and also in minimizing the amount of soil removed. More details on the sampling designs and methods, sample analysis and cleanup methods can be found in Section 6.9.

Because the subsurface cleanup boundaries could not be defined as precisely as the surface boundaries, a conservative approach was taken in determining the boundary. Usually, the cleanup area was extended beyond the last location with observed TRU activity above 160 pCi/g to at least halfway to the adjacent location. Soil volume estimates were based on these boundaries and the maximum depth with TRU activity greater than 160 pCi/g. If the subsurface soil removal area was large enough, it was subdivided into sections with a different maximum depth in each section.

The type of sampling used for checking the post-removal activity depended on the size and depth of the excavation, and on whether it was to be backfilled. Soil samples were taken from the sidewalls and sometimes the excavation floor. Portable instruments were sometimes used to roughly characterize the radiological condition of the floor and sidewalls of the excavation. IMP measurements were usually made in a pattern that provided complete coverage of the excavation. In relatively shallow excisions with no backfilling, averages of the TRU activity calculated from IMP data were used to verify that the cleanup criterion was met. In deeper excisions, soil samples were collected to make sure the contamination did not extend beyond the cleaned area while IMP data provided TRU data to compare with the cleanup criterion. If the excavated area was backfilled, the fill material was measured with the IMP before and after the backfilling. Soil stockpile areas were also measured to confirm that all contaminated soil had been removed.

The average TRU activity in the soil removed was estimated by using the arithmetic mean of all the soil profile data taken in the lifted area. This estimate was multiplied by the soil volume removed as reported by JTG to estimate the total TRU activity removed.

5.2.4 Quality Assurance Program

The external quality control program was an integral part of the overall quality assurance effort for the EIC Enewetak laboratory. In this program, a large soil sample was collected and thoroughly mixed to form a basis for interlaboratory comparisons. Starting in December 1978, and quarterly thereafter, part of this large sample was dried, ballmilled and prepared for analysis as usual on Enewetak. Then it was split into four aliquots with a minimum of 100 g in each. One remained at Enewetak for analysis and the other three were shipped to Nevada for transshipment to independent labs for analysis. Each such set of samples was designated a "batch."

Throughout the cleanup, five batches were examined by at least two laboratories. Batches 1 and 2 consisted of soil from one location on the island Janet and Batches 3 through 5 were from another location on Janet. For the purpose of comparison, all the data from a single location were combined.

Two different sets of assumptions could be possible for estimating the population variance for data from a single location. The individual samples all received the same preparation and were aliquots from the same homogenized sample. Therefore, it could be assumed that the only contributor to the variance is the counting error resulting from the approximately Poisson distribution of radioactive decay. The other assumption, which is more realistic, is that the factors such as environment, differences in chemical recovery, and sample inhomogeneity also contribute to the variance.

Table 5-1 shows the results from all Batches, along with the two sigma counting error. Lab A is the Enewetak laboratory, Lab A1 is the EIC Albuquerque laboratory, and Labs B, C, and D are the independent labs. The values reported for Lab A are actually arithmetic means based on the results of several subaliquots of the initial batch aliquot. The data for the other laboratories are based on a single analysis. Results of the comparison for each radionuclide are discussed below.

Americium - 241. The results for all laboratories were within the 99 percent confidence interval on the mean of Batches 1 and 2. All but the Lab B Batch 3 results are within the 99 percent confidence interval on the mean of Batches 3, 4 and 5. Laboratory B showed a distinct tendency to produce low results up until Batches 4 and 5. Overall, interlaboratory agreement is good, especially considering the fairly low activity in the last three Batches.

Plutonium - 238. Statistical comparison of this isotope was not very useful because of the lack of data and also because of the very low activity. Based on a general review of the results, the interlaboratory agreement appears to be reasonably good.

TABLE 5-1. RESULTS OF ENEWETAK EXTERNAL QUALITY CONTROL PROGRAM

Values are pCi/g, plus or minus 2 sigma counting error

Batch No. (Date)	^{241}Am	^{238}Pu	$^{239,240}Pu$	^{137}Cs	^{90}Sr	Lab
1 (12/78)	32.9 ± 0.4*	1.3 ± 0.06*	64.0 ± 0.62*	107.9 ± 0.72*	177 ± 3*	A
	23.0 ± 2.3	Not Done	77.2 ± 4.6	119 ± 8.3	102 ± 19	B
	30 ± 1	1.2 ± 0.1	66 ± 9	120 ± 2	156 ± 21	C
	33 ± 1.4	Not Done	71 ± 10	114 ± 2	106 ± 5	D
2 (3/79)	24.0 ± 2.4	Not Done	64.5 ± 6.4	116 ± 8	154 ± 26	B
	28 ± 1	2.4 ± 0.1	126 ± 2	107 ± 1	150 ± 2	C
	37 ± 1.4	Not Done	61 ± 8	113 ± 2	Not Done	D
3 (6/79)	6.19 ± 0.28*	0.12 ± 0.02*	9.90 ± 0.25*	10.83 ± 0.19*	207 ± 2*	A
	6.11 ± 1.00	0.05 ± 0.01	10.7 ± 0.7	9.92 ± 0.80	37.1 ± 1.0	A1
	4.01 ± 0.7	Not Done	Not Done	10.6 ± 0.85	Not Done	B
4 (9/79)**	5.91 ± 1.00	0.04 ± 0.01	9.20 ± 1.10	10.5 ± 0.6	41.9 ± 0.5	A1
	5.63 ± 0.6	Not Done	10.9 ± 0.11	10.5 ± 0.12	34.6 ± 7.8	B
5 (9/79)**	6.77 ± 1.02	0.04 ± 0.01	9.13 ± 0.98	9.96 ± 0.58	40.8 ± 0.5	A1
	5.94 ± 0.59	Not Done	11.6 ± 0.12	11.7 ± 0.12	38.2 ± 6.5	B

*Mean value and associated standard deviation based on several aliquots.
**Two batches were analyzed the last quarter.

Plutonium - 239,240. There is an outlier (Lab C) in the Batch 2 results (too high by a factor of 2) and this value was excluded in computing the mean. Besides the difference in magnitude, this result can also be discarded based on its calculated $^{239,240}Pu$- to -^{241}Am ratio of 4.5, which is far above the known ratio of 2.3 $\pm$ 0.4 for that area of Janet. With that number deleted, the 99 percent confidence interval on the mean of Batches 1 and 2 contains all but the Lab B Batch 1 result of 77.2 pCi/g. This value is 15 percent higher than the mean, but is only 0.3 pCi/g higher than the upper limit of the confidence interval. All the results for all labs are within the 99 percent confidence interval on the mean of Batches 3, 4 and 5. Therefore, except for the one outlier, interlaboratory agreement is good for these isotopes.

Cesium - 137. Results for all laboratories are within the 99 percent confidence interval on the mean of Batches 1 and 2, and all but one are within the 99 percent confidence interval on the mean of Batches 3, 4 and 5. The exception is the Lab B Batch 5 value, which is 11 percent higher than the mean, but is only 0.3 pCi/g higher than the upper limit of the confidence interval. Thus interlaboratory agreement is good for this isotope.

Strontium - 90. There were some problems noted in the Batch 1 results for this isotope, and at the time it was unclear which of the disparate results was more accurate. The Batch 2 results indicated the Lab B and D results for Batch 1 might not be reliable. The 99 percent confidence interval on the mean of Batches 1 and 2, computed with those two samples eliminated, contains all but those two samples. Including those samples more than doubles the standard deviation, leading to the conclusion that the Batch 2 results for Lab B are reliable, but the Batch 1 results are not.

There was also a problem in Batches 3, 4 and 5. The Lab A result is an outlier, while all other results lie within the 99 percent confidence interval on the mean, computed with the outlier excluded. Fortunately, Lab A1 conducted the analysis for the ^{90}Sr data actually used and it shows good agreement with other labs.

Conclusions. Overall, agreement among laboratories was good. These comparisons indicate that the results from Lab A (the EIC Enewetak laboratory) were reliable with the exception of ^{90}Sr. This caused no severe problem since Lab A1 (the EIC Albuquerque laboratory) provided the ^{90}Sr data used for the dose assessment and Lab A1 results were supported by Lab B for this isotope.

5.2.5 Other Programs

Statistical design and analysis were required for several programs and experiments not directly related to the surface and subsurface soil cleanup efforts. Among these was the plowing experiment (Plow-X) that was an investigation of a possible alternative or adjunct to surface soil removal. The experiment was designed to check the effects of deep plowing on both surface TRU activity and distribution of activity as a function of depth. The surface comparison used a randomized block design and data from the IMP. The subsurface investigation involved a multivariate analysis of variance on soil profile data. The soil samples were taken in a pattern that was selected to avoid confounding the effects of plowing with effects from using a backhoe to dig the sampling trenches. Details on the experiment and the philosophy behind it are in Section 6.7, and the results of the statistical analyses are in Tech Note 9.1.

Comparisons of ^{241}Am data from the IMP with laboratory ^{241}Am results from surface soil samples also involved statistical analyses. The earliest work, using a regression approach on Janet data (Barnes, 1978), resulted in the conclusion that the two types of data agreed reasonably well. Continuing questions about the accuracy of the IMP data, however, prompted more analyses using a somewhat different regression method and data from several islands. There were some significant differences between the two data types, so an investigation was made of the variability of ^{241}Am activity in soil. A description of the investigation and results are reported in Tech Note 8.0. The results indicated that statistical investigation of the possible differences between soil and IMP data would always be difficult because of the high variability of ^{241}Am activity in soil.

Theoretical calculations eventually led to discovery of a bias in the in situ data due to incorrect assumptions of the soil composition, density and moisture parameters used in deriving the IMP conversion factor. Tech Notes 22 and 23 describe the collection of additional data to arrive at more accurate parameters and the final correction, respectively. (See also Sections 3.2.6 and 3.2.9.)

The unique nature of the burial area for contaminated material known as the Aomon Crypt called for special sampling designs. Because the boundary of the buried material was known only in general, the entire area was core sampled on a 5 m grid in two-foot increments to a maximum depth of 28 feet. The sampling data were used to estimate horizontal and vertical boundaries of the region with TRU activity exceeding 400 pCi/g. After the soil removal was complete but before backfilling, samples were collected of the material at the bottom of the excavation, which had filled with water. Soil samples were collected and IMP measurements were taken to characterize the area after backfilling. Details on the sampling and excision methods used for the cleanup of the Aomon Crypt are in Section 6.8.

In preparation for recontouring of the PACE area on the island Sally, the soil that was to be used as fill was sampled to estimate the TRU activity. Subsurface sampling methods were used, with slight modifications to take into account the proposed depth for the fill. In several cases, elevated TRU activity was found on the surface. Extra IMP measurements were taken and handheld instruments were used to verify that the higher activity was confined to a small area and was within acceptable limits.

5.2.6 Influence of Unique Project Aspects

Detector Field-of-View. There were a number of distinctive and unusual aspects in the Enewetak cleanup project that had to be taken into consideration when choosing statistical methods. One of the most important of these considerations was the field-of-view of the in situ detector. Even though the detector is collimated, the detector response does not drop to zero at the nominal angle of the collimator. The cutoff angle at which gammas cease to enter the crystal is approximately 60° for the 60 keV gamma ray from ^{241}Am. One consequence of the lack of a clear "edge" of the field-of-view is that its diameter could reasonably be defined as anything from 21 to 26 m with the detector at full height (7.4 m). About 95 percent of the total activity detected originates in a circle of diameter 21 m, so that could be considered the "field-of-view." On the other hand, about 99 percent of the detected activity comes from a 25 m circle. Thus 25 m is also a reasonable value for the diameter of the detector field-of-view. (See Section 3.2.8.)

The sampling plan for surface soil samples was designed using a diameter of 21 m for the field-of-view. Initially, the pattern of the subsamples (see Procedure No. 4) was chosen so that different areas in the detector field-of-view were soil sampled with approximately the same probability as that in which radiation in the same areas will be detected by the in situ detector. However, the design was based on incorrect information about how the detector response changes as a function of angle, so that the composites overrepresent the center of the field-of-view. Because the primary purpose of the surface soil sampling was to obtain estimates of the ratio of TRU to ^{241}Am, which is not affected by this error, the sampling design was not corrected. However, the statistical analyses comparing IMP data and soil sample data were adversely affected, because this error makes it more difficult to identify a real difference.

The field-of-view of the detector is also a factor in selecting methods for estimating area averages. The kriging programs used numerical integration methods which were based on the assumption that the data were point values, or at least represented a small proportion of the total area. This assumption was valid for data at 50 m or larger spacing, but not for 25 m data. At 25 m spacing, adjacent detector fields-of-view actually overlap, although the common area represents only a small fraction (less than one percent) of the total activity detected. Thus it would not have been proper to use kriging on 25 m data, while the arithmetic mean of adjacent data values is a good estimate of the area average. The arithmetic mean was used for all cleanup boundary estimates, post-cleanup characterization, and certification estimates involving 25 m data.

Field Limitation. Another important set of considerations in performing statistical analyses was the limitations and difficulties inherent in a field project such as the cleanup. For example, the IMP system could only measure a limited number of points each day and the laboratory could only process a certain number of samples at a time. Also, although the lab had a wide range of analytical capabilities, it was not equipped for some types of analyses, and could only handle a few samples for some other types. In light of these limitations, it was important to use methods that made the best possible use of the amount and type of data available.

The quality of the data analyzed was also affected strongly by the various problems encountered in taking samples in the field. For example, the surface soil sampling design was quite complex to execute in the field, and it took time for a new sampling crew to learn to take these samples properly. Also, the equipment had a tendency to deteriorate or be altered inadvertently when parts were replaced, so that later data may not have represented the same population as earlier data. The primary result of these and similar field problems was to increase the sample variance, making comparisons among data sets more difficult.

Data quality was unavoidably altered to an unknown extent by the engineering operations that were necessary to allow data collection. For instance, if the vegetation were removed totally, as on Janet, the resulting soil disturbance altered the distribution of the TRU activity in the soil. If only access lanes were cut, as on other islands, soil disturbance was reduced but not eliminated. In addition, the data had to be corrected for signal attenuation from the remaining brush, using a subjective estimate of the amount of brush and an empirical brush correction factor. Because of these factors, the general principle used for choosing between alternative statistical approaches was to use the simplest method that would do the job.

Certain types of data that were reported by others to the statistician were accepted as accurate because there was no way to verify the information. Examples are the total volumes of soil removed, the nominal depth of soil profile samples taken where the surface was uneven, actual boundaries of soil lifts, brush cover estimates, and similar information. No estimates of variance or reliability could be made for such data, so they were accepted at face value.

Cleanup Criteria. The cleanup criteria were stated as averages over specified areas such as 0.25 ha, and specified depth intervals such as 0-3 cm. Therefore the statistical methods used had to be appropriate for making estimates of area averages for a given depth interval. Also, the criteria required that the estimation error be considered, so an estimate of the error also had to be made. However, it was not clear at the beginning of the project whether the criteria applied to upper bounds or lower bounds on the estimates. The conservative approach of applying the criteria to the upper bounds was actually used, that is, soil was removed if the estimate plus half its standard deviation exceeded the applicable criterion.

The subsurface cleanup criterion was difficult to interpret. Eventually the criterion was restated to reflect the limitations of the subsurface data, so the statistical analysis could aim at locating boundaries of areas to be cleaned rather than estimating subsurface averages. In some instances, though, estimating averages were necessary. For example, the criterion implies that the shallowest 5 cm subsurface increment is 2.5 -7.5 cm, but this interval was never sampled as such. Therefore, the average in this interval had to be estimated from 0-5 cm and 5-10 cm data. The method used to estimate the 2.5 - 7.5 cm average is described in Tech Note 19.0.

As the cleanup progressed, changes were made in the interpretation of various surface criteria. For more details concerning these changes, see Section 2.2.4. Both the area averaged over and the acceptable average value were altered. This meant that all the statistical analyses had to be flexible enough to allow estimates to be made for different sized areas and compared to various criteria levels. Fortunately, the kriging technique is quite flexible, so the original 50 m data could still be used. In those areas with 25 m data, it was relatively straightforward to compute the arithmetic means for various size areas.

5.3 DATA HANDLING

Data handling responsibilities during the Enewetak cleanup project included not only statistical analyses but also data base management, data quality assurance and preservation, and the display of results in clear, useful forms. The types of information involved included not only raw data and final results, but also intermediate results, narrative descriptions of statistical methods, documentation for computer programs, etc. The onsite DRI statistician, assisted by the Navy data technician, had primary responsibility for data handling on-island. Long-term data preservation was the responsibility of DRI-Las Vegas.

5.3.1 Facilities

The on-island electronic equipment for data storage and analysis consisted of a Hewlett-Packard 9831A desktop microprocessor with peripherals, which included a dot-matrix thermal printer, a four-color plotter, and a flexible disk drive. The microprocessor had a built-in tape drive for cartridge tapes, and was equipped with ROMs (read-only memories) which drove the plotter and disk drive, and made matrix operations much easier.

The microprocessor system had a wide range of analytical, data management, and display capabilities. The memory size and computing power were adequate to perform almost all the statistical analyses for the cleanup. The data base for IMP data was set up on flexible disks, to which the spectra were transferred from cartridge tape. Programs, data and results could be stored on disk or tape, and frequently were put on both media to allow more flexibility. Results could be printed or plotted either as graphic displays or in tabular form.

There were some limitations of the microprocessor system that affected the way data were handled during the project. The kriging programs were simplified in order to fit in the memory available and to run in a reasonably short time. Also, the data for the larger island Janet had to be divided into two subsets when they were run through the kriging programs because of the memory limitations. Data for all other islands could be handled in a single set per island. Because the simplifications in the kriging routine precluded analysis of data not on a regular grid, a few experimental data sets had to be analyzed in Las Vegas.

DRI-Las Vegas had the same equipment as was on-island, plus a tape drive which was used for transferring data from disk to magnetic tape and had terminals for communicating with a CDC 6400 computer. The magnetic tapes could be read by the CDC 6400 and is the medium used for permanent preservation of the data base.

5.3.2 Data Flow and Preservation

The data used during the project came from several sources and were in various forms depending on the type of the data. Data from laboratory analyses of surface or subsurface soil samples were transmitted in hard copy by the EIC lab manager to the statistician. Gamma spectra for Fission Product Data Base (FPDB) program samples were also transmitted on cartridge tapes, from which DRI extracted the gamma results to store on disk. The tapes were returned to EIC after the results were on disk.

Data from in situ measurements with the IMP were transmitted by the EG&G scientist to DRI on cartridge tapes. The tapes contained the complete gamma spectrum as well as the extracted ^{241}Am results, identifying information and comments. The data for ^{241}Am, ^{155}Eu, ^{137}Cs and ^{60}Co and printouts of relevant sections of the spectra were also available on hard copies which were retained by the EG&G scientist. The tapes were copied to flexible disk by DRI, and retained until the information on disk had been copied to magnetic tape in Las Vegas. Then the cartridge tapes were erased and reused.

The accuracy and quality of the data were checked at several stages. The laboratory and in situ detectors were calibrated routinely, and the calibration procedures were supervised by the EIC chemist and EG&G scientist, respectively. The laboratory also had both internal and external quality assurance programs as part of the standard laboratory operations.

The incoming raw data were checked by the statistician or data technician. Checks included verifying that the locations marked on the samples matched the intended locations and that the data values were consistent with other information such as known ratios of TRU to ^{241}Am. Any discrepancies would be referred to the EG&G or EIC managers for resolution. Corrections were noted on the hard copy of lab data and were made both on hard copy and the flexible disk copy of in situ data.

Analytical Data Flow. After the raw data had been verified and any errors repaired, the statistical analyses were performed. Intermediate steps in the analysis of in situ data included making corrections for detector effective area and for signal attenuation by vegetation, plus any other

necessary corrections. The laboratory data from surface soil samples were used to estimate the ratio of TRU to ^{241}Am, which was multiplied by the corrected in situ data to get raw TRU estimates.

The final step in processing data for initial surface characterization was to use the TRU data in the kriging programs to make estimates of average TRU activity. These estimates were then used to define preliminary cleanup boundaries, and to determine where to take more measurements.

Data from the additional measurements were processed to the stage of raw TRU estimates, and were then used to determine refined boundaries and estimate the volume of soil to be removed.

After each soil lift, the in situ remeasurement data were processed to the raw TRU data stage, and used to check against the applicable cleanup criterion. The final post-cleanup data were treated in the same manner, and were used in estimating the total TRU activity removed and for the final characterization.

Data Preservation. The DRI statistician was responsible for assuring the preservation of all in situ data, including the gamma spectra. During the cleanup, the EIC lab manager was responsible for preserving the laboratory gamma spectra. After the field work ended, all spectra were transferred to DRI-Las Vegas to be prepared for long-term storage.

As soon as a set of IMP data tapes came into the data processing office from the field, the EG&G scientist checked for errors and determined any efficiency correction. The tape was then copied to magnetic disk, the errors corrected, and relevant comments from the field log sheets added to the stored spectra. From this point on, there were always at least two copies of each spectrum on magnetic media. For example, the cartridge tapes were not recycled until the data had been copied to magnetic tape in Las Vegas from a second disk copy of the data. The disks used to carry the second copy to Las Vegas were also recycled, but not until the data on magnetic tape had been verified.

The data extracted from the spectra were also preserved in multiple copies. Printouts of identifying information were made both in Enewetak and at Las Vegas, and these showed the ^{241}Am data. The ^{241}Am data were arranged in matrices according to location and stored on cartridge tape, with a hard copy in the files. Matrices of computed TRU data and of estimates of area average TRU were also stored on cartridge tape with hard copies in the files.

The cartridge tapes and magnetic disks were stored in a fireproof file to protect them. When a tropical storm or typhoon approached the atoll, the tapes, disks, files and notebooks of data and results were double-bagged and sealed in waterproof plastic and stored in the fireproof file. The program disks and tapes were also stored in the file and were similarly protected during severe storms. Once, when personnel were evacuated from the atoll because of an approaching typhoon, the tapes, disks, notebooks, etc., were also evacuated with the departing personnel.

Other aspects of the preservation of programs included having copies on both disk and cartridge tape, with a documented hard copy in a programs notebook. Copies of the programs and documentation were also kept in Las Vegas.

5.3.3 Data Transmittal

Typically, formal data transmittals would be drafted by the DRI statistician, then the text and illustrations would be reviewed by the ERSP tech advisor. Necessary revisions would be made, and the document sent to the ERSP manager for review and transmittal to JTG.

Information that was ordinarily sent in formal transmittals included initial characterization estimates of TRU activity, preliminary cleanup boundaries, revised boundaries, estimates of total soil volume to be removed and of total TRU activity removed. Radiological cleanup status charts were maintained routinely, and were included in the Quarterly Operations Reports. Some Tech Notes were also included in formal transmittals when they were needed for complete understanding of the results.

The two large data bases will be maintained indefinitely on magnetic tape, but the disks will eventually be reused. Any requests for data must be directed to the Nevada Operations Office, the agency responsible for long-term retention of data collected during the Enewetak cleanup.

5.5 REFLECTIONS AND RECOMMENDATIONS

On looking back over the DRI participation in the Enewetak cleanup effort, the greatest single source of continuing problems appears to have been ambiguity in the cleanup criteria. Delays were caused by the confusion over whether to use upper or lower bounds and about what constitutes a subsurface "pocket," along with other questions that were raised because of uncertainties in interpreting the criteria. The statistics group strongly recommends that criteria be clear and detailed and written in consultation with the statisticians. It would also be helpful if enough flexibility were allowed to change the criteria if field experience indicates a need for redefining guidelines.

The second problem involved data base establishment and management. Some difficulties were due to such things as mixups in data formats or inconsistency in reporting locations, but others came from misunderstandings about who was responsible for what data base. It would be better to establish, before any data are collected, a single focus of responsibility for data base management. Then decisions about formats and programming to handle the types of information and retrievals needed could be made consistently for all the data bases.

A related concern was the poor communications among contractors before the project began. Better communication could have helped all to understand what to expect and what was expected of each other. A specific case in point is the data bases, which would have been better from the start if consultation among contractors had taken place. Communications among contractors on-island improved with time once the project began. This problem was most evident during personnel changeovers and in times of crisis, especially when decisions were being made off-atoll. Some of these difficulties would have been eased by more conscious effort to keep everyone informed.

A useful part of intra-ERSP communication was the regular staff planning and priority meetings. These began about halfway through the project, but would have been helpful from the beginning, because they kept personnel on-island informed, and encouraged more effective coordination of effort. Also helpful was the time ERSP technical people spent working in the field with the military; this reduced the amount of garbled instructions and general confusion. The practice of field participation is recommended for projects of this type.

One specific communication problem was the failure to convey clearly the inherent limitations of the technical side of the cleanup. For example, the IMP could only survey a certain number of points each day, chemical extraction of plutonium cannot be speeded up, nor can reliable estimates be made with bad or insufficient data. Above all, "Statistics can neither create nor destroy plutonium."* These limitations must be reiterated constantly, because some people are unaware of them and others tend to forget them and must be reminded.

Flexibility is an advantage in an operation like this, where many things get done only because someone invents a method or improvises some equipment to do the job. Unthinking adherence to "The Rules" will not accomplish the mission, whether it's a statistician designing sampling plans or a boat driver retrieving people from the island Alice. Educating everyone about the reality of the situation can aid flexibility, because if they understand what is behind their efforts they can seek reasonable alternatives for reaching the goal.

An increased need for thorough documentation is one of the consequences of this flexibility. Not only must procedures, methods and programs be carefully documented, but also the rationale behind them, especially when something is changed or introduced. Another benefit of this, besides the historical record it provides, is that new arrivals can use the documentation to get "up to speed" on procedures and activities. This documentation is recommended to include the keeping of candid personal logs. Oftentimes, the log books contained a piece of vital information that was not in the procedures or correspondence files. Despite the qualms attached to candor in a document which may become public, frankness greatly enhances the usefulness of a project log book.

*H. N. Friesen, November 1977.

A formal data transmittal could include tabular information, maps of estimates, charts, graphs and accompanying explanatory tests. Information was frequently exchanged informally to avoid time delays, and followup formal transmittals sent when appropriate.

Displays of data suitable for use in briefing project management were also maintained. Grid maps with data written in, aerial photographs, viewgraphs, overlay maps and similar materials were used for this purpose.

For transmitting data internally, for example, between statisticians during personnel changeovers, several methods were used. Plots of the raw variograms and models (see Section 5.3) were kept in a notebook, along with estimation results and the input parameter required by the data analysis programs. Subsurface data were displayed in several different forms, including maps showing each depth individually, multidepth data maps, and overlay maps. Field notes, daily logs and notes on computations and statistical methods were kept to document the reasoning behind the methods chosen for analysis. Program documentation, particularly on program updates, and current catalogs of the contents of magnetic disks and cartridge tapes were also maintained.

5.4 DATA BASES

There are several data bases containing data related to the cleanup project, two of which are extracts from two larger bases. The purpose of these data bases is to provide long-term capability to retrieve the data easily, and to document the initial and final condition of the islands of Enewetak Atoll. The smaller data bases contain the most commonly used data, which can be retrieved very rapidly. The larger data bases contain the complete gamma spectra, detailed identifying information, and pertinent comments. Results from alpha or beta spectroscopy are also included on the laboratory data base. The larger data bases are suitable for more detailed studies since data for gamma-emitting isotopes besides those considered during the cleanup can be extracted from the stored spectra.

One of the large data bases contains all of the spectra from in situ measurements taken with the IMP, including calibrations and the preliminary data taken to check out the system. Identifying information includes island, stake location, date and time of the measurement, serial number of the detector used, percent brush cover, file number of the disk file containing the spectrum, and comments. There are two tape copies and a flexible disk copy of the entire data base.

The other large data base contains the gamma spectra and alpha and beta spectroscopy results for laboratory data. Identifying information includes island, stake or other location identification, date and time of sample collection, type of sample, depth of sample, counting date and time, detector geometry and number, and, where pertinent, name and organization of sample collector. Extracted gamma results are stored for all isotopes for which a current calibration was available. The spectra are stored in six subsets according to type of sample: Surface, subsurface, fission products, special projects, miscellaneous, and non-soil. The miscellaneous subset contains spectra which appear to be from no particular location on an island or have no depth indicator. The non-soil subset includes the calibration spectra as well as non-soil samples. Within each subset, the spectra are stored in order by EIC laboratory number. There are two tape copies of each subset of spectra and a disk copy of the data base, although the gamma results are not stored on disk.

The compact IMP data base was extracted from the in situ data base. It contains stake locations, date of measurement, percent brush, a code for whether the data is pre- or postcleanup, the extracted ^{241}Am, ^{155}Eu, ^{137}Cs, and ^{60}Co data with estimated standard deviations, and a factor which includes all the corrections that were applied to the ^{241}Am data. For noncleanup islands, the pre-post code is replaced by an island code. This data base is on flexible disk and tape.

The Fission Product Data Base (FPDB) contains information extracted from part of the laboratory data base. It contains island and stake location, sample depth, collection date, EIC lab number and extracted gamma data for isotopes that are important in dose assessment. The results of those samples which were analyzed for ^{90}Sr, ^{241}Am, $^{239,240}Pu$, and/or ^{241}Pu, are also stored. The data are stored in the order in which the samples were analyzed, but tagsorted files exist which allow the data to be retrieved by location within an island. The FPDB exists on disk and tape.

CHAPTER SIX: SPECIAL TOPICS

6.1 INTRODUCTION

This chapter results from the situation that some topics, considered of enough importance or interest to be included somewhere, do not fit the specific subject matter or format of other chapters, and are individually too short to merit separate chapters. Topics are introduced or expanded upon in this chapter to provide background to aid understanding of the results presented in Chapter Seven. Startup operations in July 1977 were located on Island Janet, so this topic appears early. (One might dispense with Chapter Six altogether by moving text into other chapters, but then the discussion of IMP startup and preliminary surveys, on Island Janet, would not be encountered until nearly 100 pages into Chapter Seven.) The remainder of the chapter introduces topics in the approximate order the described actions occurred.

Efforts directed toward subsurface sampling and characterization were divided into two distinct phases, with a decision conference on 3-4 May 1978 as the dividing line. Prior to this date, subsurface sampling was undertaken on the ground zero islands, as a group, without clear priorities. After this date, the priorities of island cleanup provided guidance for a better directed effort. Also, since sampling requirements were dictated by island cleanup priorities, the remaining subsurface profiling was spread over the next year following the May conference and there was less need to keep track of and map data from several islands at the same time. The sample location maps shown in Section 6.9 were, therefore, never updated.

6.2 SURVEYS AND COORDINATE SYSTEMS (by Bert Friesen, H&N)

Testing of nuclear devices at Enewetak Atoll was a joint effort by military weapons specialists and civilian scientists. Preparations for a device test usually included experiments to evaluate military effects and to gather data critical to the understanding of nuclear explosion physics. Test structures and recording stations were placed with extreme precision by careful triangulation between fixed points on the atoll. The exact location of each structure or station was recorded for future reference. Surveyed benchmarks were placed on each island to facilitate remeasurement following a test and to reduce the time required to prepare for the next construction phase.

The early series of operations, like SANDSTONE and GREENHOUSE, utilized only local-control survey markers based on work performed in 1944, 1947-48, and 1949-50, which had established the locations of 16 stations covering the eastern portion of the atoll. The survey was expanded in 1951 to meet additional program requirements; however, an independent plane coordinate grid was still established at each of the zero areas for location of scientific stations. The need for an overall atoll grid was recognized at this time, and this recognition led to further expansion in 1952 to include the entire atoll. A plane coordinate system was established with the origin located at a point in the ocean southwest of the atoll such that the coral head Oscar, located in the lagoon, would have coordinates 100,000N - 100,000E (in feet). This system was initially called the IVY grid, but later came to be known as the OSCAR grid. After 1952, all locations on the atoll were specified utilizing the Oscar system. The coordinates of all survey benchmarks placed on the various islands are positive values, in feet, north and east of the origin.

Attempts to recover benchmarks during cleanup were only partially successful; no markers were found on several islands, and several markers were found with names that did not match available reference lists. Island maps in Chapter 7 show the approximate relationships between recovered benchmarks and island grids. It should be possible, with surveyor assistance, to return approximately to any soil sample or gamma scan point identified on the maps in Chapter 7, except on the few islands where no benchmark was recovered.

Janet was the first island to be surveyed and staked during the cleanup, but was not representative of work to be done later. On Janet, brush was cleared prior to surveying so placement of grid stakes was relatively unencumbered. Also, a known benchmark was selected to be the intersection of the north-south and east-west baselines. On islands staked later, the surveyors worked with the bulldozer operators to clear access lanes suitable for placing stakes on a 25- or 50-meter grid. In general, a baseline was located as a matter of convenience without regard to any benchmarks; if a

benchmark was located later a tie-in could be determined. It was not necessary to clear lanes in both directions of a square grid; a baseline could be cleared, then access lanes cleared, perpendicular to the baseline, and at appropriate intervals. In cases where the island shape was not amenable to construction of one suitable baseline, a more complex pattern of lane clearing was utilized. (For example, see Figure 6-6 of Island Belle.)

Lane clearing on islands scheduled for the in situ gamma scan was accomplished between September 1977 and March 1978. This period included action on many concurrent tasks by DOE and elements of the JTG; consequently, communication between DOE and JTG regarding layout of the island grids fell short of the intentions of the DOE/ERSP element. Military surveyors, left to their own devices, concocted 10 different grid numbering systems while surveying and staking 20 islands. An appraisal of the situation led to the conclusion that the confusion that would result from retroactively changing all island grids to a uniform numbering system would be greater than the confusion of making do with the numbering systems as developed. Stake locations are recorded on magnetic media along with all soil sample and in situ gamma data and are in the same format as these locations appear on the maps in Chapter 7.

6.3 TRANSURANICS IN THE ENEWETAK ATOLL ENVIRONMENT (by Richard Hoff, Lawrence Livermore National Laboratory, and John Stewart, DOE/NV)

The following information demonstrates which of the alpha emitting transuranic elements, from nuclear weapons debris, have been determined to be of significance and were included in the total soil transuranic (TRU) calculations during cleanup at Enewetak Atoll. In addition, this information will be used to help explain the wide range of TRU-to-americium ratios measured during the soil cleanup operations.

During the period 1948-1958, a total of 43 nuclear tests were conducted at Enewetak Atoll. The radioactive debris from nearly all of these nuclear explosions was sampled, usually by drawing air and particulate matter that were present in or very near the mushroom-shaped cloud, through a filter which was mounted on a jet-propelled aircraft. These so-called "prompt" samples, which were collected within a few hours after the explosion, were analyzed for their radioactive content. Some of the samples were analyzed as soon as possible in laboratories located at Enewetak; other samples were returned to the laboratories at Livermore, California, and Los Alamos, New Mexico, where more extensive analyses were performed. Fission products were identified by their beta- and gamma-decay characteristics. Alpha-emitting nuclides were measured directly; mass spectrometric techniques were utilized to determine the isotopic content of chemically-purified uranium (U) and plutonium (Pu) fractions in the samples.

Interpretation of these data included the use of the bomb-fraction tracer concept. When one knows the exact amount of fissile fuel (e.g., ^{235}U and/or ^{239}Pu) incorporated into a given nuclear device, postshot samples can be related to the entire device through measurement of residual amounts of the fissile fuel nuclides, making appropriate corrections for destruction as deduced from the fission products observed in the sample. Thus, small samples, taken randomly from various parts of an often huge mushroom cloud, could be used to calculate the entire inventory of observed radioactive species for a single event at various times following the explosion. The results of these analyses have been documented in classified reports.

Given these experimental observations, one can predict which long-lived radioactive species will be found in debris samples collected at Enewetak during a period 15-30 years after the cessation of nuclear testing activities at that atoll. On the other hand, prior to the survey of the Enewetak Atoll for radioactivity performed in 1972-73, knowledge of the definition of radioactive fallout within the atoll's land areas and lagoon sediments, and of concentrations of radionuclides in the vegetation, marine life, and sea water of the atoll, was limited. Given the high energy yields of many of these devices, much of the debris was driven high into the atmosphere (and stratosphere) by the violent force of the explosion. No calculational models were expected to be accurate for prediction of close-in fallout within the atoll region.

If one considers alpha-emitting species, it is known that plutonium and uranium are present in these devices in macro amounts (kilograms) as fissile fuels. The former is present as so-called "weapons-grade" plutonium which contains a high percentage of ^{239}Pu plus a nominal 5-6 atom percent of ^{240}Pu and only minor amounts of the other plutonium isotopes. One might assume that typical weapons-grade plutonium has a set of isotopic abundances as listed in Table 6-1. (Oetting, 1965)

TABLE 6-1. ASSUMED ISOTOPIC ABUNDANCES FOR WEAPONS-GRADE PLUTONIUM.

Isotope	Atom %	Half-Life (Years)	Alpha Activity %
238	0.012	87.8	2.8
239	93.35	24,100	78.3
240	6.06	6,540	18.9
241	0.55	6.10×10^5 (α)	0.018
		14.4 (β)	
242	0.02	3.87×10^5	0.001

The specific activity of this Pu is $1.62 \times 10^5 \alpha$ disintegrations per minute (dpm) per microgram (μg). Most weapons-grade plutonium will contain some americium-241 (^{241}Am), since the beta decay of ^{241}Pu produces this nuclide; beta emission is the predominant mode of decay for ^{241}Pu. Even if a specific chemical separation of americium is made to purify the plutonium, its ^{241}Am content will again increase with time following the chemical separation. Thus, although weapons-grade plutonium may contain ^{241}Am in concentrations of a few tens or hundreds of parts per million (ppm) at the time of detonation, the great majority of the ^{241}Am observed after 20-30 years has its origin in ^{241}Pu beta decay. If one assumes a 20-year decay for the above isotopic distribution, the resultant ^{241}Am is $0.249 \times 10^5 \alpha$ dpm from 1 μg of the original weapons grade Pu.

Uranium is often present in the nuclear device as enriched ^{235}U in order to serve as a fissile fuel. There may be significant amounts of uranium present with other isotopic compositions also, e.g. components containing uranium with large percentages of the isotope ^{238}U. Given information on the composition of the uranium and/or plutonium in each device prior to explosion and given knowledge of how the isotopes of these elements are transmuted by neutron-induced reactions during the explosion, one can predict which alpha-emitting nuclides will be most abundant in debris samples collected during the Atoll surveys.

The plutonium fraction represents the most important alpha-emitting species in any survey sample taken from Enewetak Atoll that has not undergone some sort of specific chemical treatment. In these samples, the most abundant plutonium alpha emitter is ^{239}Pu. Another important alpha-emitting isotope is ^{240}Pu. The radioactivity of this nuclide is often linked with that of ^{239}Pu since their alpha particle energies are almost identical and cannot be resolved from one another in ordinary alpha pulse height analysis employing solid-state detectors or Frisch-grid ionization chambers. Two more nuclides, ^{238}Pu and ^{241}Am, are present in significant amounts. These four most important alpha emitters are listed in Table 6-2 along with their half-lives and specific activities.

TABLE 6-2. MOST IMPORTANT ALPHA EMITTERS IN DEBRIS AT ENEWETAK ATOLL

Nuclide (In Order of Decreasing Abundance)	$t_{1/2}$ Half-Life (Yrs)	Alpha Specific Activity of Pure Isotope (αdpm/ μg)
^{239}Pu	24,100	1.38×10^5
^{240}Pu	6,540	5.06×10^5
^{241}Am	433	7.60×10^6
^{238}Pu	87.8	3.80×10^7

It is clear that ^{239}Pu and ^{240}Pu must be present in larger absolute amounts than the shorter-lived ^{241}Am and ^{238}Pu since, in spite of their lower specific activities, the former are the predominant alpha-emitting species.

The half-lives of these species are all long compared with the 20-30 years that have elapsed since tests were conducted at Enewetak and yet are short compared with those of ^{235}U ($t_{1/2}$= 7.1 x 10^8 yrs), ^{238}U ($t_{1/2}$ = 4.5 x 10^9 yrs), and other uranium isotopes. Thus, uranium is judged not to present a significant hazard by virtue of its alpha radioactivity at Enewetak; accurate analytical analyses for uranium in survey samples have confirmed this prediction (Hoff, 1973).

What other alpha-active nuclides might be present in the Enewetak samples and how important will their contribution to total transuranic alpha radioactivity be?

Among the Pu isotopes, ^{241}Pu will be a minor constituent; see Oetting where it is reported at an abundance of 0.55 atom percent. Other than its importance as the beta decay parent of ^{241}Am, this isotope does not contribute significantly to the potential biological dose rate of Pu because its alpha-to-beta branching ratio is quite low (α/β = 2.4 x 10^{-5}) and because it has a low beta energy (maximum energy of 0.021 million electron volts (MeV)). Another minor constituent of reactor-produced plutonium is ^{242}Pu. Since it is longer-lived than either ^{239}Pu or ^{240}Pu and is present as a minor component, it does not contribute significantly to the total activity of plutonium in Enewetak samples. In the plutonium discussed by Oetting, ^{242}Pu occurs at about 0.02 atom percent which corresponds to 1.1 x 10^{-3}% of total alpha activity. The same comments apply to the question of ^{244}Pu ($t_{1/2}$ = 8.27 x 10^7 yrs) alpha activity in Enewetak samples. This nuclide has a longer half-life and is even more rare than ^{242}Pu.

During the production of plutonium in a nuclear reactor, ^{244}Pu is isolated from the regular neutron capture sequence in Pu because of the rapid beta decay of five-hour ^{243}Pu. The only other long-lived Pu isotope that has not been discussed is ^{236}Pu ($t_{1/2}$ = 2.15 yrs). Based upon the analysis of prompt samples, this isotope is not present in sufficient quantities to contribute significantly to total Pu alpha activity.

Among the isotopes of neptunium (Np), only ^{237}Np ($t_{1/2}$ = 2.1 x 10^6 yrs) and the ^{236}Np ($t_{1/2}$ = 1.2 x 10^5 yrs) isomer are long-lived enough to be of interest. Neither isotope is present in quantities large enough to contribute importantly to overall alpha activity either before or after the nuclear explosion. Other Np isotopes are not important, although at early times one may observe very large quantities of ^{239}Np, a product of neutron capture reactions on ^{238}U, in debris samples. Its significance is that it decays by beta emission with a 2.35 d half-life to ^{239}Pu. In the debris from nuclear explosives where larger amounts of ^{238}U have been exposed to neutrons, the ^{239}Pu resulting from neutron capture reactions and subsequent decays of ^{239}U and ^{239}Np can outweigh any contribution from ^{239}Pu originally present in the device (Noshkin, 1974).

In addition to ^{241}Am, one might consider two other isotopes of americium, ^{243}Am and ^{242m}Am, as potential sources of alpha activity. The ^{243}Am half-life is 7,380 years, which is 17 times greater than for ^{241}Am. It is not an important component of americium activity in debris samples. There is no appreciable production of ^{243}Am during the explosion; the only production mechanism is via neutron capture (n,) reactions on ^{242}Pu which is a minor constituent of plutonium.

In order to calculate what ^{243}Am alpha activity one might expect, it could be assumed that, in the Pu described in Table 6-1, sufficient reactions occur to result in neutron capture by 10% of the ^{242}Pu and that the ^{241}Pu abundance does not change; i.e., as much ^{241}Pu is produced by capture as is destroyed by fission. From these conditions the composition of an americium fraction after 20 years decay can be calculated. From an initial microgram of weapons-grade Pu, decay will produce 2.53×10^4 dpm ^{241}Am and neutron capture on ^{242}Am and ^{242}Pu will produce 9.24 dpm ^{243}Am, which is about 0.04% of the total americium alpha activity. The great majority of the americium at Enewetak will contain ^{243}Am at an abundance close to 0.04%, and a conservative upper limit for ^{243}Am alpha activity is 1%. Similarly, the contribution of alpha activity from ^{242m}Am ($t_{1/2}$ = 152 years) is not important. There is no reasonable mechanism for significant production during the explosion. Also, its large neutron fission cross section leads to rapid destruction during the explosion. None of the other americium isotopes is long-lived enough to be considered.

After americium, the next heaviest element (Z = 96) is curium (Cm). One can detect ^{242}Cm alpha activity in "prompt" debris samples. Its origin is from neutron capture reactions on ^{241}Am present in the plutonium fissile fuel at the time of explosion. Since the half-life of ^{242}Cm ($t_{1/2}$ = 163 days) is short relative to the time that has elapsed since the cessation of testing, there is no significant amount of ^{242}Cm present in Enewetak debris samples now. A period of 22 years represents almost 50 half-lives; the amount of ^{242}Cm remaining after 50 half-lives is 1×10^{-15} of the original amount. Heavier Cm isotopes, some of which have longer half-lives, are not detected in significant amounts and do not add significantly to the sum of Pu and ^{241}Am alpha activities. Whatever amounts of ^{242}Cm were originally present have decayed to the ^{238}Pu daughter. Complete decay of the ^{242}Cm produces only a minor change in the amount of ^{238}Pu in the debris.

Some aspects of the preceding analysis were based upon the idea that the fissile fuel in a low efficiency nuclear explosive does not undergo large changes in isotopic content as a result of the explosion. Thus, one can discuss the isotopic content of Pu found in the debris in terms of the isotopic content of typical "weapons-grade" plutonium. On the other hand, in higher-efficiency devices, fission, neutron capture, and (n, 2n) reactions can cause appreciable changes in the isotopic composition of the plutonium. Perhaps the most striking change can arise when ^{238}U undergoes neutron capture. At high enough neutron fluxes, successive capture reactions occur and one finds contributions to the Pu isotopic inventory from beta chains that originate with ^{239}U, ^{240}U, ^{241}U, ^{242}U, and so on up to rather heavy species, e.g., to atomic mass number 257. (Ghiorso, 1955; Hoff, 1978) At Enewetak the most extreme example of this effect was observed in the debris from the Mike explosion, a high-yield test (10 megatons) conducted in November 1952. (Diamond, 1960) Since scientists studying prompt samples from the Mike test were able to detect products up to mass 255 whose presence was ascribed to multiple neutron capture reactions occurring in ^{238}U that had experienced very high neutron exposure, the plutonium isotopic content of this debris was examined to see if the results were substantially different from the previous conclusions. The isotopic abundances observed in Mike-debris plutonium are listed in Table 6-3.

The specific activity of this plutonium is $2.25 \times 10^5 \alpha$ dpm per microgram. After 20 years decay, 1 μg of this plutonium will produce 1.26×10^5 dpm ^{241}Am from the beta decay of ^{241}Pu. Thus, even for the Mike-debris plutonium, which is relatively rich in the higher mass isotopes, the contributions of ^{242}Pu and ^{244}Pu to the total Pu plus ^{241}Am alpha activity are extremely low.

TABLE 6-3. ISOTOPIC ABUNDANCE FOR MIKE EXPLOSION PLUTONIUM

Isotope	Isotopic Abundance (Atom %)	Half-Life (Yrs)	Fractional Alpha Activity (%)
238	low	87.8	low
239	70.3	24,100	42.5
240	25.5	6,540	57.3
241	2.74	6.10×10^5 (α)	6.6×10^{-2}
		14.4 (β)	
242	1.34	3.87×10^5	5.1×10^{-2}
244	0.083	8.27×10^7	1.4×10^{-5}

It becomes clear from the foregoing discussion that one can expect some variability in the ^{241}Pu isotopic abundance in various samples taken at Enewetak Atoll. Thus, the amount of ^{241}Am alpha activity that has grown into these samples, relative to the plutonium content of the samples, will show a corresponding variability. During the nominal 20-30 year decay time for these samples, there has been opportunity for appreciable chemical fractionation between plutonium and americium, depending upon individual sample history. For coralline soil samples that were exposed mainly to rainwater, the evidence seems to show that the migration rates downward through the soil for plutonium and americium are slow and not very different from each other. (Lynch, 1973) In Table 6-4 are listed activity ratios, total TRU for various types of plutonium as a function of time. The two examples of plutonium with known abundances, "weapons grade" and Mike explosion material, are compared with the median values for the total TRUα/^{241}Amα ratio from each island of the atoll; the lowest and highest values are listed in Table 6-4. A useful, although coincidental, correlation develops that the extremes in the range of median values for Enewetak samples are approximately equal to values for the known Pu examples.

TABLE 6-4. ACTIVITY RATIOS FOR TOTAL TRU ALPHA ACTIVITY TO ^{241}Am ALPHA ACTIVITY.

	Atom Ratio ^{241}Pu / $^{239,240}Pu$	Activity Ratio (Total TRUα/ ^{241}Amα)				
		20 yr	50 yr	75 yr	100 yr	1000 yr
"Weapons-grade" Pu (Table 6-1)	0.0055	7.7	5.5	5.3	5.5	17.7
Mike Explosion Pu (Table 6-3)	0.0286	2.8	2.2	2.2	2.2	5.8
Enewetak 1972-73 survey soil samples (range of median values for each island).	lowest	3.0	2.4	2.3	2.4	6.3
	highest	10.	7.3	6.9	7.3	26.0

Given the half-lives of the 14.4-year beta emitting ^{241}Pu and its 433-year daughter, ^{241}Am, and assuming only small amounts of americium present at time zero (time of nuclear explosion), one can calculate that any sample of plutonium (containing some ^{241}Pu) will contain a maximum absolute amount of ^{241}Am activity at 75 years after time zero, assuming no chemical fractionation between parent and daughter. One can also derive the fact that the maximum ^{241}Am content at 75 years is 50% greater than that observed at 20 years after time zero, i.e., at the approximate time of the 1972-73 survey. This information is reflected in the values given in Table 6-4. Thus, for any given activity ratio, total TRU /^{241}Am observed in survey samples, the projected minimum in this ratio will be 69% of the observed value. Minimum values of the ratio for median values will be in the range, 2.3-6.9. Thereafter, this ratio will increase until the ^{241}Pu parent has been depleted sufficiently that ^{241}Pu beta decay produces ^{241}Am more slowly than ^{241}Am is lost due to alpha decay.

In the preceding discussion, it has been shown that the predominant radioactivity and, presumably, predominant source of biological dose from the transuranic elements present in the Enewetak environment at this time can be ascribed to four alpha-emitting species: ^{239}Pu, ^{240}Pu, ^{241}Am, and ^{238}Pu. This concept was predicted prior to the extensive survey of the Enewetak environment in 1972-73 and is borne out by the experimental data collected during analysis of the Enewetak survey samples. It has also been shown that the observed ^{241}Am is the product of ^{241}Pu beta decay and in many circumstances the ^{241}Am will occur with the Pu isotopes in predictable amounts. The absolute amount of ^{241}Am radioactivity will reach a maximum in about the year 2028, i.e., 75 years after the time of nuclear detonation. For samples exhibiting the median value of the activity ratio, total TRU /^{241}Am , on a given island, the maximum ^{241}Am activity will range from 17% to 77% of the total Pu alpha activity. Uranium, although deposited on the Enewetak Atoll in comparable or even somewhat greater amounts than plutonium, is not an important source of radioactive contamination because of the much longer half-lives of the principally-occurring 235 and 238 isotopes. Other transuranic species, e.g., isotopes of Np, Am, or Cm, have been shown to be much less abundant (in terms of alpha radioactivity) than the major four nuclides listed in Table 6-2 and, thus, of negligible interest with respect to potential biological dose.

Based upon the above information it was determined that during the Enewetak Atoll cleanup only the transuranic (TRU) nuclides ^{239}Pu, ^{240}Pu, ^{241}Am and ^{238}Pu would be measured and reported in the TRU data base.

Experience during cleanup has shown soil ratios of TRU/^{241}Am to vary with about the same ranges as calculated from the original weapons systems data and measured during the 1972-73 survey. In general the pattern has been that islands with surface ground zeros (SGZ) of lower yield devices show a range of ratios for TRU to ^{241}Am from about 5 to 10 near the GZ, which should reflect mostly fallout from that test. At further distances from SGZ and on islands without SGZ the ratios ranged from about 2.5 to 4.0, reflecting a mixture of fallout from many tests, and suggesting the majority of transuranic fallout comes from the high yield tests, such as Mike.

The Island Pearl is a good example of the above. The measured ratios of TRU/^{241}Am in soil were 9.1 $\pm$ 1.1 within 150 meters (m) of the INCA GZ, 7.80 + 2.2 for samples taken between 150 and 350 m from SGZ, and 4.1 $\pm$ 1.28 for samples taken beyond 350 m from SGZ.

Although a detailed review of the data has not been presented here, the range in ratios of TRU/^{241}Am that were measured on the various islands is consistent with the expectations from the source terms.

6.4 ISLAND JANET (by Madaline Barnes, DRI)

6.4.1 IMP Start Up and Preliminary Surveys

As the largest of the northern islands of Enewetak Atoll, Janet (Marshallese: Enjebi) has great cultural and political importance for the driEnjebi (Enjebi people). Because of this importance, Janet is also the site of studies of radionuclides in groundwater and plants (see Section 6.11), as well as various other experiments and sampling efforts. Janet was therefore the natural choice for developing and evaluating procedures for the IMP system, as well as initial IMP measurements.

The first set of preliminary IMP data, 21-23 July 1977, consisted of measurements at the nodes of a 5 x 8 grid of sampling points at about 23 m (75 foot) spacing at the Lawrence Livermore Laboratory experimental garden on Janet. These data were used to help get the IMP data base started and checked out as well as to shake down the in situ system.

A second preliminary survey was done 29 July to 7 August 1977, at the nodes of an 11 x 12 grid with 25 m spacing at the north central edge of Janet. (Because the area was later remeasured on the regular 50 m Janet grid, neither the absolute coordinates nor the exact compass orientation of this grid was ever determined.) The 11 x 12 grid, known as the Test Grid, provided enough data to complete checkout of the in situ system and the data base programs.

6.4.2 Preliminary Statistical Analyses

There was sufficient ^{241}Am data from the Test Grid to begin the statistical analysis of Janet data by fitting an initial variogram model. (The variogram and its use in estimation are explained in section 5.2.1.) A plot of the raw variogram led to the conclusion that the ^{241}Am activity distribution pattern was anisotropic, that is, not the same in all directions. The difference could have been caused by the effect on fallout plumes of the strong prevailing northeast trade winds. The ^{241}Am activity changed most rapidly from northwest to southeast, perpendicular to the prevailing wind, and slowest along the path of the wind. The pattern was exactly what would be expected for fallout from a wind-elongated plume. The effect was especially noticeable in these data because the Test Grid is almost due southwest, that is, directly downwind, of Item ground zero, and directly upwind of the Easy/X-Ray sites.

It was very desirable for practical reasons to use 50 m instead of 25 m spacing for the cleanup sampling grids. In order to check whether 50 m spacing would yield adequate data, the Test Grid was split into four disjoint 50 m subgrids, and raw variograms computed for data from each subgrid. The variogram model estimated from the complete data set fit each subgrid raw variogram fairly well. The models estimated on the subgrid raw variograms were also very similar to the original model, except that one subgrid yielded a model which underestimated the nugget effect (see Section 5.2.1). On the basis of the good agreement between the original model and the subgrid data variogram models, the IMP measurements of Janet after the Test Grid data analysis were on a 50 m grid. A more detailed discussion of these and the following statistical analyses was published previously (Barnes, 1978).

An area on the west tip of Janet had already been staked at 25 m spacing on the standard Janet grid (origin at benchmark PORKY) before the Test Grid data analysis was complete (see Figure 7-65). The IMP had taken data at most of the points in this area by the time the change to a 50 m spacing was made. Data were therefore also taken at the remainder of the 25 m grid points already staked, but the rest of Janet was staked and measured initially on a 50 m grid.

When the initial IMP characterization measurements were complete, new variogram models were fit to the data, treating the 25 m data from the western area separately from the rest of Janet. The separation was based on the significant differences in TRU activity distribution between the western area and the rest of the island. Although the reason for the differences is not known, at least part of the reason is apparently soil recontouring activities during the testing years. For example, the TRU activity is much lower in the west, despite the presence of two ground zero sites, Easy and X-Ray, in that area. Also, the ratio of TRU to ^{241}Am (see Section 7.5.2) is different in the west than anywhere else on Janet. Later subsurface sampling revealed the presence of asphalt below the surface (see discussion on asphalt sampling below). This may have been deposited by post-event cleanup activities during the testing years. Whatever the cause of the activity differences, the result was substantially different variogram model parameters for the west data than for Test Grid data. However, both models have the same mathematical form.

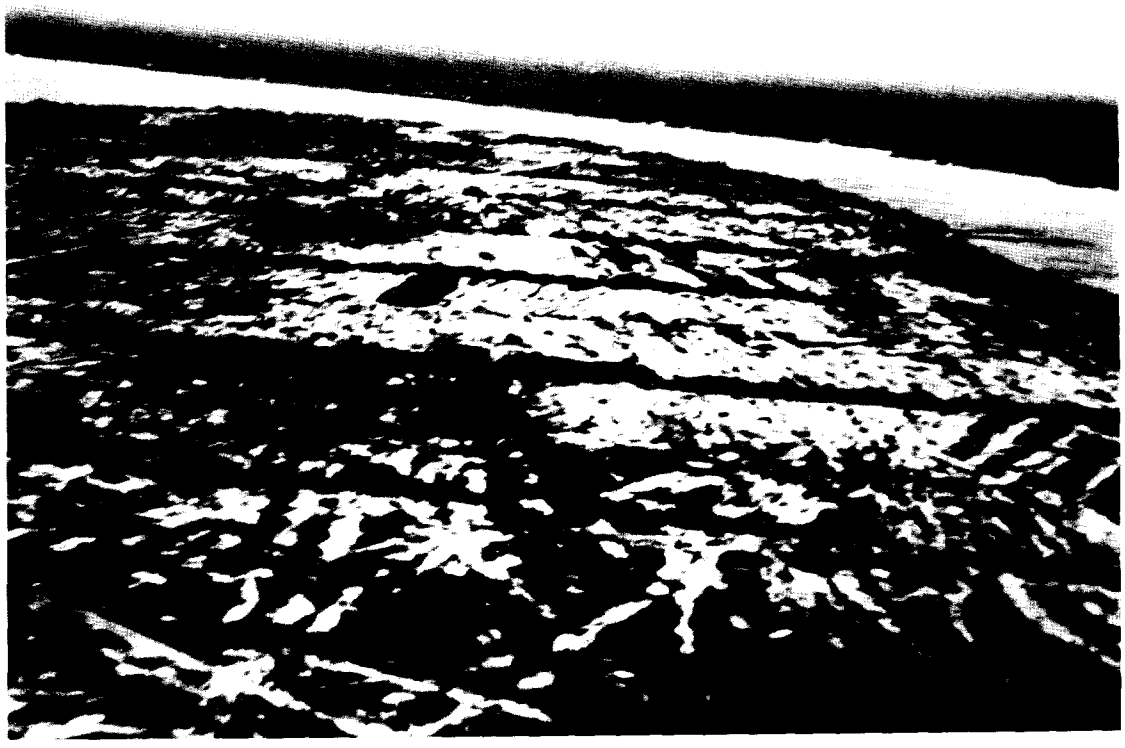


FIGURE 6-1. BRUSH WINDROWS ON ISLAND JANET. This aerial view, looking almost due north, shows the extent and direction of windrowing efforts. Brush cover on this portion of the island was heavier and more complete than on the other half of this island, or any of the other ground zero islands. (Fall 1977)

Also different from both the Test Grid model and the west model was the variogram for the 50 m Janet data. The anisotropy was much less pronounced, and it appeared even the mathematical form of the model might have changed. These changes apparently resulted from the windrow method used to devegetate Janet (Figure 6-1 and Section 6.5.2). In the process of bulldozing the vegetation into east-west windrows, the surface soil was mixed, primarily in a north-south direction along the bulldozer tracks, thereby reducing the anisotropy that was caused by wind effect. Measured surface TRU activity also decreased, partly from mixing and partly because some of the surface soil was inadvertently scraped up and deposited in and under the windrow. The soil under the windrows was eventually removed as part of the surface cleanup (see Section 7.5.2).

Because it was not clear what model would best fit the raw variogram on the 50 m data, two different models were fitted, then tested to determine which was better. One model explicitly accounts for the effect of windrowing while the other ignores the windrows. The latter model was the same mathematical form as the Test Grid and west area models, but the former model has an entirely different form.

Models are tested by eliminating each ^{241}Am data value in turn, then using nearby data and the model being tested to estimate the missing value. The difference between the estimate and the measured value is called the "kriging error," and can be used to compare different models and check the statistical assumptions. For example, one assumption is that the kriging errors are normally distributed, and this was shown to be a valid assumption for both models. Because the model which ignored windrow effects gave fewer kriging errors on the ^{241}Am activity in excess of 6 pCi/g, it was chosen for making the initial characterization estimates. The model for the 25 m data in the west area was also tested to confirm that it would yield acceptable estimates.

In two areas of Janet, both of the 50 m model tests produced more large kriging errors than anywhere else on the island. One was a 450 x 250-m rectangle near the center of Janet, and the other a triangle on the northern edge of the island just west of the north baseline, near the old Test Grid. The fact that estimates using both models gave poor results in these areas indicated the activity itself was more variable, so that more measurements would be useful. Therefore both areas were staked on a 25 m grid and measured with the IMP at the finer spacing from 6-21 January 1978. The original characterization had resulted in an estimate of 21.25 ha with TRU activity in excess of 40 pCi/g with the additional 25 m data, this estimate dropped to 20.75 ha.

6.4.3 Grid Location Problems

Because benchmark PORKY had not yet been uncovered in the dense vegetation when the surveyors began staking the 25 m grid in the west area, benchmark LEE was used as a reference instead. Unfortunately, an error was made in the process of setting out the grid from LEE, which was discovered when the vegetation was cleared from PORKY. The error resulted in the 25 m grid being shifted 7.32 m (24 feet) west and 4.88 m (16 feet) north of the intended location. In order to minimize further confusion, the area was not restaked at the time, but the 50 m grid with origin at PORKY was extended far enough west to assure complete coverage of the island.

The situation remained unchanged until the subsurface excision in December 1978. The excision site was in the area with the shifted grid, and had been sampled at locations referenced to the shifted grid. Therefore, the boundaries for the excision were transmitted to the Joint Task Group (JTG) in terms of the shifted grid. However, JTG was not informed of that fact until later and the first two lifts were made with the location based on PORKY coordinates. The misunderstanding was eventually cleared up, the excision completed as intended, and all locations thereafter were referenced to PORKY, even in the west area. For the Fission Product Data Base sampling, the 50 m grid was extended to cover all of Janet, so that all FPDB samples were taken at 50 m nodes of the PORKY grid.

6.4.4 Other Activities

In April 1978, seven additional locations were chosen for soil sampling as part of an investigation of the variability of TRU in the soil and of an apparent discrepancy between soil and IMP data (see Tech Notes 22 and 23). To try to estimate the variance of soil TRU activity within an IMP view, four composites instead of the usual two (see section 4.2.1) were taken at each location. The samples also provided a check on the ratio of TRU to ^{241}Am computed from the original soil samples.

The chemical analysis results for these samples confirmed that the soil TRU activity within a single IMP detector field of view is highly variable. Also, the variance of the sample TRU activities increased in proportion to the average TRU activity in the field of view. However, the ratio of TRU to ^{241}Am from these samples was not significantly different from the previously-estimated ratio, and the ratio variance was independent of TRU activity. The ratio of TRU to ^{241}Am for Janet was therefore not changed, and eventually soil sampling reverted to the usual two-composite method.

During the subsurface investigation of the Easy and X-Ray ground zero sites in August and September 1978, several samples of asphalt were taken. The asphalt was found 20 to 80cm below the surface, in layers 2 to 10cm thick. Soil samples from above and below the asphalt layer were also taken, and both the soil and asphalt analyzed for gamma activity. The shallower soil samples and the top of the asphalt were both relatively "cleaner" than the deeper soil and the bottom of the asphalt. Although the source of the asphalt was not known at the time, it was assumed to be part of the material said to have been buried in the X-Ray crater after that event. The information about activity on the asphalt was used to help guide the remainder of the subsurface investigations of the Easy and X-Ray sites.

Samples of surface concrete were taken in mid-September 1978, from Greenhouse Station 3.1.1, a multistory structure near the center of Janet. The samples were analyzed for gamma activity to provide JTG with information necessary to plan for proper disposal of the debris when the structure was demolished. No significant quantities of ^{241}Am, ^{137}Cs or ^{60}Co were found on any of the samples.

After the Janet cleanup was complete, scientists from Lawrence Livermore Laboratory began a study in April 1979 of ^{137}Cs movement in soil at a site near PORKY. A 100 x 100-m area was denuded of vegetation, and the IMP took measurements at 10 m spacing to establish the baseline activity. The plan was to keep the area free of vegetation to determine if the rate of ^{137}Cs movement out of the root zone was significantly altered in the cleared area. The study is still in progress as of June 1980.

6.5 VEGETATION (by Bert Friesen, H&N)

6.5.1 Vegetation in the Atoll Environment

Vegetation on the islands of Enewetak Atoll is typically a mixture of trees, shrubs, suffrutescent perennials, strand plants, clumpy grasses and sedges. Vegetation cover ranges from impenetrably dense brush to open meadow-like areas of grasses and sedges. The two most common species of brush are the small tree, Tournefortia argentea L. f. and the large shrub, Scaevola taccada (Gaertn.) Roxb. Both are evergreen and grow to an average height of 12 to 15 feet. Tournefortia grows from a single trunk and spreads readily by the dispersal of seeds. Scaevola lacks a trunk and arises from a number of decumbent or ascending main branches. The species grows readily from seed and also reproduces vegetatively by rooting at the nodes of the lower branches where they come in contact with the ground. New leaves are initiated on both plants only at the ends of the branchlets and the mature foliage on the lower portions of the branches is not replaced when it dies. The result is a thin canopy of leaves covering a tangle of bare branches with a thick layer of decomposing leaves beneath. No other vegetation appears to grow under well-established thickets of Tournefortia or Scaevola. (Tournefortia is a recently-assigned name to replace Messerschmidia, but this is not common knowledge, so the more commonly known name is used elsewhere in this report.)

Occasional stands of Pisonia grandis R. Br., Pluchea indica (L.) Less, Pluchea symphytiftolia (Mill.) Gillis, Morinda citrifolia L. var. citrifolia and Guettarda speciosa L. appear in minor quantity. Very few Pandanus sp. and Cocos nucifera L. were observed prior to cleanup, with the exception of the groves of coconut on Nancy and Vera. By April 1980, the coconut grove on Vera and the Pisonia groves on Olive and Tilda had been cleared away and new coconut trees planted as part of the rehabilitation following cleanup.

The predominant vines observed on Enewetak are two species of Ipomoea (Morning glorys) including I. macrantha R. & S. and I. pes-caprae (L.) Sweet ssp. brasiliensis (L.) v. Ooststr. Also occurring are the viny, suffrutescent perrenial, Triumfetta procumbens Forst, f., and several species of trailing, perennial herbs including Boerhavia tetrandra Forst., B. albiflora Fosberg var. powelliae Fosberg and B. repens L. The morning glory (I. pes-caprae ssp. brasiliensis) is typically the first ground cover to recolonize disturbed areas, followed by Fimbristylis atollensis St. John and a mixture of native and exotic grasses. In describing the ecological succession that occurred on Enewetak after the nuclear testing program, the role of the morning glory was stated (Woodbury, 1962) as follows:

"Once established, this morning glory may extend its long runners over fresh sand surfaces and act as a sand binder that will hold the sand in place while other vegetation becomes established. In this way, it acts as a pioneer.... With the advent of vegetative cover, some of the fish-eating birds ... begin to use the vegetation for nesting purposes.... Wherever they nest, the consequent guano brings much needed minerals from the sea ... (which are) incorporated into the plants, thence into the plant litter and again into the soil to pave the way (for plants) that could not survive well as pioneers. When the cover is adequate to provide a more hospitable environment (reduced salinity, shaded soil, lower temperature, and better nutrients), certain secondary plants enter the vegetation, particularly the prostrate vines Triumfetta procumbens and Boerhavia tetrandra and the dodder-like parasite Cassytha filiformis L. (Dodder-laurel). Other species characteristic of later stages of the vegetation may be added as conditions become more favorable and their needs become available."

For some obscure reason, certain portions of some of the islands in the atoll do not develop mature stands of trees or brush, but are covered by open meadow-like areas of grasses, sedges and viny herbs. In a tabulation of the flora of Enewetak Atoll, it is reported (St. John, 1960) that 15 taxa of grasses, of which 13 are introduced weeds, and 3 species of sedges, including 2 exotics, are present on the atoll. The commonest native grass is Lepturus repens (Forst. f.) R. Br. var. repens, while the other two native grasses, L. repens (Forst, f.) R. Br. var. occidentalis Fosberg and Thuarea involuta (Forst. f.) R. & S., are both fairly rare. Fimbristylis atollensis, the only native sedge, is also quite common. Introduced grasses which are quite abundant include Cenchrus echinatus L. (Sandbur), Cynodon Dactylon (L.) Pers. (deliberately introduced Bermuda or Couch grass for lawns and as sand binder), Digitaria setigera R. & S. var. setigera (Crab grass), Eragrostis tenella (L.) Beauv. ex Roemer & Schultes (Love grass), Setaria verticillata (L.) Beauv. (Bristly foxtail) and Tricachne insularis (L.) Nees (Sour grass).

Vegetation of some kind appears on all soil surfaces with suitable growing conditions. Habitats unsuitable for vegetation include areas with a predominance of gravel or rock without enough sand or soil to retain moisture necessary for plant growth, and beach areas routinely subjected to tidal or wave inundation. Tournefortia and Scaevola seem to be more tolerant than other trees and shrubs to the constant load of wind-borne salt along the windward side of the islands. The reason for the existence on some islands of large meadow-like areas surrounded by stands of trees and shrubs, with no young bushes in evidence, while other islands are totally covered with dense brush, is not self-evident. As will be reported in Chapter 7, areas with dense vegetation typically had higher concentrations of radionuclides than did less densely covered areas on the same island. Special attention was, therefore, given to heavily vegetated areas during soil sampling and in situ gamma scans. The mechanism whereby a significant portion of the radionuclide inventory is bound up in the biological cycle has undergone some investigation, but details will not be reported here.

The scientific names for the plants cited in this section were obtained from the following sources: Dicotyledonae (Fosberg & Sachet, 1979); Monocotyledonae, excluding the genera Digitaria and Eragrostis (St. John, 1960); Digitaria (Veldkamp, 1973); Eragrostis (Smith, 1979). The nomenclature followed is that of the authors cited above.

6.5.2 Devegetation of Island Janet

Island Janet was selected as the location of IMP startup operations in July 1977 as stated in Section 6.4.1. At this time, there were several areas on the western and northern points of the island where vegetation was relatively sparse so the IMP could maneuver from point-to-point without prior devegation of the area. However, the central and eastern portions of the island were covered with dense thickets of Messerschmidia and Scaevola. Following some experimentation, the method selected for devegetation of an area measuring about 1000 x 1000 feet consisted of dragging a 200-foot anchor chain across the brush.

Two large bulldozers, each with an end of the chain attached (Figure 6-2), drove in parallel across the terrain, keeping the chain just slightly slack. This system worked well in areas with only moderate vegetation. In especially dense growth, the chain would only partially knock the brush down, so a second pass was required in the opposite direction to the first pass. The brush was, at this point, still a tangled mass which the IMP could not traverse.

FIGURE 6-2. SYSTEM USED TO DEVEGETATE ISLAND JANET. The two bulldozers pulled the 200-foot anchor chain, stretched between them, across the brush. Vegetation was knocked down but not removed. (July 1977)

The ERSP Manager on island noted (ERSP Log, 1977), following a meeting with JTG, general agreement that "present equipment and procedures were not optimum and additional investigation is required." Alternatives considered included obtaining commerical debrushing equipment, possibly on excess from one of the military services; burning; obtaining a Rome plow; weighting the chain.

Several experiments were conducted between 13 and 18 August to evaluate burning of brush. The results were inconclusive with respect to the effect burning would have on redistribution of ^{137}Cs and ^{241}Am. Freshly cut brush would not burn, even though doused with a diesel oil/gasoline mixture.

FIGURE 6-3. WINDROWING BRUSH ON ISLAND JANET. After brush was knocked down by the anchor chain, it was pushed into windrows. (July 1977)

The next action was to push the brush into windrows (Figures 6-3 and 6-4) about 150 meters apart. The bulldozer operators maintained the dozer blade about 6 inches above ground level, but a substantial volume of dirt was still pushed into the windrows. The windrows remained in place (Figure 6-5) until near the end of the next dry season (about April 1978) when they were eventually all burned with the aid of liberal doses of diesel oil. Once in piles, the brush was of little concern to the ERSP until cleanup operations on Janet were nearing completion, at which time the remaining soil and ash mix was gamma scanned and removed if found to contain TRU above the criteria applicable to this island.

FIGURE 6-4. WINDROWS OF BRUSH ON ISLAND JANET. View to the west from the top of Greenhouse Station 3.1.1, soon after windrowing was completed. (August 1977)

6.5.2 Lane Cutting

Early devegetation experiments on Janet clearly indicated that a more expeditious method would have to be found for preparing an island for the coarse-grid IMP survey. Total removal of brush consumed too many man and machine resources, was too slow, introduced too much soil disturbance, and was not necessary for measurement of ^{241}Am gamma emissions. The last areas on Janet to be prepared for IMP access were not heavily vegetated so the bulldozer operator was instructed to push aside only that brush which interfered with line-of-sight surveying and staking by the Army engineers. When work began on Pearl, the second island to be gamma scanned, clearing of access lanes, rather than total brush removal, became standard procedure; however, several months of fine tuning was required before a method of lane clearing was developed that was accepted by all concerned agencies (Figure 6-6).

FIGURE 6-5. WINDROWS OF BRUSH ON JANET BEFORE FINAL DISPOSITION. This view is almost due east. The LLL farm is shown in the foreground, Building 3.1.1. (later removed) is in the upper right background. Morning glory vines have begun to invade the cleared area between windrows. (Spring 1978)

Initially, the method employed to clear an access lane was to set the bulldozer blade at a depth to cut about three inches of soil. This depth was sufficient to uproot most of the brush. The problem was that a mound of soil would quickly build up in front of the blade, creating an operational problem for the driver. At first, the operators tried to push all of the accumulated soil and brush down to the end of the lane which was usually at the beach. This was not practical on long lanes, so the second improvement was to build up only a small pile in front of the blade, then push this material to the side of the lane. The turning action required to deposit the detritus at laneside, then reorient to the lane direction, was found to churn too much soil on islands with a very loose, sandy soil texture, but was acceptable on islands with a more dense soil.

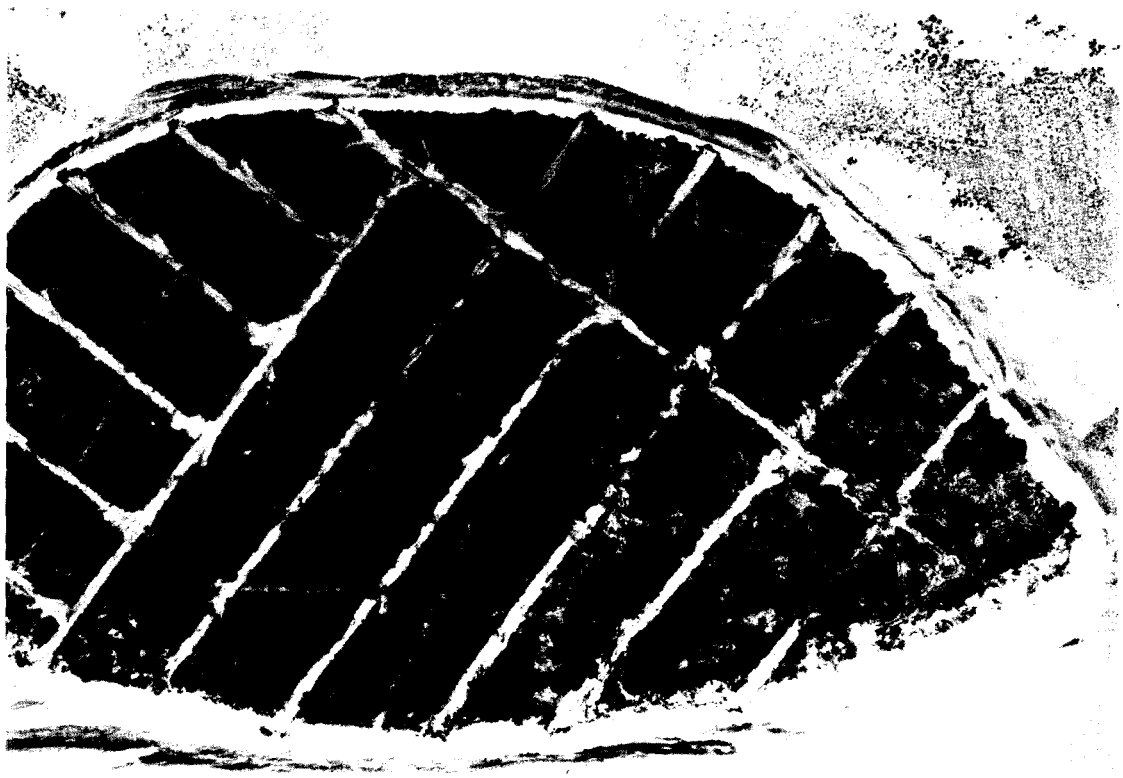


FIGURE 6-6. ACCESS LANES ON ISLAND BELLE. Lanes are 50 meters apart with grid stakes placed every 50 meters along the lane. (February 1978)

Experiments continued from island to island as new combinations of brush density and soil hardness were encountered. By the time lane clearing was completed on the major islands, the methodology had evolved to eliminate setting the blade down into the soil. The new method was to set the blade about four to six inches above the soil surface. This was found to be suitable for knocking down the larger trees and breaking off the smaller brush. Occasionally some trees would be uprooted and the stump and roots would have to be pushed aside but, in usual conditions, a lane could be cleared with minimal soil disturbance. The bulldozer operator had only to try not to leave material in the lane that could protrude up into the engine compartment of a passing IMP, or that would be too rough for the low-clearance IMP to negotiate.

6.6 PILOT SOIL REMOVAL PROJECT (by Bert Friesen, H&N)

During an inspection visit to Enewetak Atoll in January 1978, the Director, DNA, decided that a Pilot Soil Removal Project should be conducted to obtain parameters required to make reasonable estimates of the time and effort consumed in soil removal and transport, and to develop and test alternative excision and transport methods. Several islands were considered as candidate sites for the pilot project, with Sally being selected (the selection being in part influenced by proximity to the Ursula base camp). The Kickapoo GZ area was picked as the site of the first experiments. This area, located on the northern tip of Sally, encompassed less than one hectare requiring soil removal. Experience gained in the Kickapoo area formed the basis for all soil removal activities conducted during the cleanup, although some steps were later modified to increase efficiency.

(The actions described below were initiated in the Kickapoo area and continued into the Yuma and Hustead areas. The Pilot Soil Removal Project was officially concluded prior to the final efforts to complete soil removal from Sally. The exact sequence of events is not critical to this report. Work described was all done by military elements directed by the JTG, with DOE in an advisory role.)

Before soil removal could start, the vegetative cover had to be removed and several methods for accomplishing this were tested and evaluated. The most rapid technique was pushing vegetation into windrows with a bulldozer, as done on Janet, but this method mixed and spread the surface soil so that high levels of surface contamination could be spread over a larger area than initially existed. Also, the windrow would contain a substantial volume of contaminated soil which could not easily be separated from the vegetation. The second method utilized a front loader with what is called a four-in-one bucket.* This machine was initially tried and determined to be unsuccessful because it did not remove many roots and bush stumps. After realizing the drawbacks of windrowing by bulldozer, the bucket loader was reevaluated and several successful techniques were developed. Small bushes or brush could be effectively removed with minimal soil disturbance by lowering the bucket to six inches above ground and making a forward pass up to 50 feet long. For larger bushes, the bucket was clamped over the bush and the whole bush plucked from the soil and carried to the brush pile. The latter technique created the least disturbance of surface soil. A road grader with scarifier teeth was determined to be least satisfactory as a means of removing stumps and roots.

Several different combinations of machines were tested and evaluated for effectiveness at soil removal. It was quickly determined that the road grader was not effective. The bucket loader, with the bucket down and closed, could remove about 50 to 60 cubic yards of soil per hour, taking a six-inch "lift" or cut. The bulldozer, when operated in its lowest gear, made acceptable six-inch cuts when the length of push was no more than 50 feet. Each successive lateral pass had only 10 to 20 percent of the blade width in new soil. The rest of the blade was used to accumulate pushed up material. (Soil began to spill off the open end at about 50 feet.) The bulldozer could windrow about 180 to 200 cubic yards of soil per hour. The bucket loader would then be used to load the windrowed material into a dump truck.

The hauling capability of different-sized dump trucks and water craft was also evaluated. The smaller trucks were found acceptable for the sandy conditions while the largest trucks were prone to getting stuck, which was not only a nuisance but required diversion of other equipment to extricate them. Common parameters used to evaluate water craft for soil hauling are summarized in Table 6-5. This evaluation contributed substantially to the decision to configure additional LCM-8s and LCUs for bulk haul of soil. (Loading procedures were modified during the following year to obtain better results than shown in the table.) One side benefit of utilizing bulk haul was that trucks did not have to ride back and forth. This became of critical importance as more and more trucks were put out of commission by mechanical failure.

*Four separate hydraulic controls governed all possible motions of the bucket, including the ability to clamp items between longitudinal halves of the split bucket.

TABLE 6-5. COMPARISONS OF WATER CRAFT SOIL HAULING CAPABILITY

	LARC-60	LCM-8	LCM-8 BULK HAUL*	LCU	TUG with 2 Causeway Sections
Crew	8	3	3	8	6
Load, cubic yards	10	10	40	60	40
Load time, minutes	12	15	29	29	38
Travel time, loaded, minutes**	53	41	41	53	80
Offload/reload	17	17	70	41	47
Travel time, empty, minutes	48	41	36	50	63
Total time, minutes	130	114	176	173	228
Minutes per cubic yard	13	11.4	4.4	2.9	5.7

*Four previously-loaded trucks dumped into an LCM-8.
**Travel from Tilda to Yvonne.

6.7 PLOWING PHILOSOPHY AND EXPERIMENT (by Paul Dunaway, DOE)

Plowing or other methods of mixing soil bearing radioactive contamination with relatively uncontaminated soil have been used in the past at several places in the U.S. and elsewhere to reduce radioactivity concentrations per unit of weight or volume of soil (Wallace and Romney, 1975). Plowing is essentially a dilution technique. The Environmental Protection Agency (EPA) stated, "For soils with transuranium element concentrations no higher than about 10-100 times the guidance recommendations, remedial actions to bring such areas into compliance would generally involve only plowing or surface removal ..." (EPA, 1977). A screening level of 0.2 $\mu Ci/m^2$ of transuranic elements in the top cm of soil was specified by EPA. At concentrations lower than that level EPA was of the opinion that potential exposure to man from uptake (inhalation or ingestion) ordinarily would not exceed guidance recommendations (1 mrad/yr to pulmonary lung or 3 mrad/yr to bone). The Bair Committee also mentioned the possibility of plowing contaminated soil at Enewetak Atoll. The Committee did not make any recommendations as to the advisability of such an action but approved of the concept of conducting a plowing experiment (Bair, 4/1978) and later evaluating radionuclide uptake by plants in plowed versus unplowed soil (Bair, 10/1978).

In the early part of 1978, the Defense Nuclear Agency (DNA) began to formulate plans to conduct a plowing experiment at Enewetak so that they might employ the technique should it be recommended later. Accordingly, DOE assisted the DNA to perform the experiment but withheld any recommendations that the experiment be done. Dr. R. C. Jones, University of Hawaii, an expert on Pacific Ocean Atoll soils, and Dr. C. W. Francis, Oak Ridge National Laboratory, an expert on radionuclide movement in soils, were retained to advise on the experiment. ERSP personnel at Enewetak were also detailed to assist with the experiment. IMP and radiochemical assets were made available. A large moldboard plow (Post Brothers, Model PB 142RH), 1.27 m in height (share plus moldboard), was shipped from the Nevada Test Site (NTS) where the plow had been stored in the event that plowing would be recommended eventually for several contaminated areas at NTS.

Preliminary plans for the plowing experiment were developed during a planning meeting at Enewetak on 11 May 1978, with DNA, the ERSP on-site Manager, and ERSP contractor personnel. Prior to this meeting, ERSP had already started work on selection of experimental areas and acquisition of preliminary data on soil profile structure and radionuclide data (Tech Note 9.0).

Most of the requisite information about the experiment and results are contained in Tech Notes 9.0 and 9.1, in one unpublished report (Jones and Francis, 1978), and in one published report (Denham, et al, 1980). However, for continuity in this report, the following summary is provided.

Janet was selected for the experiment primarily because it was the most important northern island in terms of future residence, agriculture, or food gathering, depending on the final radiological status of the island after cleanup.

Initially, three areas on Janet were selected for preliminary examinations. After IMP surface area measurements, IMP scans of surface samples, and profile soil characterization, one of the areas was selected for more intensive measurements.

The plow arrived at Enewetak on 8 June 1978. The plow was reassembled, and a plowing trial was conducted on the island of Elmer on June 19. Plowing of the experimental plot on Janet was accomplished on June 21-22.

The plow was pulled by a D-8K Caterpillar tractor. Unfortunately, the hydraulic ram on the plow failed and could not be repaired at Enewetak. Since the plow could not be raised or lowered hydraulically, a front-end loader was used to start the plow into the ground and lift it out.

The plow had to be pulled at a fairly rapid rate (about 67 m/min) to turn the sandy soil over satisfactorily. At first, brush, vines, and buried cables wrapped around the leading edge of the plow, necessitating frequent stops and clearance of the accumulated material. After the areas were cleared of vegetation and debris, plowing proceeded more satisfactorily. The plow was effective in plowing to a depth of about 50 cm, even ripping through partially consolidated coral.

The experimental area on Janet was divided into four rows, two plowed and two unplowed, each further divided into two subparcels. The americium-241 present in the soil was used as a tracer to determine the effectiveness of plowing in mixing the soil from the surface to depth. Pre- and postplowing surface and profile measurements were made of soil types and ^{241}Am concentrations.

Plowing was relatively effective in mixing ^{241}Am at the surface down to 50cm, although "hot spots" were evident at various depths. Surface concentrations which averaged from 14 to 27 pCi/g were reduced to 1.2 to 3.6 pCi/g. Similarly, organic matter from upper levels of soil likely was mixed fairly well to lower depths, although the comparatively darker organic soil appeared here and there as thin layers in lighter colored coralline sand. (Deep disking following the plowing probably would have mixed the soil more uniformly, as is the case in usual agricultural practice; however, disking was not done in this experiment.)

No decision was made about whether plowing would be an acceptable technique for use in the cleanup program at Enewetak Atoll. Accordingly, the contaminated surface soil was removed from the two unplowed plots in late spring of 1979.

Before plowing can be recommended as a technique for treatment of a particular radioactively-contaminated area, relatively long-term plowing experiments should be conducted in the environments of interest. In desert areas such as the Nevada Test Site, it is clear that almost all of the contamination of vegetation by transuranics is due to external contamination (Romney and Wallace, 1976) and that resuspension of transuranics by wind obviously is from surface areas. In an eastern deciduous forest site near Oak Ridge, Tennessee, resuspension of soil and contamination on external surfaces of vegetation is minimal. Uptake of transuranics through roots of vegetation is very low, with the ratio of Pu(veg)/Pu(soil) observed to be in the range of 10^{-5} to 10^{-4} (Dahlman and McLeod, 1976).

On the other hand, radioisotopes such as ^{137}Cs and ^{90}Sr are taken up readily into vegetation (Colsher, 1977). Uptake of cesium from soil into vegetation is influenced strongly by competing elements such as potassium and rubidium in soil (Davis, 1963). Absorption of strontium from soil into vegetation is affected by soil calcium (Menzel and James, 1971).

It follows, then, that in areas subject to resuspension by wind, mixing of transuranics from the soil surface zone to deeper zones would reduce the potential for inhalation and ingestion doses from the transuranics. On the other hand, plowing of soil contaminated with transuranics and other radioisotopes such as ^{137}Cs and ^{90}Sr from the surface zone to deeper zones would cause deposition of those radioisotopes into root zones of plants and make possible greater uptake into the plants.

Another effect of plowing is the movement of organic material from near-surface levels to deeper levels. Since organic matter seems to be concentrated near the soil surface in most Enewetak areas, removal of this material to deeper depths could cause nutritional problems for shallow-rooted plants but might improve the soil environment for deeper-rooted vegetation.

Plowing is not necessarily an irrevocable operation. However, much more soil would have to be removed after plowing if a decision were made later to remove the contamination than if just the top layers of soil were removed to begin with. For example, to remove the contaminated soil from the plowed plots on Janet, about eight times as much soil would have to be removed than would have been the case if just a six-inch "lift" had been used to remove the contaminated soil. The two plowed plots, each measuring 25 x 50 m, had no soil removed following the plowing experiment, but soil was removed from the two unplowed plots. (See Tech Note 9.1.)

6.8 AOMON CRYPT EXPLORATION AND EXCISION (by Bert Friesen, H&N)

6.8.1 Introduction

When nuclear testing began on Enewetak Atoll, the islands of Ruby, Sally, Tilda, and Ursula were separated from each other by water channels of various widths and depths, flowing from ocean to lagoon with a brisk current. Preparations for the Yoke test on Sally in 1948 included construction of a sheetpile causeway connecting points on Sally and Tilda about 300 feet inland from the lagoon. The 500-foot long causeway formed the third side of an artificial bay between the two islands. (Later, during Operation GREENHOUSE in 1951, a woodpile trestle was constructed from Tilda to Ursula, and an earth-filled causeway built from Sally to Ruby; however, interest at the moment centers on the Sally-to-Tilda causeway.) Cessation of the established currents was quickly manifested by growth of a sand spit from Sally toward Tilda. By 1956, the artificial bay was almost totally filled with sand; only a small tidal pond remained beside the original causeway. Tower framework that was not consumed by the Yuma and Kickapoo tests was highly contaminated and suitable disposal was required for Rad Safe purposes. Similar contaminated debris from earlier tests was, for the most part, dumped in the lagoon or at sea but, for reasons which are not recorded, the decision was made to dispose of the Yuma and Kickapoo debris by placing it in the convenient tidal pond. The pond was enlarged slightly in all three dimensions; metallic debris and contaminated soil were deposited, a layer of uncontaminated soil was placed as a cover, and a concrete center monument and four corner posts were placed to mark the "crypt." The center monument carried the inscription "Contains plutonium contaminated material and sand which is covered with two feet of earth fill." The coordinates of the four corners were also given. The "crypt" area was overgrown with Messerschmidia, Scaevola and morning glory vines when the Enewetak Cleanup Project began in 1977.

FIGURE 6-7. AERIAL VIEW OF ISLAND SALLY AND THE AOMON CRYPT. The straight line separating water and vegetation is the northern side of the original sheetpile causeway connecting Sally and Tilda. Trees and shrubs have been removed and vines have invaded the Crypt area. Refilling of the PACE depression has begun—seen in the center of the photo. (Spring 1978)

6.8.2 Pre-Cleanup Explorations

Beginning in October 1977 and extending to October 1978, only a few exploratory forays were made into the Aomon Crypt area (Figures 6-7 and 6-8). Large trees and shrubs were cleared from the area bounded by the corner posts during the fall of 1977. A few test holes were dug to a depth of five feet to gather information about the water table, to check soil stability, and to collect soil and water samples for radionuclide analysis. During April 1978, seven wells were placed in the land bridge between causeway and lagoon for the purpose of measuring tidal influence in the Crypt proper. Several solubility tests were conducted to see how much of the plutonium activity would settle out with other solids (at least 98 percent settled out). Interest and activity increased during the summer of 1978 when additional exploratory excavations and water and soil sampling missions were conducted. Interest continued to increase and culminated in a meeting in Honolulu on 6-8 November 1978 wherein several excavation plans were aired, a proposed plan was selected, and participating agencies were assigned specific tasks and areas of responsibility.

FIGURE 6-8. AOMON CRYPT SURFACE AND CENTER MONUMENT. Brush had been removed from the center of the area but not the periphery. This view is almost due east toward Tilda. (Spring 1978)

The excavation plan was flexible in that several options were programmed for implementation, but actual selection of options was left to in-the-field judgement as the effort progressed. (Text that follows will present actions actually taken, but the reader should be aware that other options existed and may be reviewed by reference to appropriate planning documents.)

The first action of the plan was to conduct a magnetometer survey of the site in an attempt to locate significant volumes of ferrous debris. The survey, carried out on 17-20 November 1978, indicated that most of the debris was in the vicinity of the center monument, with only a small quantity spread out in other areas. These conclusions were, for the most part, verified by later excavation.

FIGURE 6-9. CORING DRILL AT THE AOMON CRYPT. The center monument area as viewed toward the west during drilling operations. (January 1979)

The second action involved acquisition and analysis of core samples. A truck-mounted, core-drilling rig (Figure 6-9) was brought to the site and operated by the Army Corps of Engineers, Mobile District. Core samples were obtained on a 5-meter grid for each 2-foot interval down to rock, metal, or 30 feet, whichever occurred first. The mode of operation for the drill rig was to pound the 2-inch diameter coring tool through a 2-foot interval, extract the sample, rotary drill the same interval with a 4-inch bit using drilling mud to stabilize the sidewall, then obtain the next core. By using the rotary drill while the sample was being retrieved from the coring bit, the entire process progressed at a rapid pace. Approximately 1,000 soil samples were obtained from 125 holes between 1 December 1978 and 22 January 1979. (Work was halted briefly by Typhoon Alice.)

FIGURE 6-10. SPLIT SPOON SAMPLER USED AT THE AOMON CRYPT. The technician has just removed half of the sampling tube, exposing the sample obtained. Another technician stands ready to monitor the sample prior to removal into the soil sample can. (January 1979)

As each core sample was obtained (Figure 6-10), it was scanned with a handheld instrument, then prepared for further processing as described in Section 4.2.3. Initial gamma scans were performed by the IMP detector system in a specially constructed shed near the crypt; follow-up analysis on indicated samples was performed in the RADLAB on Enewetak. Figure 6-11 shows core drilling locations at the Aomon Crypt, Figure 6-12 presents the maximum observed TRU value in each drill hole, and Figure 6-13 shows the distribution and maximum depth of drill holes with TRU values of 400 pCi/g or greater.

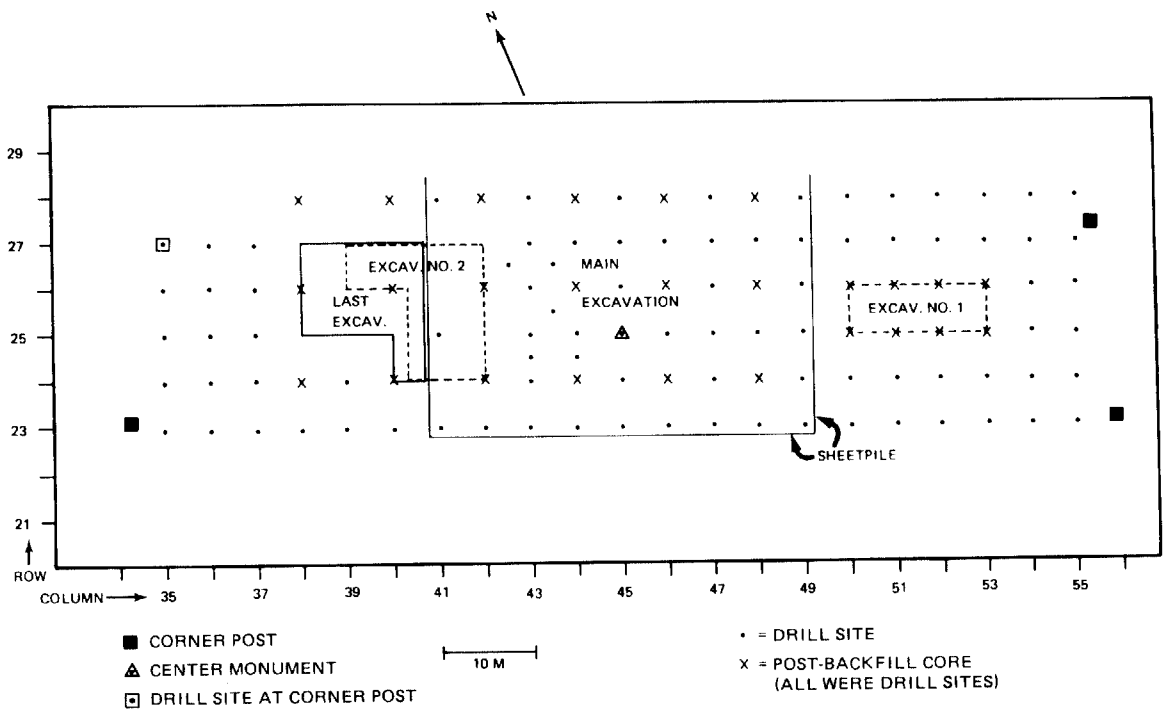
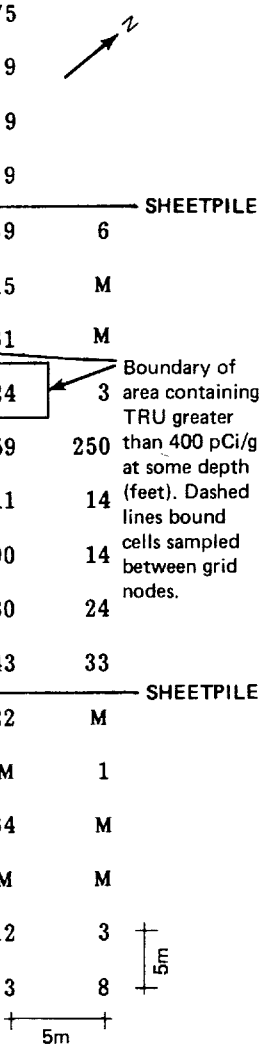


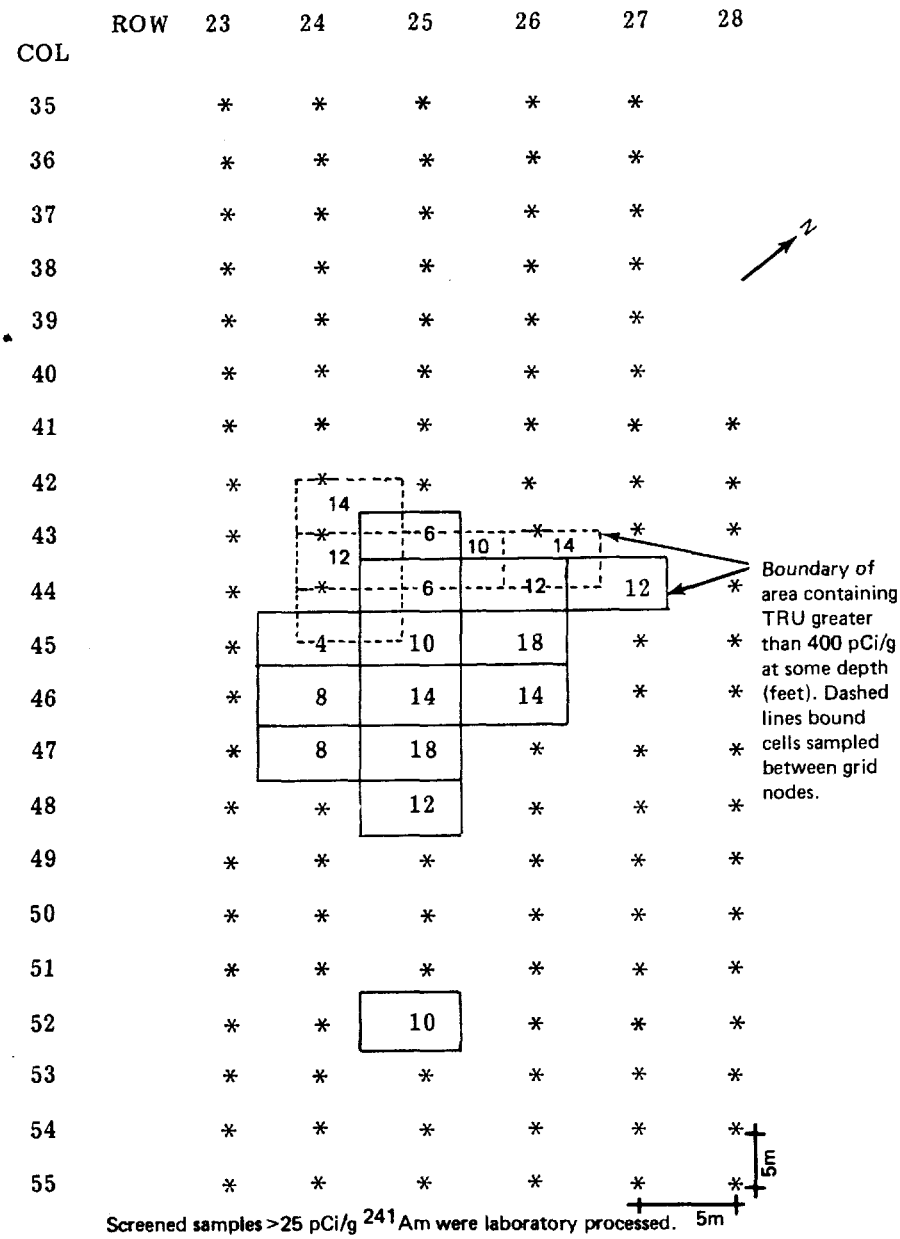
FIGURE 6-11. CORE DRILLING AND EXCAVATION LOCATIONS, AOMON CRYPT

COL \ ROW	23	24	25	26	27	28
35	27	36	18	6	M	
36	M	3	157	18	6	
37	7	131	131	22	75	
38	82	39	33	15	9	
39	15	9	58	12	9	
40	M	22	8	8	9	
41	M	10	3	32	39	6
42	12	6	53	9	15	M
43	94	7	1294	227	31	M
44	132	274	5287	630	724	3
45	241	524	1818	1559	259	250
46	114	1131	875	1547	111	14
47	20	481	823	261	90	14
48	30	20	569	101	130	24
49	20	65	169	78	43	33
50	23	77	79	282	22	M
51	57	79	26	43	M	1
52	149	92	693	47	34	M
53	M	23	3	7	M	M
54	12	8	13	10	12	3
55	32	16	6	M	3	8



SYMBOLS: M = Less than MDA (Minimum Detectable Activity).
IMP screened samples >25 pCi/g ^{241}Am were laboratory processed.
Laboratory results overrode IMP screening results.

FIGURE 6-12. MAXIMUM OBSERVED TRU VALUE IN THE AOMON CRYPT, pCi/g, ALL DEPTHS



Screened samples >25 pCi/g ^{241}Am were laboratory processed.
Laboratory results overrode IMP screening results.
* = No sample from this hole showed TRU >400 pCi/g.

FIGURE 6-13. MAXIMUM DEPTH OF TRU GREATER THAN 400 pCi/g IN THE AOMON CRYPT, FT

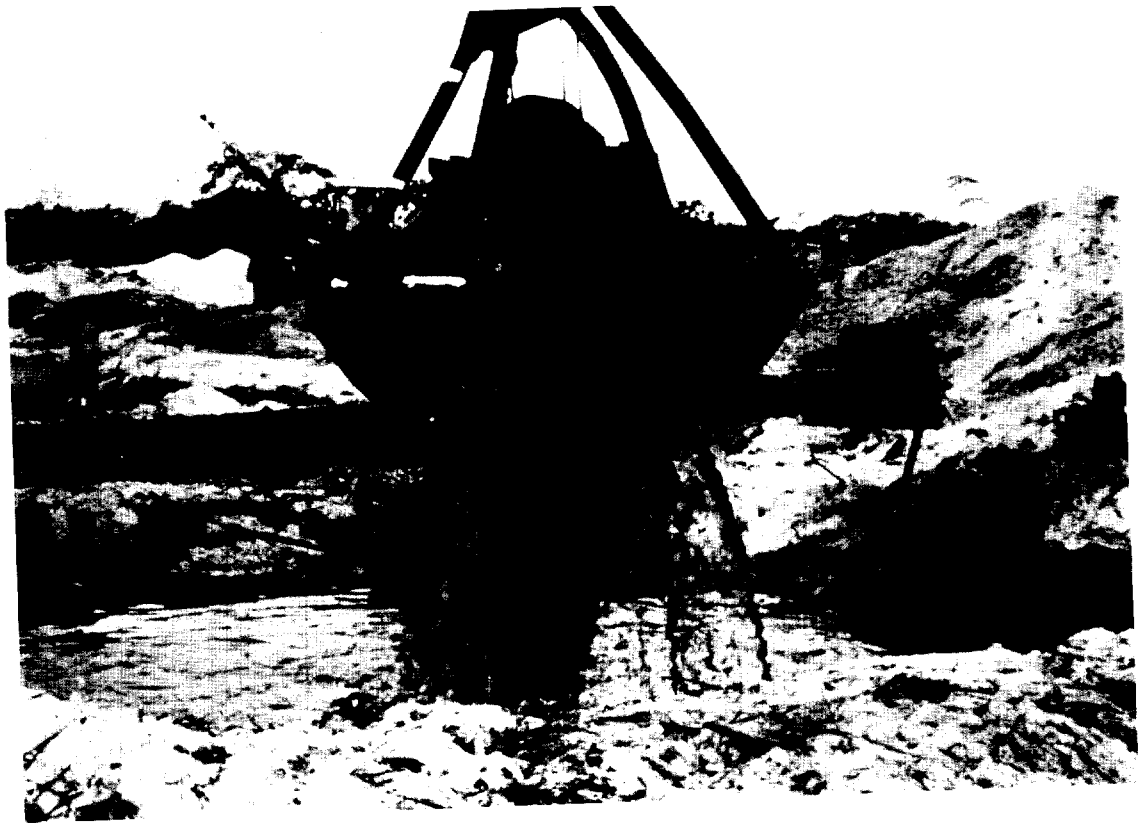


FIGURE 6-14. DEBRIS REMOVAL DURING AOMON CRYPT EXCAVATION. Long sections of "I" and "H" beams had to be removed prior to driving of sheetpile in this area. The clamshell bucket was used as a grapple to search for debris since the water in the hole was too dirty for more precise methods. (February 1979)

The U.S. Army element excavated soil in search of metallic debris at two locations outside of the area eventually bounded by the sheetpile. The locations of these searches were based on results of the magnetometer survey, but no significant debris was found at Excavation Site 1, shown on Figure 6-11. A substantial volume of debris was removed from Excavation Site 2 (Figure 6-14), then the soil was replaced in the hole so the sheetpile could be driven. Metallic debris had to be removed first so as to not interfere with driving of sheetpile. (After the main excavation was completed, the soil was again removed from Excavation Site 2 and transported to Yvonne.)

FIGURE 6-15. AOMON CRYPT JUST BEFORE BACKFILLING. All excavation completed, the pool is ready for backfill. (May 1979)

6.8.3 Excision

When all the necessary equipment and materials were assembled, Holmes & Narver, Inc., the base support contractor, drove the sheetpile and excavated the soil and debris from the enclosed area. Approximately 10,600 cubic yards of soil and debris were removed from the Crypt area between 22 January 1979 and 30 April 1979. Excavation was halted when the sheetpile started to cave in along one side. The average depth of excavation was about 20 feet. During the course of excavation, it was observed that a fine grey-black, rubbery material would drain with the water from a pile of freshly excavated soil. Samples of the rubbery material were found to contain higher levels of TRU activity than the soil from which it drained. When all cells within the sheetpile area showed, by bottom sediment sampling, TRU concentrations less than 400 pCi/g, the pond (Figure 6-15) was allowed to stand undisturbed for several days. Then a "blanket" of cement mixed with soil was carefully placed on the bottom in an attempt to lock in any of the rubbery material which might have settled there.

FIGURE 6-16. AOMON CRYPT AREA NEAR JOB COMPLETION. The last few sheetpile are being removed. Backfill material came from the beach in left foreground. The PACE area in the background has been totally recontoured. (June 1979)

The last actions at the Crypt included backfilling the entire area with clean beach sand from Tilda, removing the sheetpile (Figure 6-16), then core sampling to verify the material near the surface met criteria. Locations of post-backfill coring are shown in Figure 6-11. The largest TRU values obtained from the 5-foot cores were 2.9 pCi/g from within the sheetpile area and 42.4 pCi/g from the location of Excavation Site 1.

6.9 SUBSURFACE SAMPLING AND EXCISION (by Bert Friesen, H&N)

The Enewetak Radiological Survey (See Section 2.1.4) provided guidance with respect to possible locations where subsurface contamination might be found. In general, these locations were limited to islands used for nuclear tests. Also in general, the more tests conducted on an island, and the larger the yield of nearby tests, the more complex was the distribution of radioactive elements in the subsurface soil. At GZ locations like Item on Janet, Inca on Pearl, and Kickapoo on Sally, where only one test was conducted, post-test construction and cleanup actions were minimal. Consequently, contaminants remained relatively near the surface and relatively close to the test site; apparent anomalies will be discussed later. At GZ locations like Seminole on Irene, Easy/X-ray on Janet, and Yoke/Yuma on Sally, the cleanup following one test, and the construction preceding the next, created a heterogeneous mix of soil and contaminants which could be located anywhere relative to the test GZ. Because of the many nuclear tests conducted on Yvonne, this island is a special case to be separately discussed in Section 6.10. Subsurface sampling and excision progressed through a series of phases as described below.

6.9.1 Early Programs

As lane clearing progressed from one island to the next, with priority given to GZ islands, effort was directed toward finding a satisfactory method of sampling for subsurface contamination. Many possible techniques were discussed at length and discarded for some reason; usually the reason related to time and effort requirements, machinery and logistics problems, or to undeveloped detection equipment. The soil profile sampling methods described in NVO-140 (pages 93-94) were not readily adaptable to the present situation because of differences in the number of profiles required and the number of people available to do the work. For example, during the 1972-73 survey, there were approximately 18 people involved in the soil survey; during their mission, 21 profile holes were hand-dug and sampled on Irene. The hole depths and number of holes to that depth were: 0-35 cm, six; 0-65 cm, 11; 0-185 cm, four. The initial sampling effort outline for Irene in November 1977 included 27 profiles each to a depth of 120 cm, the water table or bedrock, whichever occurred first. Work was to be done by a crew of five in as short a time as possible due to constraints imposed by boat availability, favorable tide conditions, the tight schedule of soil sampling on other islands and sample preparation requirements at the laboratory complex.

Profile sampling at selected 50-meter grid points on Irene was conducted from mid-November through December 1977. Holes were hand-augered with soil recovery attempted in 20-cm increments. Recovered soil was placed in a copper- and lead-lined tub and scanned for alpha, beta, and gamma with portable instruments. An attempt was made to establish correlations between laboratory counting results, portable field instruments, and the IMP's gamma detector system. None of the experiments gave acceptable quantitative results, although there was a general agreement as to the presence or absence of radionuclides. An evaluation of the augering system concluded that soil conditions were generally not amenable to this technique. When the soil was very loose and sandy, the sidewalls would cave in as the auger was pulled from the hole. On the other hand, the auger could not penetrate rocky soil and the sample could not be recovered when the hole reached the water table. Since the primary objective of the sampling was to isolate zones of high radionuclide activity, there was also the concern that contamination between zones would occur and destroy the credibility of the sampling results. Hand augering was abandoned early in the program following limited use on islands Irene, Janet, Pearl, Sally, and Yvonne.

A plan for additional subsurface sampling on Irene was prepared in late January 1978, and conducted in mid-February. Profile holes were dug by backhoe at 19 selected locations, and discrete 5 cm samples were taken from 0-5 cm, then every 20 cm centered on multiples of 20. Results of this sampling effort indicated several areas where subsurface transuranic concentrations might exceed the cleanup criteria. Another sampling mission was laid out in late February and executed during early March, this time to obtain additional samples from around grid points 13-N-1, 12-N-2, and between 10-BL-0 and 10-N-1, found earlier to have elevated levels of transuranics.

As described above, profile sampling was conducted on Irene at various times between mid-November and early March. Several reasons account for the long period required to complete this phase of sampling, chief among them being that sampling was conducted concurrently on other islands as well. Table 6-6 presents a chronology of soil sampling missions during the November-March period. Surface samples were collected as a high priority task in order to complete the characterization of the northern islands, but samples were not collected from an island until a grid had been laid out and access lanes cleared. Plans were prepared and available for soil profile sampling on ground zero islands and were implemented whenever they could be fit in between surface sampling requirements. Figures 6-17, 6-18, 6-19 and 6-20 show the locations sampled in the early subsurface investigations conducted on test islands.

TABLE 6-6. CHRONOLOGY OF SOIL SAMPLING MISSIONS, NOVEMBER 1977 - MARCH 1978

Date	TYPE OF SAMPLING: GZ Profile	TYPE OF SAMPLING: Surface
1977 NOV 8,9		Vera
14,15	Irene	
17	Yvonne	
17,18,*,21,22	Irene	
25,26,29	Irene	
30	Pearl	Pearl
DEC 1,2	Sally	Sally
2	Pearl	
7,8	Irene	
12		Olive
16	Sally	
20,21,23	Pearl	
1978 JAN 2,3	Pearl	
4,5,6	Janet	
23,25,26	Sally	
27,28,30	Sally	
FEB 8		Lucy
11,13	Irene	
14,16		Kate
16	Sally	
17	Janet	
18		Nancy
21		Alice
22		Belle, Clara, Daisy
23		Yvonne
MAR 1,3	Sally	
8,9	Irene	
9		Tilda
14		Wilma
16	Sally	
22		Sally (West end)
30		Mary, Ruby

*Conduct of soil sampling on an island was generally planned for consecutive days; however, mechanical problems with boats or backhoes, bad tide conditions and other unforeseen problems interrupted planned missions on the following dates: November 19; December 12; January 24; February 6, 10, 14, and 20; March 2,7,13, and 27.

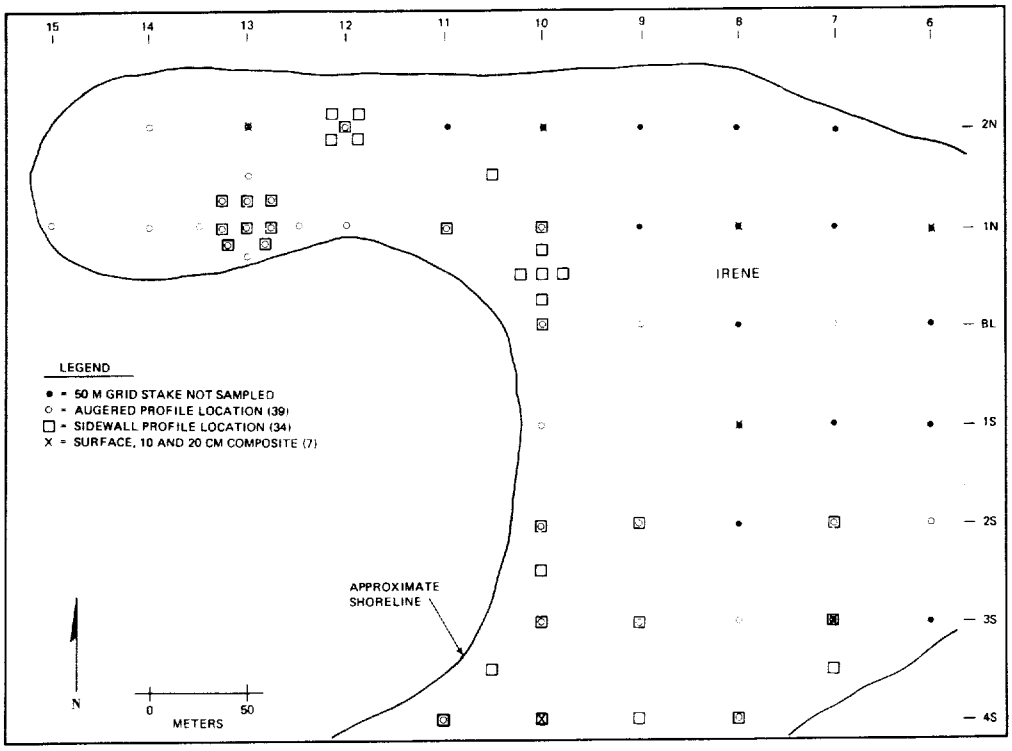


FIGURE 6-17. SUBSURFACE SAMPLING LOCATIONS ON ISLAND IRENE PRIOR TO 25 APRIL 1978

According to DNA OPLAN 600-77, the Cleanup Phase, including soil removal, was scheduled to begin 15 November 1977; debris removal did start on schedule. By mid-January 1978, DNA had become quite concerned that soil removal had not yet begun. DNA wanted to know for planning purposes which islands would require soil removal and the approximate volume of soil to be removed, identified by source as either surface or subsurface. Following an interagency problem resolution meeting in January, it was agreed that characterization of the northern islands would be completed in time to provide the necessary planning parameters to a decisionmaking conference scheduled for 3 May. Up to the end of January, the ERSP had directed efforts toward the ground zero islands, except for surface sampling on Vera and Olive. Beginning in early February, surface characterization of the other northern islands was assigned a higher priority than subsurface profiling on ground zero islands. The change in emphasis can be seen in Table 6-6. A large number of soil samples had to be collected and analyzed to meet the 3 May commitment. All sample results available on 25 April were plotted on maps and used to generate estimates of the volume of soil to be removed from each island. (Tech Note 7 provides some details on the procedure used.) Several very important decisions (discussed in Chapter Two) were made at the 3-4 May 1978 conference based, at least in part, on the soil removal estimates provided by the ERSP.

A large number of soil samples was collected to fulfill the tasks described above and they all had to be worked through the laboratory before results could be interpreted. By late April 1978, sufficient results were out of the laboratory to allow meaningful interpretation. The conclusions, in general, indicated the locations of subsurface pockets of contamination, but not the boundaries of the areas requiring excision. Detailed sampling plans were prepared and executed in an effort to define excision boundaries. By this time, the Pilot Soil Removal Project (Section 6.6) was in full swing so

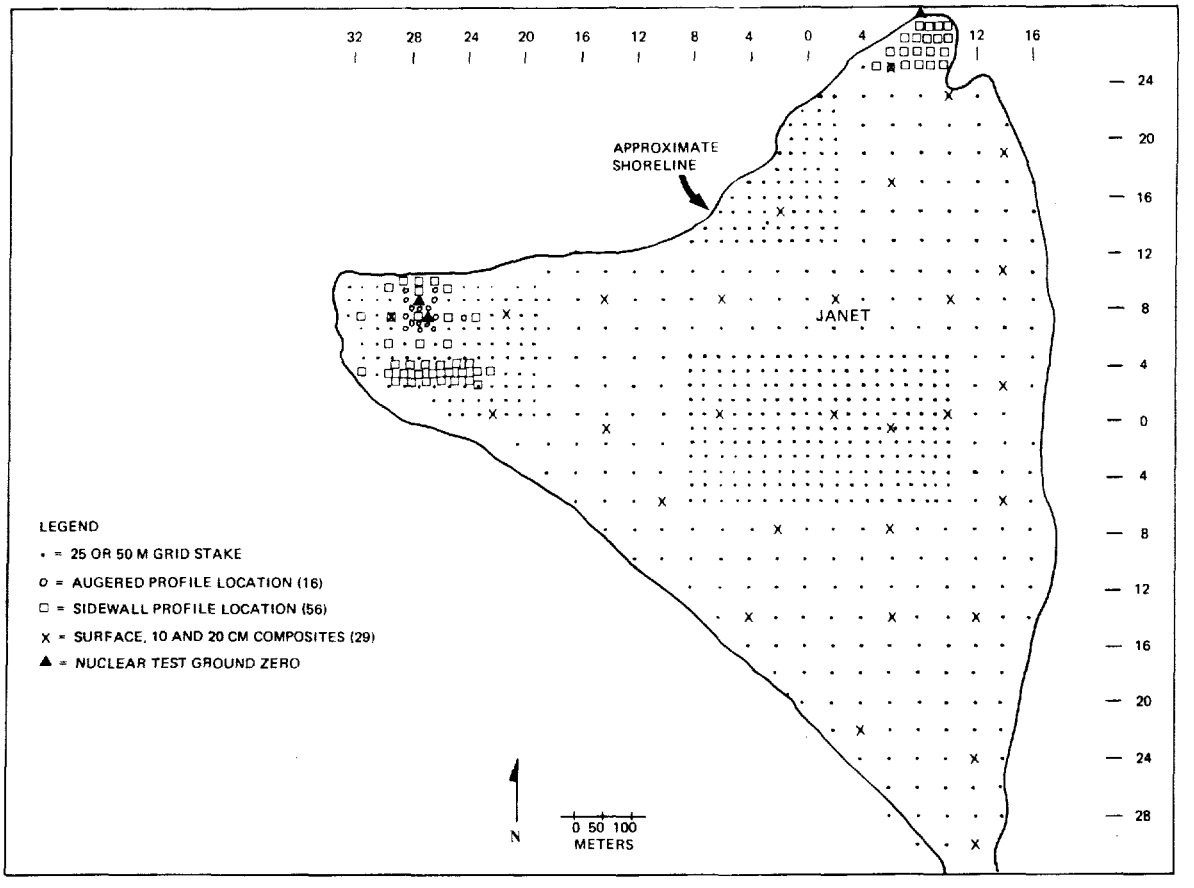


FIGURE 6-18. SUBSURFACE SAMPLING LOCATIONS ON ISLAND JANET PRIOR TO 25 APRIL 1978

first priority for soil profiling was assigned to Sally. Profile pits were dug and sampled at many selected locations in the Kickapoo and Yoke/Yuma areas in search of pocket boundaries; in some places, sampling was on a 6.25 m grid in an effort to reduce the volume of soil to be excised while strictly adhering to cleanup criteria.

Collection of large numbers of samples continued to be the normal mode of operation during subsurface investigations on Irene, Janet, and Pearl. Each sampling mission generated a backlog of samples for the laboratory; the next iteration of sampling, if required, had to wait until results of the prior iteration were available. Even though profile locations were carefully and thoughtfully selected, many locations which might have been omitted were sampled on a 6.25-m grid. Much thought was given to finding ways to reduce the number of profile pits dug, and therefore, the number of samples requiring laboratory processing. Significant improvements to the mode of operation are described in the next section.

Pockets of subsurface transuranic concentrations exceeding excision criteria were located and removed from Irene, Janet (Figure 6-21), and Sally, using the methods described above. After the required volume of soil had been removed, additional soil samples were taken from excavation-site sidewalls to verify satisfactory excision. Excavation at one site on Irene and at the two sites on Janet required several iterations of progressively smaller excisions before all evidence indicated compliance with criteria. The final evidence in each case was an IMP gamma scan of the cleaned area. If the excavation was backfilled and/or recontoured to smoother slopes, then the final configuration was again gamma scanned by IMP.

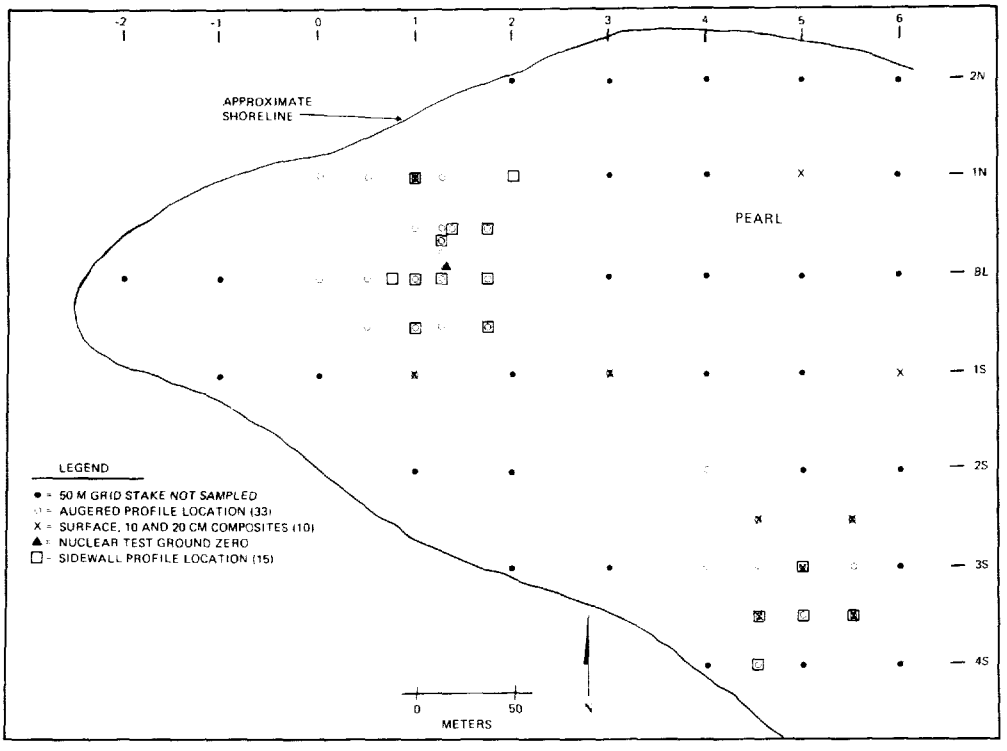


FIGURE 6-19. SUBSURFACE SAMPLING LOCATIONS ON ISLAND PEARL PRIOR TO 25 APRIL 1978

Apparent Anomalies. NVO-140 identified a number of suspected burial sites for radioactive soil or debris. The suspected sites on Janet and Pearl were identified based on the assumption that activated metal, and possibly soil, would be present around a surface ground zero following the nuclear test, and that disposition by burial in the area might have occurred. Subsurface investigation in the vicinity of the Item GZ failed to locate any activated debris and TRU concentrations in the soil were below excision criteria. No verifiable explanation has surfaced to account for this apparent anomaly; however, two possibilities have been offered. First, the topography in the vicinity of the Item GZ has changed significantly since the test, with substantial erosion of the northern tip of Janet; contaminated soil could have been eroded from its burial site and redeposited in diluted form elsewhere. Second, a gravel quarry was located on the northern tip of Janet so buried metal debris could have been unearthed and pushed aside, then treated as contaminated surface debris.

Subsurface investigation and debris removal in the vicinity of the Inca GZ on Pearl were conducted in a sequence yielding less than desirable results. A significant volume of contaminated debris was encountered during lane clearing operations. As soon as the initial IMP gamma survey was completed, and prior to any subsurface sampling, the Army began debris removal. Many long "I" and "H" beams were unearthed with substantial churning of soil in a large area surrounding the GZ and extending southeast toward the lagoon (around stake location 5-S-3). By the time subsurface sampling began, it was impossible to establish an accurate reference to the original surface and any pockets of high TRU concentrations had been churned and dispersed, possibly raising the average concentration of the new soil surface. When surface soil was removed from Pearl in 1979 (Figure 6-22), most of the churned area required removal of only one 15-cm layer. No satisfactory explanation has surfaced to account for the relatively high TRU activity localized in the vicinity of stake 5-S-3, about 270 meters from the Inca GZ.

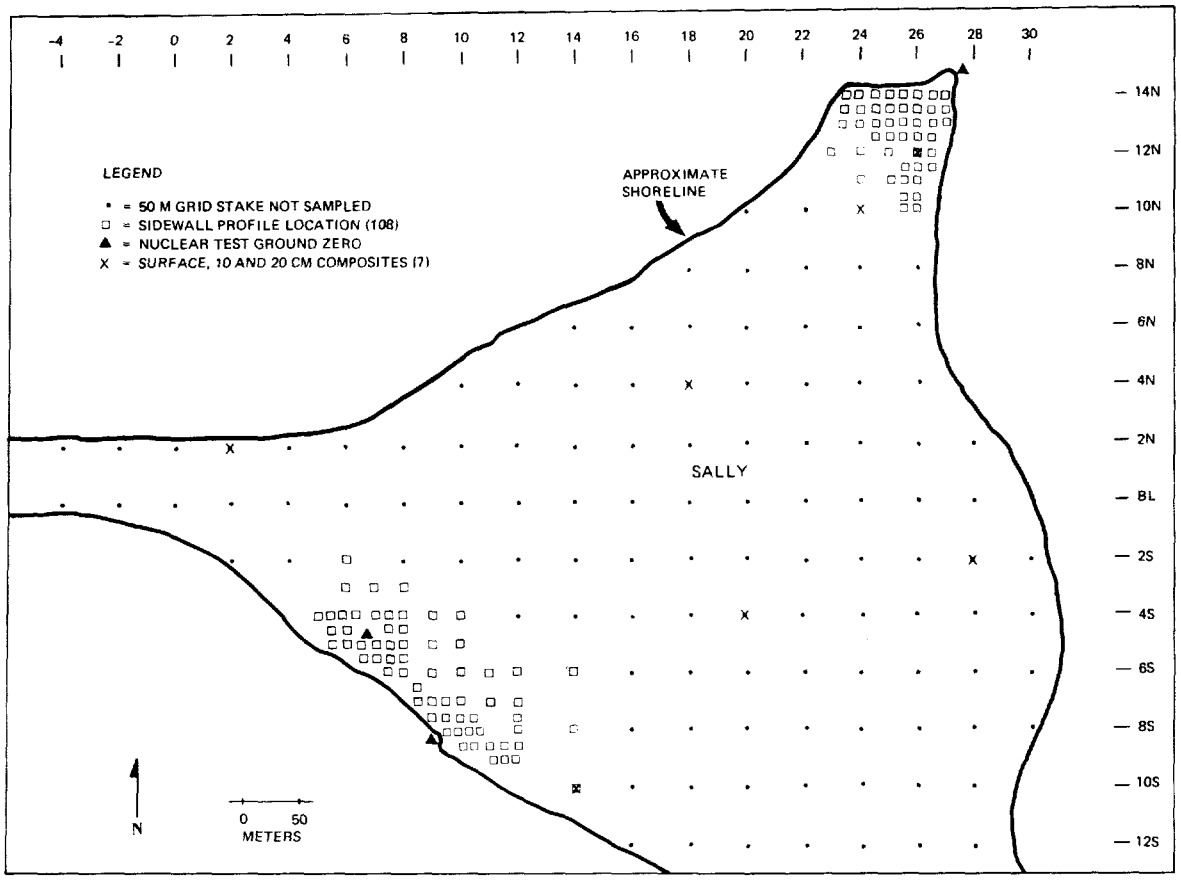


FIGURE 6-20. SUBSURFACE SAMPLING LOCATIONS ON ISLAND SALLY PRIOR TO 25 APRIL 1978

Subsurface contamination in the vicinity of the Kickapoo GZ on Sally was also an apparent anomaly. Test records indicate that the Kickapoo device did not reach the designed nuclear yield; consequently, about 200 feet of the 300-foot tower remained standing following the blast. Prior to detonation of the Mohawk device about three weeks later, the anchor cables on the Mohawk side of the remaining Kickapoo tower were cut. The blast from Mohawk scattered Kickapoo tower debris onto the reef. This debris was later collected, cut into smaller pieces, and placed in a tidal pond beside the Sally-Tilda causeway (the Aomon Crypt. See Section 6.8). Definition of subsurface contamination around the Kickapoo GZ was never accomplished with much precision. Even after all soil had been removed down to beach rock, a long, narrow strip of elevated TRU activity was measurable on the coral bedrock along the shoreline. An unproved explanation of how the contamination came to be where it is, is that the Kickapoo blast blew away the loose material in the immediate area, then when the debris was retrieved from the reef, it was spread along the beach to be cut up and small particles of plutonium fell onto the rocks where natural processes bound the plutonium into the rock. Later, wave action deposited new sand on top of the contaminated area, along with radioactive particles washed up from the reef where the tower pieces fell.

FIGURE 6-21. SUBSURFACE EXCISION ON ISLAND JANET. Soil was pushed out of the hole into a mound. The hole had standing water by the next day. Piled up soil was all removed, then the hole was backfilled and recontoured. (January 1979)

6.9.2 Final Program

Soil profile samples collected and analyzed for the FPDB program during the spring of 1979 indicated the possibility of several pockets of contamination exceeding criteria; pockets which were missed by the earlier sampling (Figure 6-23). Criteria definitions had undergone some refinement between the fall of 1977 and early 1979, so the size of a pocket which would be recommended for excision was known: If the average TRU concentration was greater than 160 pCi/g in any layer extended to an area as great as one-sixteenth hectare, then that one-sixteenth hectare would be recommended for excision to a depth sufficient to remove the layer bearing the elevated TRU activity. At the time the results of the FPDB sampling became known, there was very little time left to excise and transport soil from other islands to Yvonne and still meet the demobilization schedule set by DNA. A sampling pattern had to be developed that would yield boundary definition results much more rapidly than could be obtained from sampling on every node of a 6.25-m grid.

FIGURE 6-22. SURFACE SOIL REMOVAL FROM ISLAND PEARL. Soil was pushed into windrows, then hauled to a stockpile, at lower left, to await transport to Yvonne. Only a small area near right center required more than one soil "lift." View is almost due east. (June 1979)

Fortunately, from a time standpoint, the situation faced was different in several respects from the situation of earlier GZ investigations. The early explorations were searching for suspected burial sites based on limited prior knowledge: results in NVO-140 were from sampling pits of various depths, the pits were located in a quasi-random pattern, and the TRU/^{241}Am ratio was unknown or only approximate. In the current case, the FPDB profile pits were of uniform depth, were located at the nodes of a 50-m grid, the TRU/^{241}Am ratio was known with fair confidence, and the depth of the zone bearing high TRU concentration was indicated by the FPDB sampling results. A TRU value greater than 160 pCi/g in any FPDB sample was cause for further investigation. Sampling results from the eight grid nodes nearest the culprit could be examined for indications of the direction and areal extent of the pocket of contamination. Each node on a 50-m grid represented a quarter hectare, but excision criteria were based on the average concentration in an area of

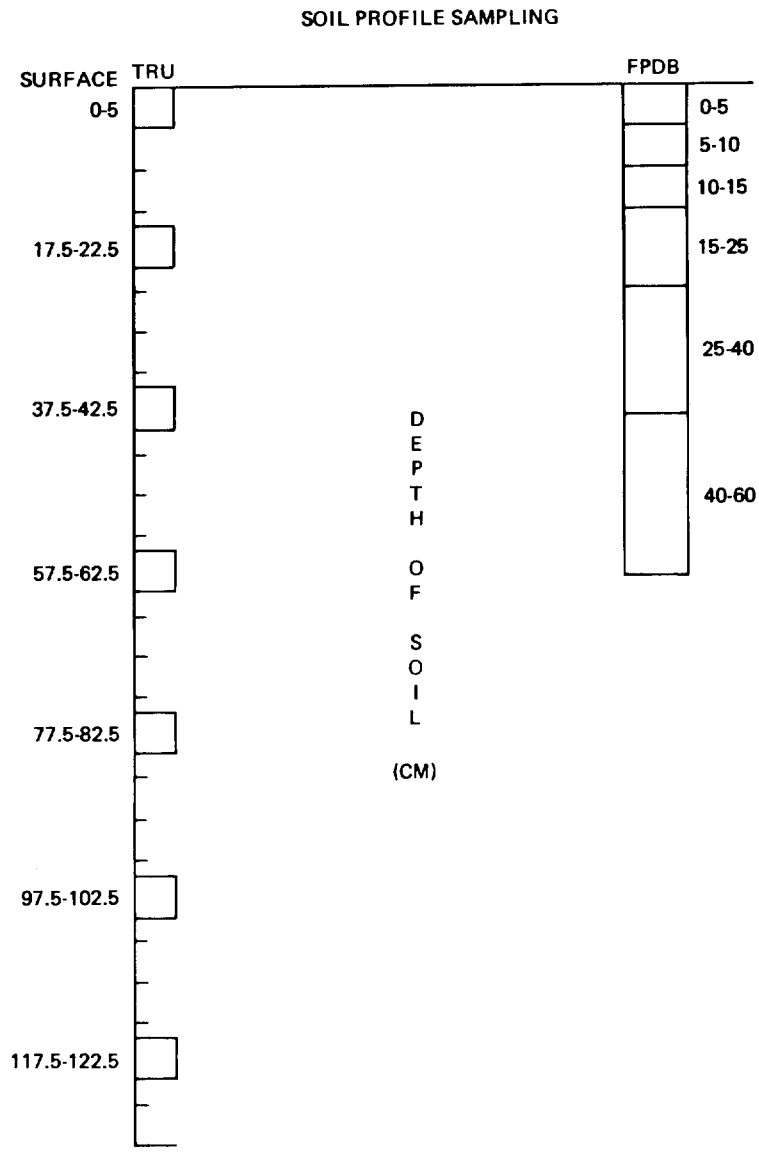


FIGURE 6-23. COMPARISON OF TRU AND FISSION PRODUCT SOIL PROFILE SAMPLING PLANS

one-sixteenth hectare, which required data on a 6.25-m grid. The latter requirement stemmed from a policy decision that at least four values were needed to obtain an average; each value from a 6.25-m grid would represent one sixty-fourth hectare and any four adjacent points would be averaged to obtain the one-sixteenth hectare value. The iterative sampling procedure that was developed greatly reduced the number of samples which had to be collected and analyzed, and "zeroed-in" on excision boundaries (Figure 6-24) with few iterations. (Details of the procedure appear in Appendix B, Tech Note 18.) Use of the IMP detector system for sample scanning contributed separately to both the reduced number of samples requiring laboratory processing and shorter lag time in obtaining guidance for additional iterations of sampling. However, the utility of the iterative procedure is not dependent upon a "field-operative" system like the IMP.

FIGURE 6-24. SOIL REMOVAL AREAS ON ISLAND IRENE. Subsurface soil was removed from what appears as four cleared areas in this aerial photograph. The 14-N-1 area is near the lower left; three other locations toward the top of the picture had soil removed following the FPDB survey. The Seminole Crater is at picture center. (July 1979)

Sample Scanning by IMP. In the early months of 1978, a large number of soil profile samples were collected in GZ subsurface investigations. As analyses came out of the laboratory, it became evident that a large percentage of the samples contained less than the minimum detectable activity of ^{241}Am or ^{239,240}Pu. Discussions were held to search for an acceptable means of reducing the number of samples submitted to the RADLAB without impairing the thoroughness of GZ investigations. The EG&G scientist on duty at the time suggested using the IMP gamma detector system to scan samples for ^{241}Am. Samples with very low activity would not be submitted to the RADLAB. With only minor experimentation, a system was developed, tested and implemented. (Details of the system appear in Appendix B, Tech Notes 6.0 and 6.1, and examples of field use appear in Tech Notes 9.0 and 18.0, and in Section 6.8, Aomon Crypt Exploration and Excision.) A general rule evolved to determine the level of ^{241}Am activity above which all samples would be submitted to the RADLAB: Using the appropriate TRU/^{241}Am ratio, any sample with indicated TRU greater than about one-half the applicable guideline would be laboratory processed; in addition, 10 percent of the samples below the cutoff would be laboratory processed for quality control purposes. For example, Aomon Crypt soil with TRU-activity greater than 400 pCi/g was to be excised, and the applicable TRU/^{241}Am ratio was 6.17. For convenience, the ^{241}Am cutoff was set at 25 pCi/g (400/6.17 = 64.8; 64.8/2 = 32.4; 32.4 - 25 = 7.4, which allowed for about a 30 percent error). Core sampling at the Aomon Crypt produced in excess of 1,000 samples, of which fewer than 200 required RADLAB processing. Significant savings of time and effort were realized by using the IMP detector to sort, or screen, soil samples collected in the plowing experiment, the Aomon Crypt excavation, and the subsurface explorations following the FPDB sampling program.

6.10 YVONNE FIG/QUINCE EXCISION (by Bert Friesen, H&N)

6.10.1 Introduction

Radiological surveys of Yvonne in 1971 and 1972 revealed several areas with levels of radioactivity sufficiently high to generate concern among participating health physicists. In May, 1972, radioactive particles retrieved from the vicinity of the Quince and Fig ground zero were analyzed and determined to have relatively high concentrations of ^{239}Pu. This was a unique situation, which is further detailed in the Enewetak Fact Book. AEC officials were concerned that if milligram-sized particles could readily be found, there was a strong likelihood they might be picked up in shoe soles, tire treads, etc., and could lead to significant contamination of other areas and islands. On the basis of a recommendation by the AEC, the Air Force, having administrative control at the time, imposed a quarantine on the island. The quarantine restricted access to the island but permitted legitimate work visits under appropriate controls. The high levels of radioactivity in the Fig/Quince area continued to be of concern until a clean layer of soil was applied to the area as the last step of the cleanup described in following sections. (The Quince test was conducted before the Fig test, so normal references to the series would be Quince/Fig, but Fig/Quince seems easier to say and became common usage.)

6.10.2 Pre-Excision Characterization

The DNA philosophy regarding cleanup priorities, discussed in Section 2.2.5, assigned a high priority to Yvonne. The DOE position held that Yvonne would likely remain quarantined and that the limited cleanup assets should be expended to produce the long-term result most beneficial to the people of Enewetak, such as cleaning Janet to a degree commensurate with habitation guidelines. The DOE and DNA agreed to participate in a conference, held 4-5 October 1977, to discuss the radiological characterization of Yvonne. The conference was an attempt to determine the level of effort required to obtain information upon which to base estimates of the volume of soil likely to exceed cleanup criteria. Specific tasks were identified and a plan of action set forth, calling for completion of the data-gathering effort by 15 January 1978. Soil samples were collected by the FRST, from both surface and subsurface locations, and processed in the ERSP Laboratory. Although the ERSP cooperated in this effort, the ERSP staff never believed the data gathered were sufficient to adequately define subsurface pockets of elevated TRU activity.

On 27 January 1978, the JTG requested that effort be expended to obtain data on surface soil contamination in the Fig/Quince and Cactus Crater areas on northern Yvonne because of the need to construct facilities in or near those areas. DOE responded on 31 January that no data were being developed for Yvonne and suggested a planning meeting to determine the kind and amount of effort needed to meet the JTG request. No formal meeting was held, but after several informal discussions, DOE received a letter on 15 February requesting an in situ survey of the Fig/Quince and Cactus Crater areas so that Army construction teams could avoid areas where the transuranic levels on the surface exceeded 400 pCi/g. The survey was conducted and results transmitted to JTG on 2 March 1978. The data obtained were used as guidance for the location of roadways through the Fig/Quince area and for the location of facilities at the Cactus Crater (Figure 6-25) work site. No additional effort was expended on characterization until later in 1978.

A meeting to discuss the cleanup of Yvonne was held 17 October 1978. Element representatives reviewed the status of debris cleanup and previous characterization efforts. DOE reiterated its judgement that additional in situ surveys were needed and many more surface and subsurface soil samples would have to be collected and analyzed before any reliable excision volume estimates could be constructed. One valuable task assigned as a result of this meeting was to correlate the FRST data collected earlier with the standard grid that had evolved. Even though the earlier results were in terms of gross alpha only, the data did signal the presence or absence of transuranics.

Interest in the radiological characterization of Yvonne next surfaced in a letter to ERSP from JTG dated 9 December 1978. The letter requested submittal of a plan for a characterization update to include type of measurements to be taken and method of sampling, time factors for individual tasks and total time to radiologically characterize the island, number of stakes to be surveyed and placed by area, estimated depth of excision to meet Conditions A and D, and an estimate of support required. DOE responded on 15 December with all the requested information, except for estimated

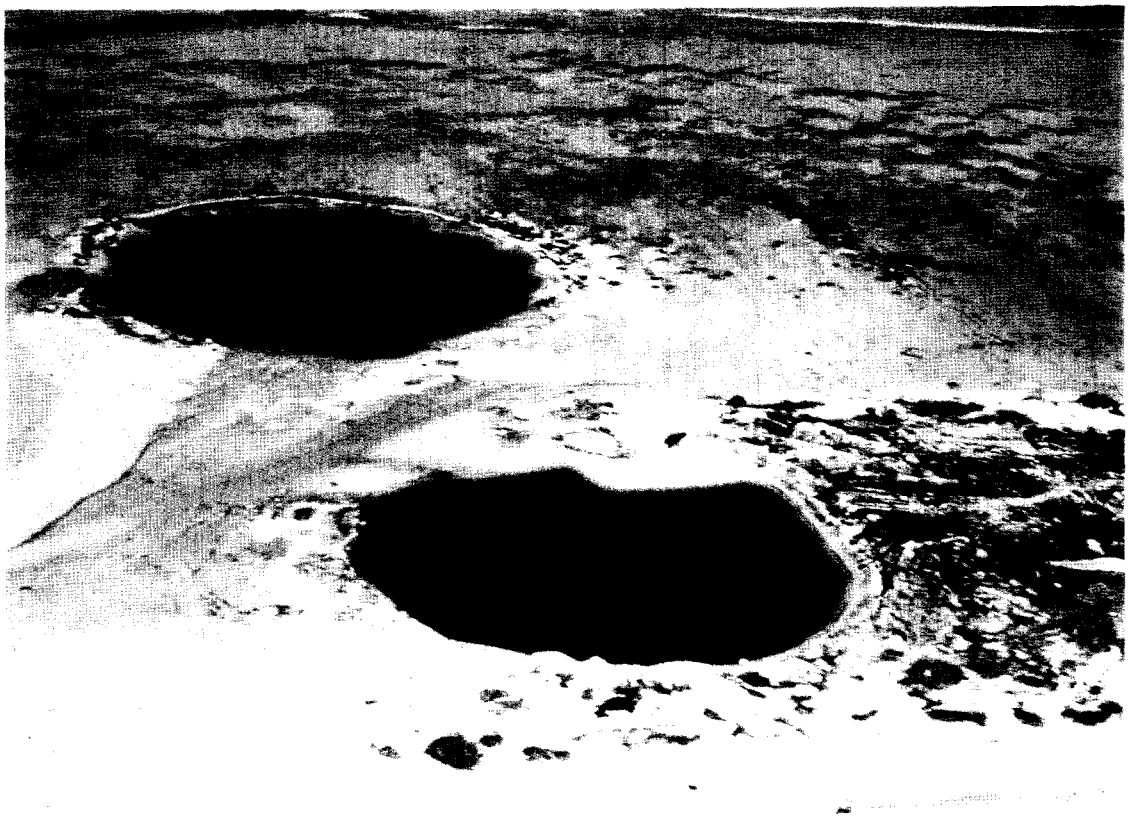


FIGURE 6-25. CACTUS AND LACROSSE CRATERS ON ISLAND YVONNE. Cactus Crater, foreground (viewed from the west), was selected as the disposal site for all contaminated debris and soil removed from other islands during the cleanup. (Spring 1977)

depth of excision to meet Conditions A and D, which could not be provided until better subsurface information became available. No further action was taken until JTG issued a tasking letter on 6 February 1979 including assigned priorities for five identified areas of the island. Soil sampling and the in situ survey began immediately on Southern Yvonne and was completed in a few days.

The in situ survey of the area between Fig/Quince and Cactus Crater was in progress on 15 February when DNA requested information upon which to base a decision regarding additional cleanup of Yvonne versus cleanup of Pearl. The response provided to DNA on 24 February summarized the status of information for both islands and provided volume estimates indicating that for Yvonne about 18,000 yd^3 of soil would have to be excised to bring the surface TRU concentration down to 160 pCi/g, or about 13,000 yd^3 if the target level was 400 pCi/g. The volume estimate to remove areas with surface TRU greater than 80 pCi/g from Pearl was 23,500 yd^3. The information supplied was only one of a large number of diverse factors considered in making the decision to excise soil from Pearl first, then the Fig/Quince area.

FIGURE 6-26. CACTUS CRATER/DOME ON YVONNE. Debris and soil disposal is nearing completion and placement of cap sections is well underway. (Summer 1979)

6.10.3 Fig/Quince Excision

By 14 April 1979, the top 20 cm of soil had been removed ("lifted") from about three hectares surrounding and including the Fig/Quince area, and post-lift in situ measurements were completed. All measurements in the area were made on a 25-m grid, so each node represented a one-sixteenth hectare square. Prior to any lift (removal of the top 20 cm of soil), 47 squares had indicated TRU greater than 160 pCi/g, with an average of about 600 pCi/g. The indicated TRU concentration increased in a few of the squares following the first lift with one square, 0-BL-0, showing an increase from about 4,100 pCi/g up to about 7,000 pCi/g. (These numbers are only "about" because the TRU/^{241}Am ratio was approximated from NVO-140 data; samples with high levels of radioactivity were not processed in the RADLAB for reasons explained in Chapter 4.) The post-lift average TRU in the 47 squares was about 560 pCi/g. When the extra high values at 0-BL-0 are removed from the computations, the pre- and post-lift means become about 515 and 420 pCi/g, respectively. The number of squares with indicated TRU above 160 pCi/g was reduced to 30 by the soil removal; the average of these 30 was about 810 pCi/g including point 0-BL-0 and about 580 pCi/g excluding 0-BL-0.

FIGURE 6-27. CACTUS DOME ON ISLAND YVONNE. At project completion, a concrete-capped dome 25 feet high and 370 feet in diameter exists where a 30-foot deep crater used to be. (April 1980)

On 27 May 1979, a working conference was held by JTG to determine a plan to achieve the maximum effectiveness in a limited cleanup effort within the Fig/Quince area. Data available at the time indicated that up to 6,000 yd^3 of soil could be placed in the Cactus Dome (Figure 6-26) following completion of soil removal from other islands, but a conservative decision was made to save space for 4,000 yd^3, "just in case", until all other soil removal was actually completed. A detailed plan was devised to remove soil, 20 cm at a lift, from one-sixteenth-hectare squares, with the square indicated to have the highest TRU activity being lifted first. After each lift, the IMP would return to do a new gamma scan. The process would be repeated until 2,000 yd^3 had been removed to the soil/cement operation at the Cactus Crater/Dome. (A 20-cm lift from one-sixteenth hectare produced about 160 yd^3 of soil, so 12 squares could be treated. Some squares were lifted once, others as often as five times because of the "highest first" concept. In essence, subsurface excision was being done based on "surface" measurements rather than subsurface profiling.)

Prior to implementation of the above plan, DOE recommended that several small areas with high activity be excised. These "hot" spots were excised, resulting in a 17 percent reduction in average TRU activity in one small area and a 46 percent reduction in another; one spot increased 6 percent. Small-area excision continued for several days with significant results; the action plan then returned to the plan devised in the 27 May meeting. When the 2,000 yd^3 target volume was reached, the excision process was halted in the Fig/Quince area until soil removal from other islands was completed, including about 15,000 yd^3 from Pearl. Soil excision on the basis of the "highest first" continued in the Fig/Quince area until the Dome was filled to design capacity.

The average indicated TRU activity in the Fig/Quince area was significantly reduced by soil removal but was not reduced below 160 pCi/g in every square. With reference to the same 47 squares mentioned earlier, the average TRU activity following the final lift was about 145 pCi/g. Fifteen squares had indicated TRU greater than 160 pCi/g, with an average of about 240 pCi/g. The highest TRU value was about 700 pCi/g at 0-BL-0.

6.10.4 Follow-up Actions

Final soil removal from the Fig/Quince area was followed by backblading to smooth out the hummocks. A few days later, on 6 August 1979, four members of the DOE/ERSP staff, accompanied by one member from RADCON, conducted a detailed survey of the Fig/Quince area with portable instruments to locate and pick "hot" particles as a last cleanup step. Very few particles were located; however, numerous pieces of contaminated metallic debris were found and transported to the Dome by bucket loader. Meanwhile, soil profile samples had been collected and analyzed from the vicinity of the 1310 bunker in search of a source of clean soil to use as a cover to be placed over the Fig/Quince area. The soil just north of the bunker was determined to be suitable and was used to cover Fig/Quince to a depth of one foot.

Upon completion of the Cactus Dome (Figure 6-27) and demobilization of all construction facilities, the entire north end of Yvonne was surveyed by IMP on a 25-m grid. Final results are reported in Chapter 7.

6.11 DOSE ASSESSMENT AND THE FISSION PRODUCT DATA BASE (by William Robison, LLNL)

6.11.1 Relationship Between Data Base and Dose Assessment

A major purpose for developing the Fission Product Data Base (FPDB) as part of the Enewetak Radiological Survey Project (ERSP) was to supply an adequate data base after the cleanup activities to update the estimated radiological doses to a returning population. The dose assessments for alternate living patterns at Enewetak Atoll served as the basis of the recommendations of the Department of Energy (DOE) and the Department of Interior (DOI) for the resettlement of the atoll. In addition, the Enewetak people and their legal counsel may use the assessment as the basis for their decisions on their preferences for the use of the atoll.

The dose assessments, therefore, played a crucial role in the practical and political decisions for resettlement of the atoll. These assessments are, however, only as good as the data upon which they are based. The data base developed is as thorough as time and money would allow.

Previous assessments showed that the terrestrial food chain for locally grown food crops is the most significant potential exposure pathway. The second most significant pathway is external gamma exposure. Estimation of the magnitude of the exposure through the terrestrial food chain required a detailed knowledge of the concentration of the key radionuclides in the soil on the islands in the northern half of the atoll. A detailed survey of the soil concentrations would not have been required if the common local foods such as coconut, breadfruit, Pandanus fruit, papaya, squash, etc., were available for analysis. A direct analysis of these foods would have provided the information needed for the dose assessment. However, in absence of these edible foods, concentration ratios were used (i.e., the radionuclide concentration in the edible food divided by the radionuclide concentration in the soil, both in pCi/g) for each specific radionuclide, along with the average concentration in the

soil of each radionuclide on the island. The concentration ratios of each radionuclide in each food were developed from data obtained from Lawrence Livermore National Laboratory (LLNL) test plots on Janet Island at Enewetak Atoll and Eneu Island at Bikini Atoll, and from coconut, breadfruit and Pandanus trees planted on Bikini Atoll in 1970 by the Trust Territory Government. When sufficient data were collected to ensure confidence in the concentration ratios of each radionuclide in each food, the concentration ratio could be mulitiplied by the average concentration in the soil on each island to predict the radionuclide concentration in a specific food item on that island. For example, the concentration ratio of ^{137}Cs in coconut meat is 6 in the 0-40 cm soil profile encompassing the root zone. The average concentration of ^{137}Cs in the 0-40 cm profile on Janet Island is 12 pCi/g; thus the estimated average concentration of ^{137}Cs in coconut meat of trees growing on Janet Island is predicted to be about 72 pCi/g.

This approach was used almost exclusively in the entire assessment for Enewetak Atoll and therefore required a very detailed analysis of the concentration of radionuclides in the soil on each of the islands after the cleanup project.

6.11.2 Significant Radionuclides and Exposure Pathways

The most significant radionuclides in order of the magnitude of their contribution to the total estimated dose are given in Table 6-7.

The exposure pathways in the order of the magnitude of their contribution to the total estimated dose are:

- Terrestrial foodchain
- External gamma radiation
- Marine foodchain
- Inhalation
- Drinking water

TABLE 6-7. RADIONUCLIDES CONTRIBUTING TO THE ESTIMATED DOSE OF RADIOACTIVITY TO THE POPULATION ON ENEWETAK ATOLL THROUGH LOCALLY GROWN CROPS

Radionuclide*	Half Life, y
^{137}Cs	30.9
^{90}Sr	29.12
^{60}Co	5.27
$^{239,240}Pu$	24,000
^{241}Am	432.2

*Radionuclides are listed in the order of the magnitude of their contribution, as of 1980.

The most significant radionuclide is ^{137}Cs because it constitutes a considerable part of the total estimated dose in both the terrestrial and external gamma pathways. Strontium-90 is a major component of the radiological dose through the ingestion pathway but most of the contribution from ^{60}Co is through external gamma exposure. The transuranic radionuclides will contribute very little to the total dose over the next few decades; the exposure will be primarily through the inhalation pathway by resuspension processes and secondarily through the marine pathway. The potential exposure to transuranic elements is long term, but the estimated doses are very small.

6.11.3 FPDB Soil-Sampling Procedures

The soil-sampling procedures employed during the ERSP were developed over a period of time by the LLL field team as part of a continuing environmental project in the Marshall Islands. The soil-sampling program began in February 1979 at Enewetak Atoll. This program was conducted by the DOE Nevada Operations Office (NV), receiving technical direction from LLL. A 50-m grid was established on each of the islands from Alice through Wilma, i.e., the northwest through the northeast and east side of the atoll. Soil profile samples were collected at each 50-m grid point. All soil profile samples were collected over the following increments: 0-5, 5-10, 10-15, 15-25, 25-40, and 40-60 cm. Observations indicate that a 40-cm depth encompasses most of the active root zone of the subsistence crops observed in the northern Marshall Islands. In addition, soil profiles of radionuclide concentrations provide a basis to evaluate the effectiveness of soil-removal procedures for reducing the soil radionuclides inventory and therefore the dose.

A trench was dug at each 50-m grid point using a backhoe, and samples were collected down the sidewall of the trench after scraping the sidewall to avoid any possible contamination from digging. The 0-5 cm sample was collected from a surface area out to about 25 cm on the side of the trench. The area was then expanded by about 10 cm on each side and cleared to a depth of 5 cm. The upper surface (1-2 cm) of this enlarged area (35 cm^2) was then cleared to ensure that no surface soil, or soil from a preceding increment, had fallen onto the next increment to be sampled. The next sample was then taken from the entire depth of the increment (i.e., 5-10 cm) from an area about 25 cm^2 within the enlarged area. This procedure was repeated until the final increment of 40-60 cm was collected. A total of approximately 1,000 g of soil was collected for each profile increment.

The soil samples were dried and ground into a fine powder in a ballmill. Samples were then analyzed by gamma spectroscopy to determine the ^{137}Cs and ^{241}Am concentrations and by wet chemistry procedures to determine the concentration of ^{90}Sr and, in some cases, $^{239,240}Pu$, ^{241}Am, and ^{241}Pu. Eberline Instrument Corporation used wet chemistry procedures to determine concentrations of ^{90}Sr, $^{239,240}Pu$, ^{241}Am, and ^{241}Pu. The DOE/NV was responsible for the quality control aspects of the analyses.

6.11.4 FPDB Data Storage and Retrieval

The soil concentration data from the analytical program were grouped according to the island of origin and put in a computerized data bank by DRI and supplied to LLL. The data were then reduced into an appropriate format to proceed with the dose assessment.

The radionuclide concentrations as reported by DRI are in profile increments (i.e., 0-5, 5-10, 10-15, 15-25, and 25-40). For purposes of this assessment a more useful format is the activity integrated over certain depths (0-5, 0-15, and 0-40 cm). After converting each profile into this format, the integrated activity for each island, or in the case of larger islands, for island subsections, is summarized. Selected portions of the FPDB results are reported in Tables 7-1, 7-2, and 7-3. Results of the dose assessment were prepared in booklet form (DOE, 1979), in side-by-side English and Marshallese text, and presented to the people of Enewetak at a meeting on Ujelang Atoll in September 1979.

6.12 SAMPLE ARCHIVING (by Paul B. Dunaway and Hollis A. Berry)

In the early stages of planning for the Enewetak Radiological Support Project, it was realized that representative soil samples from Enewetak should be archived. Archived samples were retained for the following potential needs: (1) rechecking anomalous data; (2) analyzing samples for other information which might be required for later ERSP needs; (3) comparing samples with samples which might be taken in future years at Enewetak; and (4) having a record for future legal actions that might arise.

Samples were retained for archiving under the following general guidelines. All samples were retained from those areas on which no remedial action was taken. In addition, the "as left" last surface samples from each cleaned area were retained. Some special samples taken from places such as Aomon Crypt were also kept. Both surface and profile samples are in the archive. The rationales for these selections are: (1) a record is needed of the condition in which untreated areas

FIGURE 6-28. LLL RESEARCH AREA ON ISLAND JANET. The "farm" viewed from the northwest at the completion of cleanup. Surface soil was removed from the area at lower left, just outside the farm area. (Summer 1979)

were left, and historic soil samples are part of the record which can be rechecked in the future; and (2) a record is also needed for the "before and after" conditions of the cleaned-up areas, and the archived samples from those areas can also be rechecked.

The archive is located in Warehouse 2106 in Area 26 of the Nevada Test Site (NTS). Reynolds Electrical & Engineering Company, Inc. (REECo), under direction from Nevada Operations Office, has the responsibilities of receiving, organizing, and keeping records of the samples.

Warehouse 2106 is a secured facility; i.e., entrances are locked and sealed, access is limited to authorized personnel, and the warehouse is included on a roving guard patrol and checked every three hours during nonworking hours. The warehouse is a general archiving facility which houses other historic samples in addition to the Enewetak samples.

Preparation of the samples at Enewetak is discussed in Chapter 4, Section 4.2.4. Approximately 15,000 samples have been placed into the archive at this time. All soil samples arriving at NTS from Enewetak or from U.S. laboratories are in 16-ounce Nalgene bottles and have been sterilized to meet U.S. Department of Agriculture importing regulations.

FIGURE 6-29. ISLAND JANET NEAR COMPLETION OF CLEANUP. The checkerboard pattern of light areas indicate locations of soil removal. A few months following the photo, vines had covered the clear areas so as to make them indistinguishable when seen from the air. Note the LLL research area toward the left point of the island. (February 1979)

All archive samples are identified by a unique six-digit number. Organization of the samples is based on this numbering system. The samples are placed on shelves in ascending order of the six-digit number so that an "open end" is left for any later samples. A cross-reference listing of the samples is maintained, with some additional key information. In addition to the listing, the original archiving weight (in grams) is recorded to assist in documenting the history of each sample after its arrival at NTS.

Retrievals of samples will be based on the unique six-digit sample numbers. Thus, upon receiving a DOE/NV-approved request for samples stored in the archives, it will be a routine procedure for removing the samples requested. Subsequent action would be required for documenting the request, preparing the samples for shipment, and shipping them. The normal response time for a routine request, after the approval reaches REECo, will be about five working days.

Since several years or even decades may pass before unforeseen needs arise to retrieve samples from the archive, it would be unwise to assume that the personnel continuity will be such that personal remembrances about the archive can be depended upon. Accordingly, the archive has been set up essentially as a permanent library, with a streamlined system which has been formalized and documented.

CHAPTER SEVEN: RADIOLOGICAL CONDITION OF ISLANDS

Text by M. G. Barnes and J. J. Giacomini, Desert Research Institute
Illustrations by Graphic Arts Group, Holmes & Narver, Inc.

7.1 INTRODUCTION

All of the islands discussed in this Chapter tend to change shape gradually as the wind and waves erode some areas and build up others. Parts of some islands are especially unstable, undergoing substantial alteration during local tropical storms. The island outlines in this Chapter show the approximate high tide line as of the fall of 1972. In those cases where significant changes in coastline have occurred since then, the approximate spring 1978 high tide lines are also shown.

The results of the 1972 soil, vegetation, and animal sampling were helpful in guiding sampling efforts during the cleanup. Summaries of the 1972 data are given in Tables 7-1, 7-2 and 7-3, and details of the 1972 sampling methods and results can be found in the Enewetak Radiological Survey (NVO-140, 1973). Descriptions of the surface and subsurface soil sampling procedures used during the cleanup are in Sections 4.2 and 6.9 of this report. Information about the in situ measuring system (the IMP) and related procedures is in Section 3.2. Many of the island discussions reference Tech Notes which can all be found in Appendix B.

Text for each island includes introductory sections labelled 'Background' and '1972 Survey Results'. Material for these sections was obtained largely from the Enewetak Fact Book (NVO-214, 1982) which was compiled for field use during the summer of 1977, and found to be an invaluable aid during the entire cleanup period. The 'Background' sections contain reference to "H + 1 hour exposure rate," and a ranking based on this value. This is a technique devised by Lynch and Gudiksen, originally published in NVO-140, pp. 81-83, as a crude effort to estimate the relative amount of fallout deposited on each island. They normalized early time radiation readings to H + 1 hour values and summed contributions from all nuclear tests on the atoll to arrive at a "total H + 1 hour exposure rate received" value for each island. The stated value is not relevant to the present radiological condition of any island.

For the purpose of reporting the radiological condition, the islands are grouped first according to radiological history, then according to geographic location. All of the nuclear events which significantly affected any island took place on or north of island Yvonne. The islands south of Yvonne are discussed in Section 7.2, "Southern Islands." Islands west of Irene are discussed in Section 7.3, "Northwest Islands." Islands which were not the site of a nuclear test, and which lie between Janet and Yvonne, are discussed in Section 7.4, "Northeast Islands." Islands used as sites for nuclear tests, and requiring some soil removal, are discussed in Section 7.5, "Soil Removal Islands."

The reports in Section 7.2 discuss the background and history of the southern islands, and summarize the 1972 and cleanup sampling results. None of these islands required soil excision (except for one very small area on Elmer) or large-scale sampling efforts during the cleanup. Sections 7.3 and 7.4 give the same background and summary information about the northwest and northeast islands. These sections also include maps of each island with soil and IMP sampling locations, isopleth maps showing the surface TRU characterization, and a discussion of activities during the cleanup.

There are two important aspects of these discussions that should be noted. The first deals with the usage of final IMP data versus original IMP data and a reference to Tech Note 23. Following the completion of the project, a decision was made to collect more data concerning characteristics of the Enewetak soil. This additional information resulted in a change in the IMP conversion factor which in turn affected the ^{241}Am numbers. Cleanup decisions were based on data calculated using the original conversion factor, thus, original data are used in describing what actually occurred

TABLE 7-1. RESULTS BY ISLAND FOR ^{137}Cs IN 0-15 cm SOIL SAMPLES FROM THE 1972 RADIOLOGICAL SURVEY AND THE 1979 FISSION PRODUCT DATA BASE PROGRAM.

	1972 Radiological Survey			1979 Fission Product Data Base Program		
Island	No. of Locations Sampled	Range of Activity, all depths, (pCi/g)	0-15 cm Mean, (pCi/g)	No. of Locations Sampled	Range of Activity, all depths, (pCi/g)	0-15cm Mean (pCi/g)
Alice	23	0.7 - 141	44.1	26	<0.4 - 114	39.9
Belle	36	0.4 - 170	47.5	40	<0.4 - 204	61.0
Clara	13	0.8 - 110	35.4	8	0.3 - 105	22.4
Daisy	20	0.9 - 33	10.5	26	<0.4 - 34	6.8
Edna	8	2.7 - 6.4	4.7	5	<0.4 - 7	2.9
Irene	58	0.2 - 41	7.3	53	<0.4 - 54	6.1
Janet	139	0.6 - 180	27.0	364	<0.4 - 142	16.4
Kate	26	0.1 - 37	13.1	18	<0.4 - 35	7.8
Lucy	28	0.1 - 25	10.3	22	<0.4 - 40	11.7
Percy	6	0.1 - 17	7.3	2	<0.4 - 2	0.6
Mary	22	0.03 - 26	8.4	12	<0.4 - 18	6.0
Mary's Dau.	*	*	*	3	<0.4 - 72	12.3
Nancy	25	0.01 - 28	11.6	11	<0.4 - 60	10.8
Olive	26	0.1 - 28	7.7	50	<0.4 - 60	7.5
Pearl	53	0.2 - 55	12.4	72	<0.4 - 43	7.2
Pearl's Dau.	*	*	*	2	<0.4 - 7	5.6
Ruby	5	0.7 - 7.2	3.2	3	1.1 - 11	2.0
Sally	27	0.1 - 30	5.7	137	<0.4 - 43	3.5
Sally's Ch.	6	0.03 - 29	8.9	4	<0.4 - 13	6.9
Tilda	32	0.04 - 20	4.2	48	<0.4 - 20	3.2
Ursula	31	0.1 - 7.8	2.6	15	<0.4 - 4	1.2
Vera	25	0.03 - 12	4.4	48	<0.4 - 20	3.0
Wilma	23	0.3 - 7.2	2.0	17	<0.4 - 5	1.3
Yvonne+	51	0.02 - 3.6	1.0	14	<0.4 - 11	1.5
Sam	5	0.02 - 0.5	0.38	**	**	**
Tom	5	0.07 - 0.56	0.32	**	**	**
Uriah	8	0.02 - 0.23	0.11	**	**	**
Van	6	0.05 - 0.20	0.14	**	**	**
Alvin	5	0.03 - 0.29	0.11	**	**	**
Bruce	13	0.02 - 1.1	0.40	**	**	**
Clyde	4	0.02 - 0.13	0.06	**	**	**
David	48	0.03 - 1.0	0.40	**	**	**
Rex	7	0.02 - 1.2	0.51	**	**	**
Elmer	51	0.02 - 1.2	0.32	**	**	**
Walt	5	0.04 - 0.3	0.15	**	**	**
Fred	24	0.02 - 0.48	0.25	**	**	**
Glenn	28	0.01 - 1.8	0.60	**	**	**
Henry	15	0.004 - 0.7	0.25	**	**	**
Irwin	8	0.008 - 0.47	0.13	**	**	**
James	8	0.02 - 0.22	0.08	**	**	**
Keith	13	0.01 - 0.81	0.28	**	**	**
Leroy	11	0.5 - 10	5.06	8	<0.4 - 28	4.2

* Not sampled in 1972 survey
**Not sampled in 1979 FPDB survey
\+ South of 1310 bunker

TABLE 7-2. RESULTS BY ISLAND FOR ^{90}Sr IN 0-15 cm SOIL SAMPLES FROM THE 1972 RADIOLOGICAL SURVEY AND THE 1979 FISSION PRODUCT DATA BASE PROGRAM.

	1972 Radiological Survey			1979 Fission Product Data Base Program		
Island	No. of Locations Sampled	Range of Activity, all depths, (pCi/g)	0-15 cm Mean, (pCi/g)	No. of Locations Sampled	Range of Activity, all depths, (pCi/g)	0-15cm Mean (pCi/g)
Alice	23	14 - 430	107.9	7	1.3 - 347	85.9
Belle	36	9.8 - 670	148.9	11	3.5 - 339	107.4
Clara	13	13 - 310	99.2	4	1.4 - 243	42.8
Daisy	20	3.4 - 380	107.7	8	1.9 - 144	34.8
Edna	8	30 - 220	68.6	3	4.3 - 48	21.7
Irene	56	8.4 - 570	52.8	15	0.6 - 136	31.0
Janet	140	1.6 - 630	72.9	99	<0.1 - 244	31.9
Kate	26	1.6 - 200	43.5	6	1.0 - 31	13.3
Lucy	28	4.4 - 83	30.1	8	1.0 - 94	21.9
Percy	6	3.6 - 73	34.6	2	2.0 - 7	5.4
Mary	22	1.2 - 140	34.8	4	1.1 - 46	14.2
Mary's Dau.	*	*	*	1	5.2 - 107	41.9
Nancy	25	3.6 - 110	39.3	6	<0.15 - 82	20.1
Olive	26	2.0 - 70	21.5	12	<0.12 - 83	16.2
Pearl	52	2.3 - 140	28.3	17	0.4 - 38	11.4
Pearl's Dau.	*	*	*	1	1.3 - 28	18.0
Ruby	5	7.1 - 63	24.3	1	5.5 - 9	5.8
Sally	27	0.9 - 140	16.0	39	<0.10 - 25	4.4
Sally's Ch.	6	3.0 - 89	25.0	4	1.0 - 60	16.7
Tilda	32	2.2 - 54	19.1	15	<0.12 - 25	5.6
Ursula	31	0.9 - 19	8.2	15	<0.08 - 70	3.0
Vera	25	1.1 - 68	12.5	13	0.2 - 29	4.8
Wilma	23	0.3 - 19	6.0	5	0.2 - 19	2.9
Yvonne+	47	0.1 - 20	3.3	5	<0.13 - 5	1.1
Sam	5	0.5 - 0.8	0.72	**	**	**
Tom	5	0.18 - 1.2	0.72	**	**	**
Uriah	8	0.05 - 1.0	0.45	**	**	**
Van	6	0.10 - 0.81	0.41	**	**	**
Alvin	5	0.21 - 0.74	0.44	**	**	**
Bruce	13	0.03 - 1.8	0.59	**	**	**
Clyde	3	0.12 - 0.36	0.23	**	**	**
David	47	0.08 - 2.6	0.55	**	**	**
Rex	6	0.03 - 1.6	0.51	**	**	**
Elmer	51	0.02 - 5.1	0.76	**	**	**
Walt	5	0.25 - 0.6	0.41	**	**	**
Fred	24	0.16 - 1.5	0.61	**	**	**
Glenn	28	0.09 - 3.9	1.37	**	**	**
Henry	14	0.13 - 2.2	0.75	**	**	**
Irwin	8	0.14 - 1.6	0.69	**	**	**
James	8	0.13 - 2.2	0.69	**	**	**
Keith	13	0.03 - 1.8	0.88	**	**	**
Leroy	11	0.42 - 34	16.8	8	0.15 - 20	5.1

* Not sampled in 1972 survey
** Not sampled in 1979 FPDB survey
+ South of 1310 bunker

TABLE 7-3. RESULTS BY ISLAND FOR $^{239,240}Pu^{\dagger}$ IN 0-15 cm SOIL SAMPLES FROM THE 1972 RADIOLOGICAL SURVEY AND THE 1979 FISSION PRODUCT DATA BASE PROGRAM.

	1972 Radiological Survey			1979 Fission Product Data Base Program		
Island	No. of Locations Sampled	Range of Activity, all depths, (pCi/g)	0-15 cm Mean, (pCi/g)	No. of Locations Sampled	Range of Activity, all depths, (pCi/g)	0-15cm Mean (pCi/g)
Alice	22	3.9 - 68	15.6	26	<2 - 226	20.5
Belle	35	4.2 - 100	27.1	40	<2 - 245	34.5
Clara	13	3.5 - 88	31.6	8	<2.5 - 54	16.0
Daisy	20	3.8 - 98	31.6	26	<2 - 121	25.4
Edna	8	13 - 24	19.4	5	9.4 - 28	17.8
Irene	56	2.4 - 280	26.2	53	<4 - 187	29.5
Janet	138	0.1 - 175++	16.2	364	<3 - 119	10.1
Kate	26	0.2 - 50	11.3	18	<1.5 - 27	5.0
Lucy	28	1.5 - 23	7.7	22	<1.5 - 74	10.1
Percy	6	1.5 - 23	9.0	2	<1.5 - 2.7	1.7
Mary	22	0.9 - 35	10.1	12	<1.5 - 27	7.2
Mary's Dau.	*	*	*	3	<1.5 - 44	8.4
Nancy	25	1.3 - 28	10.1	14	<1.5 - 48	8.0
Olive	26	1.9 - 30	8.4	50	<2 - 72	6.4
Pearl	52	0.3 - 530	38.3	72	<3.5 - 130	15.5
Pearl's Dau.	*	*	*	2	<6 - 85	44.8
Ruby	5	3.0 - 24	14.5	3	<3.5 - 7.5	5.6
Sally	27	0.2 - 130	11.0	137	<2 - 72	2.2
Sally's Ch.	6	5.6 - 78	26.9	4	<1.5 - 51	12.1
Tilda	29	1.1 - 34	6.5	48	<1.5 - 20	2.0
Ursula	31	0.2 - 4.2	1.8	15	<1.5 - 2.5	0.6
Vera	25	0.6 - 25	4.3	48	<1.5 - 22	2.2
Wilma	22	0.1 - 5.3	1.8	17	<1.5 - 10	1.1
Yvonne+	49	0.02 - 50	8.7	14	<4.5 - 93	11.6
Sam	5	0.03 - 0.2	0.09	**	**	**
Tom	5	0.01 - 0.13	0.08	**	**	**
Uriah	8	0.02 - 0.12	0.09	**	**	**
Van	6	0.04 - 0.11	0.08	**	**	**
Alvin	5	0.02 - 0.11	0.06	**	**	**
Bruce	13	0.02 - 0.22	0.09	**	**	**
Clyde	4	0.04 - 0.11	0.06	**	**	**
David	48	0.004 - 0.23	0.05	**	**	**
Rex	7	0.02 - 0.06	0.04	**	**	**
Elmer	50	0.01 - 5.5	0.21	**	**	**
Walt	5	0.02 - 0.06	0.04	**	**	**
Fred	23	0.02 - 0.4	0.08	**	**	**
Glenn	28	0.005 - 0.3	0.11	**	**	**
Henry	14	0.07 - 0.23	0.14	**	**	**
Irwin	8	0.01 - 0.22	0.13	**	**	**
James	8	0.02 - 0.16	0.08	**	**	**
Keith	13	0.01 - 0.17	0.11	**	**	**
Leroy	11	0.02 - 2.3	1.15	8	<3 - 24	1.7

† $^{239,240}Pu$ estimated from ^{241}Am data
* Not sampled in 1972 survey
** Not sampled in 1979 FPDB survey
+ South of 1310 bunker
++This value is suspect in light of other information. The next highest activity was 116 pCi/g, which appears to be a reliable value.

during cleanup. Final numbers using the revised conversion factor are the basis for all final tables and isopleths. The second aspect deals with the computation of the standard deviation on some of the ratio of TRU to ^{241}Am. Subsequent to the project, a programming error was discovered that caused the standard deviation to be calculated incorrectly. The standard deviations reported in the following chapter are correct. Additional information concerning this problem is in the preface to Appendix B.

The ground zero islands, which are also the islands where cleanup was done, are discussed in Section 7.5. The same maps and information as for other northern islands are included, and in addition there are maps of the pre-cleanup condition, subsurface sampling, and post-cleanup isopleths for 0-40 cm average ^{137}Cs and ^{90}Sr activities. All the isopleths were drawn by hand using the final activity data along with other related knowledge. For example, the activities of TRU, ^{137}Cs and ^{90}Sr are known to be very low on the beaches, and this information was sometimes used to close an isopleth line.

The microfiche of raw data at the back of this report includes pre-cleanup and final post-cleanup surface data, all subsurface data, and all the data from the Fission Product Data Base Program (FPDB) (see Section 6.11) for all islands. Copies of all Island Certifications also appear in the microfiche; only summary statements from the Certifications are presented in this Chapter. Specimens of two Certification formats are presented in Section 7.6.

7.2 SOUTHERN ISLANDS

7.2.1 David

Background

Island David (Marshallese: Japtan), an island 32.0 hectares in area, lies immediately north of the Deep Passage in the southeast section of the Atoll. It was the site of a German coconut plantation in the nineteenth century, and some of those trees were still present when the cleanup began.

The island was used as a housing area for research animals, as a radio receiver site, and as a recreational area at various times during the nuclear test operations. There were no ground zero sites, no known or suspected burial sites, nor any contaminated materials on David. David received fallout from only three nuclear events and the accumulated H + 1 hour exposure rate was just 1 R/h.

After the end of nuclear test operations, a 3,000 square foot building was constructed to house equipment during the time Enewetak Atoll was a missile target area. This building and several other structures remained until the cleanup. Some of them were rehabilitated for use by the driEnewetak.

1972 Survey Results

Soil samples were taken at 50 locations on David during the 1972 survey, and a number of vegetation and animal samples were also taken. Profile samples to 115 cm depth were taken at seven locations, and 0-15 cm core samples were taken at the other 43. The activities of ^{137}Cs, ^{90}Sr and $^{239,240}Pu$ were very low, rarely exceeding 1.0 pCi/g, and tended to be constant or decrease slowly with depth. Tables 7-1, 7-2 and 7-3 give summary results for 0-15 cm data on ^{137}Cs, ^{90}Sr and $^{239,240}Pu$, respectively.

Characterization Results

Soil samples were taken at eight locations during the cleanup using the standard procedure (see Section 4.2.1). The TRU activity was less than 0.5 pCi/g in all the samples, so David met Condition C with no soil removal. No IMP measurements were made on David because the TRU activity was too low for the results to be meaningful. No samples were taken for the Fission Product Data Base Program because the 1972 data were sufficient for the dose assessment (see Section 6.11). The island average transuranics value reported in the Certification is 0.2 pCi/gm for surface soil, and the transuranics classification is Residence.

7.2.2 Elmer

Background

Island Elmer (Marshallese: Medren) lies just south of the Deep Passage in the southeastern area of the Atoll, and has an area of 80.0 hectares. Elmer was one of the main support islands during nuclear testing operations, so many buildings, concrete pads and other facilities were constructed on the island. Most of these remained until the cleanup. The metal debris and structures were uncontaminated except for parts of a few former laboratory buildings.

There were no ground zero sites on Elmer, no known or suspected burial sites, except possibly for an old decontamination area. Elmer's accumulated H + 1 hour exposure rate of 2.6 R/h resulted from fallout from five events.

1972 Survey Results

Soil samples were taken at 51 locations on Elmer, with 0-125 cm profile samples taken at eight locations, and 0-15 cm core samples at the remaining 43 locations. Several animal and vegetation samples were also taken.

One location on Elmer showed unusually high gamma exposure readings in the 1972 aerial survey results. This was determined to have been caused by a ^{60}Co source which had been left behind when test operations ended; the source was subsequently removed. Other areas of the island which had somewhat elevated activity were near old decontamination and laboratory facilities.

The depth distributions of ^{137}Cs, ^{90}Sr and $^{239,240}Pu$ activities were all roughly similar, either decreasing slowly with depth or remaining constant at a very low activity. Tables 7-1, 7-2, and 7-3 summarize the 0-15 cm data for ^{137}Cs, ^{90}Sr and $^{239,240}Pu$, respectively.

Characterization Results

IMP measurements were taken at 25 m spacing in the area of Elmer where the laboratory and decontamination facilities had been. A total of 91 locations were measured in October and November 1978, and no significant concentrations of TRU activity were found. Six soil samples were also taken using the standard procedure (see Section 4.2.1), and the activities of ^{137}Cs and TRU were less than 1.0 pCi/g in all the samples.

Soil was removed by Joint Task Group personnel in the summer of 1978. This contamination appeared to have been caused by laboratory or technical activities during testing operations. Portable instruments were used to locate the contamination and define the cleanup boundaries.

No other soil removal was required for Elmer to satisfy Condition C. The data from the 1972 survey were determined to be sufficient for the dose assessment (see Section 6.11), so Elmer was not sampled in the Fission Product Data Base Program. The island average transuranics value reported in the Certification is 0.3 pCi/gm for surface soil, and the transuranics classification is Residence.

7.2.3 Fred

Background

Island Fred (Marshallese: Enewetak) is the largest island in the Atoll at 130.0 hectares. It was one of the main support bases during nuclear testing operations and also was a support area for various programs after nuclear testing including the cleanup of the Atoll. There were many structures, concrete pads, and an 8,000-foot runway on Fred when the cleanup began. A number of the buildings were rehabilitated for use by the people of Enewetak, and the runway was also left in place. Because of the numerous buildings, Fred had only sparse vegetation.

There was also a large quantity of metal debris, especially at the north end of this island and in the lagoon near the center of the island. Neither the structures nor the debris were radioactively contaminated.

There were no known or suspected burial areas and no ground zero sites on Fred. However, one area was known to have been used for decontamination, and drains or drain outfalls from these might have some residual contamination. Fallout from four nuclear events affected Fred, resulting in a total H + 1 hour exposure rate of 2.6 R/h.

1972 Survey Results

Soil samples were taken at 24 locations on Fred, with 0-125 cm profiles at four locations and 0-15 cm core samples at the remaining 20 locations. Several vegetation samples were also taken.

The depth distributions of ^{137}Cs, ^{90}Sr and $^{239,240}Pu$ were similar, either decreasing gradually with depth or remaining constant at a low activity level. The surface activity of all four isotopes was very low throughout the island. Tables 7-1, 7-2 and 7-3 summarize the results for 0-15 cm data for ^{137}Cs, ^{90}Sr and $^{239,240}Pu$, respectively.

Characterization Results

IMP measurements were made in August 1979 at 14 locations in the former decontamination area. The 1972 aerial survey results (see Section 3.1) were used to select several other IMP sampling locations that had the greatest potential for showing measurable TRU activity. Measurements were also taken at enough additional points to provide a representative sampling of the island. None of these 28 locations showed any significant ^{241}Am or ^{60}Co activity.

The 1972 data were considered to be adequate, so no surface soil samples or Fission Product Data Base samples were taken. The island average transuranics value is stated in the Certification to be less than 0.5 pCi/gm for surface soil, and the transuranics classification is Residence.

7.2.4 Leroy

Background

Island Leroy (Marshallese: Biken) is the westernmost island in the Atoll. Although generally included among the southern islands, it is isolated from all other islands, standing alone on the reef just north of the Southwest Passage. Its area is about 5.5 hectares, and it is heavily vegetated, mostly with pisonia and coconut trees.

There were no ground zero sites on Leroy, but the island was subject to fallout from 13 events, two of which were within ten miles of the island. It ranks 23rd among the islands of the Atoll in total H + 1 hour exposure rates with 235 R/h. Leroy had no known or suspected burial sites for radioactive material, but there were some remnants of the scientific stations used during three of the nuclear test operations.

1972 Survey Results

During the 1972 survey, 11 sites were soil sampled, and several vegetation and animal samples were taken. Eight of the sites had 0-15 cm core samples, and the other three had 0-35 cm profiles. Tables 7-1, 7-2 and 7-3 contain a summary of the soil sampling results. Activity of $^{239,240}Pu$, ^{137}Cs and ^{90}Sr in general declined with depth.

Characterization Results

The activity of all the 1972 samples was so far below all the cleanup criteria that an IMP survey was not considered necessary.

Surface soil samples were taken at four sites using the standard surface sampling pattern, giving a total of eight composites. Two additional composites were taken at a fifth site at 10 cm depth. The TRU values ranged from 0.71 pCi/g to 4.32 pCi/g, showing good agreement with the 1972 results.

Leroy was also sampled for the Fission Product Data Base in support of the dose assessment. Because no grid lanes were cut on this island, the eight sampling locations, shown in Figure 7-1, are only approximate. The results are summarized in Tables 7-1, 7-2 and 7-3. The activity declined with depth, as had the 1972 samples, and since the maximum TRU value was 37.3 pCi/g in a 0-5 cm sample, no further investigation was done.

The island average transuranics value reported in the Certification is 2.5 pCi/gm for surface soil, and the transuranics classification is Residence.

7.2.5 Other Southern Islands

All of the 14 islands in the southern half of Enewetak Atoll that were not discussed in sections 7.2.1 through 7.2.4 are less than 17 hectares (ha) in area. None had any known or suspected burial areas or ground zero sites, and there were few scientific stations and relatively little debris on these islands. The accumulated H + 1 hour exposure rate was very low for all these islands.

The 14 islands listed in Table 7-4 were sampled during the 1972 survey; in most cases, the sampling included some 0-15 cm cores, a few 0-35 cm profile samples, and some animal and vegetation samples. In general, the depth distributions of ^{137}Cs, ^{90}Sr and $^{239,240}Pu$ followed one of two patterns: In areas with dense vegetation, the activity decreased slowly within the top 20 cm, while in sparsely-vegetated areas, activity was homogeneous and very low. Tables 7-1, 7-2 and 7-3 summarize the results for 0-15 cm core samples from these islands for ^{137}Cs, ^{90}Sr and $^{239,240}Pu$, respectively.

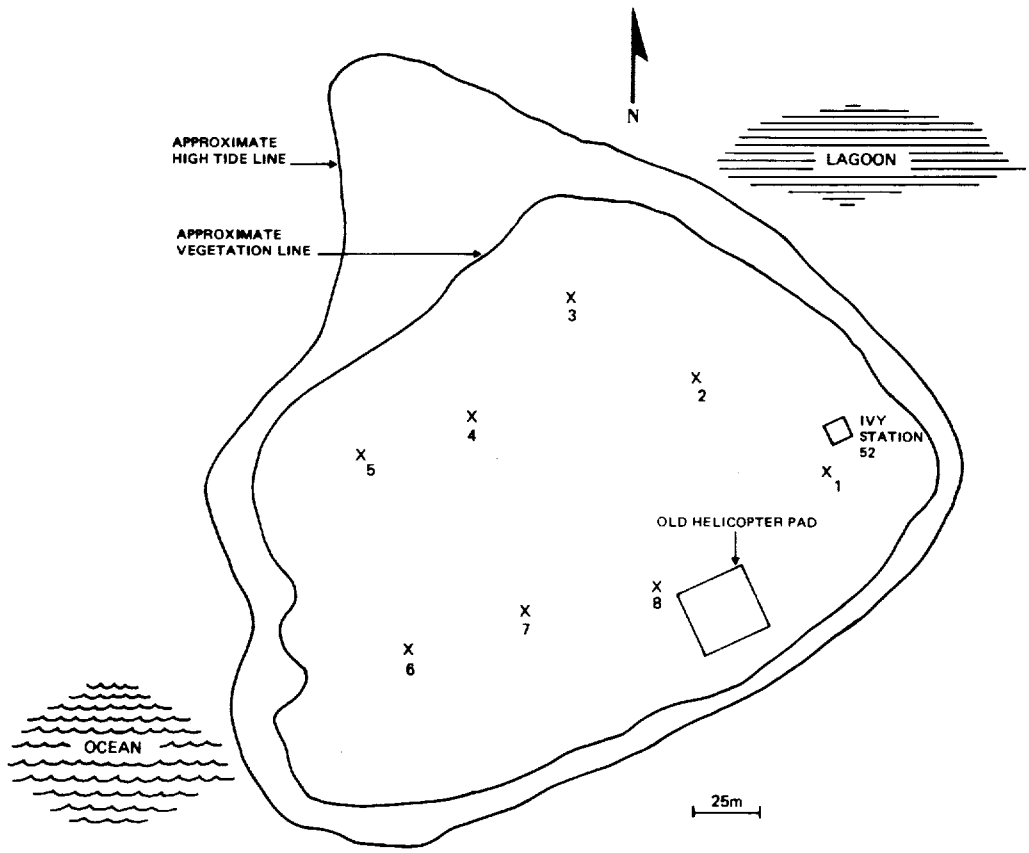
Surface soil samples were taken on these islands during the cleanup. All samples had TRU activity less than 1 pCi/g. No IMP measurements were made because the surface TRU activity was too low to obtain meaningful data. Also because of the low activity, no Fission Product Data Base samples were taken.

Consideration was given to sampling the reference points Mack and Oscar in the lagoon. Oscar is now a concrete pillar washed by waves at high tide, and it was impossible to sample the concrete surface safely. The above-surface structure at Mack no longer exists; only a subsurface prominence remains. Sampling of Mack was therefore considered to be neither feasible nor necessary.

Other than debris removal, no cleanup was required on any of the southern islands.

TABLE 7-4. NUMBER OF SOIL SAMPLING LOCATIONS ON SMALL SOUTHERN ISLANDS.

Site Name	Marshallese Name	Island Size (ha)	Number of Soil Sampling Locations 1972	1979
Sam	Boko	0.4	5	4
Tom	Munjor	0.7	5	4
Uriah	Inedral	1.6	8	4
Van	none	2.7	6	4
Alvin	Jinedrol	0.9	5	4
Bruce	Ananij	10.0	13	4
Clyde	Jinimi	1.2	4	4
Rex	Jedrol	2.2	7	4
Walt	Bokandretok	0.3	5	4
Glenn	Ikuren	16.8	28	5
Henry	Mut	16.3	15	4
Irwin	Boken	12.0	8	4
James	Ribewon	7.6	8	4
Keith	Kidrenen	9.8	13	4



X = LOCATION OF FISSION PRODUCT DATA BASE SAMPLES
(ALL LOCATIONS APPROXIMATE)

FIGURE 7-1. SAMPLING LOCATIONS ON ISLAND LEROY

7.3 NORTHWEST ISLANDS

7.3.1 Alice

Background

Island Alice (Marshallese: Bokoluo) is the westernmost of the northern islands of Enewetak Atoll. It has an area of 9.0 hectares with mostly sandy soil and vegetation cover ranging from light to dense.

There were no nuclear events on Alice during testing operations but there were several scientific stations and, at one time, a runway down the center of the island. The runway was gone by the time of the cleanup, but a helicopter pad made of pierced steel matting remained, and there was other scrap metal scattered over the island. Besides the scrap metal and other scattered debris, a three story photo bunker remained on Alice at the time of the cleanup.

During nuclear testing operations, the soil on the northeastern end of Alice was graded, and all the brush stripped. The brush had grown back by 1972.

There were no known or suspected contaminated burial areas on Alice, and the metal scrap had no activity above background except for a derelict landing craft on the east beach. As a result of nearby nuclear events, Alice ranks ninth among the islands in the Atoll in total H + 1 hour exposure rate, having received 3,383 R/h.

1972 Survey Results

Soil samples were taken at 23 locations on Alice during the 1972 survey. At four locations, 0-35 cm profiles were taken, a 0-65 cm profile was taken at one location, and 0-15 cm core samples were taken at the other 18 locations. A few vegetation samples were also taken on Alice.

At two of the 0-35 cm profile locations, the activity of $^{239,240}Pu$ either rose with depth or remained constant. One of these was on the ocean-side beach, and the other was in the northeast area where the soil was graded during test operations. At the other profile locations, $^{239,240}Pu$ activity fell with depth. The depth distribution of ^{90}Sr and ^{137}Cs generally followed the same pattern as $^{239,240}Pu$. Tables 7-1, 7-2 and 7-3 summarize the results for 0-15 cm data for ^{137}Cs, ^{90}Sr and $^{239,240}Pu$, respectively.

Surface Characterization

Alice was initially measured with the IMP on a 50 m grid in early February 1978, at the locations shown in Figure 7-2. Detector SN:496 was used to make the measurements, and it was inadvertently operated at an incorrect bias voltage.

Soil samples to determine the ratio of TRU to ^{241}Am were taken 21 February 1978 at five locations, with two composites at each of three depths for a total of 30 samples. (See Section 4.2.1 for details on the procedure.) These samples were used to estimate the ratio of TRU to ^{241}Am to be 3.2 ± 0.09 (see Tech Note 2.7).

Although the values for ^{241}Am determined from soil samples are rarely the same at a given location as the ^{241}Am measured by the IMP, the discrepancy in the Alice data was unusually large. The problem was traced to the incorrect operating voltage on the detector, which had affected measurements on several islands. A correction factor of 1.6 ± 0.24 was determined by remeasuring several locations on Sally at the correct voltage, and the data values measured at the incorrect voltage were multiplied by this factor. (Tech Note 5.0 contains details on the determination of this value.)

Even with the correction factor, Alice IMP data still showed a large discrepancy from the soil data, so additional measurements and soil samples were taken in April 1978. Seven locations, one of which had been sampled in February, were soil sampled, taking four composites instead of the usual two. The ratio of TRU to ^{241}Am determined from these samples was the same as the ratio previously determined.

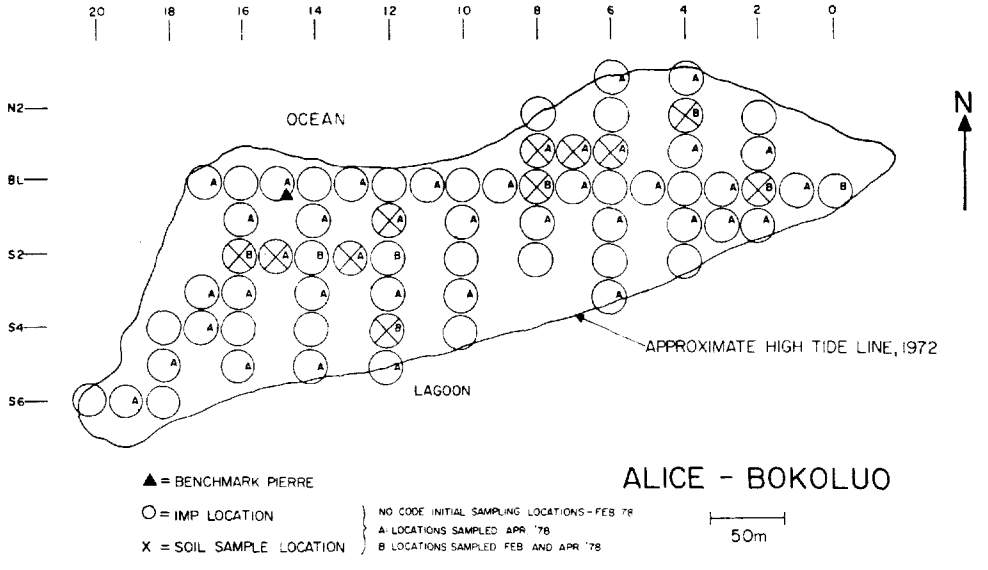


FIGURE 7-2. COASTLINE AND DATA COLLECTION LOCATIONS FOR ISLAND ALICE

IMP measurements were made at 45 locations; eight were at locations originally measured on the 50 m grid and the remainder were on intermediate 25 m grid nodes. Figure 7-2 shows the additional soil and IMP sampling locations.

Two of the eight repeat IMP measurements were not comparable to the original data because the soil at those locations was severely disturbed when the photo bunker was demolished and removed. The other six repeat measurements were used to compute an additional correction factor of 1.72 ± 0.18 (see Tech Note 5.1). This correction resolved most, but not all, of the remaining discrepancy between soil and IMP data.

In July 1978 it was discovered that detector SN:496 had suffered a step-function loss of efficiency during the period 17-21 March 1978 as a result of mechanical damage. The measurements on Alice had been done after the damage, so an additional detector effective area correction factor of 1.16 should have been applied (see Tech Note 5.2). The computed voltage correction would then have been 2.00 instead of 1.72. The final characterization of Alice for surface TRU activity included both voltage corrections, the efficiency correction, and was based on final IMP data (see Tech Note 23 for discussion of original versus final data).

Fission Product Sampling and Subsurface Investigations

Alice was sampled on a 50 m grid for the Fission Product Data Base Program (FPDB) in support of the dose assessment (see Section 6.11). Samples were taken at 26 locations and soil from seven of these was analyzed for ^{90}Sr. Tables 7-1, 7-2 and 7-3 summarize the results for 0-15 cm data for ^{137}Cs, ^{90}Sr, and $^{239,240}Pu$, respectively.

Two locations, 4-BL-0 and 14-S-4, each had one subsurface sample with TRU activity in excess of 160 pCi/g. The two locations were investigated using the method described in Tech Note 18. No further evidence of subsurface contamination was found, as shown by the results in Figures 7-4 and 7-5. It was concluded that the two elevated subsurface observations resulted from surface soil being disturbed and mixed during lane-cutting and debris-removal activities.

Final Characterization

Figure 7-3 shows isopleths on the surface TRU activity on Alice, based on final data, including all voltage and efficiency corrections. Island averages for TRU, ^{137}Cs and ^{60}Co are given in Table 7-5. The island average transuranics value reported in the Certification is 76 pCi/gm for surface soil, and the transuranics classification is Food Gathering.

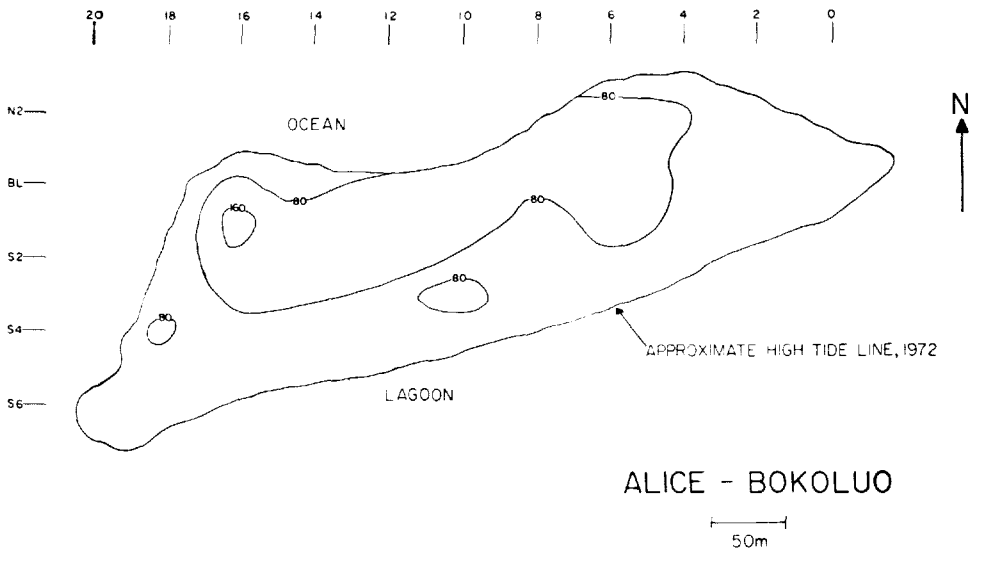


FIGURE 7-3. ISOPLETHS ON FINAL ESTIMATED SURFACE TRU ACTIVITY IN pCi/g FOR ISLAND ALICE

TABLE 7-5. POST CLEANUP ISLAND AVERAGE TRU* IN SURFACE SOIL AND AVERAGE EXPOSURE RATES FOR ^{137}Cs AND ^{60}Co

Island	Approx. Area, ha	Number of Points on Primary Grid	TRU, pCi/g Range	TRU, pCi/g Mean	^{137}Cs R/h @ 1 m	^{60}Co R/h @ 1 m
Alice	9.0	27	6.4 - 185.7	75.9	29.3	17.4
Belle	12.0	43	11.8 - 155.9	95.2	35.8	15.2
Clara	3.0	24	19.9 - 75.2	40.1	18.3	9.2
Daisy	8.5	30	10.4 - 122.8	43.3	4.4	7.0
Edna	4.0	12	23.8 - 39.1	32.7**	-	-
Edna D.	0.5	2	87.5 - 121.9	103.0**	-	-
Irene	18.0	61	6.0 - 131.2	31.5	3.3	13.0
Janet	118.0	376	0.1 - 63.4	19.8	10.2	3.3
Kate	6.5	21	3.7 - 52.9	20.2	5.0	1.8
Lucy	8.0	28	1.6 - 81.5	35.0	6.1	2.6
Percy	0.8	6	1.9 - 17.1	5.8**	-	-
Mary	5.0	12	5.0 - 54.8	18.5	3.1	1.4
Mary D.	0.5	4	8.8 - 138.8	54.3**	-	-
Nancy	4.5	47	7.1 - 64.7	33.5	6.8	2.2
Olive	16.5	54	2.8 - 65.3	19.7	5.1	1.9
Pearl	22.0	76	7.7 - 98.6	36.4	4.0	7.0
Pearl D.	0.5	3	69.1 - 165.2	122.8**	-	-
Ruby	1.5	9	1.8 - 12.7	8.2	0.6	3.8
Sally	40.0	153	0.1 - 81.2	7.5	2.0	1.5
Sally C.	0.8	6	12.5 - 33.4	20.7**	-	-
Tilda	21.0	58	0.4 - 19.9	6.6	2.3	0.7
Ursula	16.0	16	0.3 - 4.4	1.9	0.9	0.3
Vera	15.5	57	1.0 - 13.3	7.2	1.7	0.5
Wilma	6.5	20	0.4 - 7.7	3.3	0.8	0.3
S. Yvonne***	15.5	135	0.1 - 34.4	7.8	0.6	2.5
N. Yvonne	21.5	298	0.1 - 275.2	41.2	2.6	5.0

* TRU is defined as the sum of ^{241}Am, ^{238}Pu, $^{239,240}Pu$ in soil.
** TRU from soil samples; ^{137}Cs and ^{60}Co results not computed.
*** South of 1310 bunker.

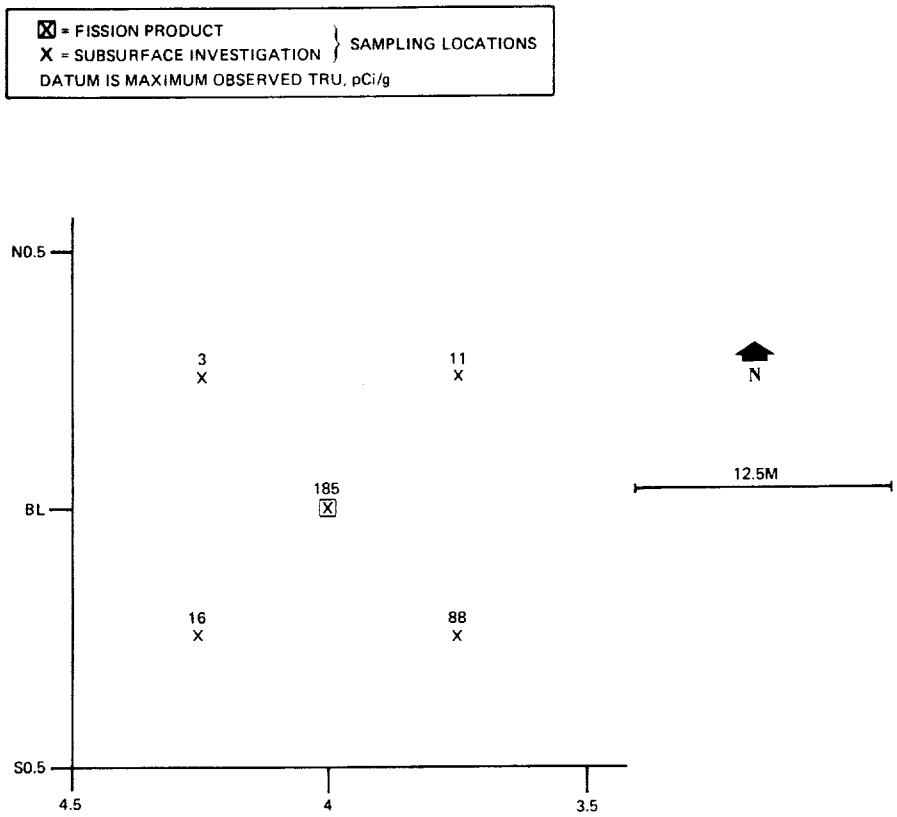


FIGURE 7-4. SUBSURFACE SAMPLING RESULTS, LOCATION 4BLO, ISLAND ALICE

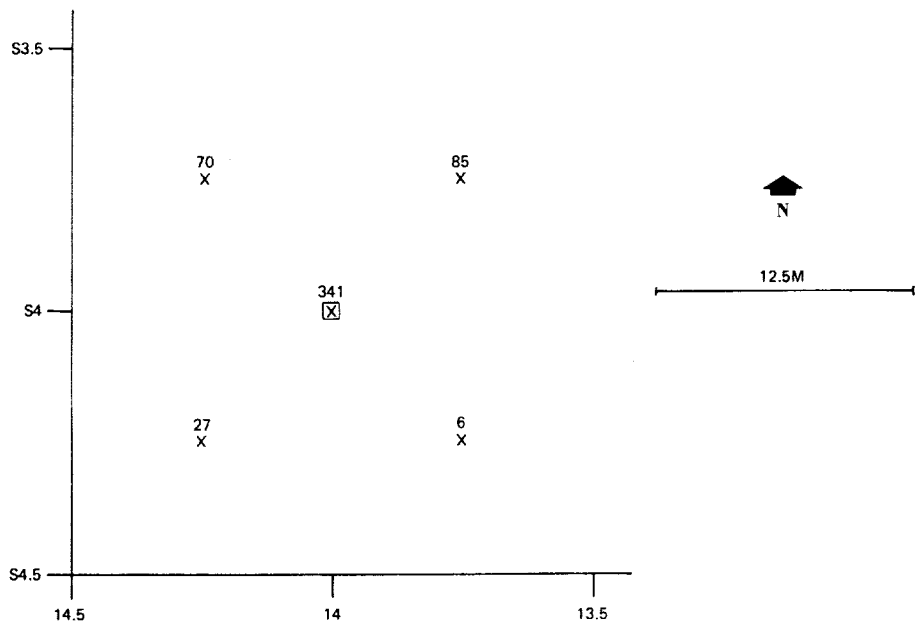


FIGURE 7-5. SUBSURFACE SAMPLING RESULTS, LOCATION 14S4, ISLAND ALICE

7.3.2 Belle

Background

Island Belle (Marshallese: Bokombako) with an area of 12.0 hectares is the largest in the six-island chain that lies west of Irene. The soil on Belle is mostly sandy and, except for two sparsely-vegetated areas near the east end of the island, is covered with dense vegetation.

There were no ground zeros on Belle during nuclear testing operations, but there were a few scientific stations on the island. Some of the stations and some metal and concrete debris remained on Belle until the cleanup. There were no known or suspected areas of buried contamination on Belle. As a result of fallout from several nearby nuclear events, Belle ranks 10th among the islands in the Atoll in total H + 1 hour exposure rate with 3,382 R/h.

1972 Survey Results

During the 1972 survey, soil samples were taken at 36 locations on Belle, and a few vegetation samples were also taken. At four of the soil sampling locations, 0-35 cm profile samples were taken, at one location a 0-55 cm profile sample was taken, and 0-15 cm core samples were taken at the other 31 locations.

The depth distributions of ^{137}Cs, ^{90}Sr and $^{239,240}Pu$ activities all followed a similar pattern, in which activity dropped steeply with depth below 5 cm. The distribution of activity of these isotopes on the island surface appeared to be related to vegetation density. In the sparsely-vegetated areas on the east end of Belle, the average activity was as much as a factor of three lower than in the areas with dense vegetation. However, the actual difference in activity might be less because only a few samples were taken in the less-vegetated sections so they might not be representative. Also, the results of the aerial surveys of 1972 and 1977 (see Section 3.1) did not indicate a difference as large as a factor of three, nor did the IMP measurements during the cleanup. The results of the 1972 sampling for 0-15 cm data on ^{137}Cs, ^{90}Sr and $^{239,240}Pu$ are summarized in Tables 7-1, 7-2 and 7-3, respectively.

Surface Characterization

Belle was initially measured by the IMP on a 50 m grid from 13-16 February 1978 at the locations shown in Figure 7-6. There had been some disturbance of the soil when the lanes were cut to allow the grid to be staked. This disturbance had only a minor effect on the IMP measurements, but later subsurface investigations were strongly influenced by the soil mixing.

Soil samples to determine the ratio of TRU to ^{241}Am were taken at five locations, with two composites at each of three depths for a total of 30 samples (see Section 4.2.1 for sampling procedure). The soil sample results were used to estimate the ratio to be 3.8 $\pm$ 0.09 (see Tech Note 2.8). Figure 7-6 shows the soil sampling locations.

Detector SN:496 was used for the IMP measurements on Belle, and because it had been operated at an incorrect bias voltage, the calculated ^{241}Am values were too low. Tech Note 5.0 describes the data and methods used to compute a correction factor of 1.6 for the data. Because the 1.6 factor was applicable to only part of the islands affected by the voltage problem, Belle was later completely remeasured at the original locations on the 50 m grid. The results confirmed that the factor of 1.6 was valid for Belle.

The corrected IMP ^{241}Am data and the estimated ratio of TRU to ^{241}Am were used to estimate TRU values at each location. These values were then used to make kriging estimates of 0.5 ha average TRU activity and of the 0.5 s upper bound on the estimated average where s is the kriging standard deviation (see Section 5.1). No upper bound on a 0.5 ha average exceeded 160 pCi/g in TRU activity based on original data (see Tech Note 23 for discussion of original versus final data). It was concluded that Belle met Condition A without soil removal.

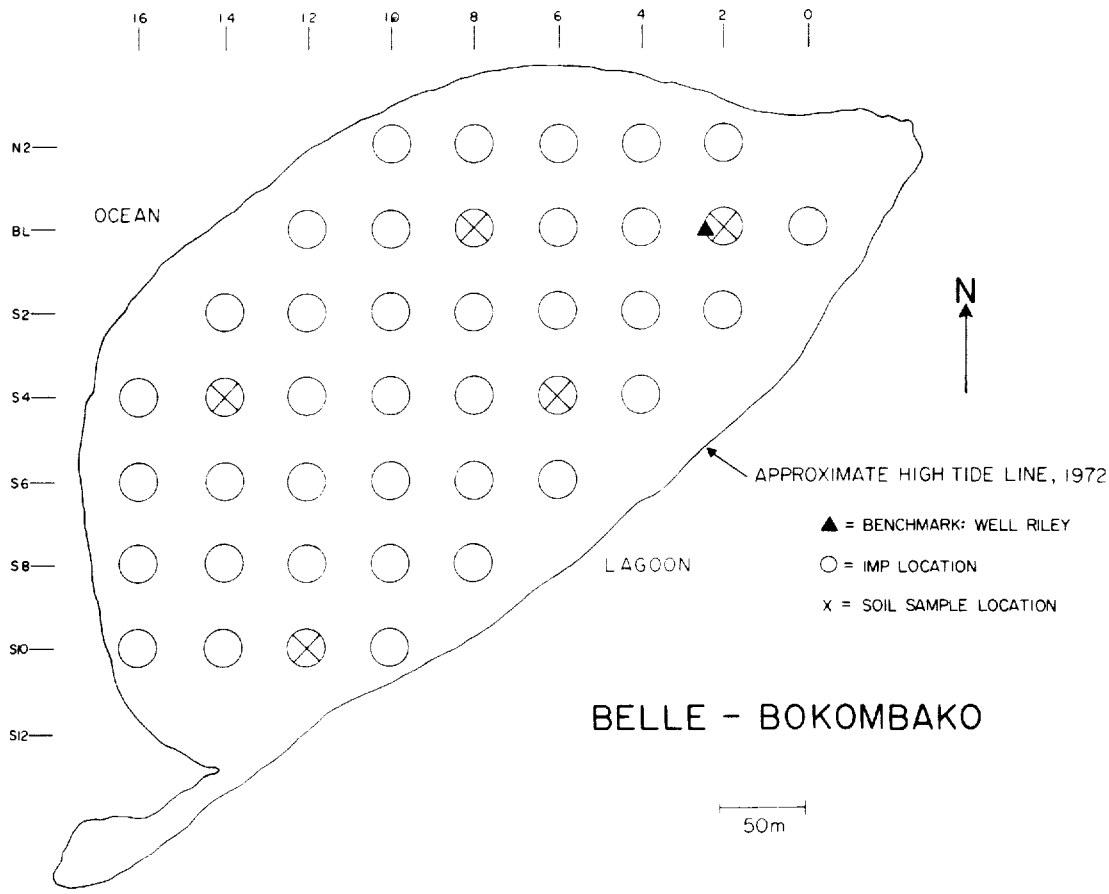


FIGURE 7-6. COASTLINE AND DATA COLLECTION LOCATIONS FOR ISLAND BELLE

Fission Product Sampling and Subsurface Investigations

Belle was sampled on a 50 m grid for the Fission Product Data Base (FPDB) sampling program in support of the dose assessment (see Section 6.11). There were 40 sampling locations, and soil from 11 of these was analyzed for ^{90}Sr. Tables 7-1, 7-2 and 7-3 summarize the results for 0-15 cm data on ^{137}Cs, ^{90}Sr and $^{239,240}Pu$, respectively.

Analysis of the FPDB samples showed that eight locations had subsurface TRU activity exceeding 160 pCi/g. All eight locations, 0-BL-0, 2-N-2, 6-N-2, 8-N-2, 12-BL-0, 14-S-2, 16-S-6, and 16-S-8, were investigated in July 1979 using the method described in Tech Note 18. As shown by Figures 7-7 and 7-8 respectively, no further evidence of elevated subsurface activity was found at 0-BL-0 or 2-N-2. At all of the other locations several iterations of sampling were done, including one set that was inadvertently taken at the wrong distance at locations 14-S-2, 16-S-6, and 16-S-8. Other than the original FPDB samples which exceeded 160 pCi/g, no sample deeper than the 0-5 cm interval had TRU activity exceeding 160 pCi/g. This result led to the conclusion that the elevated subsurface activity in the FPDB samples resulted from surface soil having been mixed and turned under. (All the subsequent samples were taken in undisturbed areas.)

Many of the 0-5 cm samples had TRU activity greater than 160 pCi/g but none of the 5-10 cm or deeper samples did (other than the original FPDB samples). It was therefore not obvious whether there might be some 0.0625 ha with TRU activity exceeding 160 pCi/g in the 2.5 - 7.5 cm layer, which was considered to be the shallowest subsurface 5 cm increment. The method described in

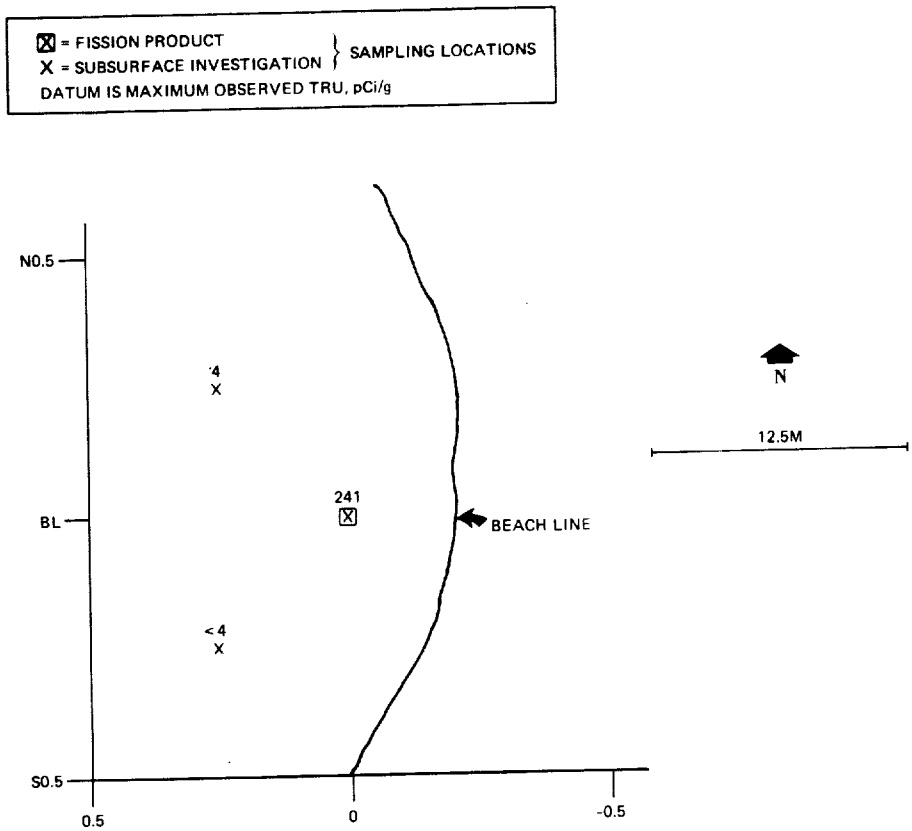


FIGURE 7-7. SUBSURFACE SAMPLING RESULTS, LOCATION OBLO, ISLAND BELLE

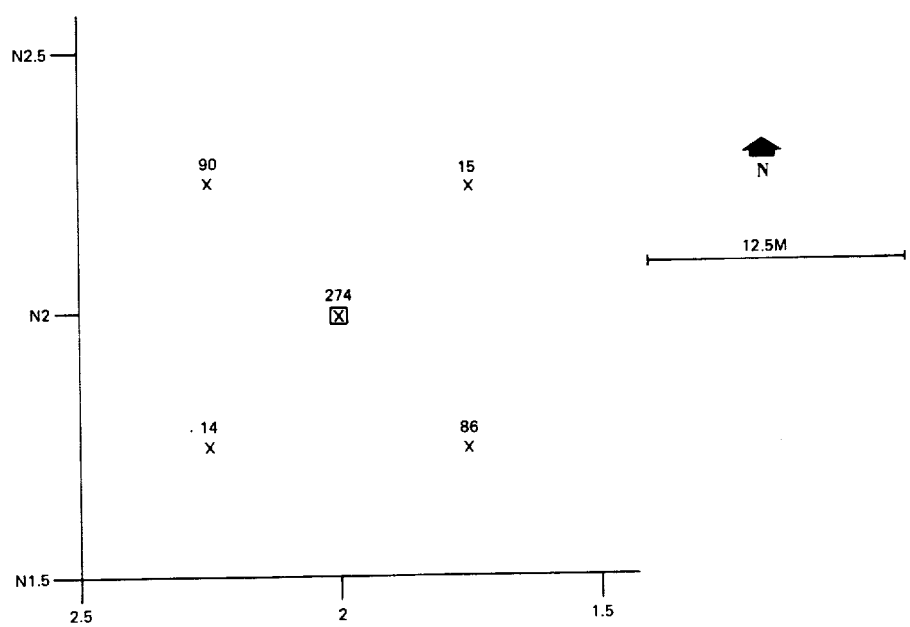


FIGURE 7-8. SUBSURFACE RESULTS, LOCATION 2N2, ISLAND BELLE

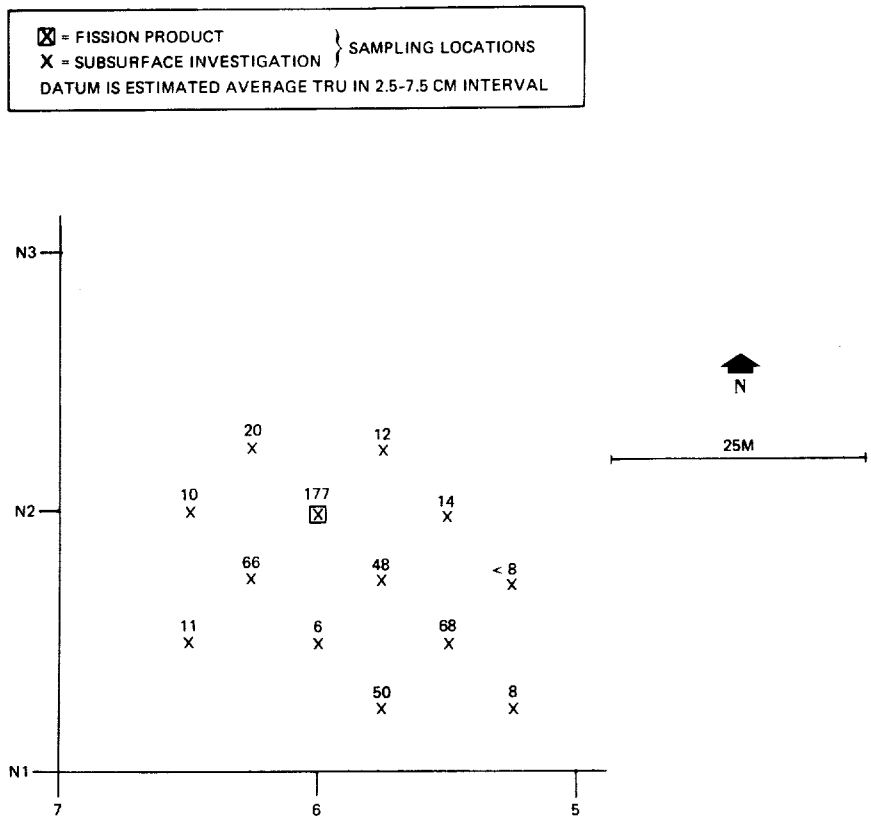


FIGURE 7-9. SUBSURFACE SAMPLING RESULTS, LOCATION 6N2, ISLAND BELLE

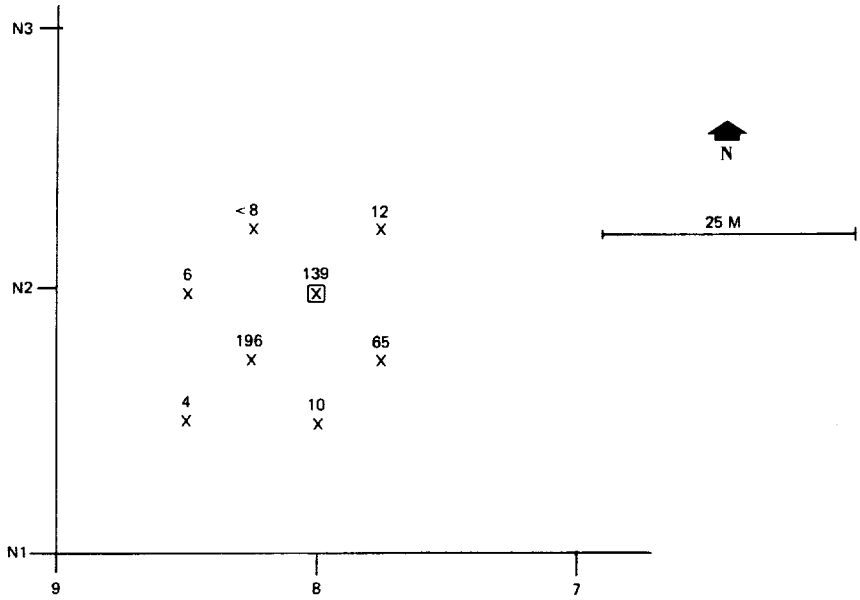


FIGURE 7-10. SUBSURFACE SAMPLING RESULTS, LOCATION 8N2, ISLAND BELLE

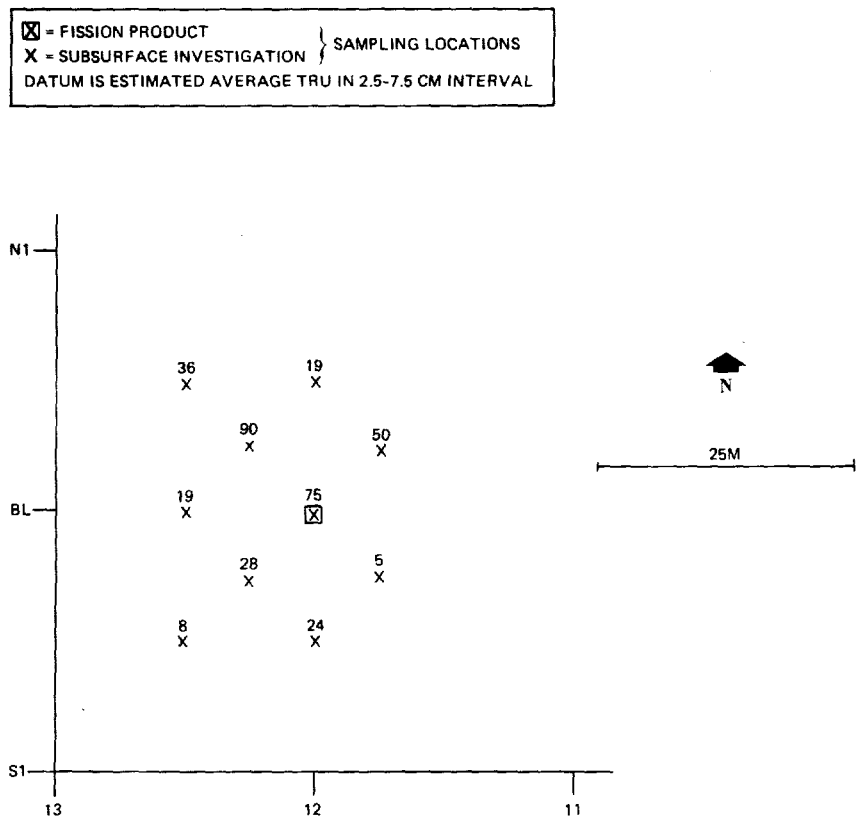


FIGURE 7-11. SUBSURFACE SAMPLING RESULTS, LOCATION 12BLO, ISLAND BELLE

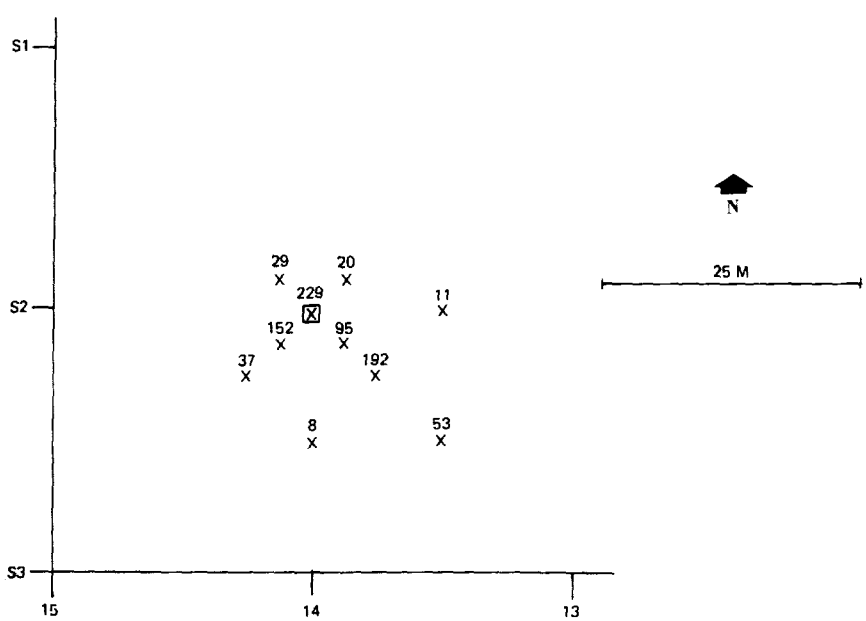


FIGURE 7-12. SUBSURFACE SAMPLING RESULTS, LOCATION 14S2, ISLAND BELLE

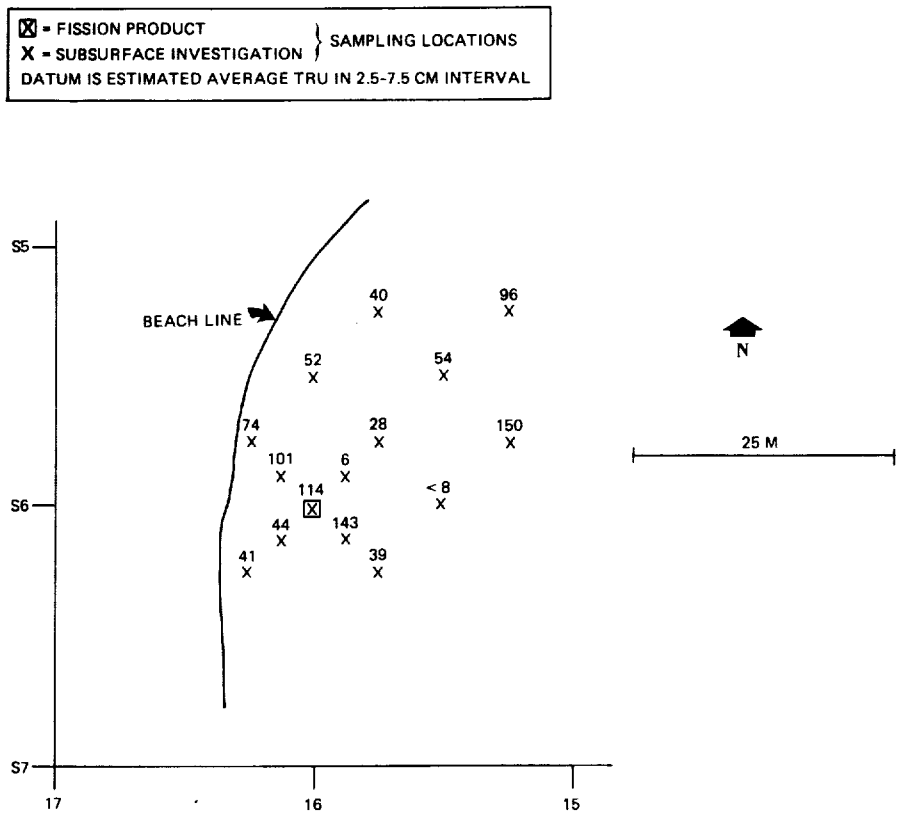


FIGURE 7-13. SUBSURFACE SAMPLING RESULTS, LOCATION 16S6, ISLAND BELLE

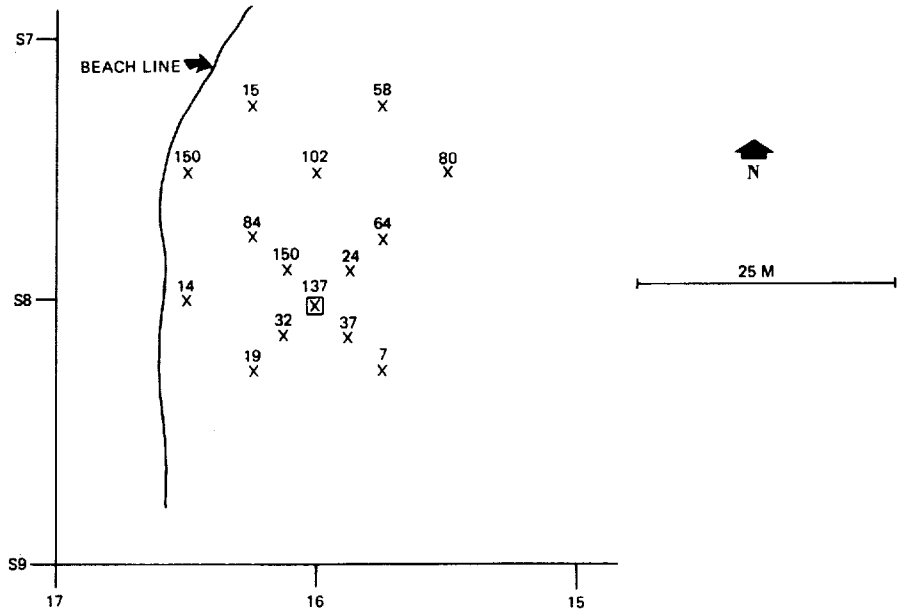


FIGURE 7-14. SUBSURFACE SAMPLING RESULTS, LOCATION 16S8, ISLAND BELLE

Tech Note 19 was devised to estimate activity in the 2.5 - 7.5 cm interval from 0-5 cm and 5-10 cm data. The method was applied to data for 6-N-2, 8-N-2, 12-BL-0, 14-S-2, 16-S-6 and 16-S-8, and the results are shown in Figures 7-9 to 7-14, respectively. No estimated 0.0625 ha average TRU activity exceeded 160 pCi/g for the 2.5 - 7.5 cm interval, and all deeper samples had lower TRU activity. Belle thus satisfied Condition D without any soil removal.

Final Characterization

Figure 7-15 shows the isopleths on the TRU activity on Belle based on final data. Table 7-5 summarizes island average results for ^{137}Cs, ^{60}Co and TRU from IMP measurements. The island average transuranics value reported in the Certification is 95 pCi/gm for surface soil, and the transuranics classification is Food Gathering.

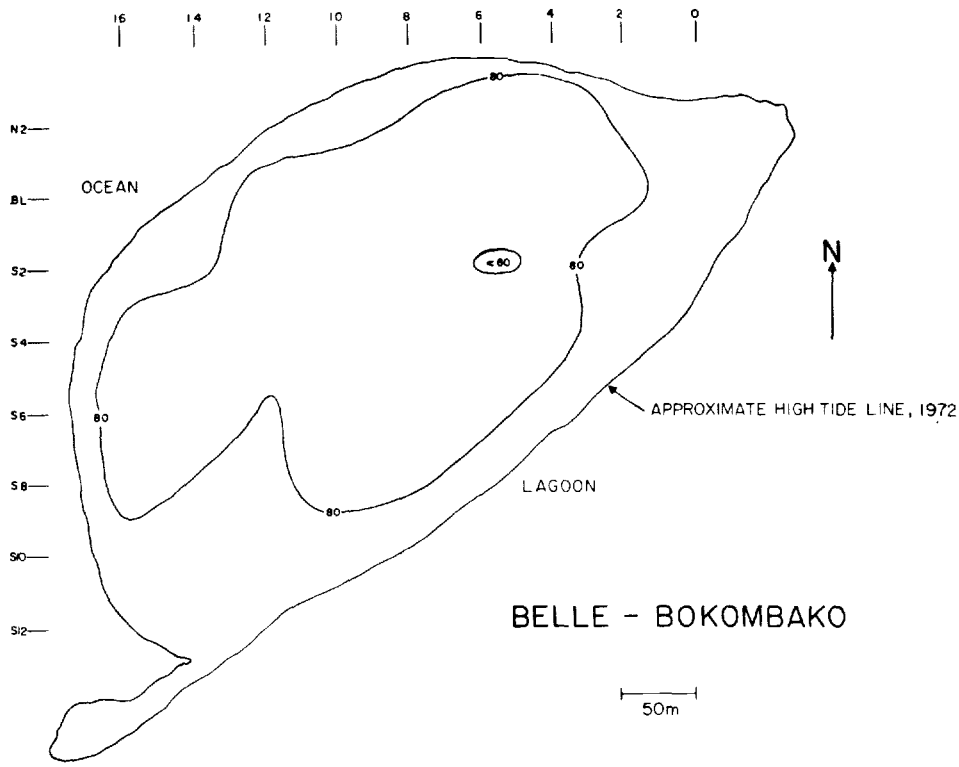


FIGURE 7-15. ISOPLETHS ON FINAL ESTIMATED SURFACE TRU ACTIVITY IN pCi/g FOR ISLAND BELLE

7.3.3 Clara

Background

Island Clara (Marshallese: Kirunu) is one of the set of six islands that are westernmost of the northern islands. It has an area of approximately 3 hectares, and is very sandy, long and slender in shape, with heavy vegetation. Several scientific stations were put on Clara during test operations. One of these remained until the cleanup, and was removed by blasting, severely disturbing the soft soil. The blasting occurred after the initial surface characterization, but prior to sampling for the Fission Product Data Base. Clara had no ground zero sites, but a number of nuclear events were nearby so that it ranks eleventh in total H + 1 hour exposure rate among islands of the Atoll with 3,154 R/h. There were no known or suspected burial sites for radioactive materials on Clara.

1972 Survey Results

During the 1972 survey, the soil was sampled at 13 sites on Clara, and a few vegetation samples were taken. Nine of the sites had 0-15 cm core samples, three had 0-35 cm profiles, and one had a 0-55 cm profile. As shown by Table 7-3, the overall surface $^{239,240}Pu$ activity was far enough below the Condition C criteria to warrant the assumption that no area would require more intensive sampling than any other.

In general, the activity of $^{239,240}Pu$ declined steeply with depth, indicating that no elevated subsurface activity would be expected. Activity of ^{137}Cs and ^{90}Sr also declined with depth, though much more slowly than did $^{239,240}Pu$ activity. Tables 7-1 and 7-2 summarize the ^{137}Cs and ^{90}Sr results, respectively, for the 0-15 cm samples.

Surface - Characterization

Clara was surveyed with the IMP on a 25 m grid, 13-15 February, 1978. A total of 24 locations were sampled, as shown in Figure 7-16. Soil samples for computing a ratio of TRU to ^{241}Am were taken on 22 February, 1978 at four locations, also shown in Figure 7-16. Each location was sampled at three depths, so that the estimated ratio of 4.23 $\pm$ 0.30 was based on a total of 24 samples.

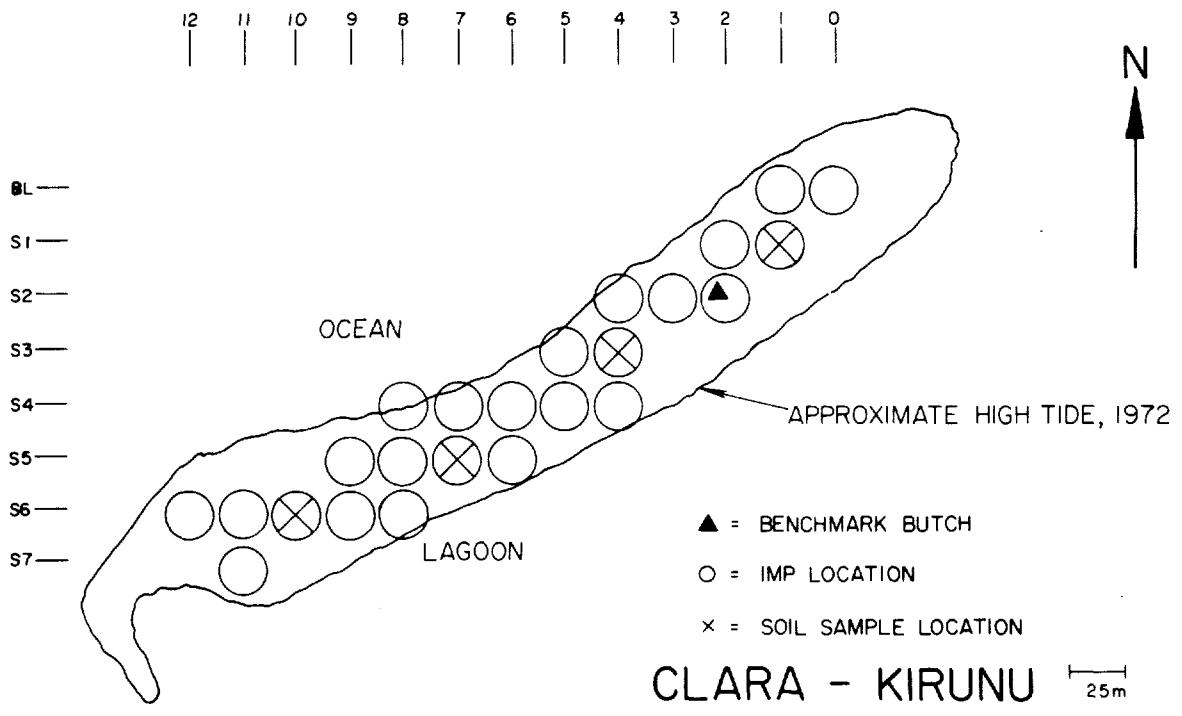


FIGURE 7-16. COASTLINE AND DATA COLLECTION LOCATIONS FOR ISLAND CLARA

The grid spacing of 25 m for IMP sampling rather than the usual 50 m spacing was chosen because Clara is so narrow the larger spacing would have resulted in too few samples to fit a variogram and make estimates. With data at 25 m spacing, estimates are based on averages of adjacent data rather than kriging. Figure 7-17 shows the isopleths of final TRU activity based on the IMP data. (See Tech Note 23 for a discussion of original versus final data.) Table 7-4 summarizes island average TRU, ^{137}Cs and ^{60}Co activity from IMP data.

Severe soil disturbance from lane-cutting activities may have affected the IMP data, particularly along the baseline. The effect is unlikely to have been even as much as a 10% attenuation in the reading (see Tech Note 4.0), therefore no correction was made. The island surface was severely disturbed again, after the surface survey was complete, when the one scientific station left from testing activities was removed with high explosives. The surface characterization was not affected by this, but it was a factor in later subsurface investigations.

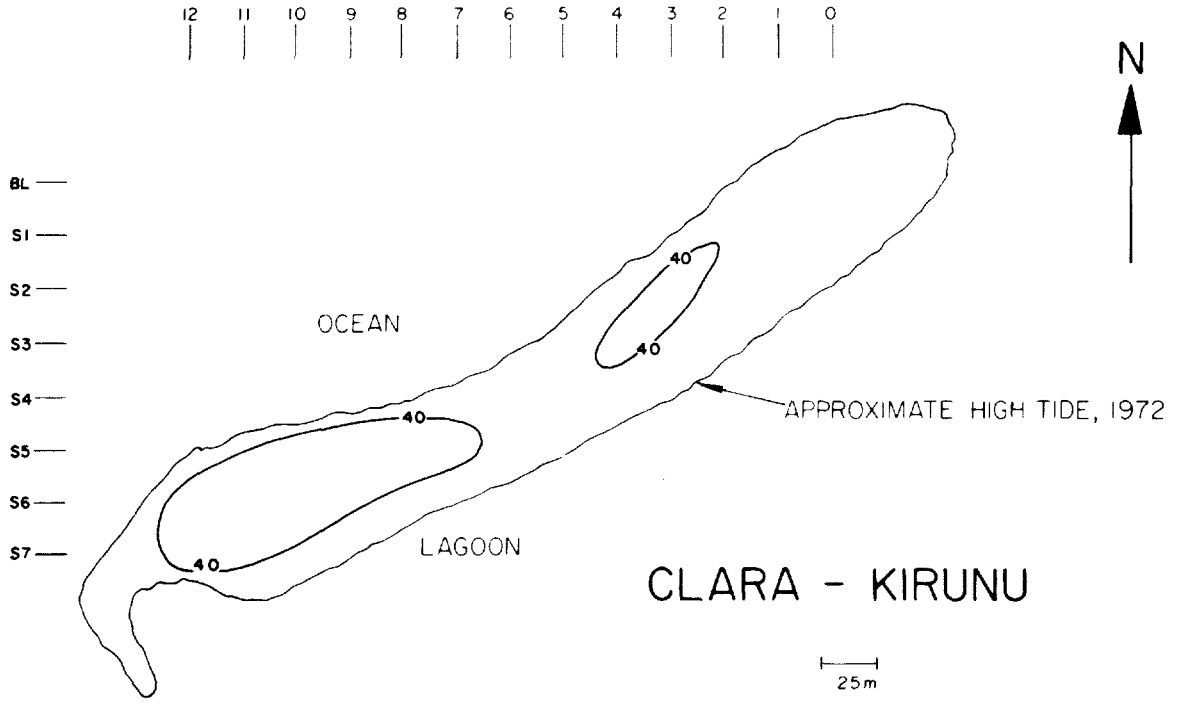


FIGURE 7-17. ISOPLETHS ON FINAL ESTIMATED SURFACE TRU ACTIVITY IN pCi/g FOR ISLAND CLARA

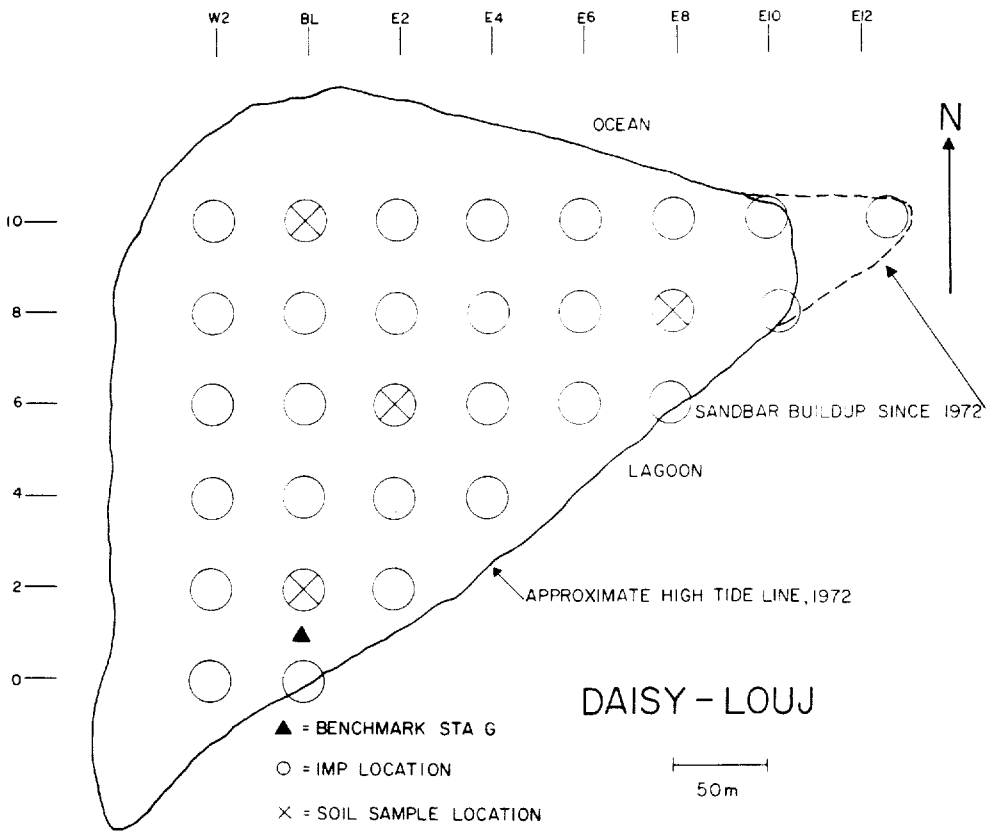


FIGURE 7-19. COASTLINE AND DATA COLLECTION LOCATIONS FOR ISLAND DAISY

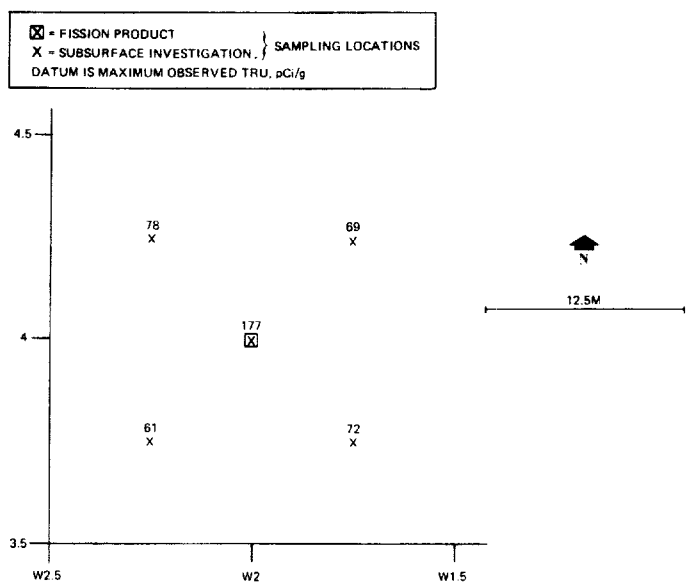


FIGURE 7-20. SUBSURFACE SAMPLING RESULTS, LOCATION 4W2, ISLAND DAISY

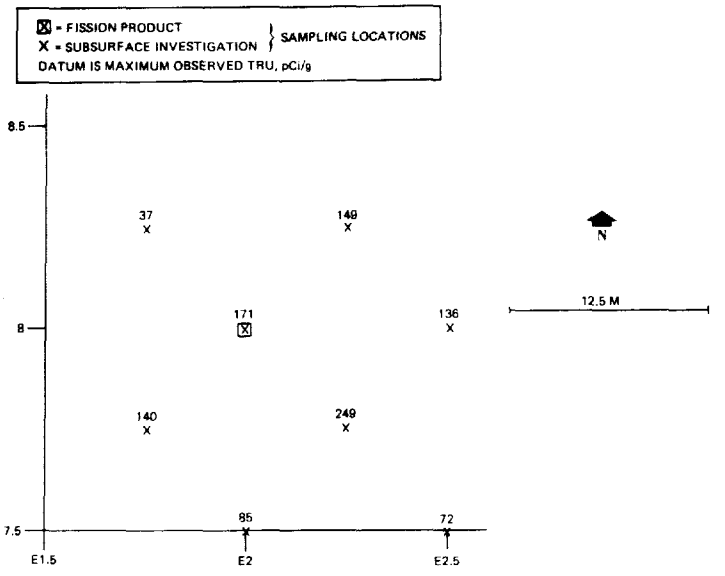


FIGURE 7-21. SUBSURFACE SAMPLING RESULTS, LOCATION 8E2, ISLAND DAISY

Final Characterization

Figure 7-22 shows isopleths on the surface TRU activity on Daisy, based on final IMP ^{241}Am data. Table 7-5 summarizes the island means for TRU, ^{137}Cs and ^{60}Co data from IMP measurements. The island average transuranics value reported in the Certification is 43 pCi/gm for surface soil, and the transuranics classification is Agricultural.

7.3.5 Edna

Background

Island Edna (Marshallese: Bokinwotme), a small, sandy island only 4.0 hectares (ha) in area with a small amount of vegetation, is located on the western edge of the Mike event crater. The island shape tends to be altered in every major storm by wind and wave action on the sandy soil. There were no test structures on Edna, nor were there any contaminated scrap, suspected burial areas or ground zero sites. However, because of its proximity to several large nuclear events, Edna ranks third among islands of the Atoll in total H + 1 hour exposure rate, with 9,533 R/h.

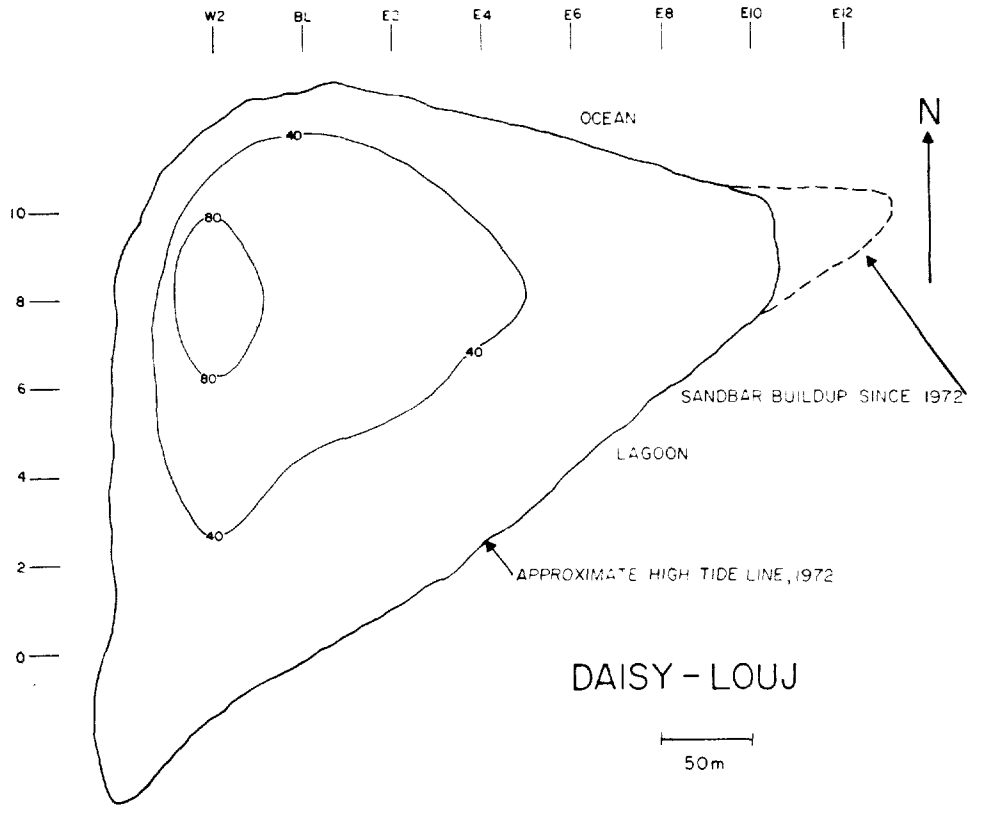


FIGURE 7-22. ISOPLETHS ON FINAL ESTIMATED SURFACE TRU ACTIVITY IN pCi/g FOR ISLAND DAISY

1972 Survey Results

Soil samples were taken at eight locations on Edna during the 1972 survey; two of these were profile samples to 35 cm and the others were 0-15 cm core samples. One area of vegetation was also sampled.

The results for 0-15 cm data for ^{137}Cs, ^{90}Sr and $^{239,240}Pu$ are summarized in Tables 7-1, 7-2, and 7-3, respectively. For all four isotopes, the activity was relatively homogeneous, both across the surface of the island and with depth. This is probably a result of mixing and dilution from wave and wind effects on Edna, which is frequently completely under water during tropical storms.

Surface Characterization and Fission Product Sampling

Edna is too small for IMP measurements to have been useful, so only soil samples were taken during the cleanup. Fifteen locations were sampled, with four composites at twelve locations and two composites at the other three. Only surface samples were taken, so there were a total of 54 samples. (This was a modification of the usual procedure described in Section 4.2.1.) No ratio of TRU to ^{241}Am was estimated because there were no IMP data. Tech Notes 2.19 and 2.19A describe the results of the soil sampling, which are also shown in Figure 7-23, along with the sampling locations. The maximum TRU activity in any soil sample was less than 40 pCi/g, so no soil removal was required on Edna. Table 7-5 summarizes the soil sample results of the TRU activity.

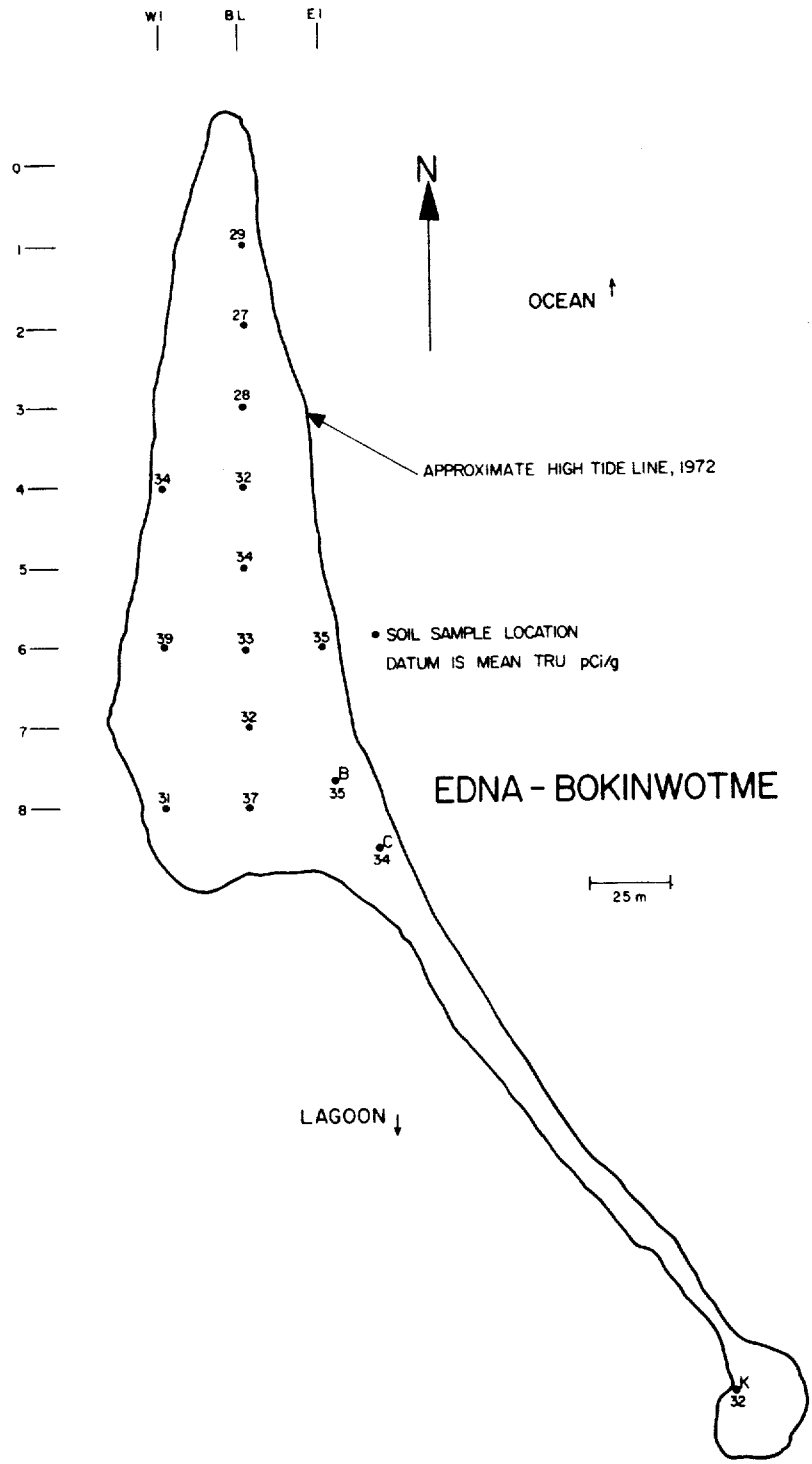


FIGURE 7-23. COASTLINE AND DATA COLLECTION LOCATIONS FOR ISLAND EDNA

Five locations were sampled on Edna as part of the Fission Product Data Base Program in support of the dose assessment (see Section 6.11). Soil from three of the locations was analyzed for ^{90}Sr. Tables 7-1, 7-2 and 7-3 summarize the results for 0-15 cm data for ^{137}Cs, ^{90}Sr and $^{239,240}Pu$, respectively.

The island average transuranics value reported in the Certification is 33 pCi/gm for surface soil, and the transuranics classification is Residence.

7.3.6 Edna's Daughter

Edna's Daughter, a tiny islet about 0.5 hectares (ha) in area with a few bits of vegetation, is located on the reef just north of the Mike event crater. The island has no Marshallese name, and was not mentioned as existing during nuclear testing activities. Its location suggests that it may have grown up around throwout from the Mike event. The islet is visible in 1972 aerial photographs, but was not sampled in the 1972 survey. No data are available on the amount, if any, of exposure to Edna's Daughter due to fallout from nearby nuclear events. There were no scientific stations, no debris, no ground zero sites, and no burial areas on Edna's Daughter.

Because of its small size, no IMP measurements were made on the island, nor were any accurate maps drawn. However, soil samples were taken at two locations, with two composites at each of three depths for a total of 12 samples. The approximate locations and the results of the soil sampling are shown in Figure 7-24 and are summarized in Table 7-4. The highest TRU activity in any soil sample was 122 pCi/g, so Edna's Daughter met Condition D without any cleanup. This island was not sampled in the Fission Product Data Base program.

The island average transuranics value reported in the Certification is 103 pCi/gm for surface soil, and the transuranics classification is Food Gathering.

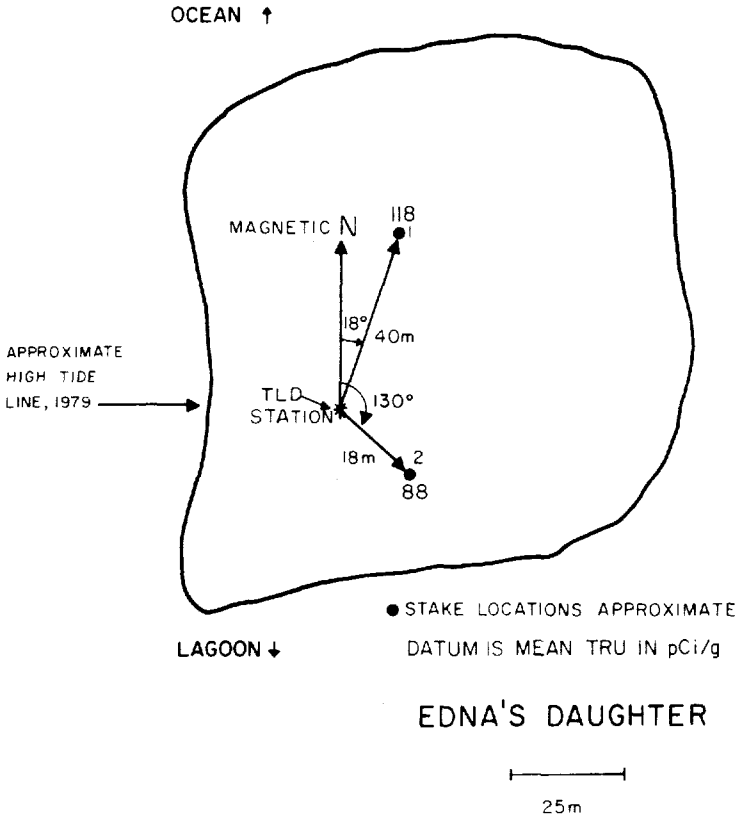


FIGURE 7-24. COASTLINE AND DATA COLLECTION LOCATIONS FOR ISLAND EDNA'S DAUGHTER

7.4 NORTHEAST ISLANDS

7.4.1 Kate

Background

Island Kate (Marshallese: Mijikadrek) has an area of 6.5 hectares (ha) and is the northernmost in the chain of islands southeast of Janet, forming the northeastern quadrant of the Atoll. Before any cleanup, the island was sparsely vegetated along the lagoon side and over a portion of the interior, while the rest of the island was covered with moderate vegetation. The soil is loose and sandy. Many test structures and scientific stations were located on Kate, and several remained until the cleanup. These were removed during the cleanup along with other metal debris and rubble. Some soil disturbance may have occurred during the testing years because of the construction of these scientific stations. No ground zero sites were located on Kate and it ranks 15th among the islands in the Atoll in total H + 1 hour exposure rate with 1,753 R/h. There were no known or suspected burials of radioactive material on this island.

1972 Survey

During the 1972 survey, soil samples were taken at 26 sites on Kate and a few vegetation and animal samples were taken. Of the 26 soil sample locations, 23 were 0-15 cm core samples and 3 were 0-65 cm profile samples. One profile result showed a steady decrease in $^{239,240}Pu$, ^{137}Cs, and ^{90}Sr activities with increasing depth, one showed a homogeneous distribution of low activities and one showed an increase of activities to 20 cm but a steady decrease below that depth. Overall, the results indicated no elevated subsurface activity would be expected. Tables 7-1, 7-2 and 7-3 give the 0-15 cm summary results for ^{137}Cs, ^{90}Sr and $^{239,240}Pu$, respectively, for data collected in 1972.

Characterization

Kate was initially measured with the IMP in March 1978 on a 50 m grid. To determine a TRU to ^{241}Am ratio, soil samples were collected on 28 February 1978 at five locations with two composites at three depths for a total of 30 samples. (See Section 4.2.1 for more information on soil sampling.) A ratio of 2.69 $\pm$ 0.03 was estimated using the soil sample results (see Tech Note 2.10). Both IMP and soil sample locations are shown in Figure 7-25.

Using the ratio estimated and the ^{241}Am IMP values, TRU numbers were calculated. These TRU values were used to compute the kriging estimates and 0.5 s upper bounds, where s is the standard deviation of the kriging error (see Section 5.1). The 0.5 s upper bound on the highest 0.25 hectares (ha) average TRU estimate was 40.3 pCi/g based on original data. (See Tech Note 23 for discussion of original versus final data.) However, these results were based on IMP data collected before debris removal, and as previously mentioned, Kate was the site of many test structures. Therefore, it was suspected that debris removal, which caused substantial soil dusturbance, may have changed the surface radiological condition of the island.

Kate was remeasured with the IMP on the same 50 m grid in March 1979 after the completion of the debris removal activities. Additional surface soil samples were collected at the same five locations previously sampled with four composites at each location for a total of 20 samples. (The soil sampling procedure had changed for a short time period during the cleanup.) A ratio of 2.74 was calculated from these new soil sample results which was not significantly different from the ratio originally estimated, thus the old ratio was used to compute TRU values. Estimates and 0.5 s upper bounds based on the remeasurement data were calculated using the kriging technique. It was obvious from the data that some soil mixing had occurred. After debris removal, the 0.5 s upper bound on the highest 0.25 hectares (ha) TRU estimate was 33.5 pCi/g based on original data.

Figure 7-26 shows the isopleths of TRU activity computed from the final IMP data. Table 7-5 gives island averages for computed TRU, ^{137}Cs and ^{60}Co activities for the final IMP data.

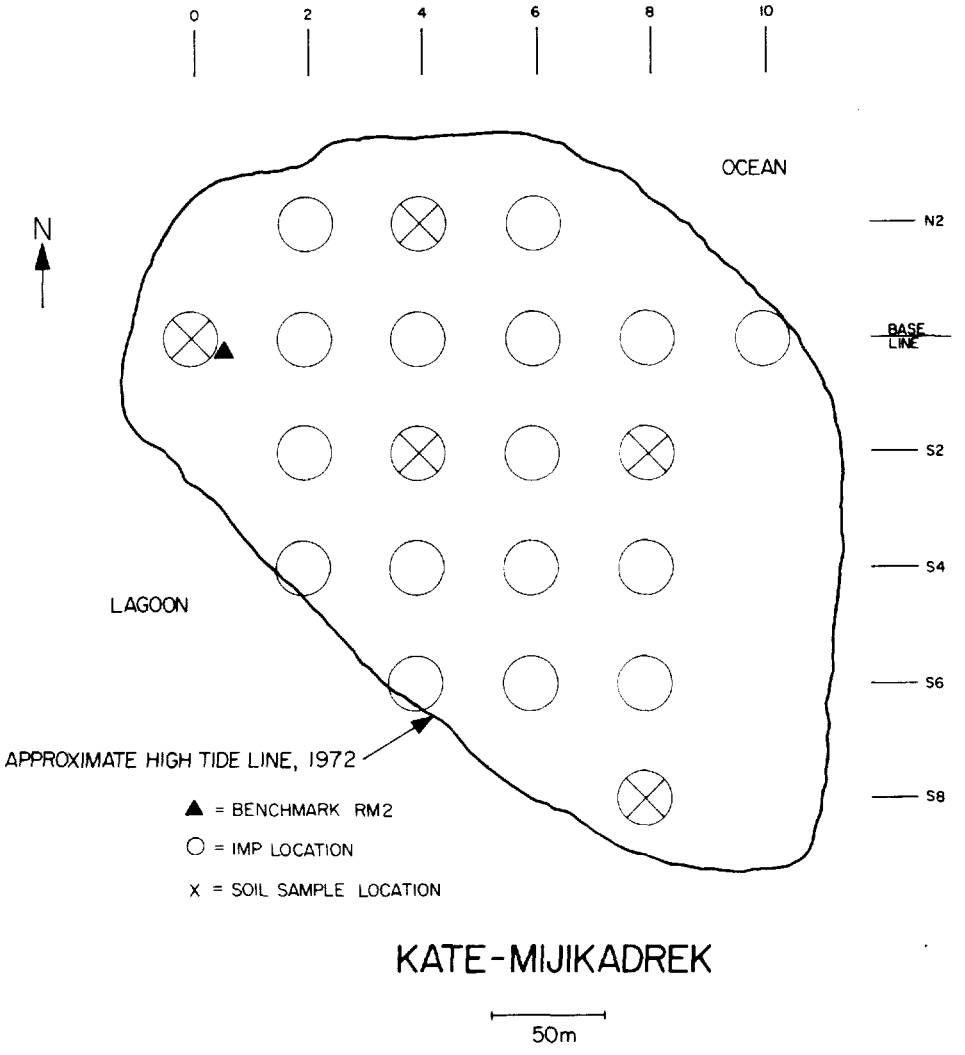


FIGURE 7-25. COASTLINE AND DATA COLLECTION LOCATIONS FOR ISLAND KATE

Fission Product Sampling

Fission product sampling was conducted on Kate in March 1979 in support of the dose assessment (see Section 6.11). Soil samples were collected on the 50 m grid already established with ^{90}Sr analysis done on soil from six of the 18 sampling locations. The results from this sampling corroborated the assumption that no subsurface pockets of elevated TRU activity were likely to exist on Kate. Tables 7-1, 7-2 and 7-3 give summary statistics for the 0-15 cm depths for the ^{137}Cs, ^{90}Sr and estimated $^{239,240}Pu$ results, respectively, for these data.

The island average transuranics value reported in the Certification is 20 pCi/gm for surface soil, and the transuranics classification is Residence.

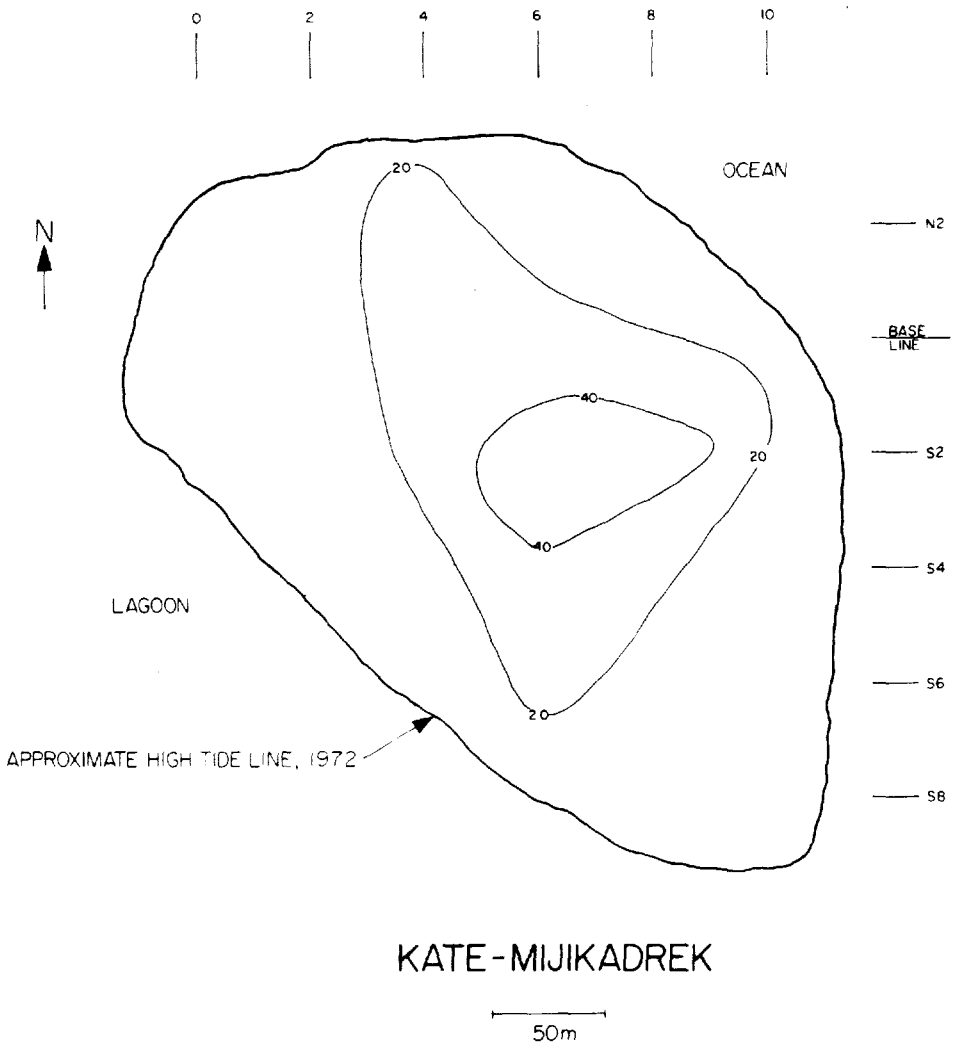


FIGURE 7-26. ISOPLETHS ON FINAL ESTIMATED SURFACE TRU ACTIVITY IN pCi/g FOR ISLAND KATE

7.4.2 Lucy

Background

Island Lucy (Marshallese: Kidrinen) is one of the northeastern islands, having an area of about 8 hectares (ha). The island is covered with low, dense vegetation except for the southeastern part where it is moderately vegetated. The soil is loose sand. During the testing years, Lucy was used for biomedical studies and sampling but the debris remaining at the time of cleanup were in small pieces. No ground zero sites were located on this island and it ranks 14th among the islands in the Atoll in total H + 1 hour exposure rate with 1,776 R/h. There were no known or suspected burials of radioactive material on Lucy.

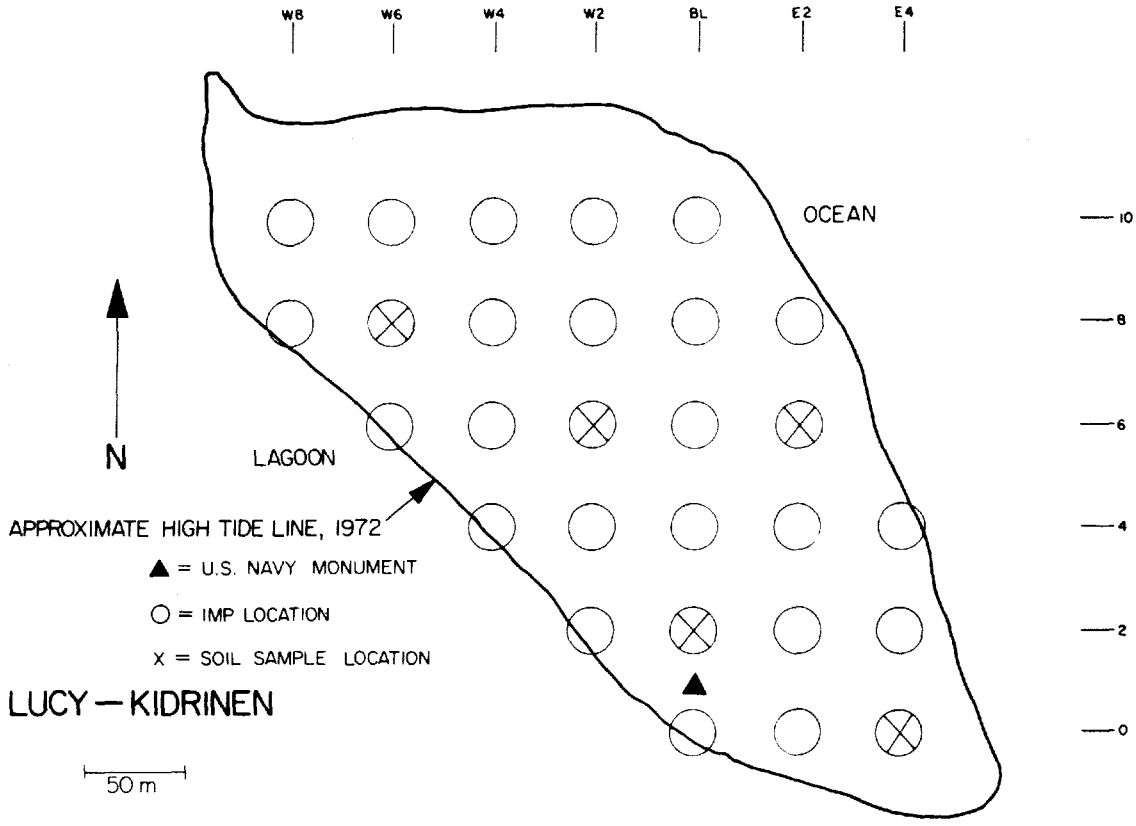


FIGURE 7-27. COASTLINE AND DATA COLLECTION LOCATIONS FOR ISLAND LUCY

1972 Survey

Twenty-eight locations were sampled during the 1972 survey and a few vegetation and animal samples were also collected. Of the 28 locations, 23 were 0-15 cm core samples, two were 0-35 cm profile samples, two were 0-65 cm profiles, and one was a 0-115 cm profile sample. The profile samples indicate a steep decrease in activity with increasing depth to a depth of 10 cm, then a more gradual decrease or leveling off in activity below this depth. Generally, the $^{239,240}Pu$ activity shows a sharper decrease than the ^{137}Cs and ^{90}Sr activities. The $^{239,240}Pu$ soil profile results did not indicate that elevated subsurface TRU activity would be expected. Tables 7-1, 7-2 and 7-3 give summary statistics for the ^{137}Cs, ^{90}Sr and $^{239,240}Pu$, respectively, for the 0-15 cm core samples.

Characterization

Lucy was staked on a 50 m grid and IMP measurements first taken in February 1978. To determine a TRU to ^{241}Am ratio, soil samples were collected at five locations with two composites at each of three depths for a total of 30 samples. (See Section 4.2.1 for more information on surface soil sampling.) A ratio of 2.59 $\pm$ 0.03 was calculated based on these soil sample results (see Tech Note 2.6). Figure 7-27 shows the locations of the IMP measurements and the soil sampling.

Before any estimates of 0.25 hectare averages were made, comparisons between the IMP ^{241}Am data and the soil sample results collected at the same five locations indicated a significant difference. This difference had not been observed on any of the data collected from other islands.

The reason behind this unusual discrepancy was because detector SN:496, used to measure Lucy, had been mistakenly operated at a bias of -2000v rather than -3000v. An experiment was conducted on Sally to determine a factor to apply to the IMP data collected when the detector was operated at the lower voltage. (See Tech Note 5.0 for details on this experiment.)

The decision was made in March 1978 to remeasure Lucy with the IMP on the same 50 m grid to verify the correction factor computed from Sally data. The same detector was used to remeasure the island and was operated at the correct voltage. These new data indicated that the correction factor applied to the original data was appropriate.

Using the corrected IMP data and the estimated ratio, TRU numbers were calculated based on original data. (See Tech Note 23 for discussion on original versus final data). Estimates of the 0.5 s upper bounds on the 0.25 hectare averages were made using the kriging technique, where s is the standard deviation of the kriging error (see Section 5.1). Lucy met condition B without any soil removal.

An additional problem in efficiency with detector SN:496 was discovered shortly after Lucy was remeasured. Because the agreement between IMP measurements and the soil sample results was never as good as other islands, more IMP measurements (with detector SN:386) and soil samples were collected in March 1979. Only six locations on the initial 50 m grid were remeasured by the IMP because of a higher priority mission, but seven locations were soil sampled, where five of the locations were the original sites and the other two were new locations. The six IMP spectra showed no significant difference when compared to the corrected initial data. The soil sample results also confirmed the initial data were acceptable after they were corrected for the low voltage problem.

Isopleths of surface TRU activity based on final data are shown in Figure 7-28. Table 7-4 gives the island averages for computed TRU, ^{137}Cs and ^{60}Co activities from IMP measurements.

Fission Product Sampling

Soil samples were collected on the 50 m grid already established in support of the dose assessment (see Section 6.11). Soil from eight of the 22 sampling locations was analyzed for ^{90}Sr. Tables 7-1, 7-2 and 7-3 summarize the results for 0-15 cm data for ^{137}Cs, ^{90}Sr and estimated $^{239,240}Pu$ results, respectively.

The island average transuranics value reported in the Certification is 35 pCi/gm for surface soil, and the transuranics classification is Agricultural.

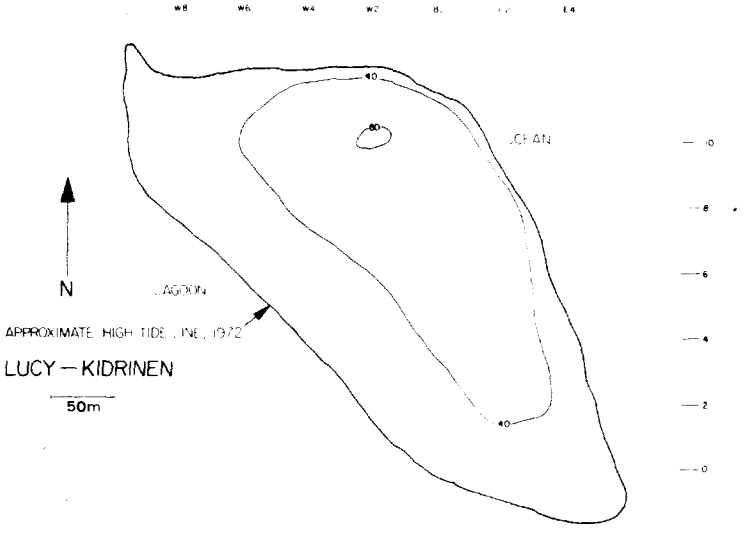


FIGURE 7-28. ISOPLETHS ON FINAL ESTIMATED SURFACE TRU ACTIVITY IN pCi/g FOR ISLAND LUCY

7.4.3 Percy

Background

Island Percy (Marshallese: Taiwel), a small sandbar of only 0.8 hectares in area, is located between Lucy and Mary in the northeastern quadrant of the Atoll. There is no vegetation on Percy. No ground zero sites were located on this island nor were there any known or suspected burial sites. The only structure on the island was an overturned submarine cable terminal box which was the first debris removed during the cleanup.

1972 Survey Results

Six locations were soil sampled during the 1972 survey; at five of these 0-15 cm core samples were taken and at the remaining location a 0-35 cm profile sample was taken. The profile indicated an increase in activities for ^{137}Cs, ^{90}Sr and $^{239,240}Pu$ to a depth of 8.5 cm, then a steady decline in activities below that.

Characterization and Fission Product Sampling

IMP measurements were not taken on Percy because of its small size but soil samples were collected during the cleanup. Six locations were surface sampled with four composites at each location for a total of 24 samples (see Section 4.2.1 for details on the soil sampling procedure). No ratio of TRU to ^{241}Am was established because there were no IMP data. The results of the soil sampling are shown in Figure 7-29 along with the sampling locations. Table 7-4 summarizes the TRU results. The maximum TRU activity of any soil sample was 17 pCi/g. (See Tech Note 2.18 for additional results for this sampling.)

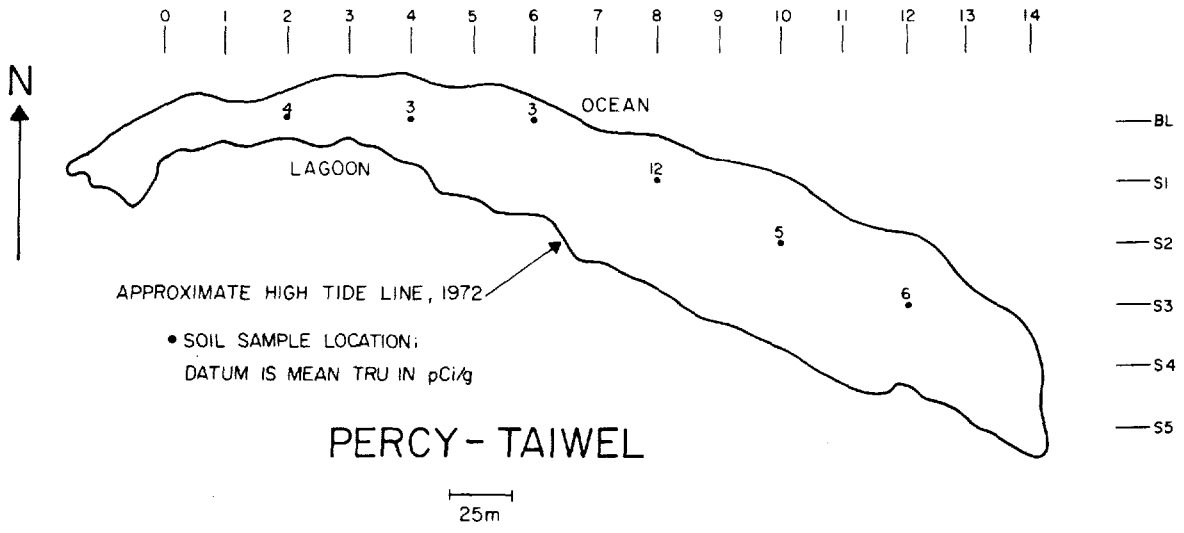


FIGURE 7-29. COASTLINE AND DATA COLLECTION LOCATIONS FOR ISLAND PERCY

Two locations were sampled on Percy for the Fission Product Data Base Program in support of the dose assessment (see Section 6.11). Soil from both locations was analyzed for ^{90}Sr. Tables 7-1, 7-2 and 7-3 give summary statistics for the 0-15 cm data for ^{137}Cs, ^{90}Sr and $^{239,240}Pu$, respectively, for this sampling.

The island average transuranics value reported in the Certification is 6 pCi/gm for surface soil, and the transuranics classification is Residence.

7.4.4 Mary

Background

Island Mary (Marshallese: Bokenelab) is one of the smaller northeastern islands, having an area of only 5 hectares. The island is moderately vegetated, with large areas being entirely clear except for the thick ground cover of grass and morning glory vines. There were few scientific stations on Mary during testing activities, and no ground zero sites. Debris removal activities during the cleanup caused little soil disturbance. Mary ranks 12th among the islands in the Atoll in total H + 1 hour exposure rate with 2,785 R/h; there were no known or suspected burial sites of radioactive material.

1972 Survey

Soil samples were collected at 22 locations on Mary during the 1972 survey and a few vegetation and animal samples were taken. Of the 22 soil samples, 19 were 0-15 cm core samples and 3 were 0-35 cm profile samples. One profile result only had results down to a depth of 7.5 cm so no inferences about distribution can be made. Of the remaining two profiles, one showed the activity of ^{137}Cs, ^{90}Sr and $^{239,240}Pu$ declined steadily with depth, and the other profile showed a homogeneous distribution of low activity for all four isotopes. This last profile may be explained by construction activity on the island during the testing operation.

Tables 7-1, 7-2 and 7-3 give the 0-15 cm summary results for ^{137}Cs, ^{90}Sr and $^{239,240}Pu$, respectively, for data collected in 1972.

Characterization

Mary was measured with the IMP in late March 1978. Soil samples were collected around the same time at five locations with two composites at three depths for a total of 30 samples. (See Section 4.2.1 for details on surface soil sampling.) A ratio of TRU to ^{241}Am of 2.94 $\pm$ 0.13 was estimated using these soil sample results (see Tech Note 2.15). Soil sample and IMP locations are shown in Figure 7-30.

Using the ratio estimated and the ^{241}Am IMP results, TRU values were calculated. Due to the small size of this island and few data points, no kriging estimates were made. The individual TRU values reported indicated that Mary met Condition C based on original data. (See Tech Note 23 for discussion of original versus final data.)

Following the initial characterization of Mary, it was discovered that the detector that measured this island experienced a loss in efficiency causing calculated ^{241}Am IMP values to be low. A correction factor was estimated for this problem and the data corrected for the final characterization. (See Tech Note 5.2 for details on this problem and the determination of the correction factor.)

Figure 7-31 shows the isopleths of TRU activity after correcting the final IMP data for the appropriate efficiency. Table 7-4 gives island means for computed TRU, ^{137}Cs and ^{60}Co for the final IMP data.

Fission Product Sampling

Twelve locations on Mary were soil sampled for the Fission Product Data Base Program in support of the dose assessment (see Section 6.11). Soil from four of the locations was analyzed for ^{90}Sr. Tables 7-1, 7-2 and 7-3 summarize the results of this sampling for the 0-15 cm data on ^{137}Cs, ^{90}Sr and $^{239,240}Pu$, respectively.

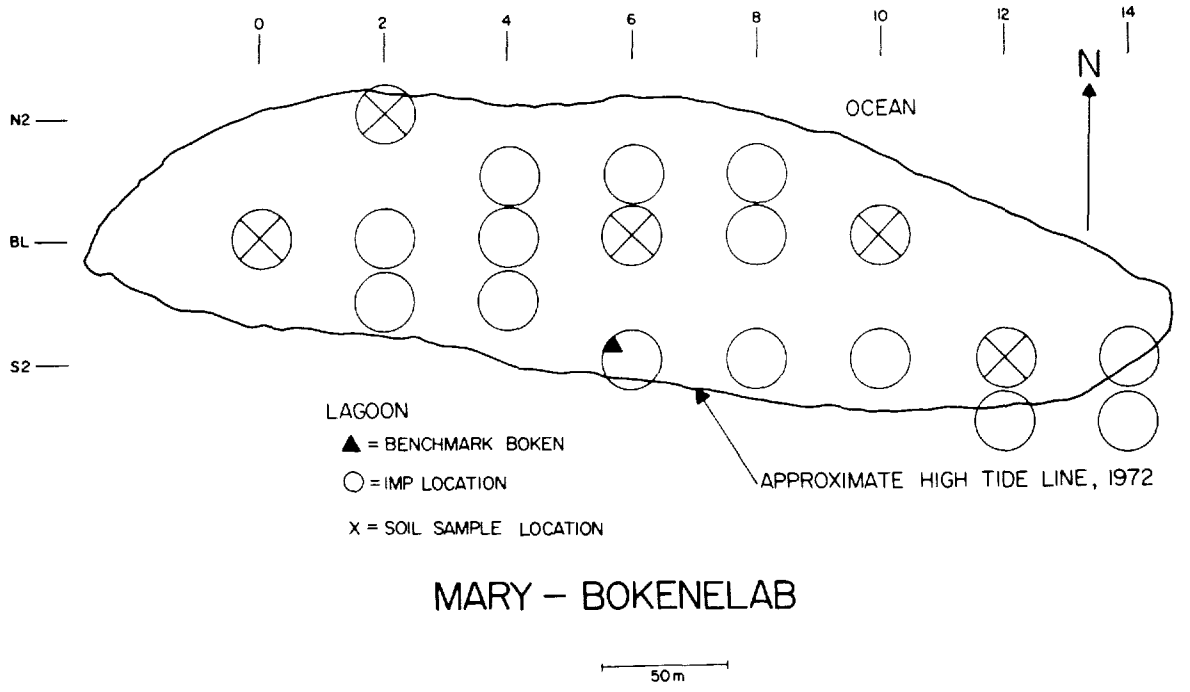


FIGURE 7-30. COASTLINE AND DATA COLLECTION LOCATIONS FOR ISLAND MARY

The island average transuranics value reported in the Certification is 19 pCi/gm for surface soil, and the transuranics classification is Residence.

7.4.5 Mary's Daughter

Mary's Daughter is a small islet about 0.5 hectare in area located between Mary and Nancy. The island has no known Marshallese name and was not sampled during the 1972 survey. There is very little vegetation on this island. No data are available on the amount of exposure this island received as a result of nearby nuclear events. No debris, no ground zero sites and no burial areas were known or suspected on Mary's Daughter.

Because of its small size, no IMP measurements were taken on the island but soil samples were collected at four locations with two composites at each location for a total of 8 samples (see Section 4.2.1 for details on the soil sampling procedure). The locations and the TRU results of this sampling are shown in Figure 7-32, and a summary of the results is given in Table 7-4. The maximum TRU activity in any soil sample was 138.8 pCi/g (see Tech Note 2.22).

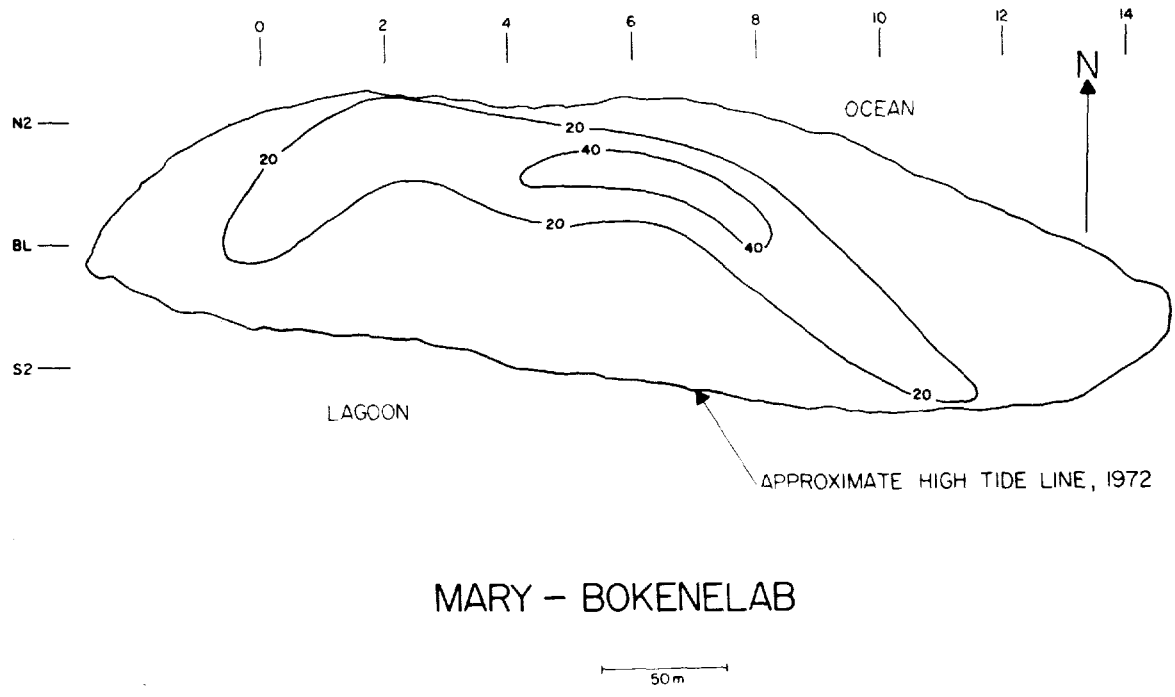


FIGURE 7-31. ISOPLETHS ON FINAL ESTIMATED SURFACE TRU ACTIVITY IN pCi/g FOR ISLAND MARY

Mary's Daughter was sampled at three locations for the Fission Product Data Base Program in support of the dose assessment (see Section 6.11). Soil from one of the locations was analyzed for ^{90}Sr. The results for the 0-15 cm data for ^{137}Cs, ^{90}Sr and $^{239,240}Pu$ are summarized in Tables 7-1, 7-2 and 7-3, respectively, for this sampling.

The island average transuranics value reported in the Certification is 54 pCi/gm for surface soil, and the transuranics classification is Food Gathering.

7.4.6 Nancy

Background

Island Nancy (Marshallese: Elle) is located in the northeastern quadrant of the Atoll and has an area of 4.5 hectares. It is very long and slender in shape with sandy soil and was heavily vegetated prior to the cleanup. Very little debris remained on this island and there were no known or suspected burials of radioactive material. Nancy had no ground zero sites and is ranked 17th of all islands in the Atoll with 1,251 R/h accumulated H + 1 hour exposure rate.

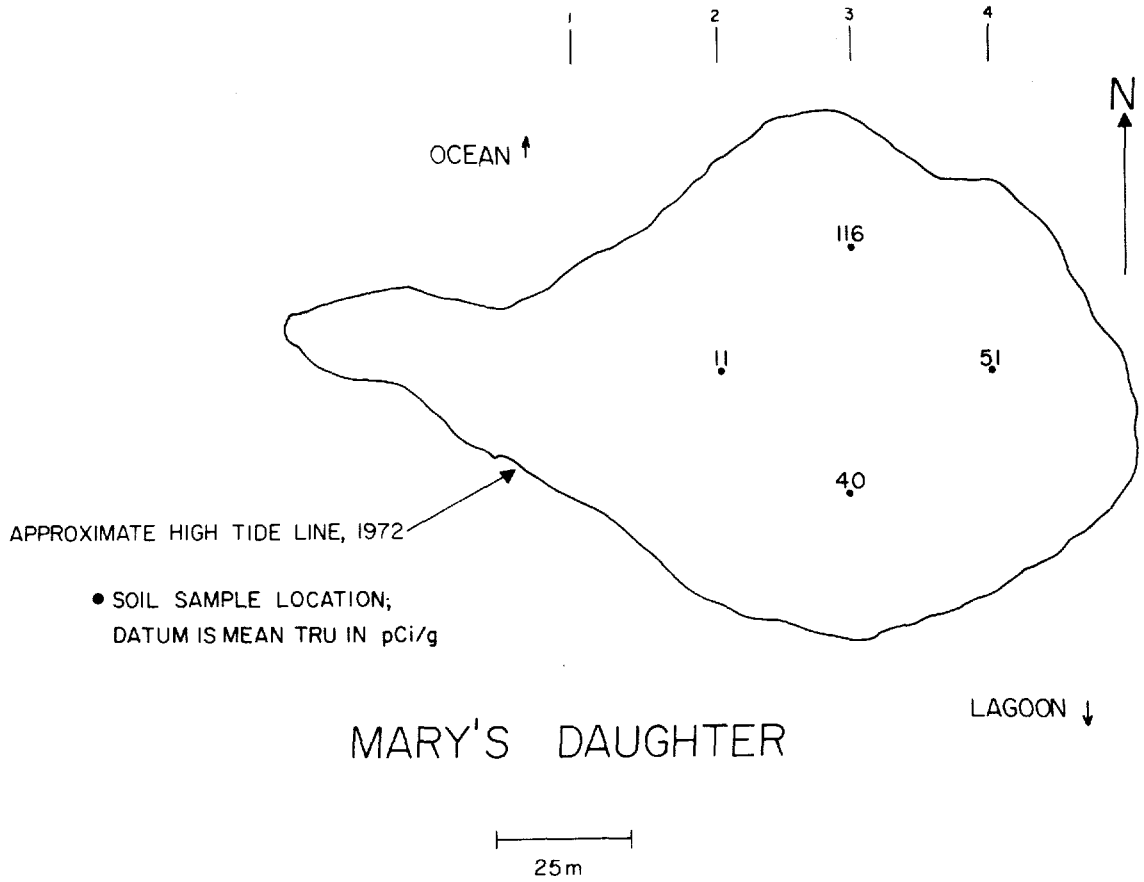


FIGURE 7-32. COASTLINE AND DATA COLLECTION LOCATIONS FOR ISLAND MARY'S DAUGHTER

1972 Survey

Twenty-five locations were soil sampled during the 1972 survey, and a few vegetation samples were also collected. Four of the samples were 0-35 cm profiles and 21 were 0-15 cm core samples. Most of the profiles show a steady decrease in activity with increasing depth for the isotopes, ^{137}Cs, ^{90}Sr an $^{239,240}Pu$. The exception was a profile taken on the beach where the activities for ^{137}Cs and $^{239,240}Pu$ increased to a depth of 7.5 cm and then steadily decreased, and the ^{90}Sr activity dropped at 3.5 cm, increased at 7.5 cm, and then decreased rapidly with increasing depths.

Tables 7-1, 7-2 and 7-3 summarize the results of the 1972 sampling of Nancy for 0-15 cm data on ^{137}Cs, ^{90}Sr and $^{239,240}Pu$, respectively.

Characterization

Nancy was measured with the IMP in March 1978 on a 25 m grid because of the small size of this island. Soil samples were collected at five locations with two composites at each of three depths for a total of 30 samples. (See Section 4.2.1 for more information on soil sampling.) The results from these samples were used to estimate a ratio of TRU to ^{241}Am of 2.7 $\pm$ 0.05 (see Tech Note 2.11). Both the IMP and soil sample locations are shown in Figure 7-33.

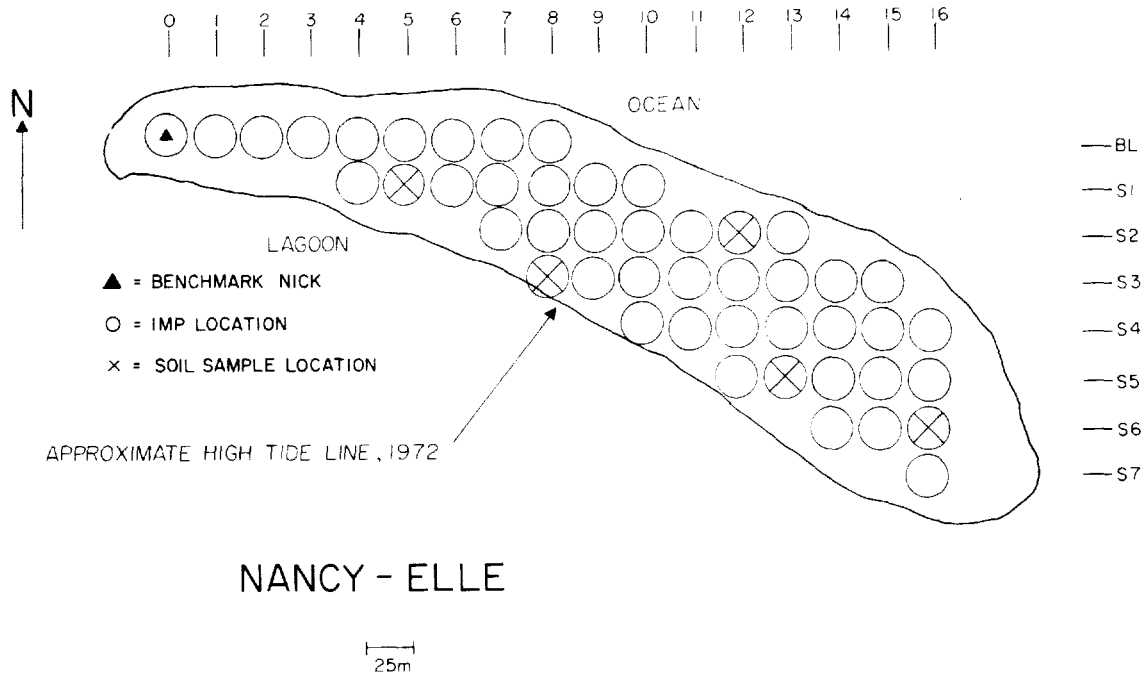


FIGURE 7-33. COASTLINE AND DATA COLLECTION LOCATIONS FOR ISLAND NANCY

Using the ^{241}Am IMP data and the estimated ratio, TRU values were calculated based on original data. (See Tech Note 23 for discussion on original versus final data.) To get a 0.25 hectare estimate, the average of four TRU values forming a square was calculated rather than using kriging (see Section 5.1). Nancy met Condition B without any soil removal.

Nancy was measured with detector SN:496, immediately before this detector experienced a drop in efficiency. Also, the agreement between the soil sample results and the IMP measurements was not as good as for other islands, therefore seven more locations were soil sampled in February 1979. Five of the seven were previously sampled and the remaining two were new sites. The results from this additional sampling indicated greater variability in the soil samples and the IMP values were within the range of soil sample results. The conclusion was drawn that the original IMP data from Nancy were valid.

Figure 7-34 shows isopleths on surface TRU activity based on final data. Table 7-4 summarizes the island averages for computed TRU, ^{137}Cs and ^{60}Co data from IMP measurements.

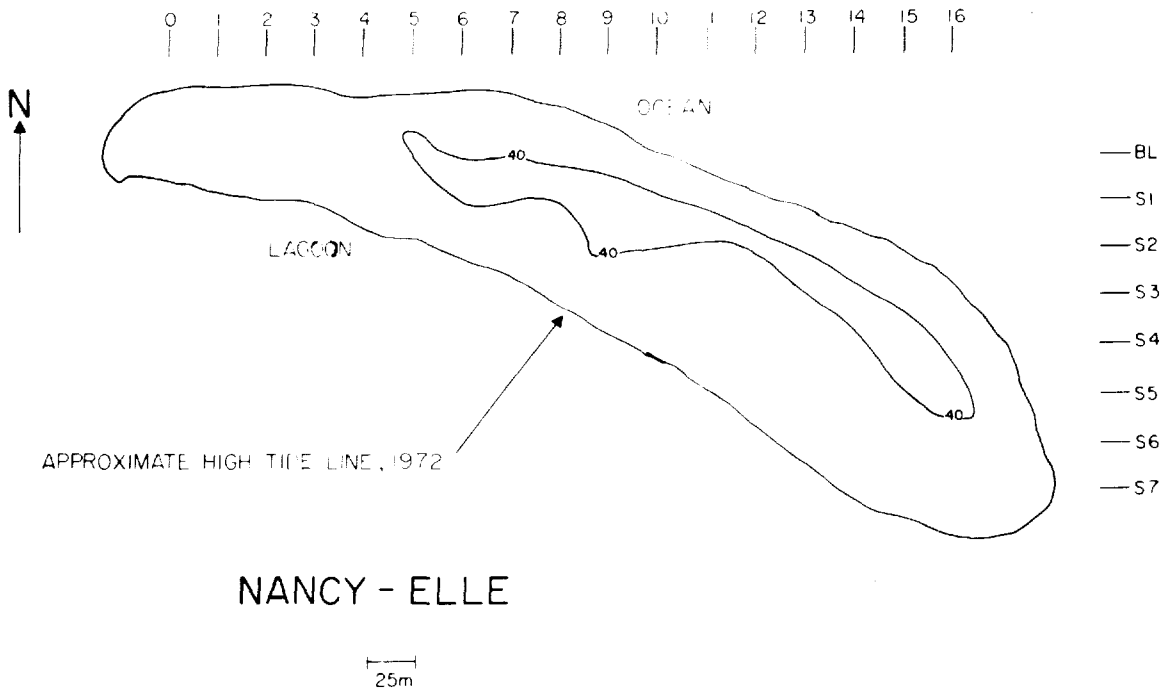


FIGURE 7-34. ISOPLETHS ON FINAL ESTIMATED SURFACE TRU ACTIVITY IN pCi/g FOR ISLAND NANCY

Fission Product Sampling

Nancy was sampled on a 50 m grid for the Fission Product Data Base Program in support of the dose assessment (see Section 6.11). Soil samples were collected at fourteen locations with ^{90}Sr analysis done on soil from six of these locations. Tables 7-1, 7-2 and 7-3 give summary statistics for the 0-15 cm data for ^{137}Cs, ^{90}Sr and $^{239,240}Pu$, respectively.

The island average transuranics value reported in the Certification is 34 pCi/gm for surface soil, and the transuranics classification is Agricultural.

7.4.7 Olive

Background

Island Olive (Marshallese: Aej) is one of the larger of the northeastern islands, having an area of 16.5 hectares. It is very densely vegetated except for the southeastern point, which is a sand spit pointing toward Pearl. The soil is very loose sand, and the lane-clearing for the grid baseline caused extensive soil disturbance. Only one test structure, a recording bunker, is on the island and it was not removed during the cleanup. No ground zero sites were located on Olive and it ranks 16th among the islands in the Atoll with 1252 R/h in total H + 1 hour exposure rate. There were no known or suspected burials of radioactive materials on this island.

1972 Survey

During the 1972 survey, soil samples were collected at 26 sites and a few vegetation and animal samples were also taken. Four of the 26 locations had 0-35 cm profile samples while the remaining 22 were 0-15 cm core samples. The profile results indicated that the activities of ^{137}Cs, ^{90}Sr and $^{239,240}Pu$ declined steadily with increasing depth at three of the locations. The other location showed a homogeneous distribution of low activities for these isotopes.

A distinction was made between sparse and dense vegetation for the soil sample results. Higher surface activities for these isotopes were associated with the heavier vegetated area, whereas lower activities were found in the less densely vegetated portion of the island. The 1972 aerial data also showed this distinction.

Tables 7-1, 7-2 and 7-3 summarize the 0-15 cm data collected on Olive in 1972 for ^{137}Cs, ^{90}Sr and $^{239,240}Pu$, respectively.

Characterization

Olive was measured with the IMP in December 1977 on a 50 m grid. Soil samples were collected at four locations with two composites taken at each of three depths for a total of 24 samples (see Section 4.2.1 for details on the sampling procedure). Using the surface results only, a ratio of TRU to ^{241}Am of 2.74 ± 0.46 was estimated (see Tech Note 2.3). Figure 7-35 shows both the IMP and soil sample locations.

Using the ^{241}Am IMP data and the estimated ratio, TRU values were determined based on original data. (See Tech Note 23 for discussion of original versus final data.) Area averages were computed using the kriging technique and estimates of the 0.5 s upper bounds on the 0.25 hectare averages were made, where s is the standard deviation of the kriging error (see Section 5.1). No 0.25 hectare upper bound exceeded 40 pCi/g, so Olive met Condition C without soil removal.

A soil disturbance experiment was conducted on Olive to determine how much reduction in surface activity was due to lane-cutting activities. The conclusion based on this experiment was a reduction is observed but is significant only when the disturbance is very extreme. No adjustments to IMP data were ever made based on soil disturbance.

Figure 7-36 shows isopleths on surface TRU activity based on final data. Table 7-4 summarizes the island averages for computed TRU, ^{137}Cs and ^{60}Co data for IMP measurements.

Fission Product Sampling

Olive was sampled on a 50 m grid for the Fission Product Data Base Program in support of the dose assessment (see Section 6.11). Soil samples were collected at 50 locations with ^{90}Sr analysis done on soil from 12 of these locations. Tables 7-1, 7-2 and 7-3 give summary statistics for the 0-15 cm data on ^{137}Cs, ^{90}Sr and computed $^{239,240}Pu$, respectively.

The island average transuranics value reported in the Certification is 20 pCi/gm for surface soil, and the transuranics classification is Agricultural.

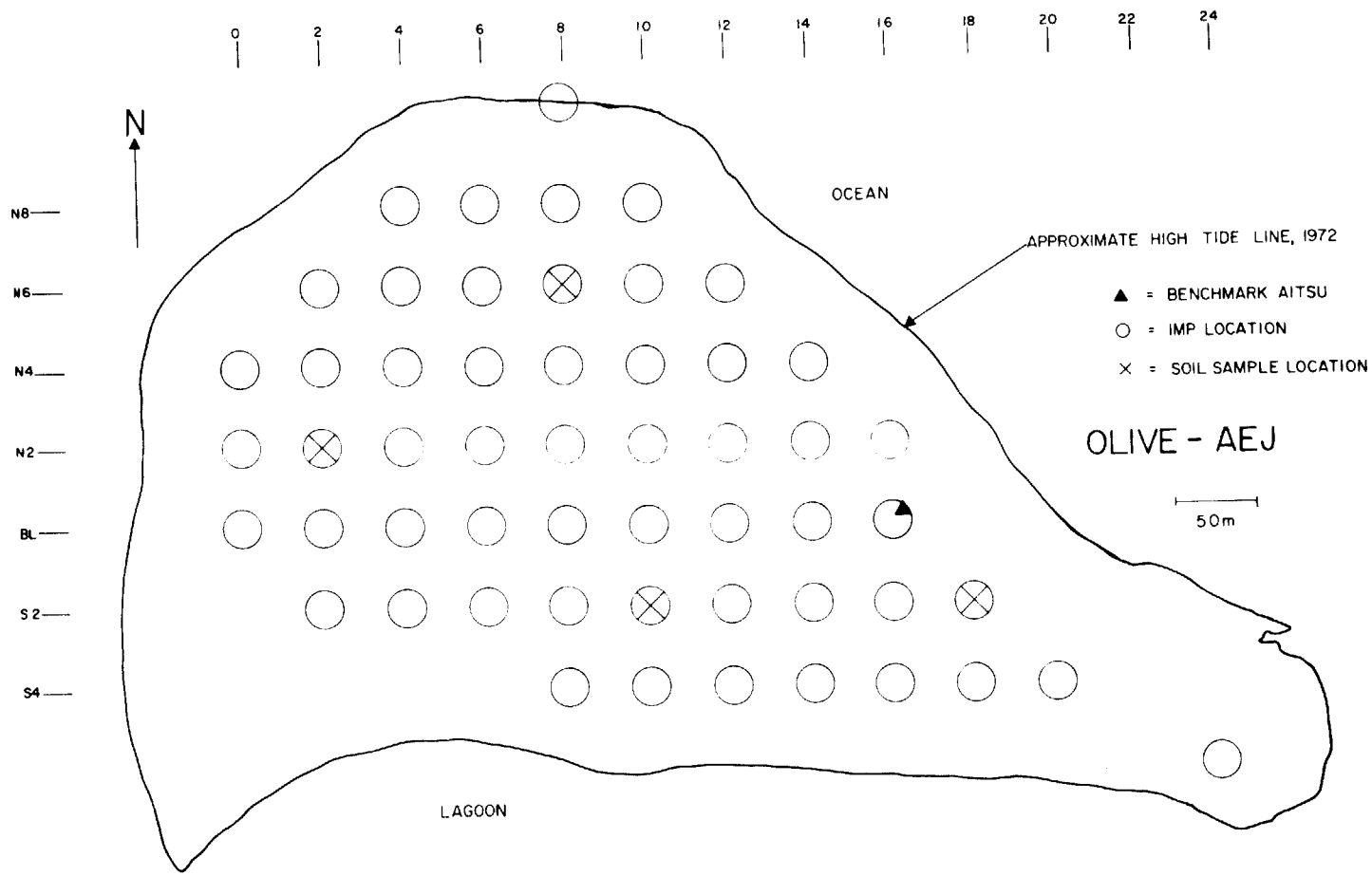


FIGURE 7-35. COASTLINE AND DATA COLLECTION LOCATIONS FOR ISLAND OLIVE

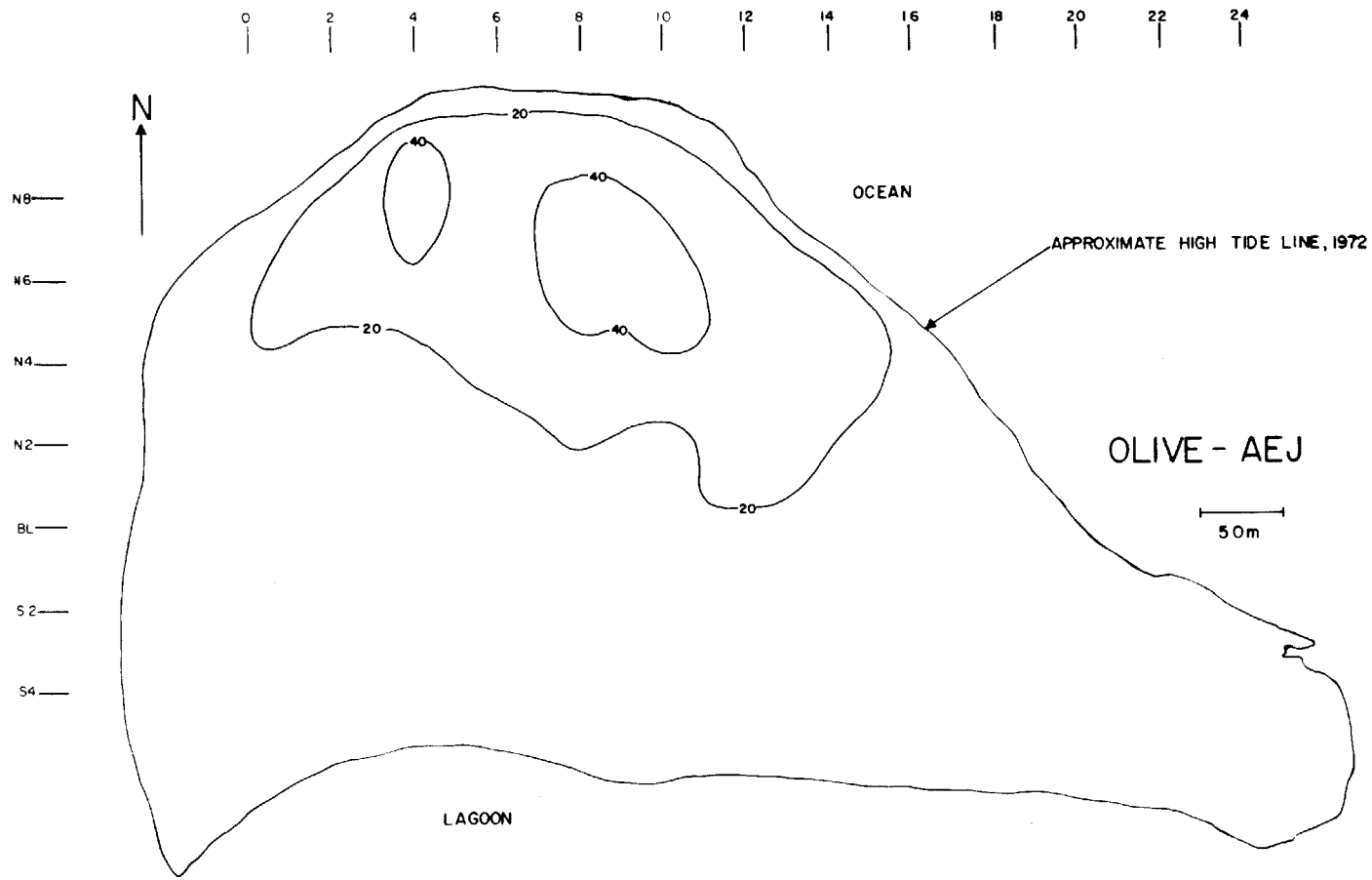


FIGURE 7-36. ISOPLETHS ON FINAL ESTIMATED SURFACE TRU ACTIVITY IN pCi/g FOR ISLAND OLIVE

7.4.8 Pearl's Daughter

Pearl's Daughter, a small islet about 0.5 hectare in area with sparse vegetation, is located on the reef east of Pearl. The island has no known Marshallese name and was not sampled during the 1972 survey. The surface of the island is covered with large black chunks of coral. No data are available on the amount of exposure received by Pearl's Daughter as a result of nearby nuclear events. There were no ground zero sites, no debris and no burial areas known or suspected on this island.

No IMP measurements were taken on Pearl's Daughter because of its small size, but soil samples were collected. Three locations were sampled on the surface with four composites at each location for a total of 12 samples (see Section 4.2.1 for details on the soil sampling procedure). The results and locations of the soil sampling area shown in Figure 7-37. Table 7-4 summarizes the results. The maximum TRU activity for any soil sample was 165.2 pCi/g and the highest average TRU concentration for any location was 142.1 pCi/g, so Pearl's Daughter met Condition A (see Tech Note 2.17).

Soil samples were collected at two locations on Pearl's Daughter for the Fission Product Data Base Program in support of the dose assessment (see Section 6.11). Soil from one location was analyzed for ^{90}Sr. Tables 7-1, 7-2 and 7-3 give summary statisitics on the 0-15 cm data for ^{137}Cs, ^{90}Sr, and $^{239,240}Pu$, respectively, for this sampling.

The island average transuranics value reported in the Certification is 123 pCi/gm for surface soil, and the transuranics classification is Food Gathering.

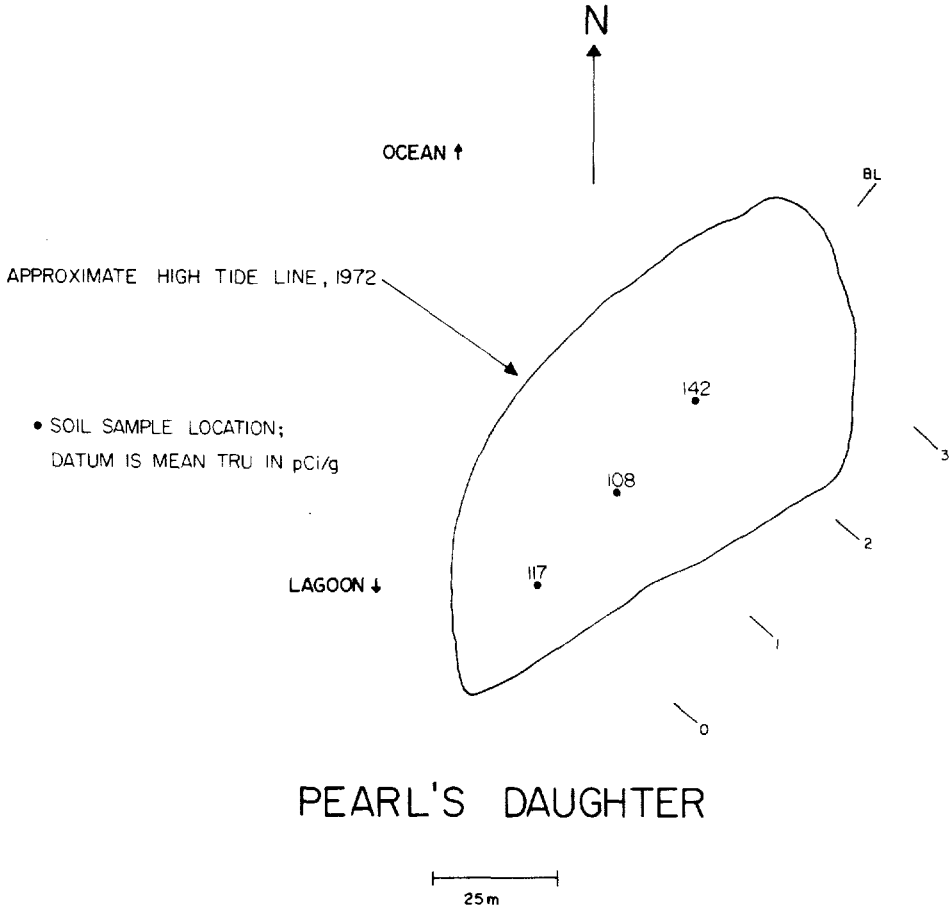


FIGURE 7-37. COASTLINE AND DATA COLLECTION LOCATIONS FOR ISLAND PEARL'S DAUGHTER

7.4.9 Ruby

Background

Island Ruby (Marshallese: Eleleron) is a small moderately vegetated islet, 1.5 hectares in area, lying between Pearl and Sally. This island was originally much larger and was connected to Sally by a causeway, but most of the island was destroyed by the George and Mohawk nuclear events which were conducted there. (See Section 7.5 for more information on Ruby and the changes it went through due to the testing operations.) Some debris remained on Ruby but was removed during the cleanup operation. This island ranks 2nd among the islands in the Atoll with 10,643 R/h total H + 1 hour exposure rate, but most of the land mass receiving this exposure has been blasted or eroded away. There were no known or suspected burials of radioactive materials on Ruby.

1972 Survey Results

Five locations were soil sampled during the 1972 survey and a few vegetation samples were also taken. There was only one profile sample and the other four locations had 0-15 cm core samples. The one profile showed a homogeneous distribution of low activities for ^{137}Cs, ^{90}Sr and $^{239,240}Pu$. Tables 7-1, 7-2 and 7-3 summarize the results of the 1972 sampling for the 0-15 cm data for ^{137}Cs, ^{90}Sr, and $^{239,240}Pu$, respectively.

Characterization

Ruby was measured by the IMP at 9 locations with a 25 m spacing in March 1978. Four locations were soil sampled to determine a ratio of TRU to ^{241}Am with each location having two composites at each of three depths for a total of 24 samples (see Section 4.2.1 for details on surface sampling). A ratio of 6.42 $\pm$ 0.39 was estimated for Ruby (see Tech Note 2.16). Figure 7-38 indicates both IMP and soil sample locations.

Using the ratio and the ^{241}Am IMP results, TRU values were calculated. Due to the small size of this island and few data points, no kriging estimates were made. All computed TRU values were below 10 pCi/g based on original data. (See Tech Note 23 for discussion of original versus final data.)

After this initial characterization of Ruby, it was discovered that the detector used to measure Ruby experienced a loss in efficiency and the calculated ^{241}Am IMP data were low. A correction factor was estimated and the data adjusted for the final characterization. (See Tech Note 5.2 for details on this problem and the determination of the correction factor.)

Figure 7-39 shows the isopleth of TRU activity based on final data after the IMP data were corrected for the detector efficiency. Table 7-4 gives island means for computed TRU, ^{137}Cs and ^{60}Co activities for the final IMP data.

Two locations were sampled to a depth of 80 cm to verify that no subsurface pockets of contamination existed on Ruby. The subsurface samples were taken because the original island was the site of two ground zeros. One 80 cm data result did indicate an elevated TRU activity but it was below 160 pCi/g.

Fission Product Sampling

Three locations were sampled on Ruby for the Fission Product Data Base Program in support of the dose assessment (see Section 6.11). Soil from one of the three locations was analyzed for ^{90}Sr. Tables 7-1, 7-2 and 7-3 summarize the 0-15 cm data for ^{137}Cs, ^{90}Sr and $^{239,240}Pu$, respectively.

The island average transuranics value reported in the Certification is 8 pCi/gm for surface soil, and the transuranics classification is Residence.

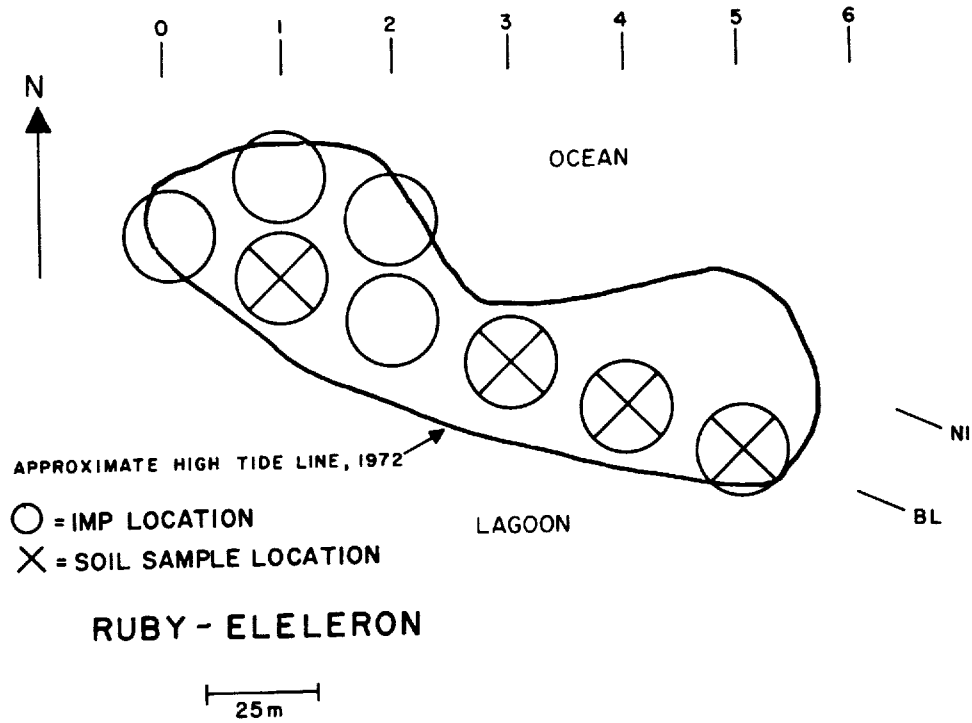


FIGURE 7-38. COASTLINE AND DATA COLLECTION LOCATIONS FOR ISLAND RUBY

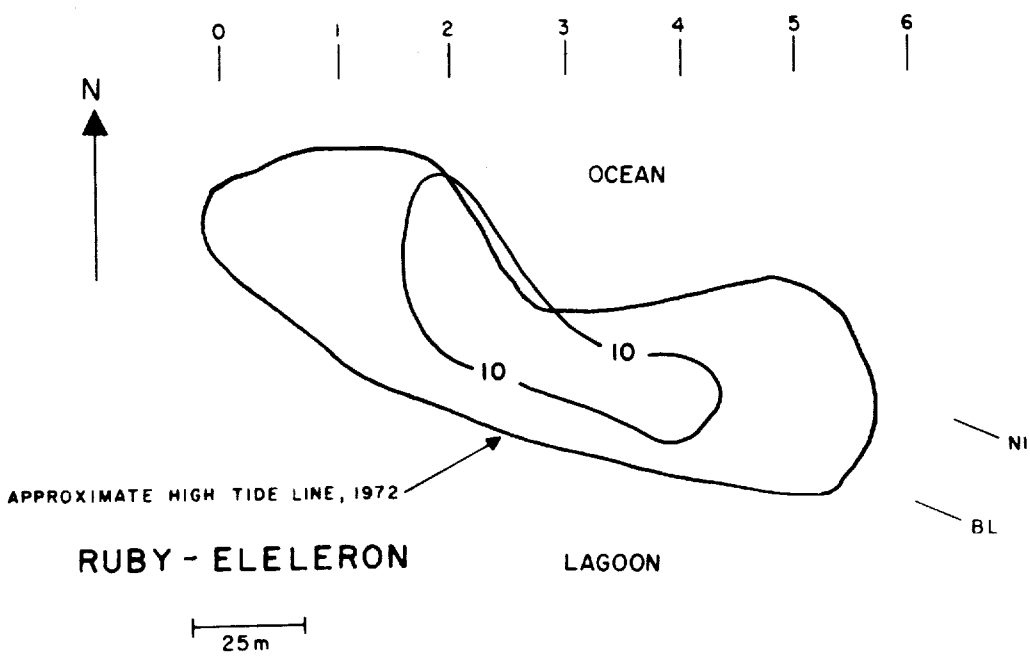


FIGURE 7-39. ISOPLETHS ON FINAL ESTIMATED SURFACE TRU ACTIVITY IN pCi/g FOR ISLAND RUBY

7.4.10 Sally's Child

Background

Sally's Child is a heavily vegetated islet with an area of 0.8 hectares located on the reef east of Sally. The island has no known Marshallese name and was not used during the testing operations for scientific purposes. There were no debris, no ground zero sites, and no burials on Sally's Child. No data are available on the amount of exposure this island received as a result of nearby nuclear events.

1972 Survey Results

During the 1972 survey, soil samples were collected at six locations on Sally's Child; two of the locations were profile sampled and the other four had 0-15 cm core samples. The profile results generally indicated the distribution of activities for ^{137}Cs, ^{90}Sr and $^{239,240}Pu$ to be declining steadily with increasing depth. The exception to this was one ^{90}Sr profile which showed activity dropping initially down to 3 cm, increasing steadily to 20 cm and then decreasing again.

The 0-15 cm data for ^{137}Cs, ^{90}Sr and $^{239,240}Pu$ are summarized in Tables 7-1, 7-2 and 7-3, respectively, for the 1972 sampling.

Characterization and Fission Product Sampling

Sally's Child did not have any IMP measurements taken due to its small size, but soil samples were collected at six locations. Each location was sampled at the surface with four composites for a total of 24 samples (see Section 4.2.1 for details on the soil sampling procedure.) No ratio of TRU to ^{241}Am was computed because there were no IMP data. The results and the locations of the soil sampling on Sally's Child are shown in Figure 7-40. Summary results of the TRU activity are shown in Table 7-4. The maximum TRU activity of any soil sample was 33.4 pCi/g (see Tech Note 2.20).

Sally's Child was sampled at four sites for the Fission Product Data Base Program in support of the dose assessment (see Section 6.11). Soil from all four locations was analyzed for ^{90}Sr. Tables 7-1, 7-2 and 7-3 summarize the 0-15 cm data for ^{137}Cs, ^{90}Sr and $^{239,240}Pu$, respectively, for this sampling.

The island average transuranics value reported in the Certification is 21 pCi/gm for surface soil, and the transuranics classification is Residence.

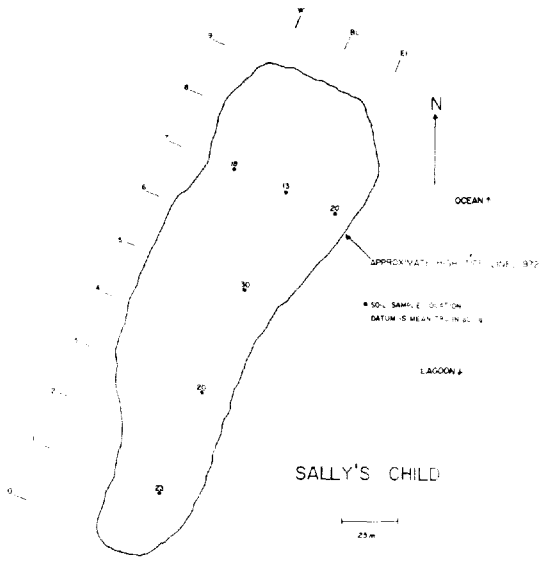


FIGURE 7-40. COASTLINE AND DATA COLLECTION LOCATIONS FOR ISLAND SALLY'S CHILD

7.4.11 Tilda

Background

Island Tilda (Marshallese: Bijire) is the middle island of the Sally-Tilda-Ursula complex, interconnected by a landfilled causeway to Sally and a plank-and-pile bridge to Ursula. It has an area of 21 hectares and was moderately to densely vegetated before the cleanup project. There was extensive soil disturbance during the cleanup in the southern part of this island because it was used for a sanitary landfill for the forward camp on Ursula. Several test structures still remain on Tilda but the asphalt runway was removed. No ground zero sites were located on this island and it ranks 18th among the islands in the Atoll with 774 R/h accumulated H + 1 hour exposure rate. There were no known or suspected burials of radioactive materials on this island, though the landfill causeway to Sally contained a major burial (see Section 6.8).

1972 Survey

Soil samples were collected at 32 sites during the 1972 survey and a few vegetation samples were also collected. Of the 32 sites, 28 had 0-15 cm core samples and 4 had 0-35 cm profiles. Two of the profiles showed the activities of ^{137}Cs, ^{90}Sr and $^{239,240}Pu$ to be declining steadily with increasing depth, and the other two profiles indicated a homogeneous distribution of low activities for the four isotopes.

The results from the core samples indicated a difference in activities related to the amount of vegetation. The more densely vegetated area of Tilda yielded higher average activities of these isotopes than the moderately vegetated area. The 1972 aerial survey also showed this distinction in activity.

Tables 7-1, 7-2 and 7-3 summarize the results of the 1972 sampling of Tilda for 0-15 cm data on ^{137}Cs, ^{90}Sr and $^{239,240}Pu$, respectively.

Characterization

Tilda was measured with the IMP on a 50 m grid in March 1978. Soil samples were collected at six locations with two composites at each of three depths for a total of 36 samples. (See Section 4.2.1 for more information on soil sampling.) The results from these soil samples were used to estimate a ratio of TRU to ^{241}Am of 2.76 ± 0.11. (See Tech Note 2.13.) Figure 7-41 shows the locations of the IMP measurements and the soil sampling.

The ratio was used to estimate TRU values from the IMP ^{241}Am data based on original data. (See Tech Note 23 for discussion of original versus final data.) Using these TRU numbers, estimates of the 0.5 s upper bounds on the 0.25 hectare averages were made using the kriging technique, where s is the standard deviation of the kriging error (See Section 5.1). Tilda met Condition C without any soil removal.

Tilda was also the site of an experiment to compare soil sample results with IMP measurements on a controlled basis. The details of this experiment are given in Tech Note 8.0. Another experiment conducted by the Joint Task Group on Tilda dealt with different techniques to remove brush and soil in anticipation of cleanup.

Isopleths of surface TRU activity based on final data are shown in Figure 7-42. Table 7-4 gives the island averages for computed TRU, ^{137}Cs and ^{60}Co activities from IMP measurements.

Fission Product Sampling

Tilda was sampled on a 50 m grid for the Fission Product Data Base Program in support of the dose assessment (see Section 6.11). Samples were collected at 48 sites, and soil from 15 of these was analyzed for ^{90}Sr. Tables 7-1, 7-2 and 7-3 give summary statistics for the 0-15 cm depths for the ^{137}Cs, ^{90}Sr and estimated $^{239,240}Pu$ results, respectively, for this sampling.

The island average transuranics value reported in the Certification is 7 pCi/gm for surface soil, and the transuranics classification is Residence.

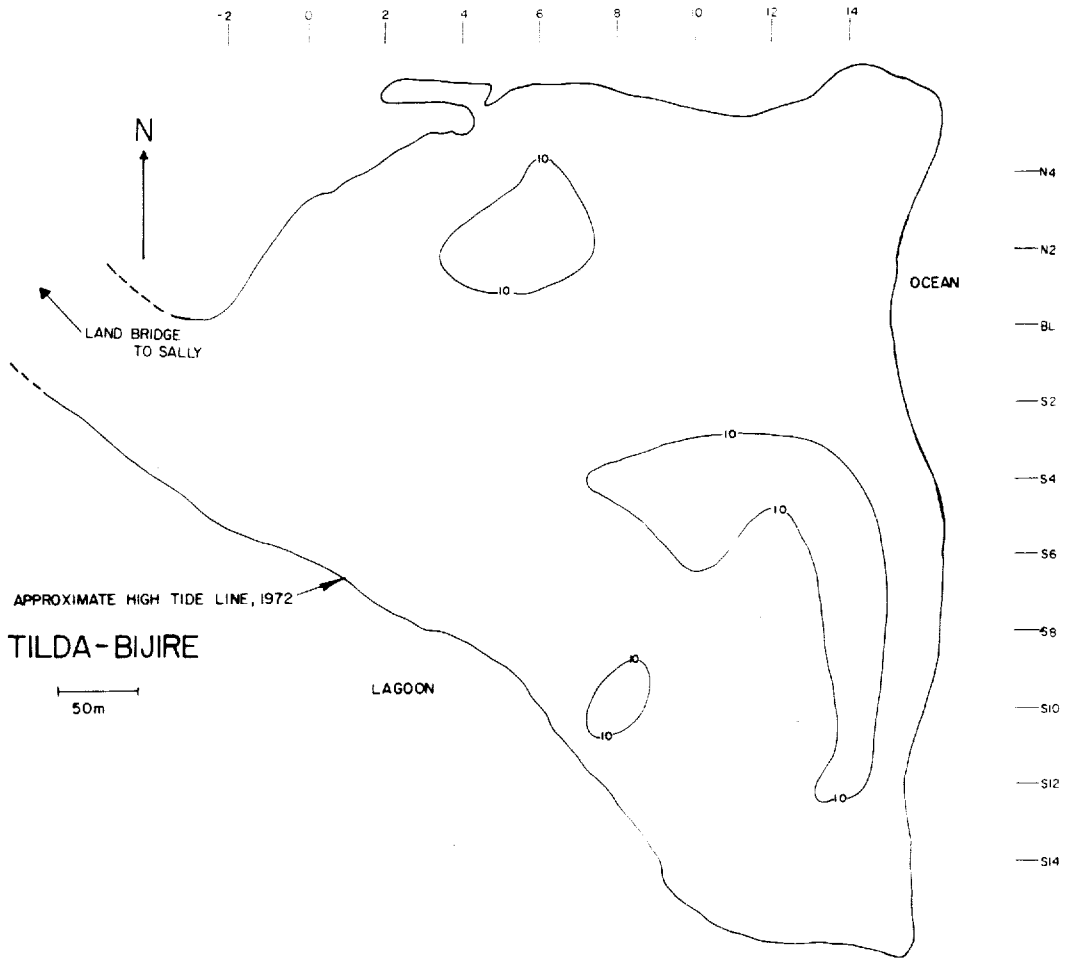


FIGURE 7-42. ISOPLETH ON FINAL ESTIMATED SURFACE TRU ACTIVITY IN pCi/g FOR ISLAND TILDA

line with conservative health physics practices, ERDA would recommend an air sampling program and a minimal program to monitor fresh excavation during initial phases of earth moving operations to document that the soil conditions and actual air concentrations are within national guidelines."

1972 Survey Results

Soil samples were collected at 31 locations on Ursula during the 1972 survey, and a vegetation and an animal sample were also taken. At 28 locations, the samples were 0-15 cm cores and three locations were profile sampled from 0 to 35 cm. Each of the profile results showed a different distribution of activity with depth. One showed a homogeneous distribution of ^{137}Cs, ^{90}Sr and $^{239,240}Pu$ activities down to a depth of 15 cm, and then a steady decline in activity below that depth. Another profile indicated a slight increase in activities of the four isotopes with increasing depth but the level of activities was still low. The third profile showed that the $^{239,240}Pu$ activity dropped sharply and then increased slightly, whereas the ^{137}Cs and ^{90}Sr activities dropped less sharply and then leveled off.

Tables 7-1, 7-2 and 7-3 summarize the 0-15 cm data for ^{137}Cs, ^{90}Sr and $^{239,240}Pu$, respectively, for the 1972 sampling of Ursula.

Characterization and Fission Product Sampling

Ursula was staked on a 100 m grid because camp facilities made the staking of a 50 m grid impossible. Soil samples were collected on this 100 m grid for the Fission Product Data Base Program (FPDB) in support of the dose assessment (see Section 6.11). Fifteen locations were sampled and soil from all of the locations was analyzed for ^{90}Sr. Tables 7-1, 7-2 and 7-3 summarize the 0-15 cm data for ^{137}Cs, ^{90}Sr and $^{239,240}Pu$, respectively.

IMP measurements were also taken on this same 100 m grid in March 1979. Soil samples to determine a ratio of TRU to ^{241}Am were not collected, but based on results of the FPDB sampling, a ratio of 2.80 $\pm$ 0.11 was calculated. All TRU values were less than 5 pCi/g based on original data. (See Tech Note 23 for a discussion of original versus final data.)

Figure 7-43 indicates the IMP locations and Figure 7-44 shows the isopleth of the TRU activity based on final data. Table 7-4 gives island averages for computed TRU, ^{137}Cs, and ^{60}Co activities for the final IMP data.

The island average transuranics value reported in the Certification is 1.9 pCi/gm for surface soil, and the transuranics classification is Residence.

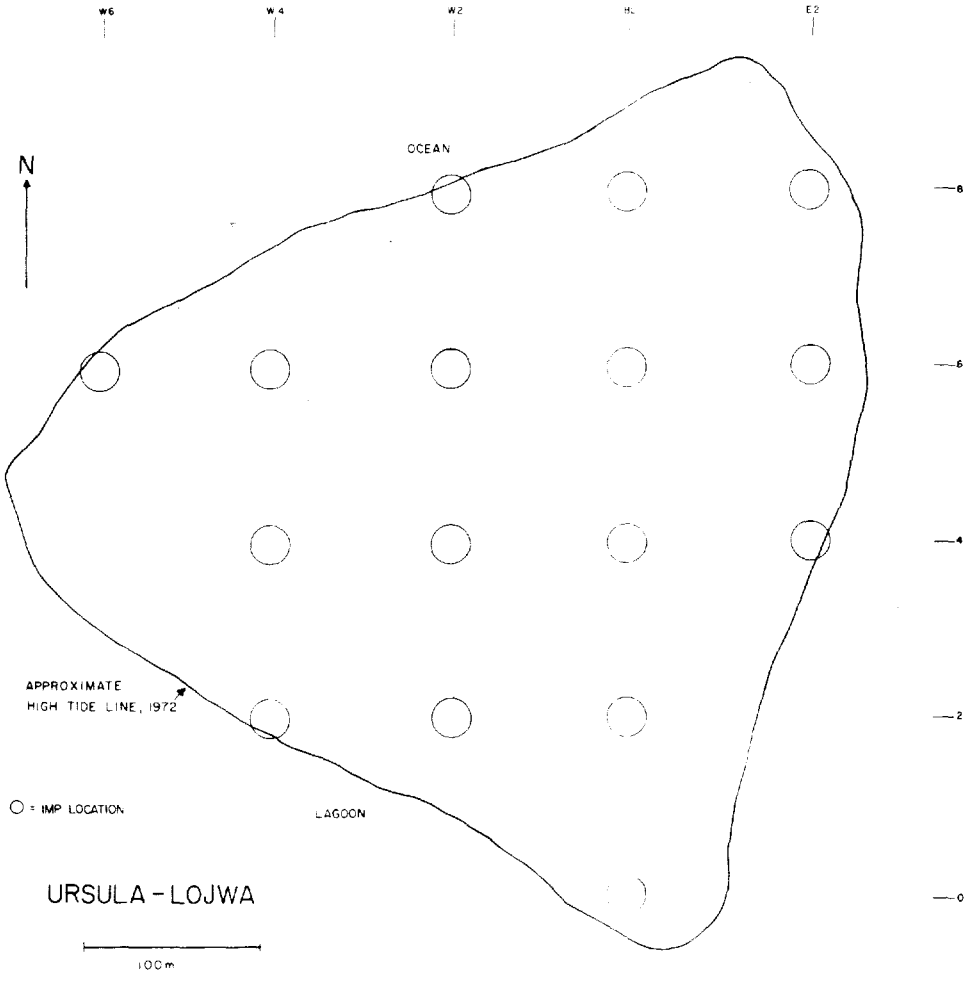


FIGURE 7-43. ISOPLETHS ON FINAL ESTIMATED SURFACE TRU ACTIVITY IN pCi/g FOR ISLAND URSULA

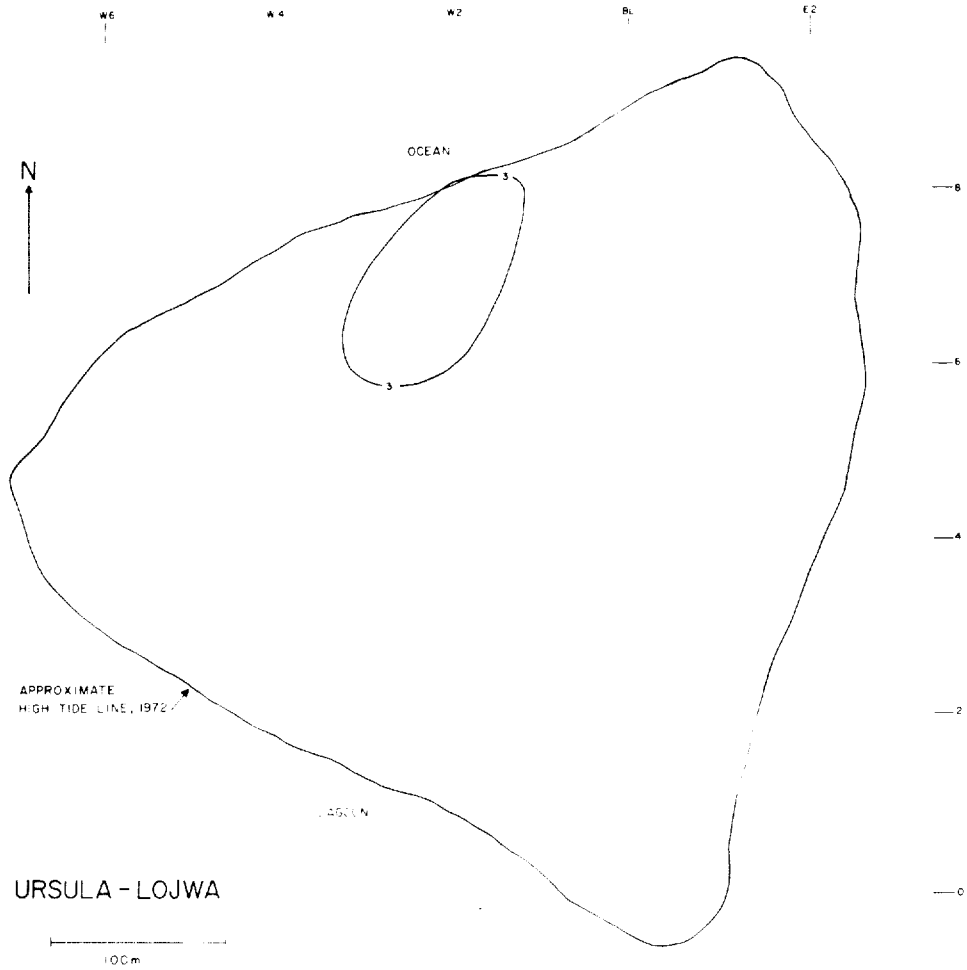


FIGURE 7-44. ISOPLETHS OF FINAL ESTIMATED SURFACE TRU ACTIVITY IN pCi/g FOR ISLAND URSULA

7.4.13 Vera

Background

Island Vera (Marshallese: Alembel) is a moderately-sized island in the east-northeastern part of the Atoll, having an area of 15.5 hectares. The island was densely vegetated and had several mature coconut palms. Few pieces of debris remained from the test operations thus no significant soil disturbances occurred due to debris removal. No ground zero sites were located on Vera and it ranks 22nd of all islands in the Atoll in total H + 1 hour exposure rate with 270 R/h. There were no known or suspected burials of radioactive materials on this island.

1972 Survey

During the 1972 survey, soil samples were collected at 25 sites on Vera and a few vegetation samples were also taken. Three of the 25 locations were 0-35 cm profile samples and the remaining 22 locations were 0-15 cm core samples. The results from the profile samples indicated a steady decrease in activity with increasing depth for ^{137}Cs, ^{90}Sr and $^{239,240}Pu$ data. Tables 7-1, 7-2 and 7-3 give 0-15 cm summary results for ^{137}Cs, ^{90}Sr and $^{239,240}Pu$, respectively, for the data collected in 1972.

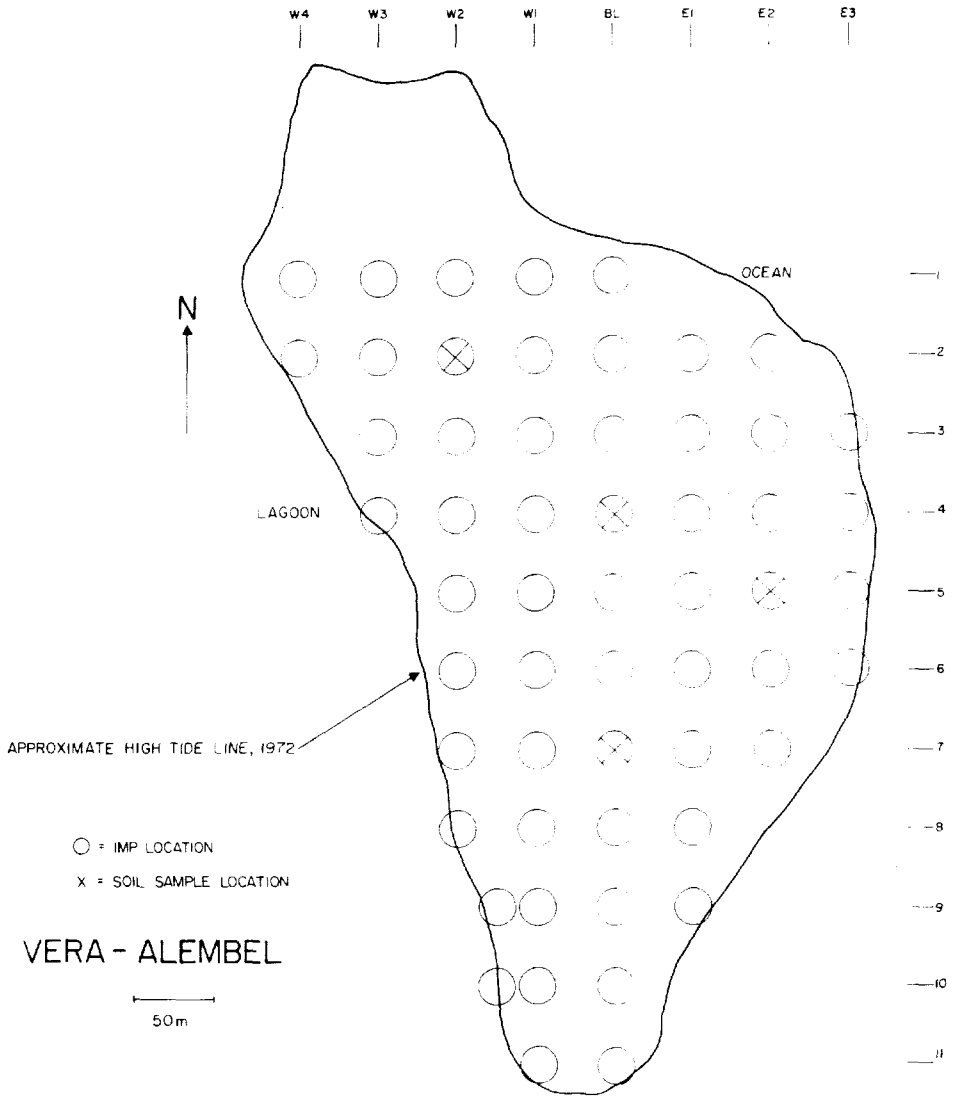


FIGURE 7-45. COASTLINE AND DATA COLLECTION LOCATIONS FOR ISLAND VERA

Characterization

Vera was staked on a 50 m grid and IMP measurements taken on this grid in November 1977. Soil samples were collected at four locations with two composites at each of three depths for a total of 24 samples (see Section 4.2.1 for more details concerning soil sampling). Based on the results from this soil sampling, a ratio of TRU to ^{241}Am of 2.5 $\pm$ 0.15 was estimated. (See Tech Note 2.2A.) Both IMP and soil sample locations are shown in Figure 7-45.

Using the IMP ^{241}Am data and the estimated ratio, TRU numbers were calculated based on original data. (See Tech Note 23 for discussion on original versus final data.) Estimates of the 0.5 s upper bounds on the 0.25 hectare averages were made using the kriging technique, where s is the standard deviation of the kriging error (see Section 5.1). No upper bound on any TRU average exceeded 40 pCi/g so that Vera met Condition C without any soil removal.

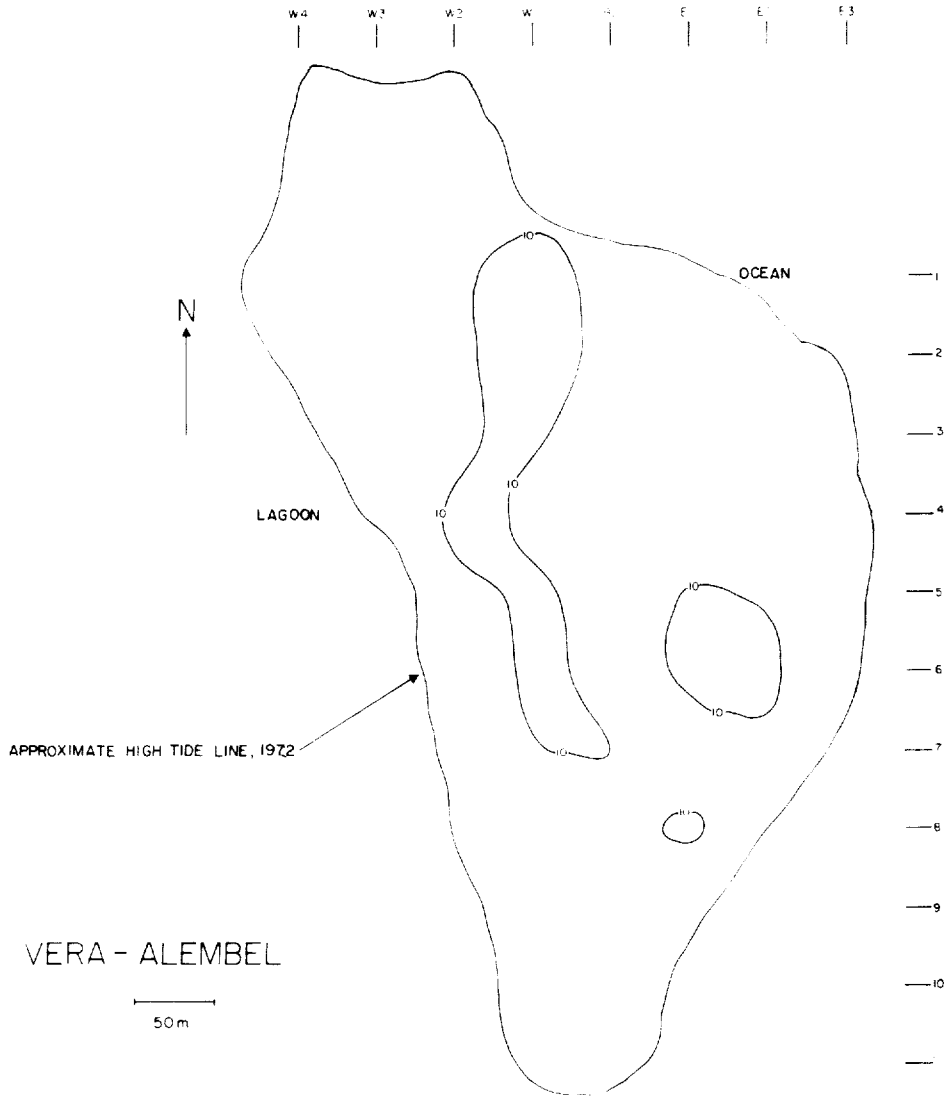


FIGURE 7-46. ISOPLETHS ON FINAL ESTIMATED SURFACE TRU ACTIVITY IN pCi/g FOR ISLAND VERA

Isopleths of surface TRU activity based on final data are shown in Figure 7-46. Table 7-4 gives island averages for computed TRU, ^{137}Cs, and ^{60}Co activities for the final IMP data.

Fission Product Sampling

Vera was soil sampled on a 50 m grid for the Fission Product Data Base project in support of the dose assessment (see Section 6.11). Samples were collected at 48 locations, and soil from 13 of these were analyzed for ^{90}Sr analysis. The results for the 0-15 cm data for ^{137}Cs, ^{90}Sr, and estimated $^{239,240}Pu$ are summarized in Tables 7-1, 7-2 and 7-3, respectively.

The island average transuranics value reported in the Certification is 7 pCi/gm for surface soil, and the transuranics classification is Residence.

7.4.14 Wilma

Background

Island Wilma (Marshallese: Billae) is a small island in the east-northeastern part of the Atoll with an area of 6.4 hectares. The island is densely vegetated and was the site of several scientific stations used during the nuclear testing program. There appeared to be some soil disturbance as a result of debris removal, but all IMP measurements were made after debris removal. Wilma had no ground zero sites and ranks 21st among the islands in the Atoll with a 294 R/h total H + 1 hour exposure rate. There are no known or suspected burials of radioactive material on this island.

1972 Survey Results

During the 1972 survey, soil samples were collected at 23 locations and one vegetation sample was taken. Of the 23 samples, 19 were 0-15 cm core samples, two were 0-35 cm profiles, and two were 0-65 cm profiles. The profile results indicated the activities of ^{137}Cs, ^{90}Sr and $^{239,240}Pu$ to be declining steadily with increasing depth. Tables 7-1, 7-2 and 7-3 summarize the results for ^{137}Cs, ^{90}Sr and $^{239,240}Pu$ activities, respectively, for the 0-15 cm core samples.

Characterization

Wilma was measured with the IMP on a 50 m grid in March 1978. To determine a TRU to ^{241}Am ratio, four locations were soil sampled with each location having two composites at each of three depths for a total of 24 samples (see Section 4.2.1 for more information on soil sampling). A ratio of 2.76 ± 0.09 was estimated based on these results (see Tech Note 2.14). Both IMP and soil sample locations are shown in Figure 7-47. TRU values were calculated using the estimated ratio and the

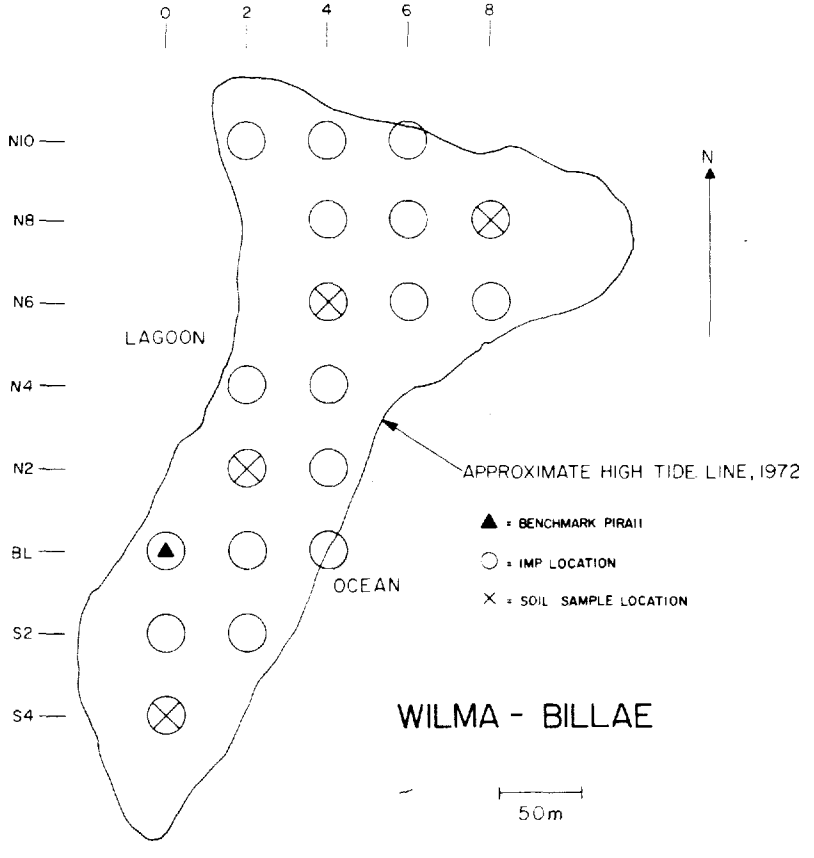


FIGURE 7-47. COASTLINE AND DATA COLLECTION LOCATIONS FOR ISLAND WILMA

IMP ^{241}Am numbers. Estimates and upper bounds on 0.25 hectare averages were not computed because of insufficient data collected on this small island. All calculated TRU values were less than 10 pCi/g based on original data. (See Tech Note 23 for discussion on original versus final data.)

Wilma was measured with a detector that experienced a loss in efficiency causing the calculated ^{241}Am IMP values to be low. This was discovered after the initial characterization was complete. A correction factor was estimated for this problem and the data corrected for the final characterization. (See Tech Note 5.2 for details on the determination of this correction factor.)

Figure 7-48 shows the isopleth on final TRU activity after correction of the IMP data for detector efficiency. Table 7-4 gives island averages for computed TRU, ^{137}Cs and ^{60}Co activities for the final IMP data.

Fission Product Sampling

Soil samples were collected on a 50 m grid for the Fission Product Data Base Program in support of the dose assessment (see Section 6.11). Of the 17 locations sampled on Wilma, soil from five of them had ^{90}Sr analysis. The 0-15 cm data for ^{137}Cs, ^{90}Sr and $^{239,240}Pu$ activities are summarized in Tables 7-1, 7-2 and 7-3, respectively.

The island average transuranics value reported in the Certification is 3 pCi/gm for surface soil, and the transuranics classification is Residence.

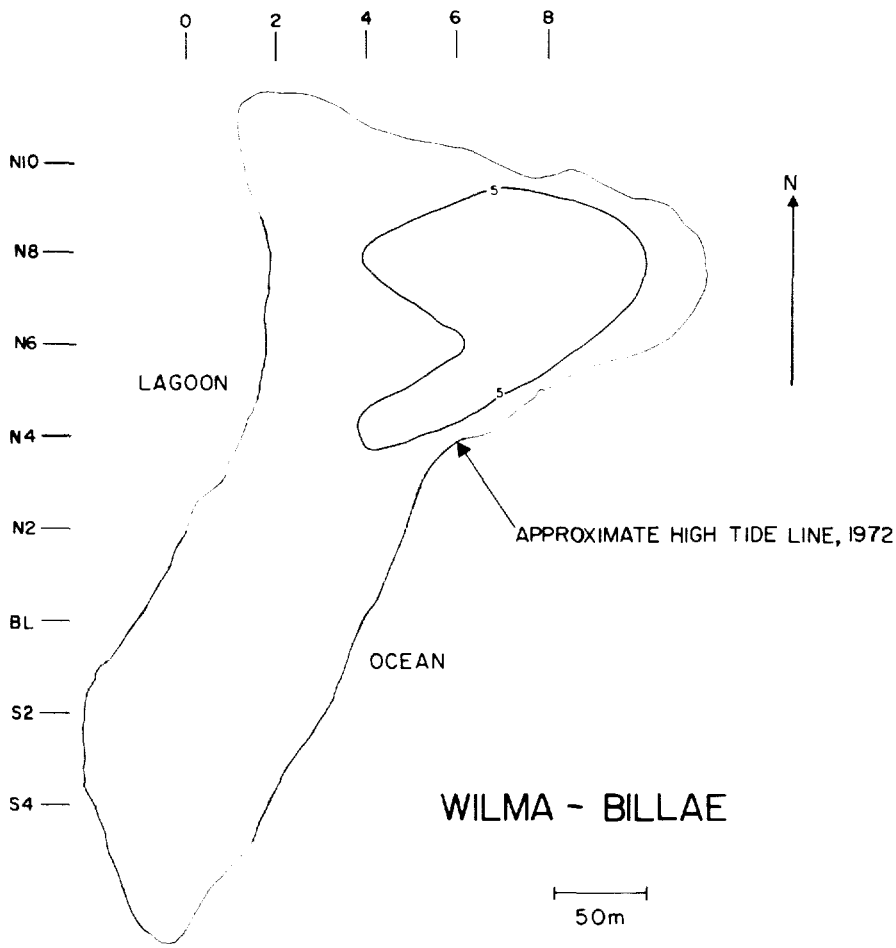


FIGURE 7-48. ISOPLETHS ON FINAL ESTIMATED SURFACE TRU ACTIVITY IN pCi/g FOR ISLAND WILMA

7.5 SOIL REMOVAL ISLANDS

Those islands which were nuclear event ground zero (GZ) sites were the most severely affected by nuclear testing operations. A typical sequence of activities for a test included site preparation and construction of test-related structures. Then, after the event, monitoring devices would be recovered, some structures might be removed, contaminated materials were buried or removed, and the soil recontoured. The event itself might have destroyed vegetation, produced a tidal wave, and perhaps destroyed or rearranged the island surface, as well as leaving radioactive contamination on the island.

In some cases, the damage extended to complete destruction. The Mike event left only a large crater in the reef where island Flora (Marshallese: Elugelab) had been. Island Gene (Marshallese: Teiteiripucchi) was damaged by several events, and eventually destroyed completely by the Koa event, which also left only a crater in the reef.

The same series of events that destroyed Gene also destroyed most of island Helen and significantly altered island Edna. The small part of Helen still in existence has merged into a sandspit which extends westward from island Irene. There is also a crater on the western edge of Irene as a result of the Seminole event. Two similar craters at the north end of island Yvonne were made by the Lacrosse and Cactus events. The Cactus crater was filled with contaminated soil and debris that was removed from other locations during the cleanup, and a 25 ft high dome of soil/cement with a clean concrete cap was built atop the crater site.

The original island of Ruby was almost completely destroyed by the George and Mohawk events; the remnants form the Cape Mixan area of island Sally and the island now known as Ruby. Because the present island is not representative of the original island, Ruby is discussed in Section 7.4 rather than as a ground zero island in this section.

The ground zero islands discussed in this section are also the islands which required soil removal in the cleanup. The general approach to surface cleanup was to use the kriging method (see Section 5.1) on IMP data on a 50 m grid to determine the approximate area requiring soil removal. Then the boundary of the cleanup area would be refined by taking IMP measurements at 25 m intervals, which provided substantial coverage of the surface. After each soil lift, the entire area lifted would be remeasured at 25 m spacing and the lift-remeasure process was repeated, if necessary, until the applicable criterion was met.

The standard procedures for surface soil sampling (see Section 4.2.1) were used for the ground zero islands. Multiple ratio of TRU to ^{241}Am populations were present on all of these islands, so many more samples were taken than the minimum called for in the procedure. The maps accompanying the individual island reports show the boundaries between populations of ratios as determined from the soil sampling results.

Subsurface soil sampling was conducted on all these islands using a variety of methods (see Section 6.9 for details) at all known or suspected burial areas. Suspected areas automatically included the immediate vicinity of all GZ's because it was common practice for event craters to be used as burial sites for contaminated material. Other areas were investigated based on information in as-built drawings, operations reports, verbal reports by nuclear testing participants, and on data from the 1972 survey. The suspected burial areas are shown on the individual island maps, and results of subsurface sampling are included in the island reports that follow.

For all of the ground zero islands except Yvonne, the island report includes the pre-cleanup surface TRU characterization and isopleths on the post-cleanup surface TRU. Also included on all but Yvonne are isopleths on the post-cleanup 0-40 cm average ^{137}Cs and ^{90}Sr activities, based on data from the Fission Product Data Base (FPDB) program. Only the final TRU isopleths are given for Yvonne because only part of the island was measured with the IMP before cleanup, and only southern Yvonne was included in FPDB sampling. Results from the 1972 survey and the FPDB program are summarized for all the islands in Tables 7-1, 7-2 and 7-3. Table 7-5 summarizes results of IMP measurement made during the cleanup, and Table 7-6 gives the volume of soil excised and the TRU activity removed during the cleanup.

TABLE 7-6. VOLUME AND TRU ACTIVITY OF SOIL EXCISED DURING THE RADIOLOGICAL CLEANUP OF ENEWETAK ATOLL

Island	Soil Volume (Cubic Meters)	TRU Activity (Curies)	Total Area with Soil Excision Area (ha)	% of Island
Sally	8,100	1.3	1.8	4.5
Aomon Crypt	7,475	0.9	0.2	1.0
Irene	3,775	1.0	0.6	3.3
Janet	40,525	2.6	15.5	13.1
Pearl	11,415	1.7	9.7	44.1
Yvonne	8,210	7.2	5.0	13.5
Totals	79,500	14.7	32.8	

7.5.1 Irene

Background

Island Irene (Marshallese: Boken), the northernmost island in the Atoll, is moderately to heavily vegetated. It is now about 18 hectares (ha) in area, but was somewhat larger, perhaps 20 ha, prior to nuclear testing activities. The change in area is the result of the Seminole event, which left a water-filled crater about 150 m in diameter in the west-central coastline of Irene. A sandspit extends outward from the main island along the southern edge of the crater, curling to the northwest and stretching several hundred meters west of the main island. The spit, formed from a combination of nuclear event throwout, a small remnant of island Helen (Marshallese: Bokaidrik) and wave-deposited sand, tends to change shape with every major storm. The only constant sections are a small vegetated area near the main body of the island and another small vegetated area about 200 m west of the main island. The latter area is all that remains of Helen, so the sandspit is known as the "Helen spit." Figures 7-49 and 7-50 are maps of Irene and the Helen spit, respectively.

The only event ground zero (GZ) on Irene was Seminole; the GZ itself was just east of the center of the crater left by that event. However, the Mike and Koa events which vaporized the nearby islands of Flora and Gene (see Section 7.5 for more details) also extensively affected Irene. Other events on barges in the Mike crater also affected Irene, eventually destroying most of Helen and forming the Helen spit from what remained. As a result of the 24 events which affected Irene and Helen, they ranked fourth and fifth in the Atoll in total H + 1 hour exposure rate with 6,184 R/h and 5,277 R/h, respectively.

Among the effects of the events on and near Irene are direct blast effects, at least one impact crater from flying debris, and repeated wave inundation. Both the shape and physical characteristics of Irene were altered by these processes. Many test structures were built on Irene, with substantial soil rearrangement in the process, leading to numerous areas of suspected buried contamination. For example, in order to provide line-of-sight from Ivy Station 200 in northeastern Irene to the Mike crater, contaminated throwout from the Seminole crater was bulldozed aside. Similar actions may have taken place during construction of a line-of-sight pipeline to the Koa GZ, and there may have been deliberate burials of contaminated soil and debris. The areas suspected of containing subsurface contamination are shown in Figure 7-49.

A great deal of debris, scrap metal, and old scientific stations remained scattered all over the island after testing ceased. Much of this debris was contaminated, and it was difficult to distinguish between contaminated and uncontaminated material because of Irene's high background activity. Some of the debris was subsurface; for example, at least one station was constructed below-grade and never removed, and many buried cables and pipes were left. A number of the cables were found during the cleanup, still in place.

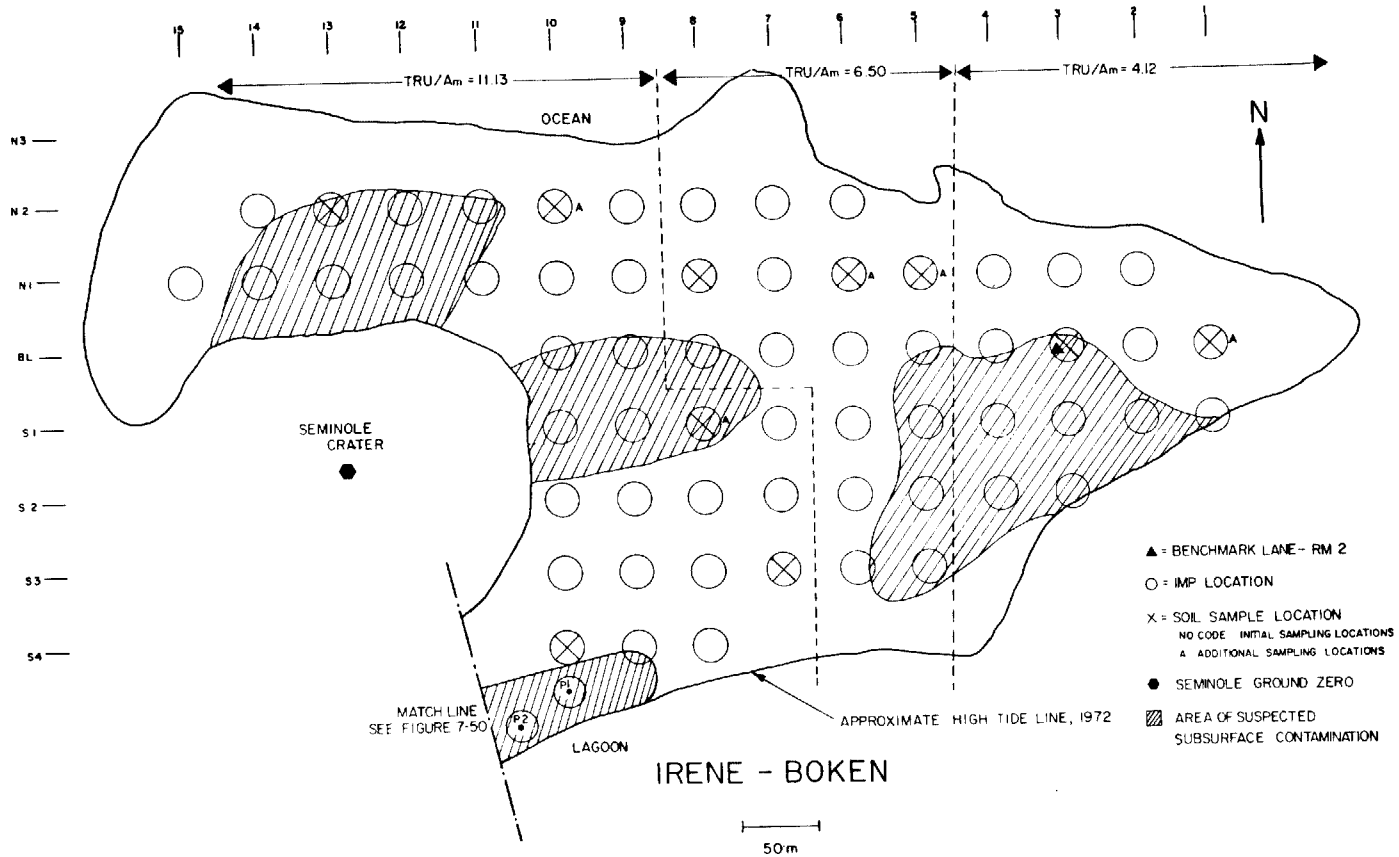


FIGURE 7-49. COASTLINE AND DATA COLLECTION LOCATIONS FOR ISLAND IRENE

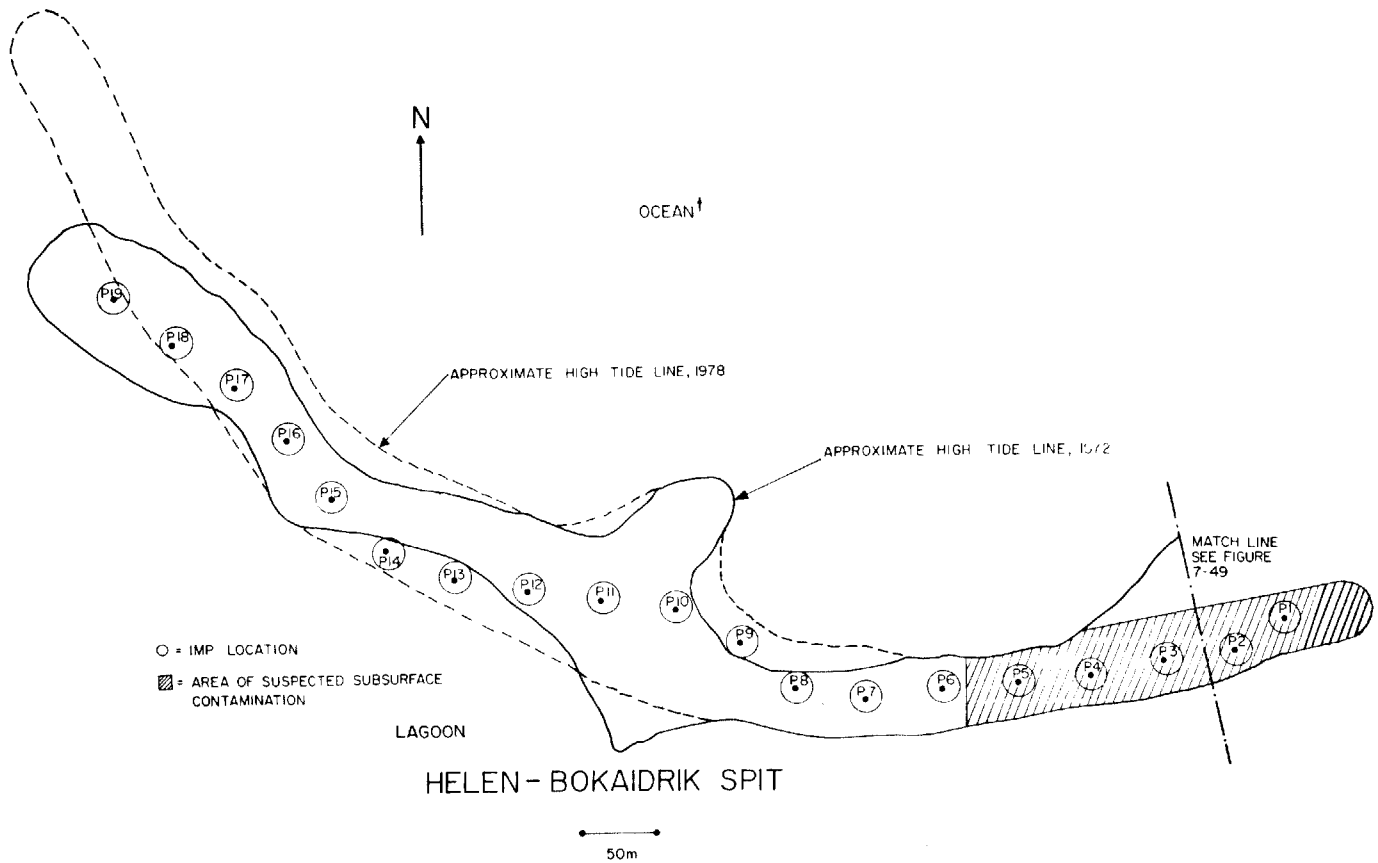


FIGURE 7-50. COASTLINE AND DATA COLLECTION LOCATIONS FOR HELEN SPIT

1972 Survey Results

A total of 58 locations were soil sampled on Irene during the 1972 survey. At 37 locations, the samples were 0-15 cm cores, 6 locations were profile sampled from 0 to 35 cm, 11 locations had 0-65 cm profiles, and 4 locations had 0-185 cm profiles. Many plant and several animal samples were also taken on Irene. The distribution of activity with depth in the soil samples was quite variable, and high subsurface activity of $^{239,240}Pu$, ^{137}Cs and ^{90}Sr was observed at several locations. The elevated activity was observed as deep as one meter, helping indicate the general locations of possible burials of contaminated soil and debris. In general, the depth distribution at a location was similar for $^{239,240}Pu$, ^{137}Cs and ^{90}Sr, and the activity dropped steeply below one meter even in locations with elevated subsurface activity. The results for 0-15 cm data for ^{137}Cs, ^{90}Sr and $^{239,240}Pu$ are summarized in Tables 7-1, 7-2 and 7-3, respectively.

The soil data indicated not only inhomogeneity in the depth distribution of activity, but also the existence of more than one $^{239,240}Pu$ to ^{241}Am isotope ratio. The ratio is usually assumed to be constant for all contamination originating from a single event. This implies that any differences observed in the $^{239,240}Pu$ to ^{241}Am ratio would be due to contamination from more than one source. The relative locations on Irene of the various ratios tended to confirm that hypothesis, so that boundaries between ratio populations might be based on geographical location.

In addition to the soil, plant and animal samples, several sampling wells were drilled for the groundwater studies in the 1972 survey. Two coconut trees were selected to be a part of the long-term study of radionuclide uptake in food plants. Efforts were made to preserve the wells and study trees during the cleanup.

Surface Characterization

The initial IMP measurements of Irene were made on a 50 m grid beginning 28 October and ending 7 November 1977. Measurements on the Helen spit were also made at 50 m intervals along the spit at the center of the area above the high tide line. These points did not fall on the nodes of the island grid, so the location was established by measuring the angles between adjacent sampling points. As shown in Figure 7-50, 19 points were taken on the Helen spit, starting at the main body of the island and extending as far out as was practicable. The sampling points on the main section of Irene are shown in Figure 7-49.

Soil samples to determine the ratio of TRU to ^{241}Am were taken initially at five locations in October 1977 (see Section 4.2.1). The results confirmed the variation in ratio of TRU to ^{241}Am seen in the 1972 data. In general, the ratio decreased with increasing distance from the Seminole GZ. This information was used to draw tentative boundaries between populations of ratios, and five more locations were sampled to confirm and better define the boundaries. Figure 7-49 shows the locations for both sets of samples and the boundaries between ratio populations that were used for initial characterization. The ratio of TRU to ^{241}Am used were 4.12 ± 0.53 for the eastern end, 6.50 ± 1.20 for the central area, and 11.13 ± 1.7 for the western end and Helen spit (see Tech Notes 2.1 and 2.1-A).

Along with the surface soil samples and measurements, samples were taken from two of the bunkers on Irene, Ivy stations 200 and 600. The samples were taken to help characterize the amount and type of activity on the concrete surface, because the bunkers were to be left in place. Tech Note 13 contains a description of the sampling, which took place on 7 July 1978, and the results of the laboratory analysis. Under worst-case assumptions, the contamination on the concrete was found to be nearly a factor of two below the release limit, so no further cleanup of the bunkers was done.

The initial surface characterization of Irene is shown in Figure 7-51. The 0.5 s upper bounds on the average TRU estimates exceeded 40 pCi/g on only 1.5 ha, where s is the standard deviation of the kriging error, and nowhere did TRU estimates exceed 80 pCi/g based on original data. (See Tech Note 23 for discussion of original versus final data.)

Although no surface cleanup was required to meet the cleanup criteria, later subsurface excavations altered the surface activity in some areas of Irene. For the Helen spit, the highest TRU value estimated from any IMP ^{241}Am value was less than 30 pCi/g.

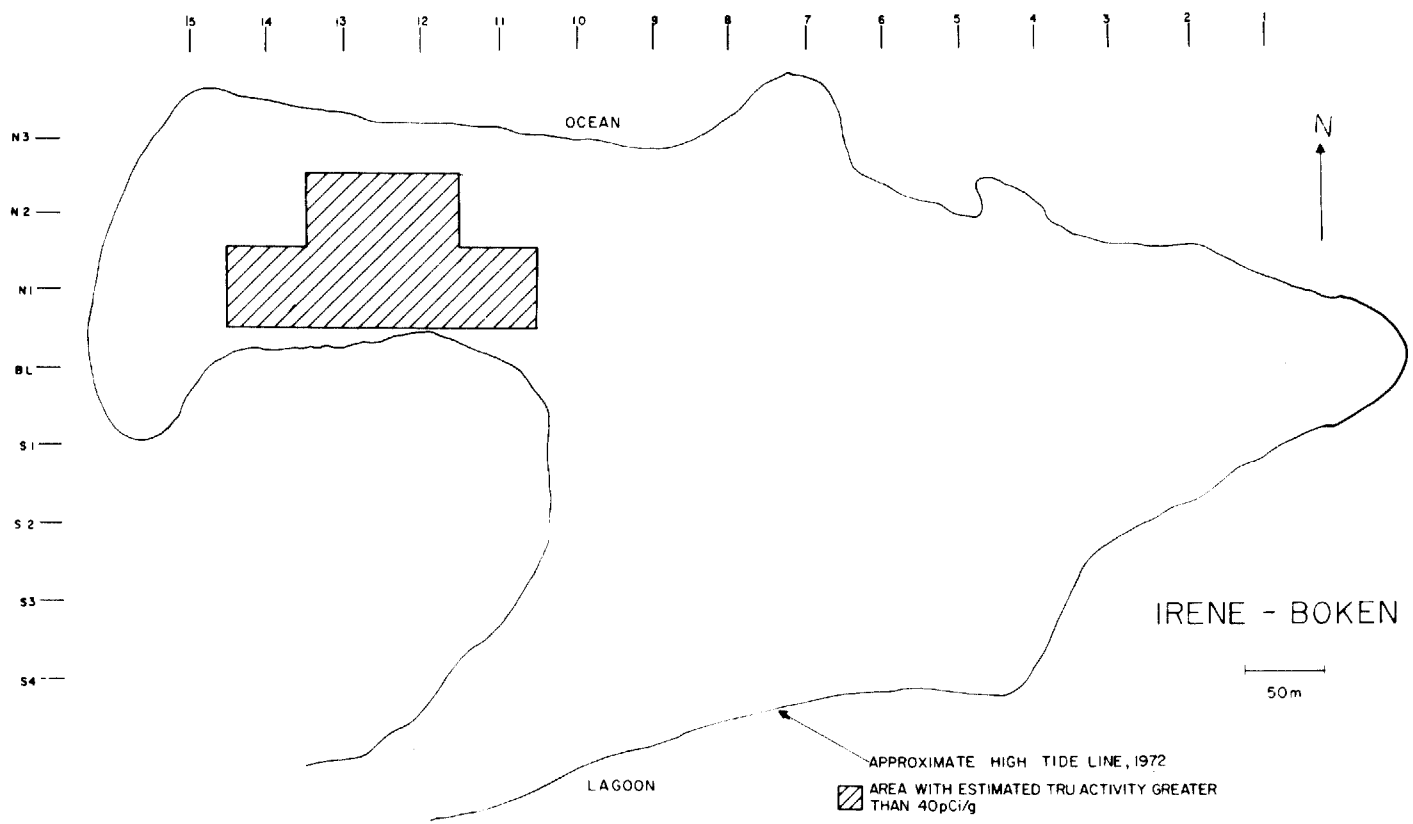


FIGURE 7-51. PRE-CLEANUP CHARACTERIZATION OF SURFACE TRU ACTIVITY FOR ISLAND IRENE BASED ON KRIGING ESTIMATES OF 0.25 HA AVERAGES

Initial Subsurface Characterization and Cleanup

Several areas of Irene, shown in Figure 7-49, were suspected to contain subsurface contamination. The investigation of these areas for possible "pockets" of contamination began in mid-November 1977 with a series of auger core samples. All the suspect areas on the main island were sampled as shown in Figure 7-52, as were points P-1 and P-3 on the Helen spit. Cores were taken in 20 cm increments, and R/h readings taken at 20-cm intervals in the core holes. The soil samples were scanned in the field for alpha activity to determine which ones would be brought to the lab for further analysis. (This procedure was later changed to eliminate the hole-logging, and all samples were submitted to the laboratory for gross alpha and/or gamma analyses.) The results showed definite subsurface contamination at location 13-N-1, and another set of auger samples was taken near 13-N-1 in December 1977. The new data confirmed the earlier results and showed that more investigation was necessary.

The sampling method was then changed from coring to profile sampling of a 5 cm increment from each 20 cm interval in the sidewall of a backhoe trench (see Section 6.9). This method was used for the next set of samples, taken in mid-February, which again covered all the suspect areas plus extra locations near 13-N-1 (see Figure 7-52). These samples again showed the subsurface contamination at 13-N-1 as well as some elevated subsurface activty at 10-BL-0, 10-N-1 and 11-S-4. No other areas showed significant subsurface activity, so an intensive profile sampling program was begun in March 1978 to define the extent of the activity in these four locations. No more contamination was found at 11-S-4, so the investigation at that location was dropped. The subsurface contamination near 10-BL-0/10-N-1 covered too small an area to require cleanup, but boundaries of soil to be excised were determined for the 13-N-1 area. Figure 7-53 shows these boundaries and also the locations sampled near 13-N-1 and 10-BL-0/10-N-1. The sampling was completed in August 1978.

Removal of the contaminated subsurface soil began in early December 1978. The delay from August to December resulted from an effort to avoid disturbing a large rookery of nesting sooty terns in the area near 13-N-1. Mid-Pacific Marine Laboratory (now Mid-Pacific Research Laboratory) made a study of the birds and concluded that the youngest chicks would be fledglings by December. The soil excision was therefore delayed until then, when the birds would be able to tolerate the noise and disturbance of cleanup activities.

The excision was begun by pushing the contaminated soil into large mounds to await stockpiling. The soil in the excavated area was then sampled, and several places which required more excision were discovered. The soil in those places was removed in January 1979 as part of the stockpiling process. In mid-February 1979 the entire lift area was again soil-sampled and also measured with the IMP, and these data showed that more soil required removal. Another lift was made in late February of 1979, and soil samples taken 12 March again showed some TRU activity in excess of 160 pCi/g. In order to speed the cleanup process, soil samples were taken immediately after the next lift on 22 March. Only the soil shown by these samples to have TRU activity greater than 160 pCi/g was removed in the next lift on 24 March, and samples were again taken immediately after that lift. For the final lift, on 30 March 1979, a method was devised to use handheld instruments to estimate TRU activity in the field while the excision was in progress. The operation could then be directed immediately to areas requiring more lifts, and TRU activity in 13-N-1 subsurface area was reduced below 160 pCi/g using this method. The entire excision area and the beach stockpile area were then remeasured with the IMP to confirm that no 0.5 hectares (ha) average TRU activity exceeded 80 pCi/g.

This phase of subsurface cleanup on Irene was completed 26 April 1979. An estimated 2,450 cubic meters (3,200 cubic yards) of soil, containing an estimated 0.6 Ci of TRU activity, were removed from Irene during this phase. Figure 7-54 shows the boundaries of the area from which soil was removed.

Fission Product Sampling and Final Subsurface Cleanup

Irene was sampled on the 50 m grid for the Fission Product Data Base Program (FPDB) in support of the dose assessment (see Section 6.11). Samples were taken at 53 locations, and soil from 15 of them was analyzed for ^{90}Sr. The Helen spit was not sampled because its unstable geography makes

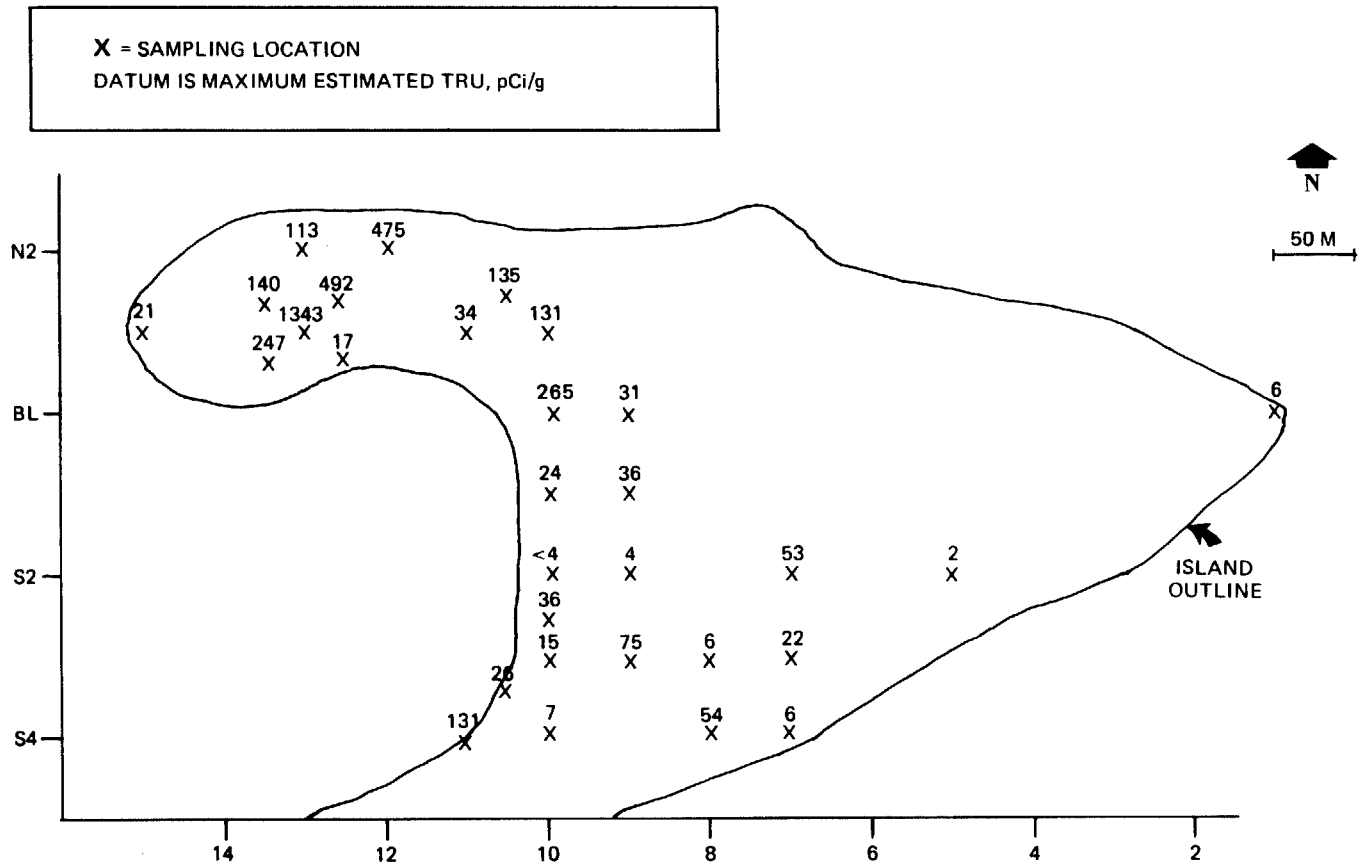


FIGURE 7-52. SUBSURFACE SAMPLING RESULTS, INITIAL SAMPLING OF ISLAND IRENE

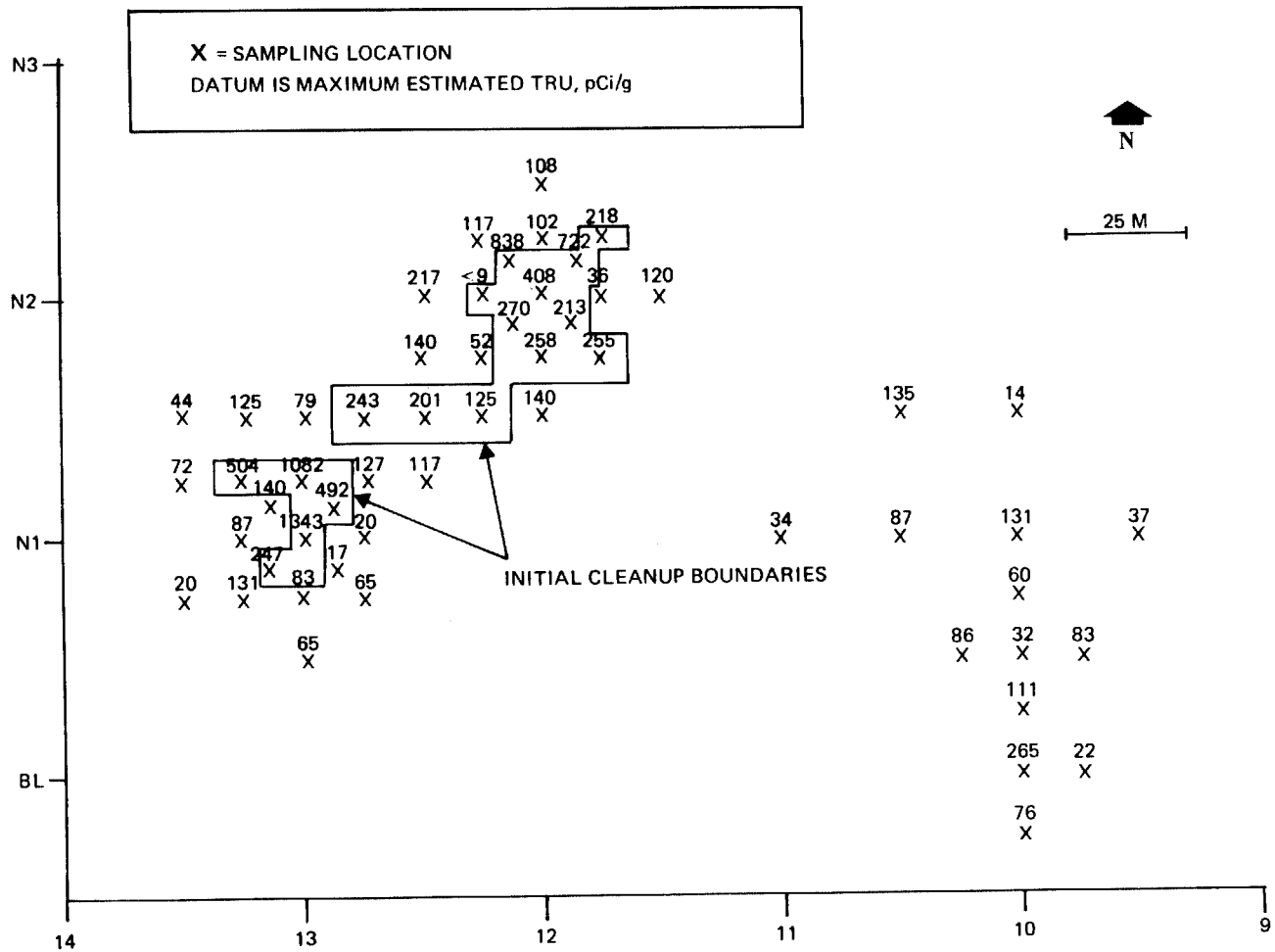


FIGURE 7-53. SUBSURFACE SAMPLING RESULTS, LOCATIONS IONI/13N1, ISLAND IRENE

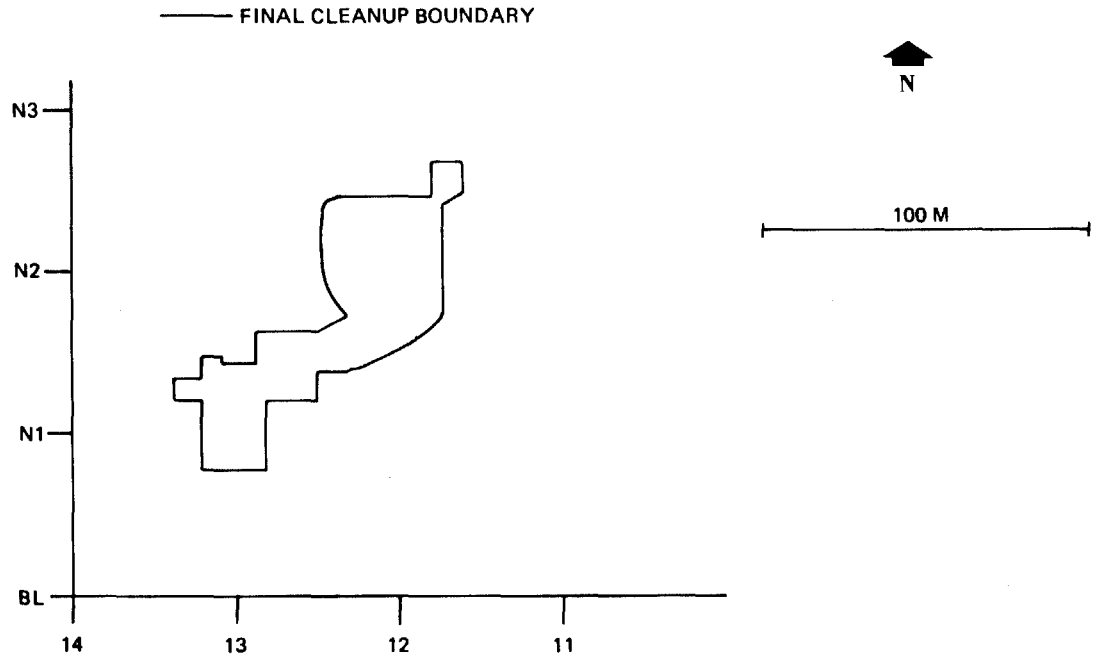


FIGURE 7-54. SUBSURFACE SOIL EXCISION, LOCATION 13N1, ISLAND IRENE

it unsuitable for habitation, agriculture or food-gathering. Tables 7-1, 7-2 and 7-3 summarize the ^{137}Cs, ^{90}Sr and $^{239,240}Pu$ results, respectively, for the 0-15 cm average; island average results for other profile ranges are shown below:

	0-5 cm	0-40 cm	0-60 cm	Total Samples
^{90}Sr, pCi/g	34.1	38.2	36.6	90
^{137}Cs, pCi/g	6.10	5.8	5.4	317

When the FPDB samples were analyzed for ^{241}Am, eleven locations were discovered to have one or more samples with TRU activity possibly exceeding 160 pCi/g. After additional chemical analysis to check the ratio of TRU to ^{241}Am, seven of the locations were confirmed to have TRU activity exceeding 160 pCi/g. The earlier subsurface investigations, sampling only 5 cm of each 20 cm interval, had failed to find these locations, while the FPDB method included samples from the entire 0-60 cm profile. The FPDB samples also yielded more specific information about the depth of subsurface activity than the auger core samples, and this information was incorporated in the followup sampling design.

Tech Note 18 describes the sampling design that was used to investigate the seven locations with elevated subsurface activity. The new design produced better boundary definition with fewer samples, resulting in a substantial savings in time and effort. The locations investigated with this method, shown in Figures 7-55 to 7-61 respectively, were: 9-S-1, 12-N-1, 6-S-2, 7-S-3, 10-N-1 and 14-N-1. After two iterations of soil sampling, it was clear that while 9-S-1 and 12-N-1 would not require cleanup, soil removal was necessary at all the other locations. Horizontal boundaries for the five soil excision areas were determined using the new method, but depths of each excision were based on standard sidewall sampling (Section 4.2.1). The investigation lasted from 3 to 16 June 1979, and soil lifts began 13 June, while two sites were still being sampled; the initial lifts were completed June 19. The excavations were soil sampled 27 June, and only 14-N-1 required more soil removal. Handheld instruments were used to direct the final lift at 14-N-1. The IMP remeasured all the locations, confirming that no 0.0625 hectare exceeded the 160 pCi/g criterion for TRU activity. Because it was too deep to leave open, the excavation at 14-N-1 was backfilled with clean beach sand. After the cleanup operations were completed, IMP measurements showed no 0.5 hectare had average TRU activity greater than 80 pCi/g.

This phase of subsurface cleanup ended 14 July 1979, after an estimated 1,350 cubic meters (1,780 cubic yards) of soil, containing an estimated 0.41 Ci of TRU activity, were removed.

The results of the FPDB sampling for 0-40 cm profile means of ^{137}Cs and ^{90}Sr for Irene are shown in Figures 7-62 and 7-63, respectively. Only the main island is included because the Helen spit was not sampled.

Final Characterization

Following the last cleanup operations on Irene, all the chemical analysis results for soil were compiled to arrive at a final set of ratio of TRU to ^{241}Am. Details of the computations and data used are in Tech Note 2.1-B. Four ratios were used for the final TRU estimates: 4.06 $\pm$ 0.21 for the east end, 6.41 $\pm$ 0.43 for the central area, 11.27 $\pm$ 0.38 for the west end (except the 14-N-1/13-N-1/12-N-2 excision areas), and 7.92 $\pm$ 0.44 for the 14-N-1/13-N-1/12-N-2 excision areas. The boundaries for each ratio population are shown in Figure 7-64, along with isopleths on the post-cleanup surface TRU activity (based on final data). Table 7-4 summarizes the post-cleanup status of Irene for TRU, ^{137}Cs and ^{60}Co from IMP data. Based on final data, one 0.5 hectare had average TRU activity estimated to be 87.7 pCi/g; all other 0.5 hectare averages were less than 80 pCi/g.

The island average transuranics value reported in the Certification is 31 pCi/gm for surface soil, and the transuranics classification is Agricultural.

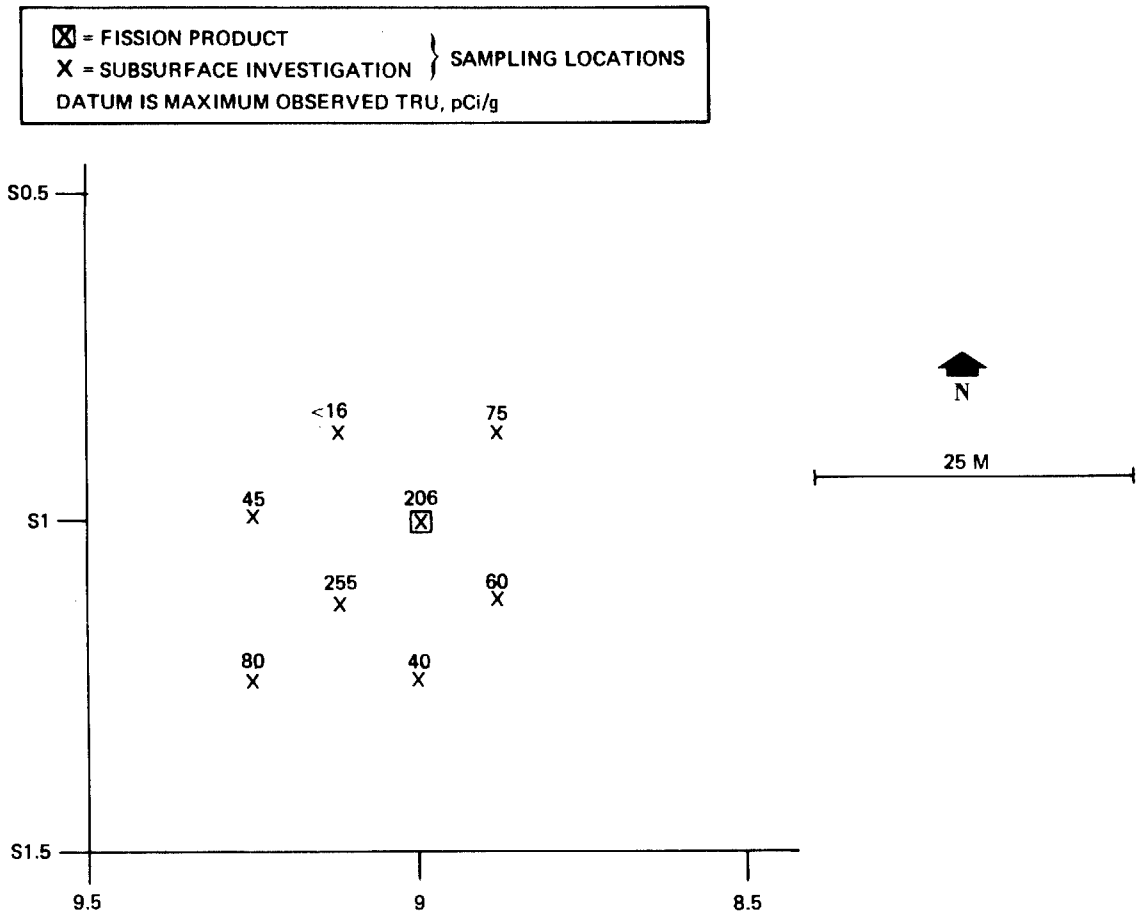


FIGURE 7-55. SUBSURFACE SAMPLING RESULTS, LOCATION 9S1, ISLAND IRENE

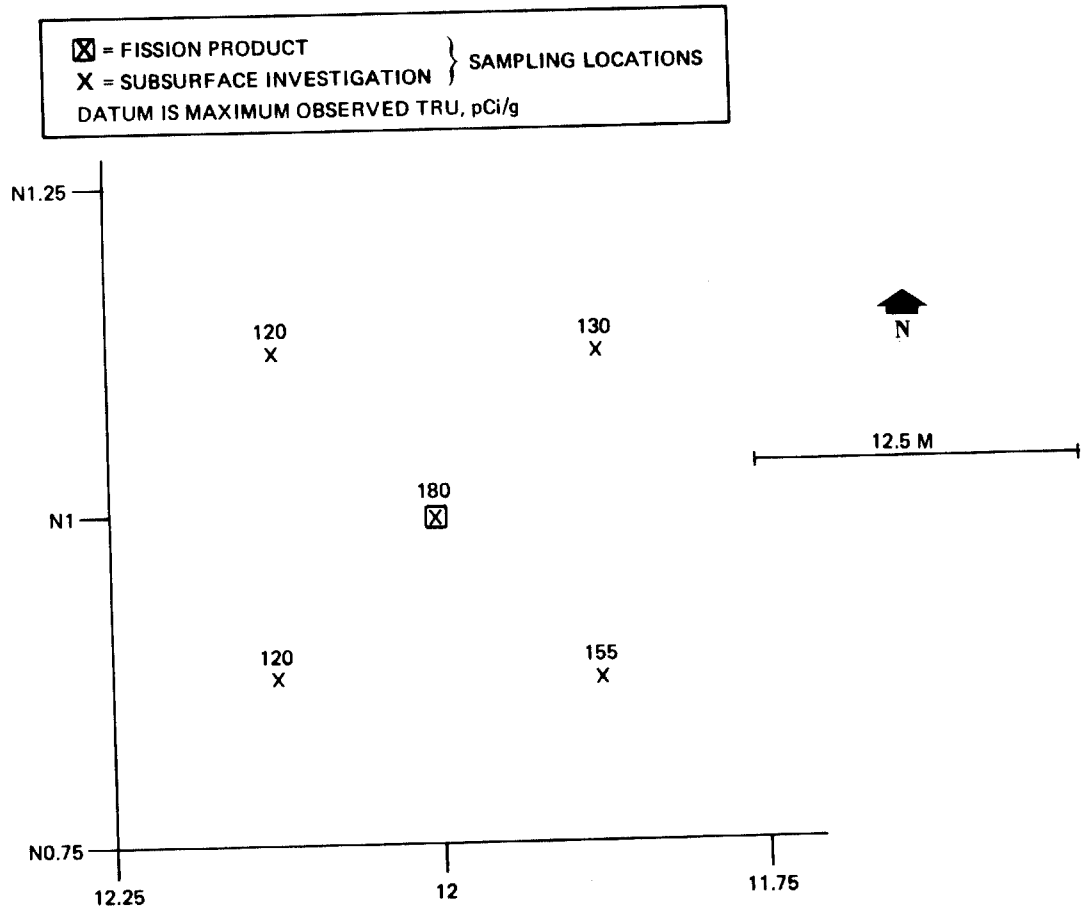


FIGURE 7-56. SUBSURFACE SAMPLING RESULTS, LOCATION 12N1, ISLAND IRENE

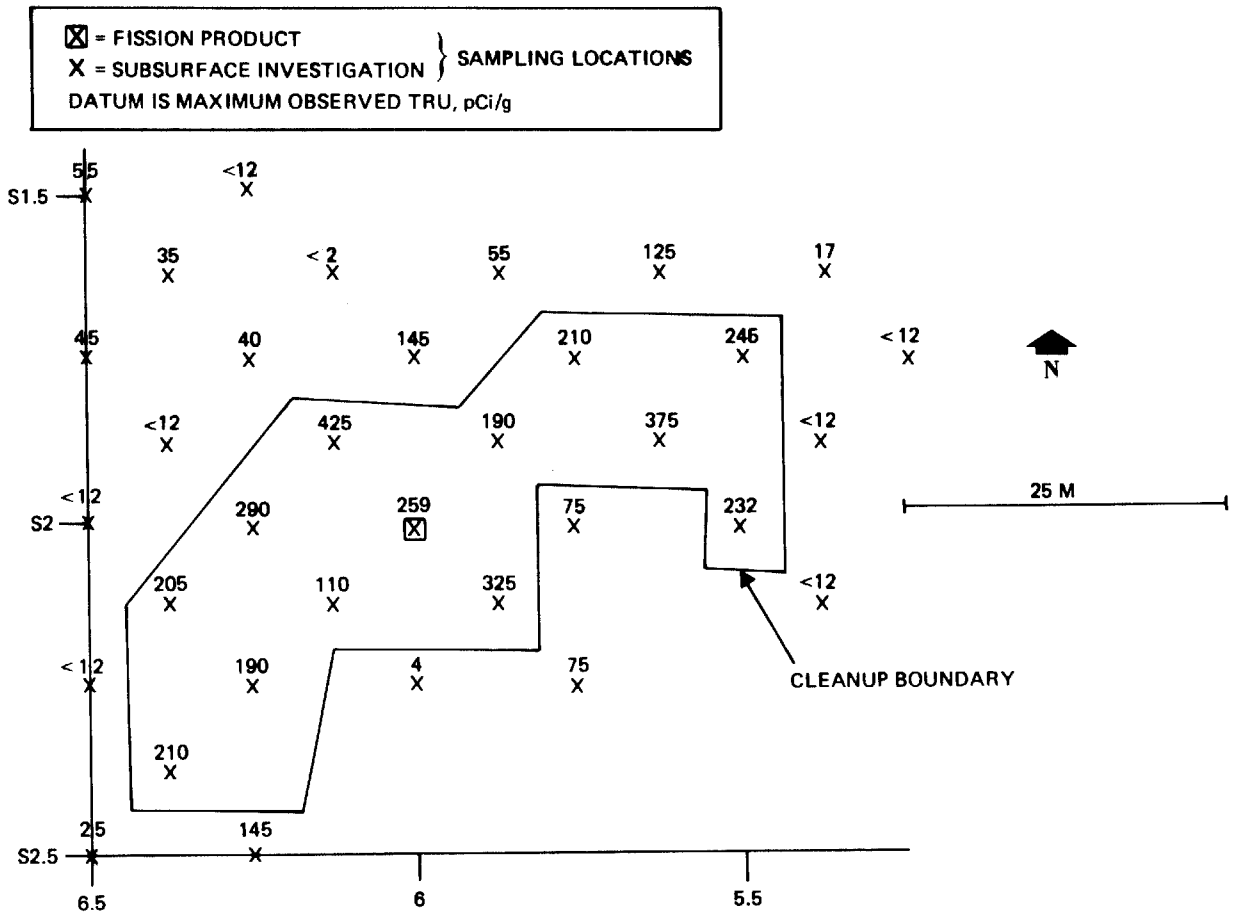


FIGURE 7-57. SUBSURFACE SAMPLING RESULTS, LOCATION 6S2, ISLAND IRENE

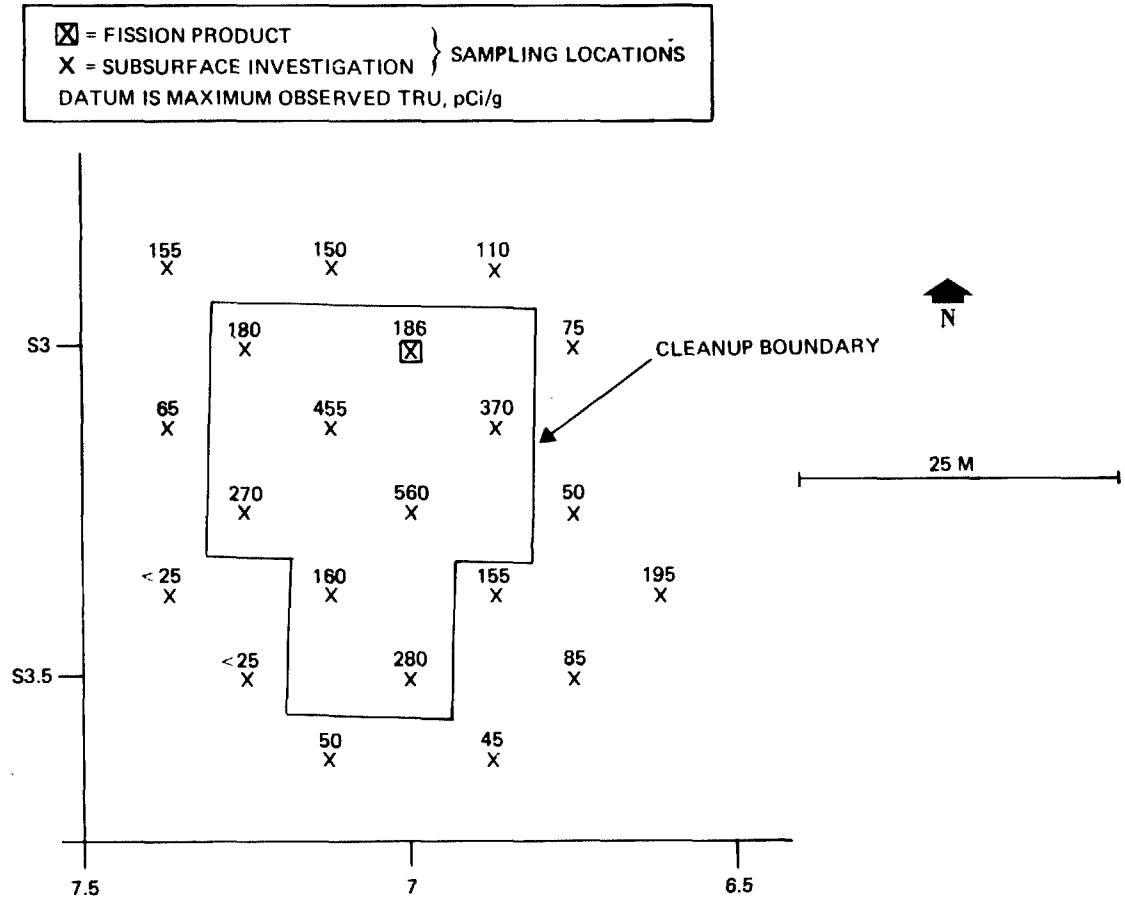


FIGURE 7-58. SUBSURFACE SAMPLING RESULTS, LOCATION 7S3, ISLAND IRENE

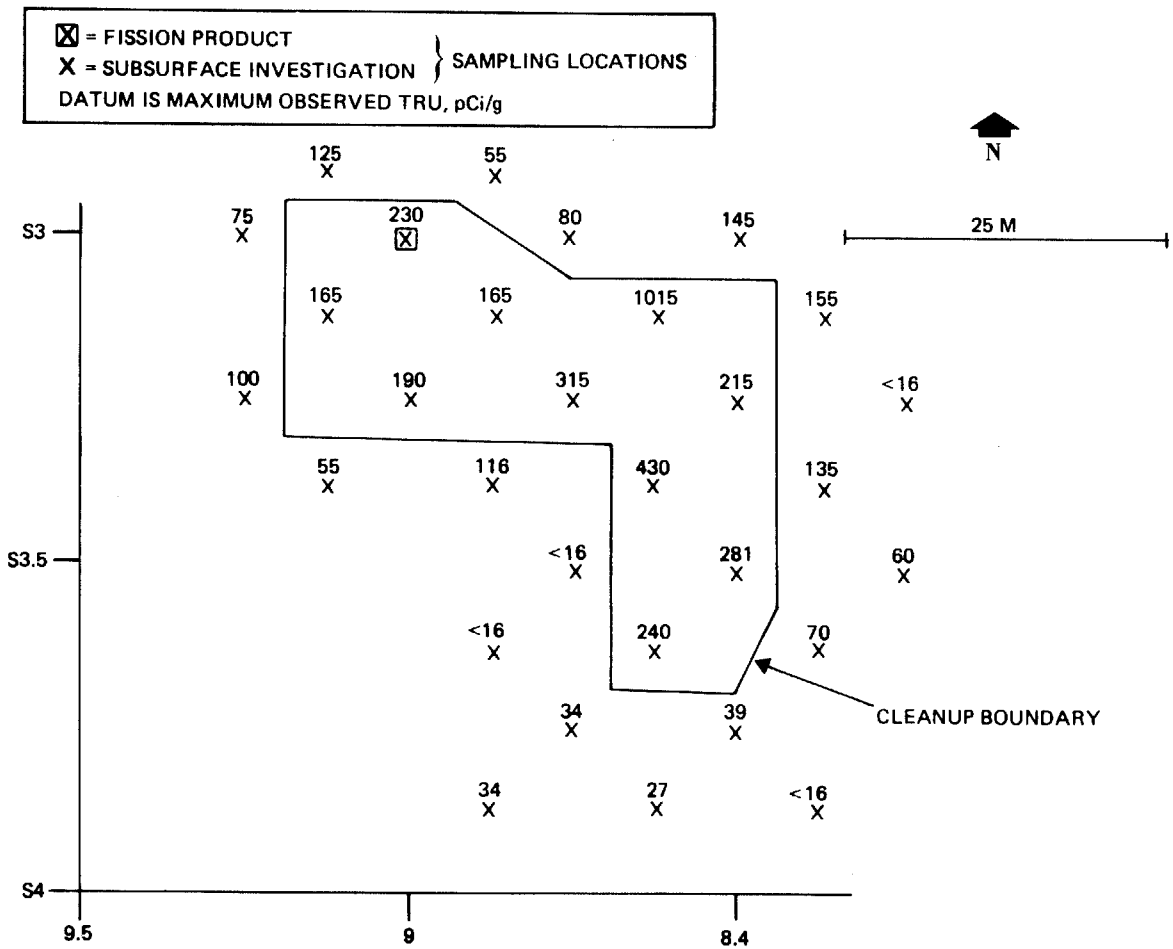


FIGURE 7-59. SUBSURFACE SAMPLING RESULTS, LOCATION 9S3, ISLAND IRENE

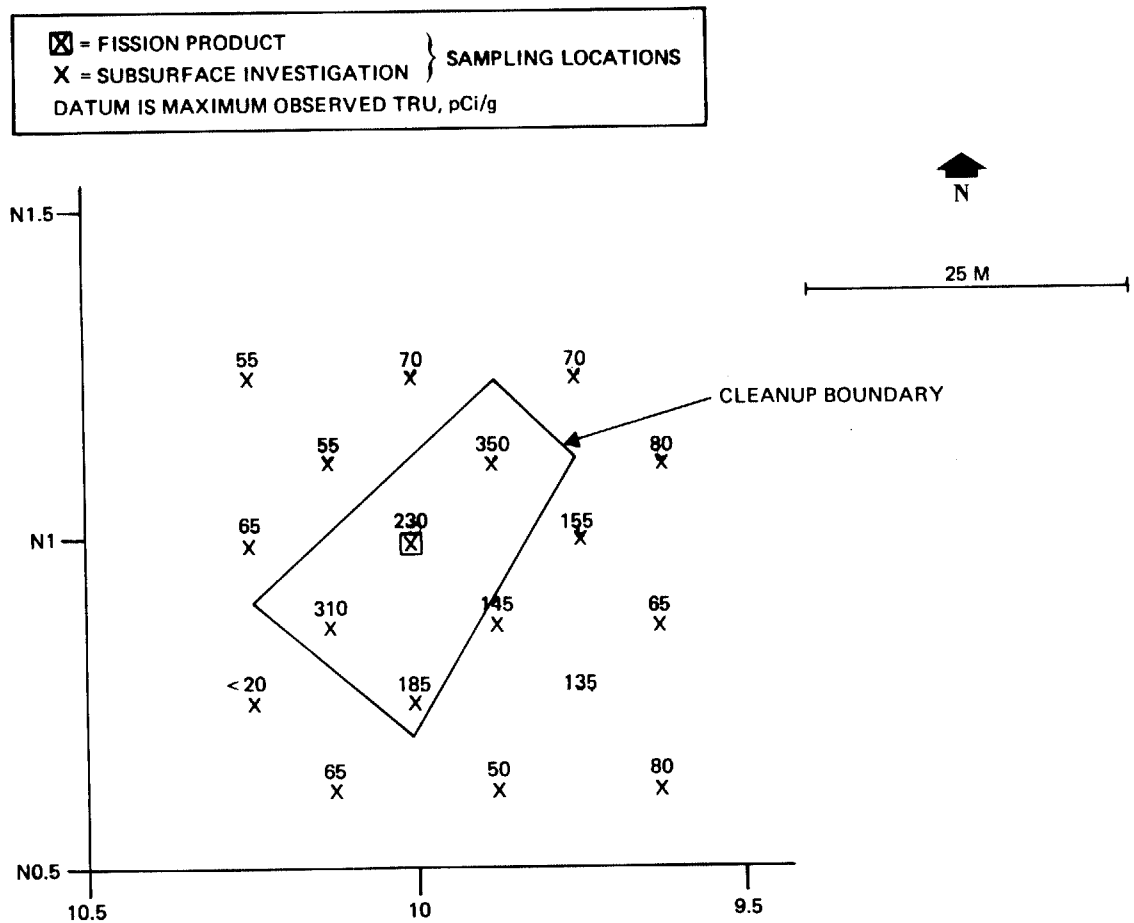


FIGURE 7-60. SUBSURFACE SAMPLING RESULTS, LOCATION 10N1, ISLAND IRENE

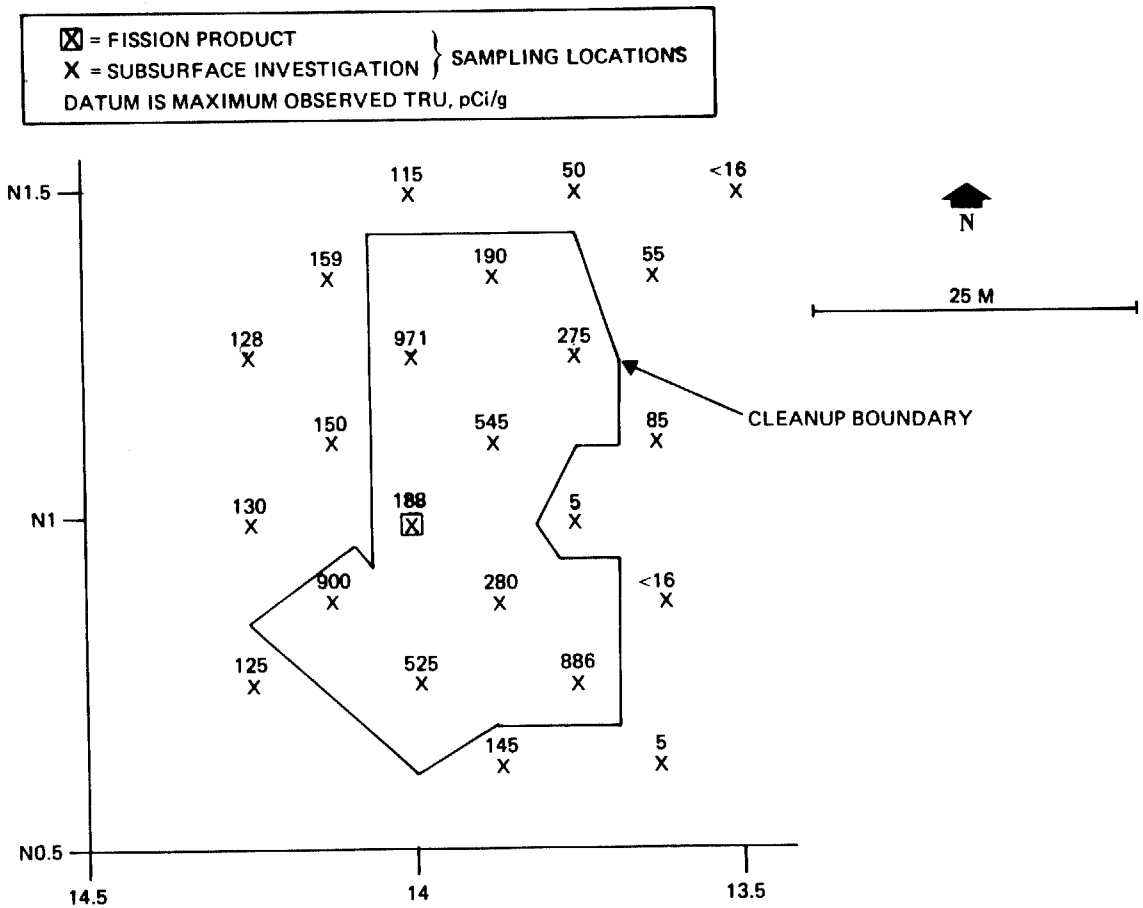


FIGURE 7-61. SUBSURFACE SAMPLING RESULTS, LOCATION 14N1, ISLAND IRENE

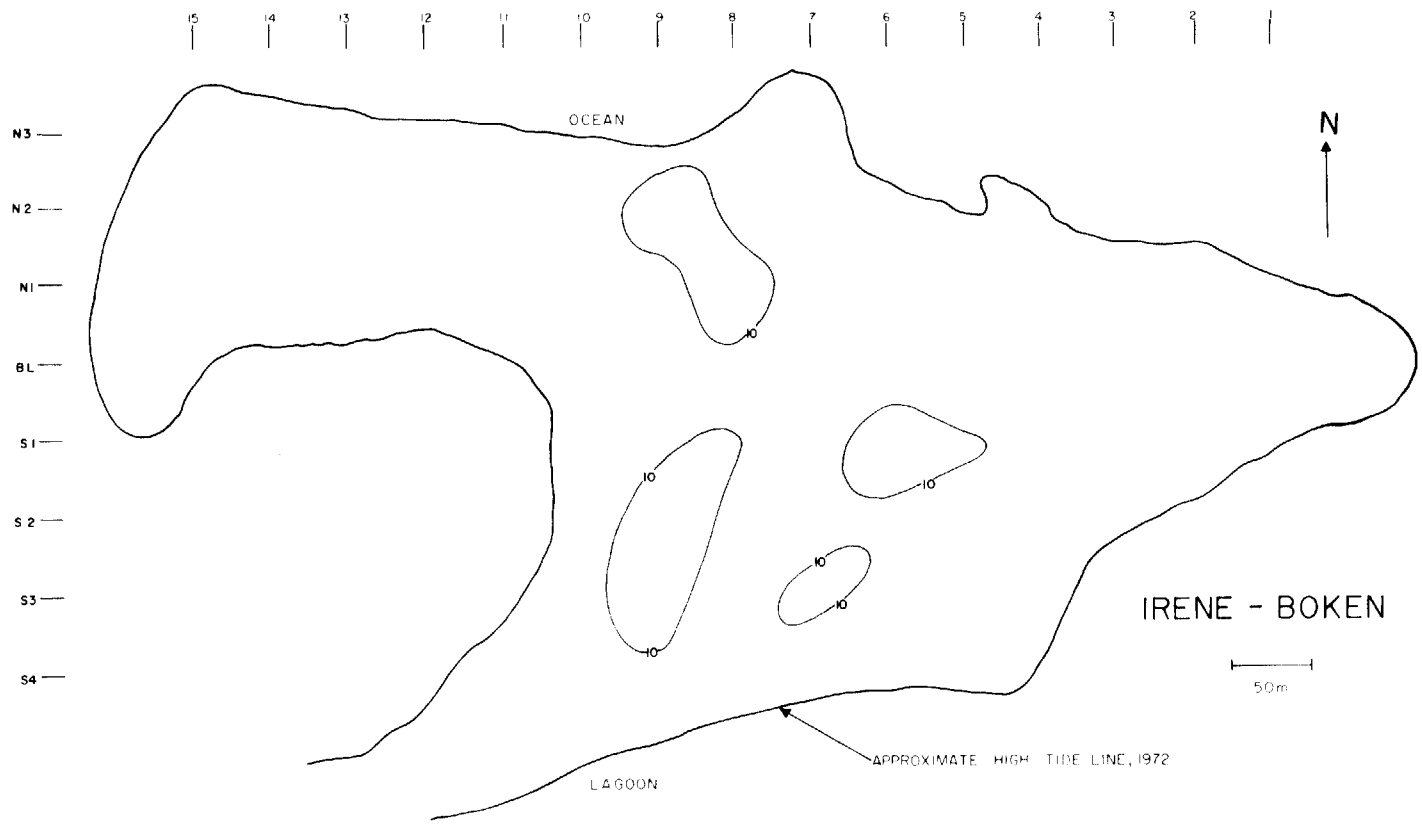


FIGURE 7-62. ISOPLETHS ON ^{137}Cs ACTIVITY IN pCi/g (AVERAGE IN TOP 40 CM) FOR ISLAND IRENE

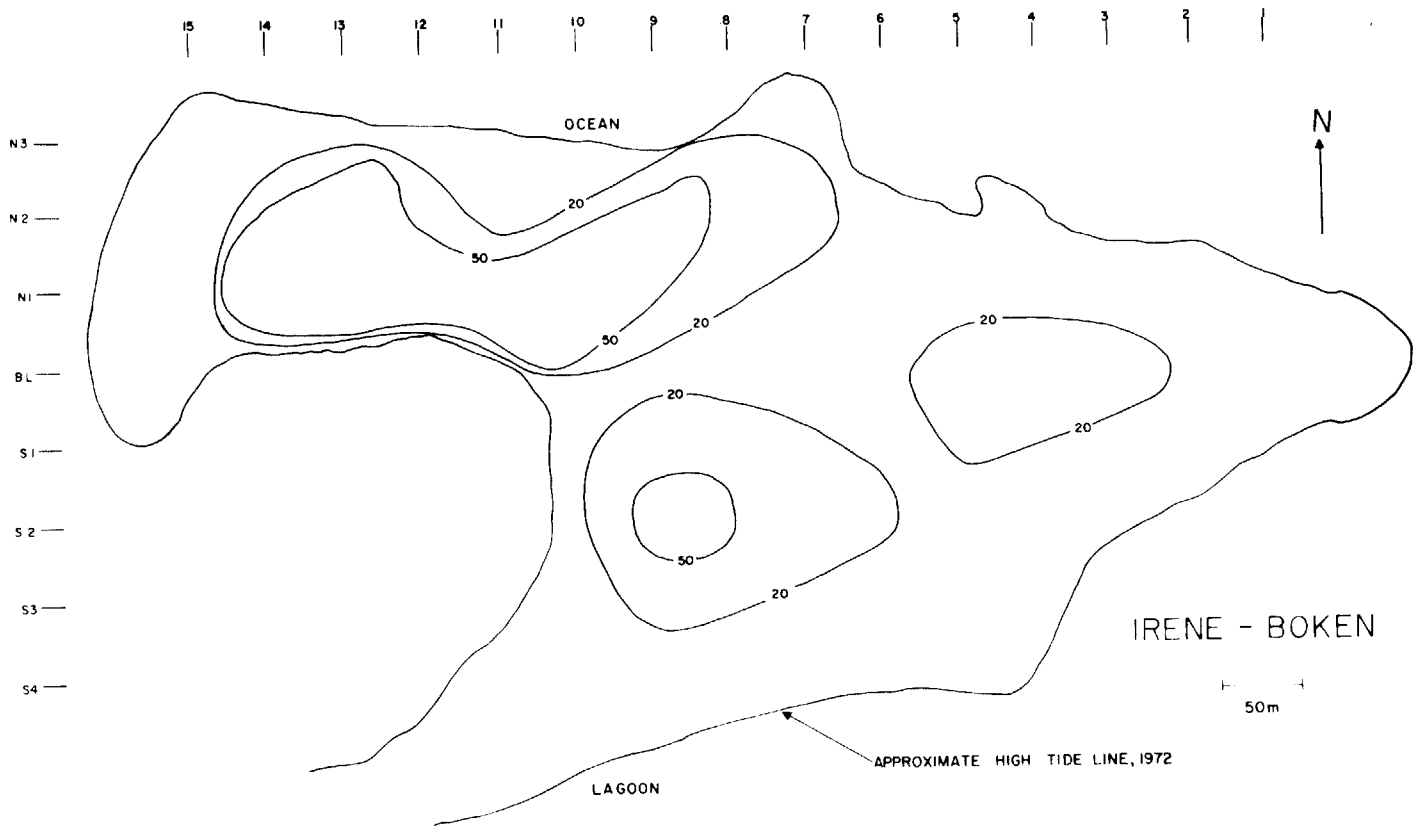


FIGURE 7-63. ISOPLETHS ON ^{90}Sr ACTIVITY IN pCi/g (AVERAGE IN TOP 40 CM) FOR ISLAND IRENE

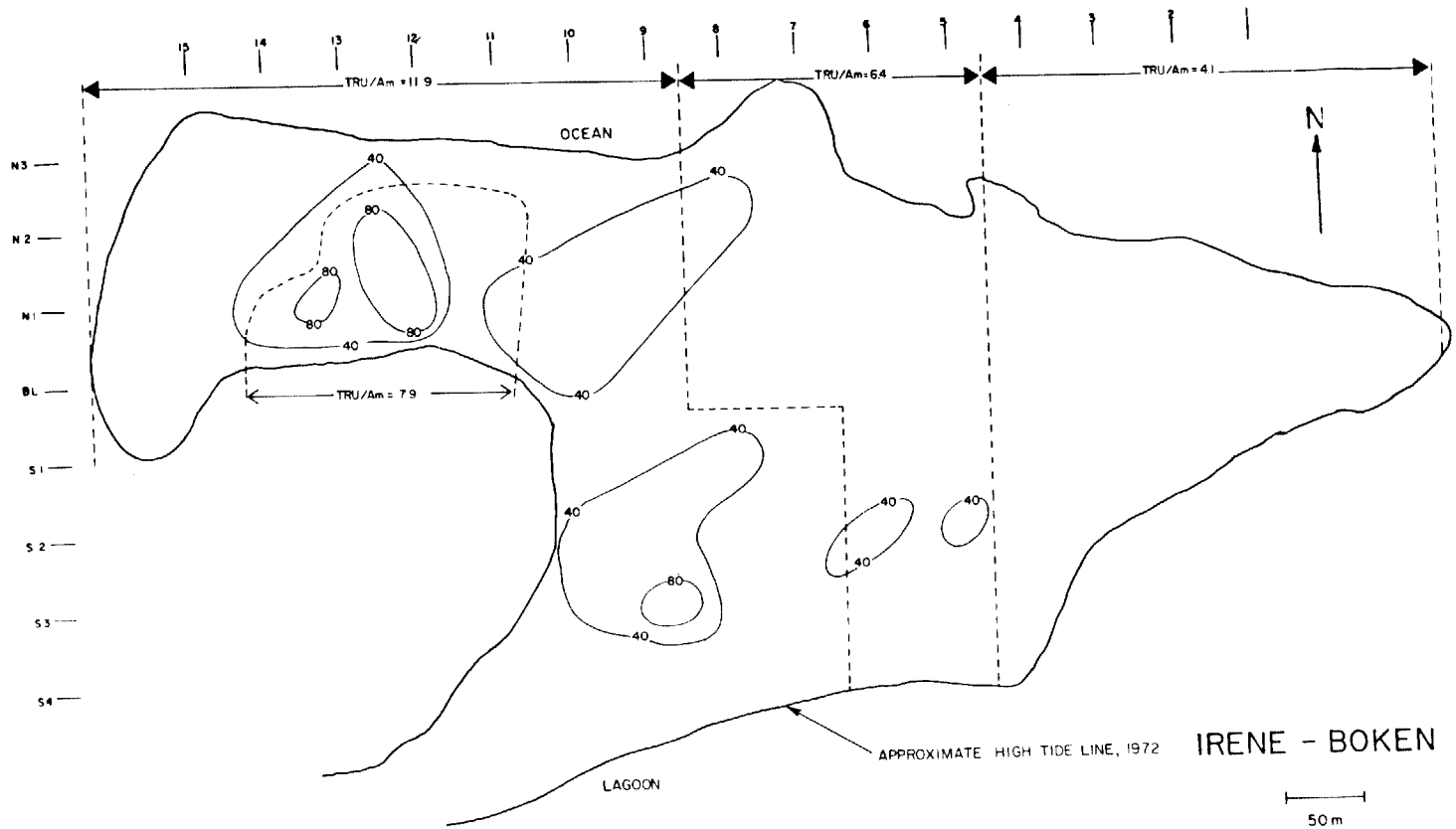


FIGURE 7-64. ISOPLETHS ON FINAL ESTIMATED SURFACE TRU ACTIVITY IN pCi/g FOR ISLAND IRENE

7.5.2 Janet

Background

Island Janet (Marshallese: Enjebi), the largest of the northern islands at 118 hectares (ha), is historically the most important island to the driEnjebi (Enjebi people). It was formerly a major coconut producing island, and it also has particular political and cultural significance for the driEnjebi. The island is roughly triangular with the points at the north, south and west. The soil ranges from very soft and sandy to very hard, and vegetation cover was moderate to dense before the cleanup began.

The Japanese built a compacted-coral runway and other facilities on Janet during World War II, and the island was involved in ground fighting. Evidence of air and naval bombardments and of ground engagements that remained until the cleanup included unexploded ordnance, rusty metal and concrete remnants.

Janet was the site of three nuclear tests, and seven more took place in the lagoon nearby. The Easy and X-Ray event ground zeros were in the center of the west tip of Janet, and the Item ground zero was at the north tip. Figure 7-65 shows these sites relative to the cleanup sampling grid. Item site is no longer on the island because the north coastline has shifted since the Item test took place in 1951. The seven lagoon events in the vicinity of Janet were 4,000 to 8,508 feet southwest of Hardtack Station 1312, a bunker on the west tip of the island. As a result of these ten events, plus 16 other events which deposited fallout on Janet, the island's cumulative H + 1 hour exposure rate was 3,501 R/h, eighth highest in the Atoll.

Many scientific stations, bunkers, and campsite slabs were built on Janet for support of nuclear testing activities, and these remained after testing ceased. Of particular concern in the cleanup were Greenhouse Station 3.1.1, a large, three-story concrete structure near the center of the island, and Hardtack Station 1312. These two structures were suspected to have some radioactive contamination on their exterior surfaces. Some of the other metal and concrete debris was also contaminated, although most of the World War II and testing debris was not contaminated.

The soil in the west area of Janet was apparently extensively stirred around in the process of site cleanup and preparation between nuclear tests. Although no definite record of such operations is available, they can be inferred from the low surface TRU activity near the Easy and X-Ray sites and the asphalt found below the surface during cleanup sampling. It is not known whether some contaminated soil was removed from the island, or whether the surface soil was simply turned over and mixed. It is known, however, that some contaminated material, possibly including plutonium-encrusted concrete from tower footings, was buried in the X-Ray event crater.

Burials of radioactive material at or near event sites appear to have been done routinely, hence Easy and Item sites were also likely to have burial areas. No burial locations were known precisely at the time of the cleanup, but two approximate locations were shown on a 1951 map and the Environmental Impact Statement indicated a third possible area. These three areas are shown in Figure 7-65.

Subsurface contamination might also have been associated with the numerous cable runs on Janet. The runs were typically excavated to several feet below grade, with soil replaced on top of the cable, forming a ridge above grade, sometimes as much as several feet. The coaxial cables were ordinarily excavated and recovered after an event, and replaced if needed for later operations. In this process, intermixing of contaminated surface soil with subsurface soil was inevitable. Some of the borrow pits dug for cable run fill might also have been used later to bury contaminated material. Some of the cables were never recovered after test operations ended - a number were discovered during the cleanup of Janet. These runs might have contained subsurface contamination. Several cable runs were still easily visible in 1979 as ridges of soil several feet high, covered with dense brush.

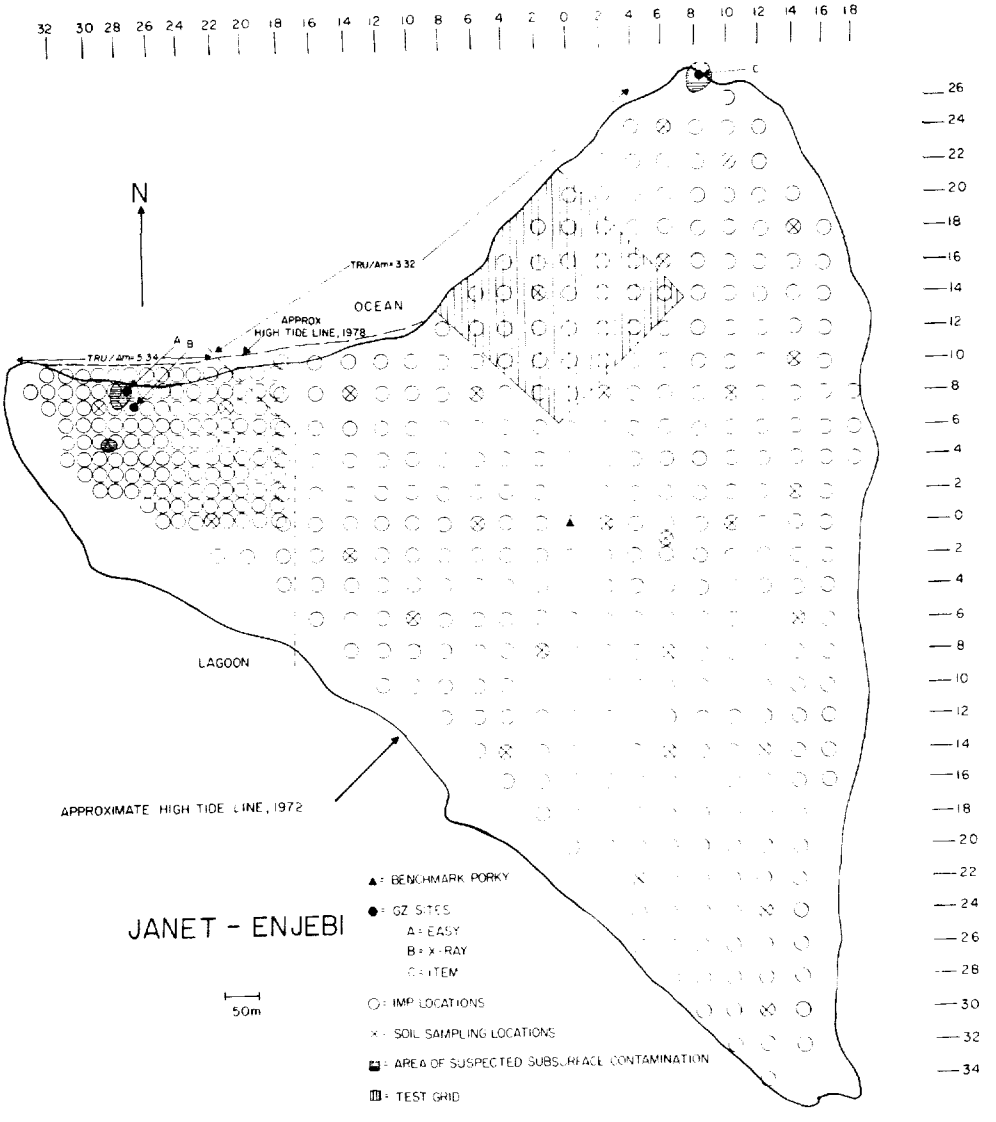


FIGURE 7-65. COASTLINE AND DATA COLLECTION LOCATIONS FOR ISLAND JANET

Besides the radioactive contamination on Janet, there was also some chemical contamination by beryllium contained in rocket engine fuel. The engine was being tested in 1968 on a pad near Hardtack Station 1312 when it malfunctioned, damaging Station 1312 and contaminating the area with beryllium. The combination of decontamination efforts at the time of the incident and erosion since then should have removed most of the beryllium before the radiological cleanup began.

1972 Survey Results

Because of its size and importance to the Enewetak people, Janet was sampled intensively during the 1972 survey. Out of a total of 140 soil sampling locations, ten were profile sampled to 185 cm, two were 125 cm profiles, one was a 65 cm profile, one was a 35 cm profile, and the remaining 126 were 0-15 cm core samples. To help investigate relationships between radioactivity in the soil and in the food chain, a number of plant and animal samples were taken.

The $^{239,240}Pu$ activity in profile samples generally declined steeply with depth, falling to less than 1 pCi/g by 30 cm or shallower. Of three locations which were exceptions to the pattern, two had no $^{239,240}Pu$ activity greater than 1 pCi/g at depth even though the activity was rising. The third location with an anomalous pattern was near the Easy and X-Ray sites, where buried contamination was already suspected to exist. Table 7-3 summarizes the $^{239,240}Pu$ results for Janet.

The depth distribution of ^{137}Cs and ^{90}Sr was similar to the pattern for $^{239,240}Pu$, although activity of these two isotopes did not decline as steeply as $^{239,240}Pu$ activity. The one profile which showed a significant increase in ^{137}Cs and ^{90}Sr activity below 30 cm was the same location near Easy and X-Ray which had the anomalous $^{239,240}Pu$ depth distribution. Summaries of the ^{137}Cs and ^{90}Sr results are in Tables 7-1 and 7-2, respectively.

In 1975, as part of the follow-up on the 1972 survey, Lawrence Livermore Laboratory established a garden plot on Janet to study radionuclide uptake in food plants. The results would aid in building dose-assessment models, and specifically to help determine when Janet might again be suitable for agriculture and habitation. Additional soil samples were also collected in the garden area to provide better information on soil-to-plant transfer coefficients for radionuclides. A study of radionuclides in groundwater was also begun at this time; this involved drilling several wells and taking water samples.

Both the garden and groundwater studies continued throughout and beyond the radiological cleanup, so care was taken during cleanup to try to avoid damage to the study areas.

Surface Characterization

Because Janet was the first island measured with the in situ system, several preliminary experiments and sets of IMP measurements were done on Janet to develop procedures and evaluate the system. Details of these early efforts are in Section 6.4. After the initial break-in period, a 25 m grid, known as the Test Grid, was staked and measured in August 1977 to provide a test of the data collecting system and also data for preliminary statistical analyses. Although the absolute coordinates of the Test Grid were never established, its approximate boundaries are shown in Figure 7-65.

As described in Section 6.4, the statistical analysis of the Test Grid data led to the conclusion that 50 m spacing for the Janet grid would give enough data for acceptable estimates. Meanwhile, part of the west tip of the island had already been staked at 25 m spacing and the IMP had nearly completed measurements in that area. (This 25 m grid was inadvertently shifted from its intended location. See Section 6.4). The IMP survey of the 25 m grid was therefore completed at that spacing in September 1977, and that block of data was handled separately in the statistical analyses. The remainder of Janet was initially staked and measured at 50 m spacing. The 50 m grid was located correctly, so it was extended far enough west to make certain that estimates of TRU activity from the 25 m and 50 m grids would completely cover the island. It was further concluded that the kriging method (see Section 5.1) gave acceptable estimates, and the data satisfied the assumptions made in using this method.

In order to put in the stakes for the 50 m grid on Janet, most of the island required extensive devegetation efforts. The primary method was to bulldoze the vegetation into long, east-west windrows. One effect of this method was to reduce the apparent effects of the wind on the distribution of TRU activity (Section 6.4), and another was to decrease the measured surface activity. Because the raw variogram (Section 5.1.1) was also affected, the statistical results on the Test Grid data could not be used. Therefore, the analysis was repeated, the two candidate models on the 50 m data were tested, and the better one chosen to estimate 0.25 hectare average TRU activity. There were two areas of Janet where neither model estimated well due to higher variability in the physical distribution of contamination. These areas were staked and measured on a 25 m grid to provide more data. The in situ sampling of the west area began 23 August 1977, and this area plus the 50 m grid were completed 16 November 1977. The two additional 25 m areas were sampled by the IMP from 6 January to 8 February 1978. Figure 7-66 shows the areas estimated to have TRU activity above 40 pCi/g on the 0.25 hectare averages, using all the 25 m data as well as the 50 m data. (Note that these estimates were based on original data. See Tech Note 23 for discussion of original versus final data). The total area shown in Figure 7-66 as having 0.5 s upper bounds on the TRU activity estimates above 40 pCi/g is 20.75 ha, where s is the standard deviation of the kriging error; without the additional 25 m data, the estimate was 21.25 ha.

In order to arrive at estimates of TRU from IMP ^{241}Am data, soil samples were taken to determine the ratio of TRU to ^{241}Am. Two composites were taken at each of 29 locations, using the method described in Section 4.2.1, for a total of 58 samples.* The locations sampled are shown in Figure 7-65. The estimated ratios of TRU to ^{241}Am fell into two distinct groups corresponding to location on Janet. All the samples from the Easy/X-Ray area on the west tip had higher ratios than the samples from elsewhere on Janet. The change from one ratio to the other was abrupt, matching an abrupt change in the ^{241}Am data from the IMP, as well as a distinct change in soil characteristics. The change in the soil, visible on the 1972 aerial photographs, also matched an abrupt drop in gamma activity measured in the 1977 aerial survey (see Section 3.1). The boundary between populations of ratio of TRU to ^{241}Am was therefore drawn on the basis of the 1972 aerial photographs, and is shown in Figure 7-65. The ratios of TRU to ^{241}Am used for the initial characterization and cleanup were 5.34 ± 0.69 for the west area and 3.32 ± 0.42 for the rest of the island.

Surface Cleanup

The surface cleanup of Janet was accomplished in stages, with the first lifts coming from the areas with the highest activity. All areas with average TRU activity exceeding 60 pCi/g had already been measured by the IMP at 25 m spacing as part of the additional work on the two small areas. About half the area with TRU activity between 50 and 60 pCi/g had also been measured by the IMP on a 25 m grid. No further fine grid surveys were made until all the areas with average TRU activity exceeding 50 pCi/g had been lifted. It was recognized at that point that the total amount of soil to be removed could be minimized by taking more data to refine the excision boundaries.

The remaining areas with TRU activity greater than 40 pCi/g were therefore measured with the IMP at 25 m spacing before being lifted. The fine grid survey was also extended 25 m beyond the above 40 pCi/g areas to allow better revised estimates.

After each soil lift, the lifted area plus a boundary of points beyond the lift were measured with the IMP. New estimates were computed by averaging the IMP data values, since kriging is not the best method to use for data from a 25 m grid; the detector field of view includes most of the surface at 25 m spacing (see Section 5.1.1). If the new TRU estimate still exceeded 40 pCi/g, the sequence of lifting and remeasuring was repeated, although very few areas actually required additional lifts. To save time and maintain a smooth operation, fine grid IMP surveys, lifts in areas already measured, and post-lift IMP surveys were done concurrently in different parts of the island.

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*Results from only 50 of the samples were actually used in the ratio computation. See Tech Note 2.6.

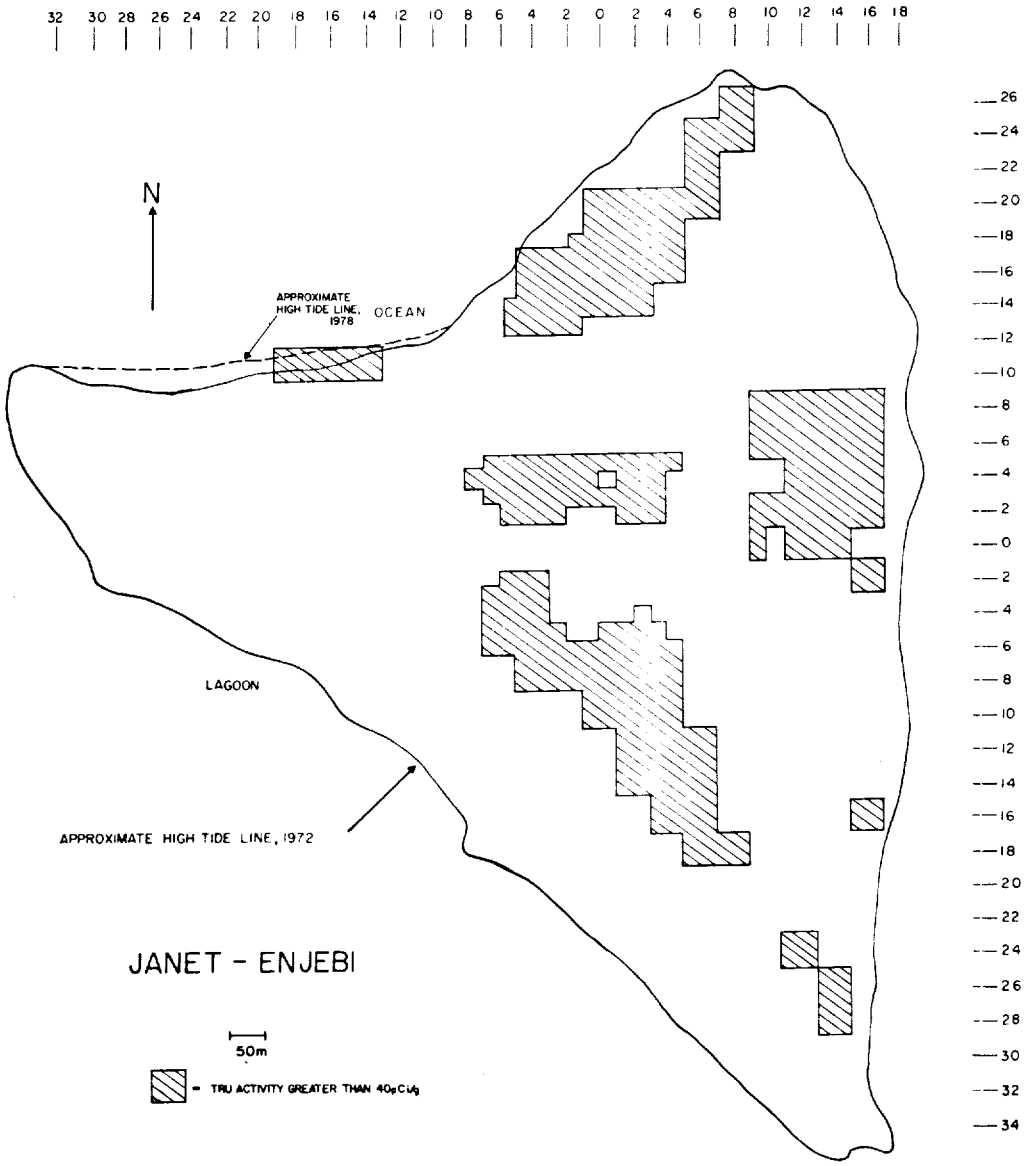

FIGURE 7-66. INITIAL CHARACTERIZATION OF SURFACE TRU ACTIVITY FOR ISLAND JANET BASED ON KRIGING ESTIMATES OF 0.25 HECTARE AVERAGES

The windrows that had been piled up during devegetation activities were removed after all the soil known to require cleanup had been lifted. Before removing them, each was first soil sampled and measured with the IMP at approximately 25 m intervals. The windrows with TRU activity less than 40 pCi/g were used for backfill at the subsurface excision locations. The remaining windrows were removed from the island as contaminated soil. After the windrows were removed, the soil underneath was measured with the IMP at 25 m intervals. At nine locations, the soil exceeded 40 pCi/g in TRU activity and was removed.

A total of 37,850 cubic meters (49,500 cubic yards) of contaminated soil, containing an estimated 2.33 curies of TRU activity (based on final data), was removed from Janet in the surface cleanup. The areas from which surface soil was lifted are shown in Figure 7-67. The surface cleanup phase began 6 July 1978 and was completed 23 March 1979.

Subsurface Cleanup

The areas suspected of being contaminated burial sites on Janet, shown in Figure 7-65, were investigated using the sidewall sampling method (see Section 6.9). In each case, a 25 m sampling grid was laid out to cover the suspect region; Figures 7-68 and 7-69 show these locations for the Item and Easy/X-Ray areas, respectively. The initial results of the soil sampling indicated the need for more data, so additional samples were taken at new locations, also shown in Figures 7-68 and 7-69. No further samples were taken in the Item area because the new data showed that no 0.0625 hectares (ha) average TRU activity exceeded 160 pCi/g. Figure 7-68 also gives the highest sample TRU for each sampling location for Item.

There was still not enough data in the Easy/X-Ray area to arrive at a conclusion. In fact, several more iterations of sampling were required to finally define the boundaries of the two areas requiring excision. The boundaries and the highest sample TRU at each location are shown in Figure 7-69. The boundaries were established on the basis of the best available data type, the first preference being TRU from soil chemistry. Second choice was TRU computed from ^{241}Am IMP screening (see Sections 3.3, 4.3 and 6.9). If only gross alpha data from the laboratory were available, they were used, except when the data were on a possible excision boundary or showed TRU activity near 160 pCi/g. In those cases, the archived soil sample was retrieved and a laboratory gamma analysis performed.

After the soil in the two subsurface pockets had been removed, new sidewall and bottom samples were taken in the excavation to verify that enough soil had been removed. The results showed more soil required excision and two more lifts were required to remove all the TRU contamination exceeding 160 pCi/g. One of the extra lifts was caused by problems with the shifted grid in the west area (Section 6.4). After it was verified that the excisions were complete, the sites were backfilled with clean material from the windrows. A final IMP survey was then done to establish the radiological condition of the new surface.

The subsurface cleanup began 6 December 1978, and was completed 18 April 1979. An estimated total of 2,000 cubic meters (2,600 cubic yards) of soil containing an estimated 0.19 curies of TRU activity was removed in the subsurface cleanup of Janet.

Fission Products Sampling and Subsurface Investigations

Janet was sampled at 50 m intervals, at the same locations as the initial IMP measurements, for the Fission Product Data Base (FPDB) in support of the dose assessment (see Section 6.11). In the west area, where the initial IMP survey was at 25 m spacing and the grid was shifted, only the 50 m points were sampled, and the correct grid was used (see Section 6.4).

Samples were taken at 364 locations, and soil from 99 of these was analyzed for ^{90}Sr. All the samples were analyzed for gamma activity, and the results for the 0-15 cm profile for ^{137}Cs and ^{90}Sr are summarized in Tables 7-1 and 7-2. A summary of island average results for selected other profile ranges is given below.

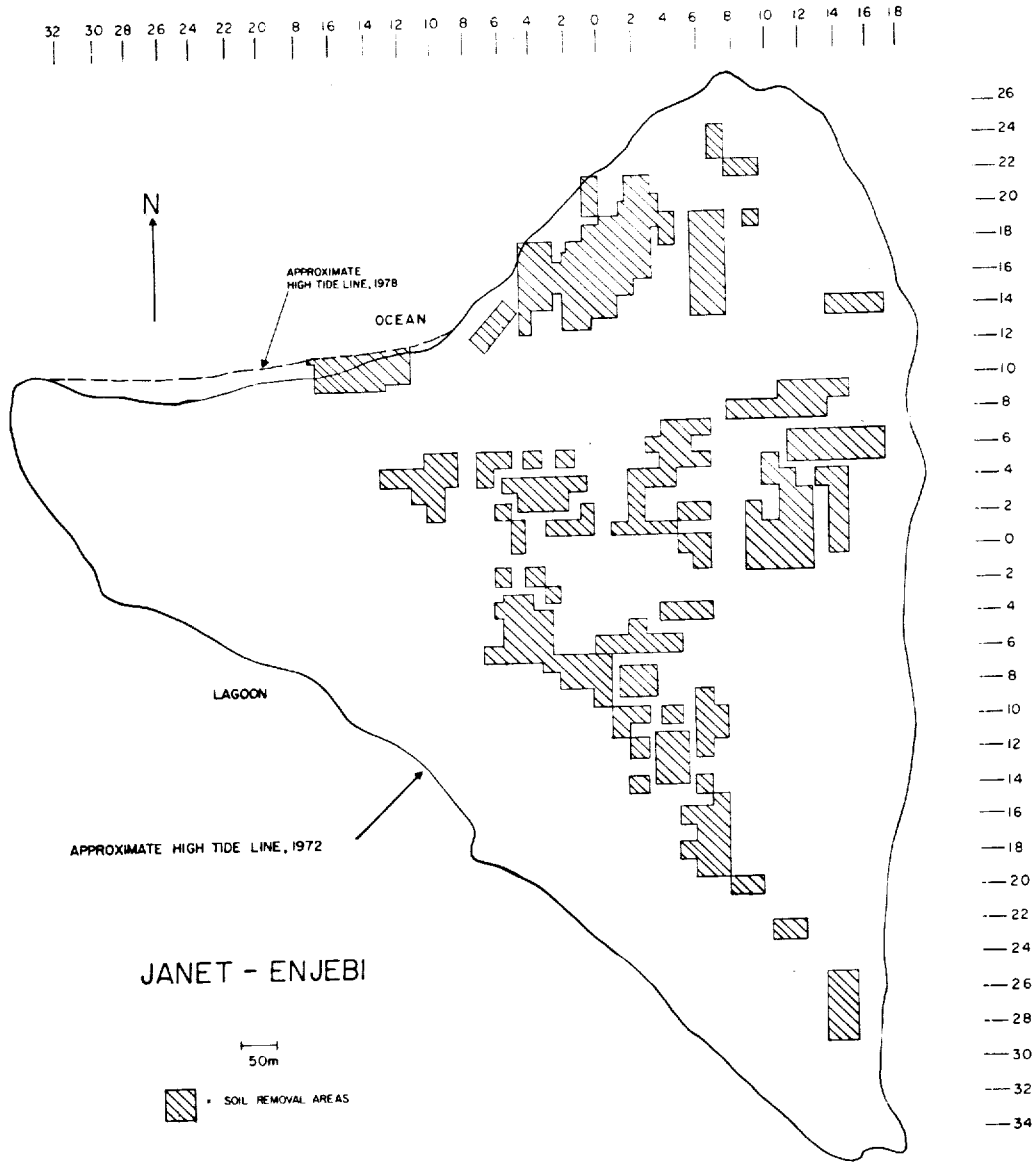

FIGURE 7-67. AREAS OF SOIL REMOVAL FOR SURFACE CLEANUP OF ISLAND JANET

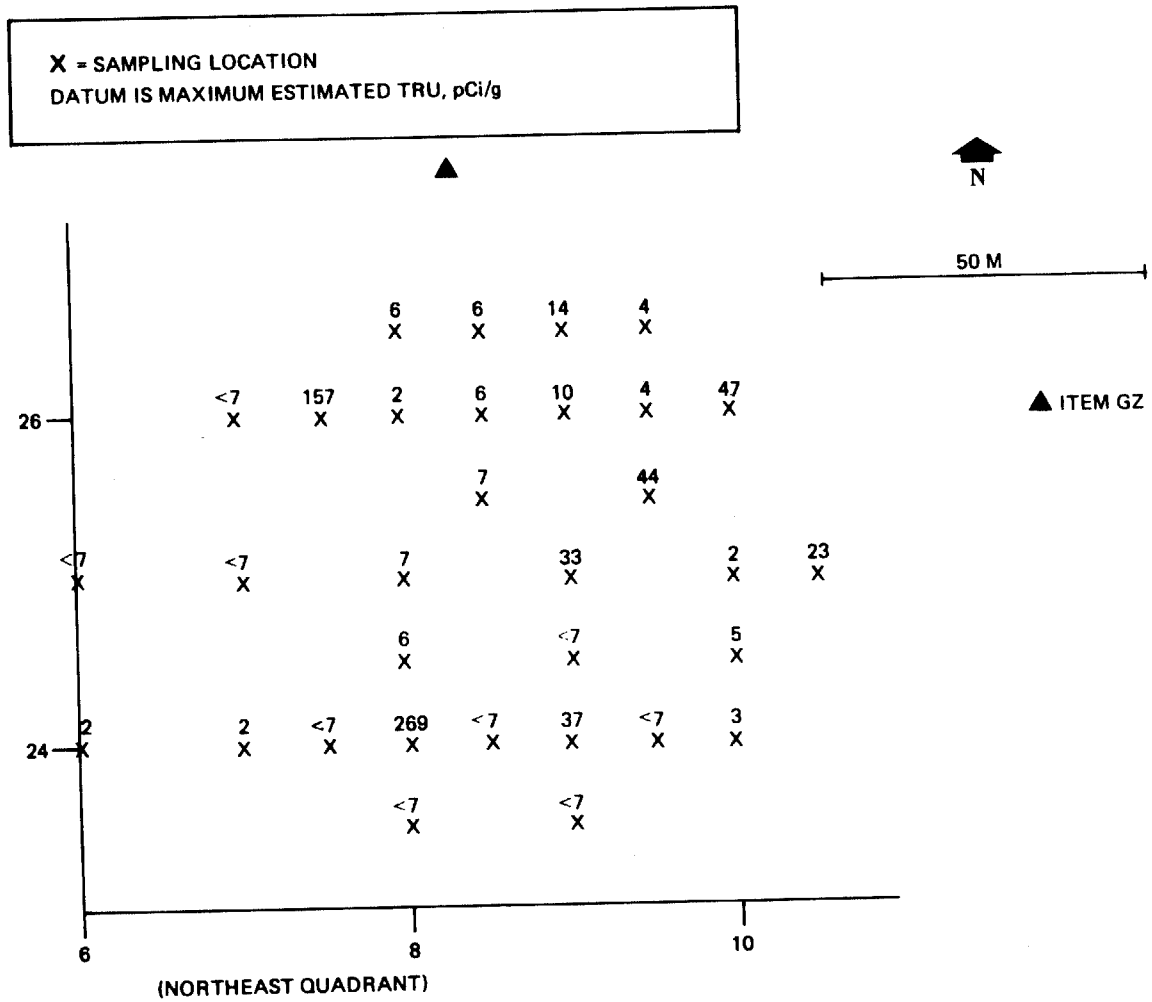

FIGURE 7-68. SUBSURFACE SAMPLING RESULTS, ITEM GZ, ISLAND JANET

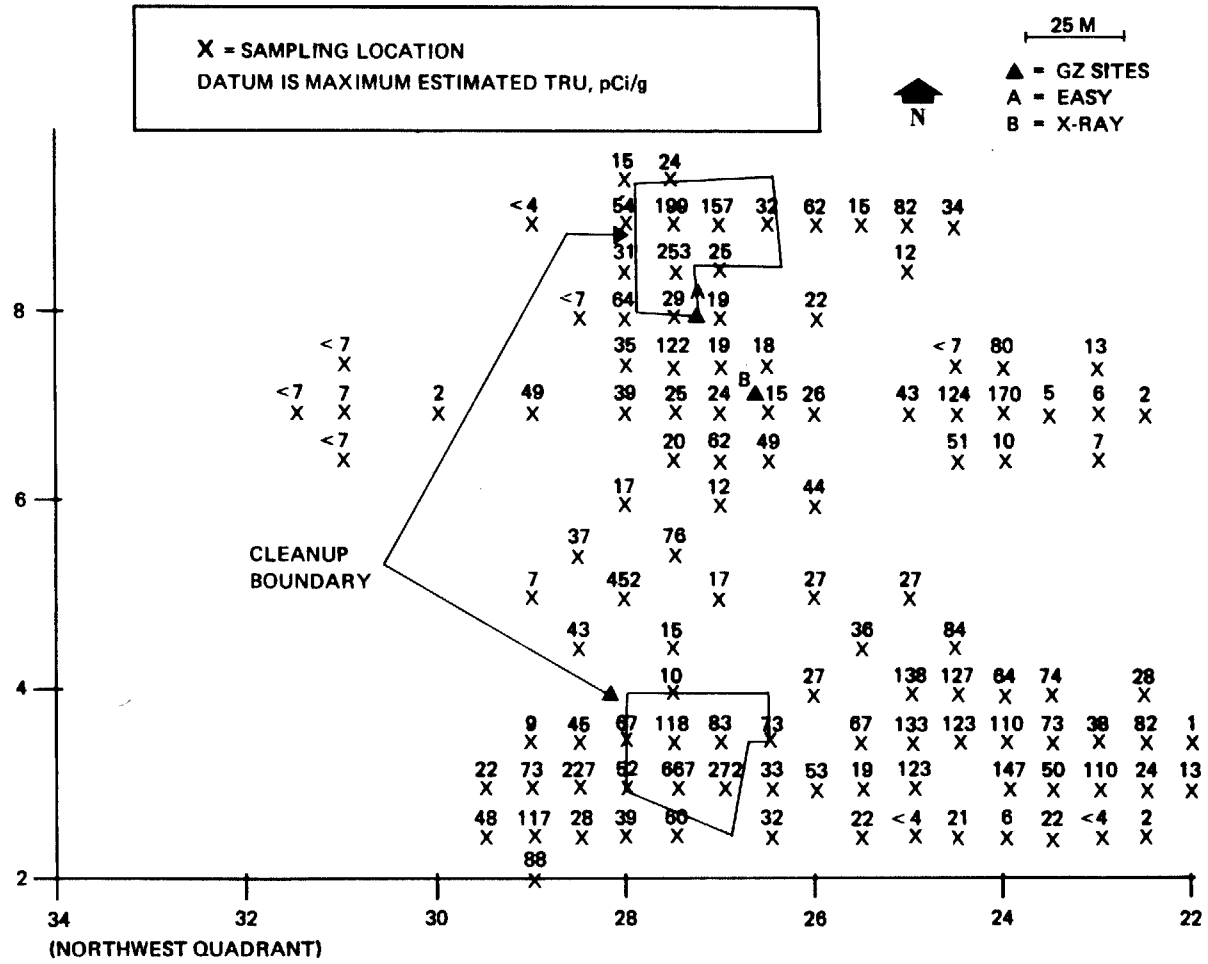

FIGURE 7-69. SUBSURFACE SAMPLING RESULTS, EASY/X-RAY GZ AREAS, ISLAND JANET

	0-5 cm	0-40 cm	0-60 cm	Total Samples
^{90}Sr, pCi/g	40.6	21.8	17.0	573
^{137}Cs, pCi/g	20.5	10.4	7.9	2,126

Table 7-3 summarizes the 0-15 cm results for $^{239,240}Pu$, as estimated from ^{241}Am. When the 50 m samples had been analyzed for ^{241}Am, two locations showed estimated subsurface TRU activity exceeding 160 pCi/g. The two locations, NW 20-4 and SW 6-10, were investigated by taking sidewall samples at 6.25 m or 12.5-m intervals around the original high values. As shown by Figure 7-70, there was no further evidence of elevated subsurface TRU activity at SW 6-10. However, the sampling around NW 20-4 revealed TRU activity greater than 160 pCi/g at one additional location, NW 19-5, so the sampling was extended around that location. A third TRU value greater than 160 pCi/g was found in the additional samples. The investigation was terminated at this point because no 0.0625 hectare centered on either NW 20-4 or NW 19-5 had average TRU activity greater than 160 pCi/g. In addition, the one-hectare area centered on NW 20-4 was thoroughly sampled (186 samples at 40 locations), yet only three of those samples had TRU activity exceeding 160 pCi/g. At 33 of the 40 locations, the highest TRU value was near the surface - 20 cm or shallower. The average over the layer with highest activity, including all three high TRU values, was less than 100 pCi/g. The sampling locations around NW 20-4 and the highest TRU value at each are shown in Figure 7-71. Because no 0.0625 hectare with average TRU activity exceeding 160 pCi/g was found in these investigations, no subsurface excision was done at either location.

Overall results of the FPDB characterization of Janet for ^{137}Cs and ^{90}Sr are shown as isopleths on the 0-40 cm profile means in Figures 7-72 to 7-79. The isopleths are shown separately for the four quadrants of Janet for added clarity and detail.

Final Characterization

It was decided in April 1979, after all other cleanup activities were complete, to excise the Plow-X control plots (see Section 6.7) because no further experimental use of the area was contemplated. The soil excision and IMP resurvey were completed 10 May 1979; 720 cubic meters (940 cubic yards) of soil containing an estimated 0.05 curies of TRU activity were removed from this area.

The post-cleanup isopleths on TRU activity based on final data on Janet are shown by quadrant in Figures 7-80 through 7-83. Table 7-4 summarizes the island average results for ^{137}Cs, ^{60}Co and TRU activity from IMP data.

The island average transuranics value reported in the Certification is 20 pCi/gm for surface soil, and the transuranics classification is Residence.

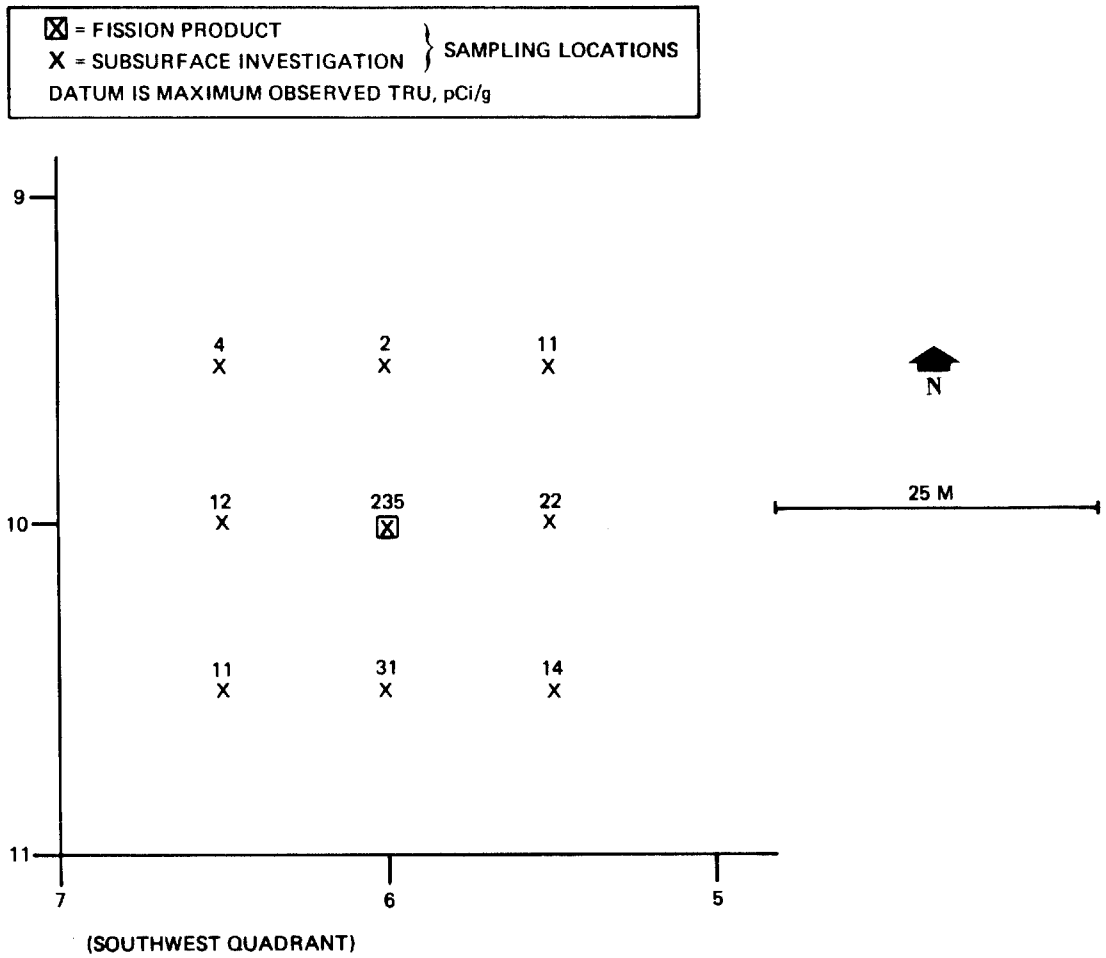

FIGURE 7-70. SUBSURFACE SAMPLING RESULTS, LOCATION SW6-10, ISLAND JANET

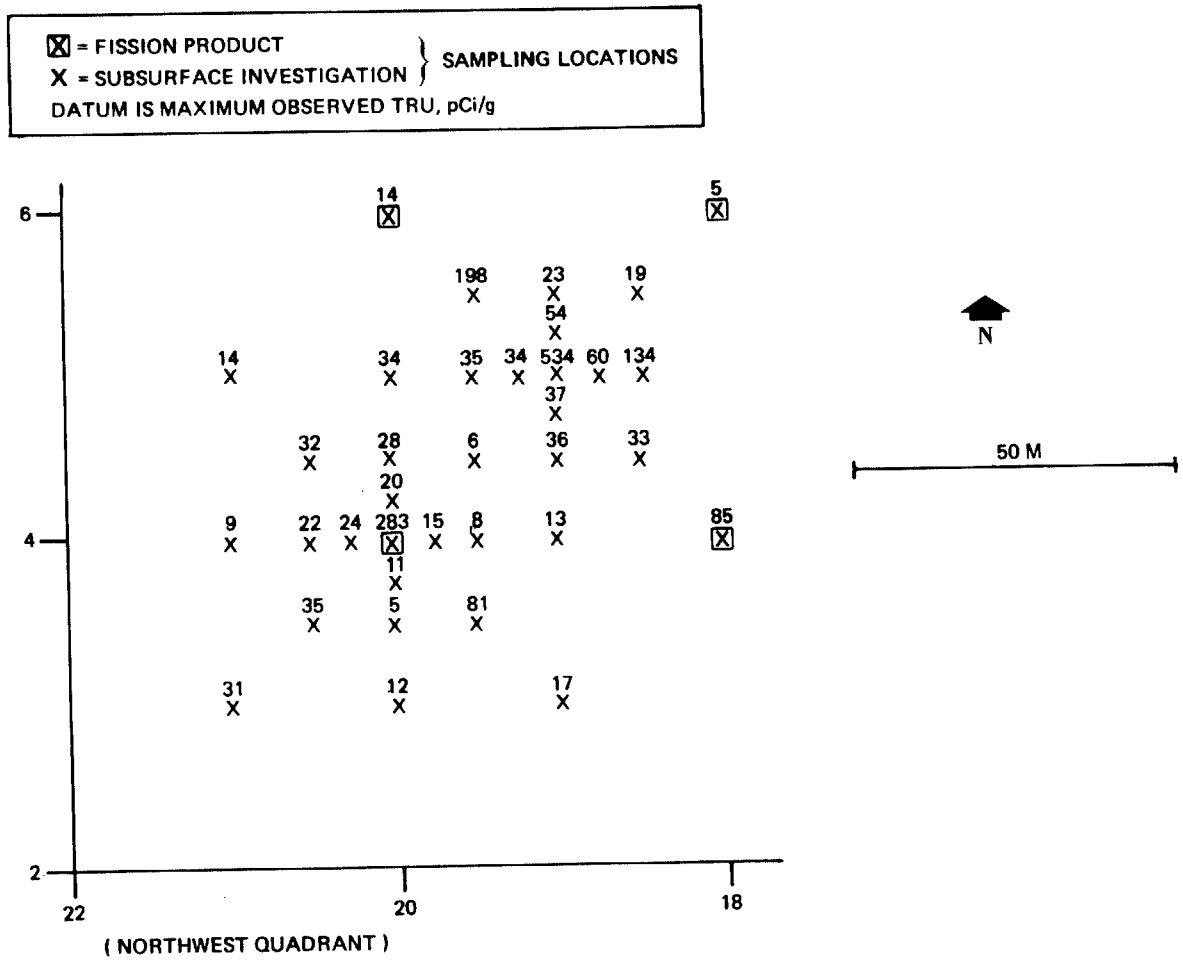

FIGURE 7-71. SUBSURFACE SAMPLING RESULTS, LOCATION NW20-4 , ISLAND JANET

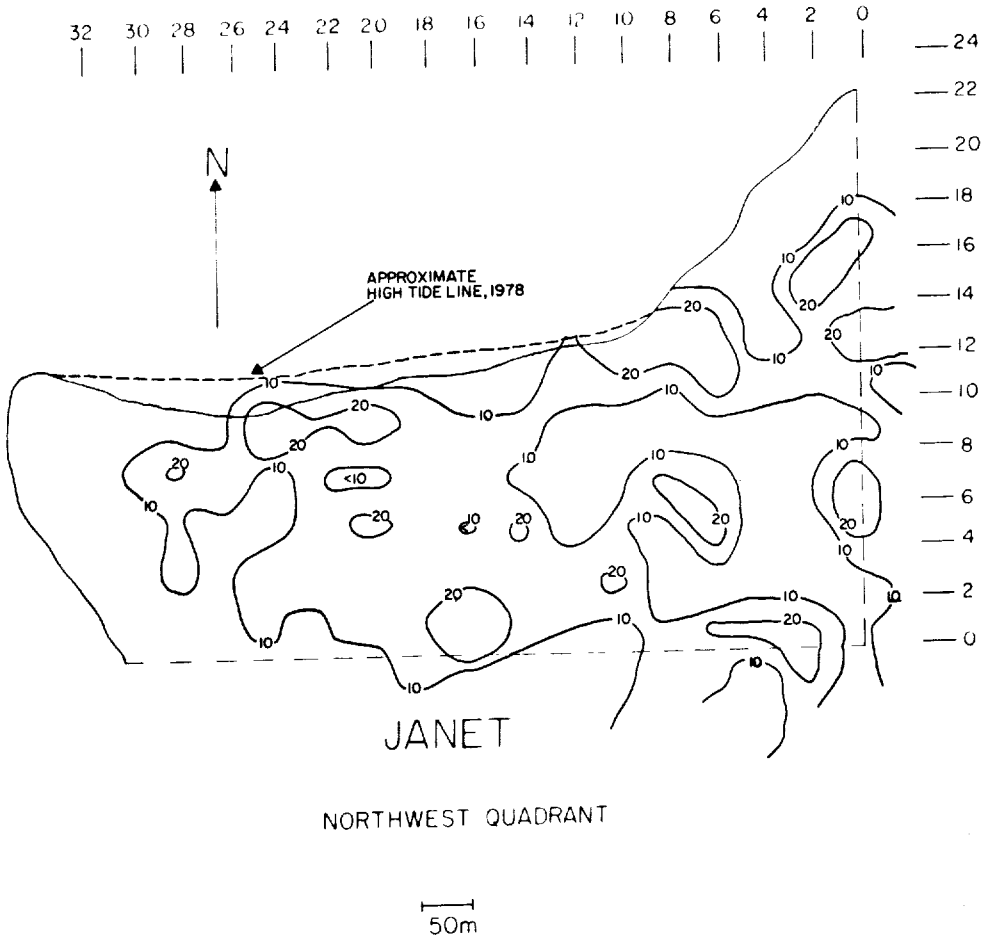

FIGURE 7-72. ISOPLETHS ON ^{137}Cs ACTIVITY IN pCi/g (AVERAGE IN TOP 40 CM) FOR NW QUADRANT OF ISLAND JANET

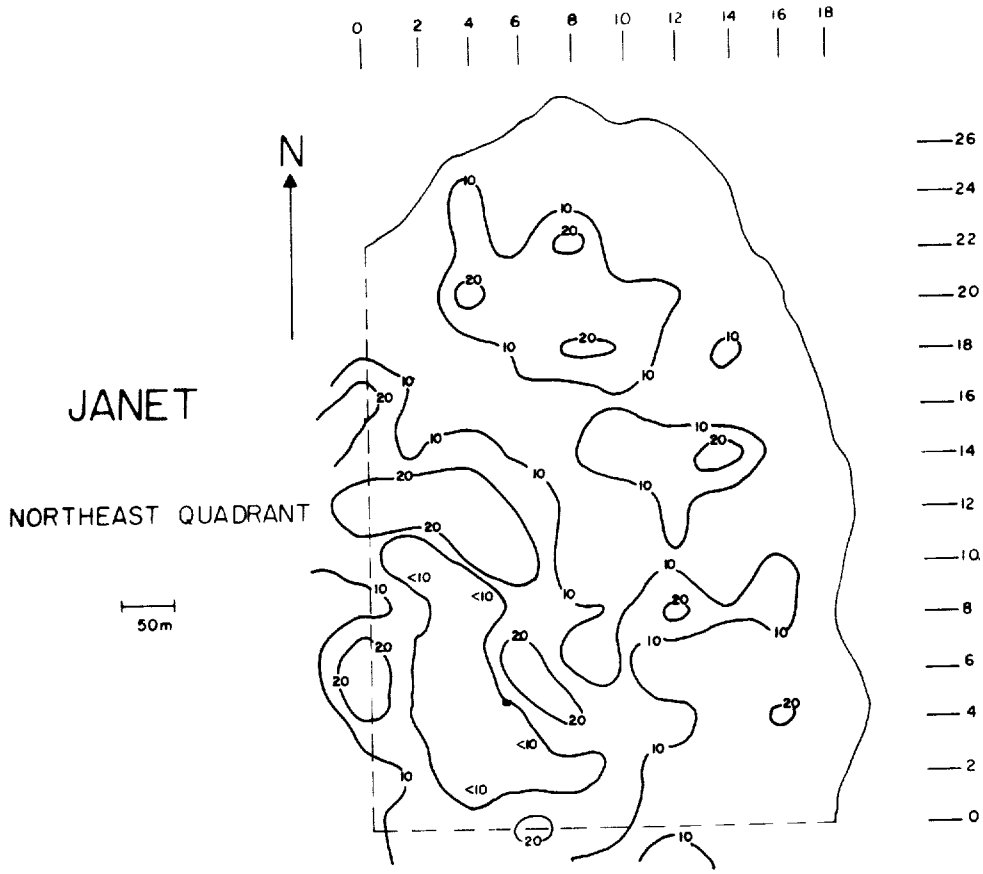

FIGURE 7-73. ISOPLETHS ON ^{137}Cs ACTIVITY IN pCi/g (AVERAGE IN TOP 40 CM) FOR NE QUADRANT OF ISLAND JANET

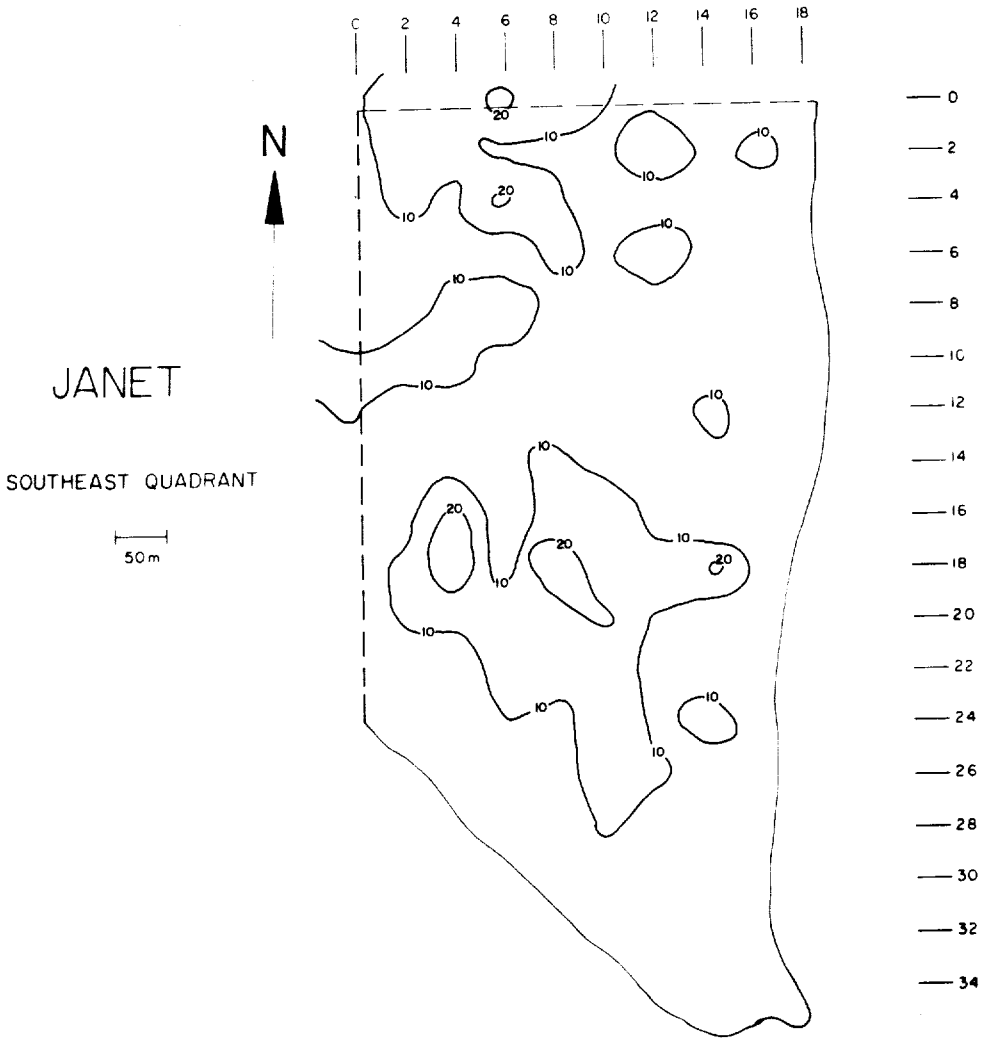

FIGURE 7-74. ISOPLETHS ON ^{137}Cs ACTIVITY IN pCi/g (AVERAGE IN TOP 40 CM) FOR SE QUADRANT OF ISLAND JANET

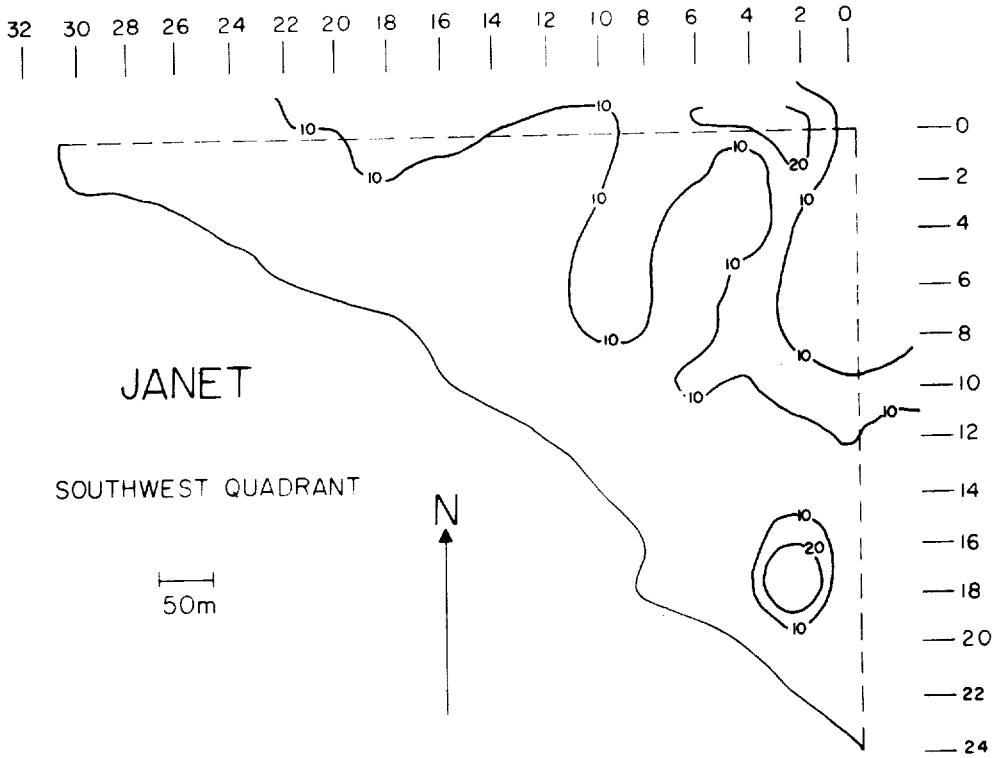

FIGURE 7-75. ISOPLETHS ON ^{137}Cs ACTIVITY IN pCi/g (AVERAGE IN TOP 40 CM) FOR SW QUADRANT OF ISLAND JANET

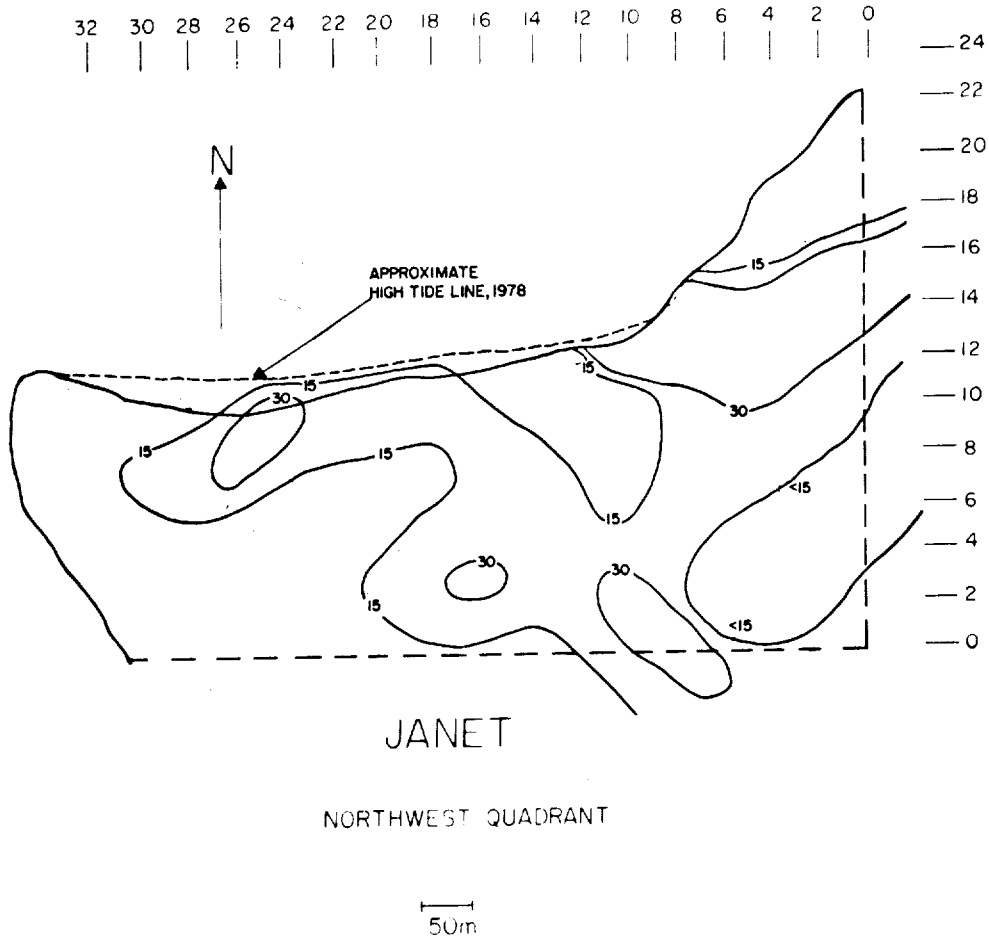

FIGURE 7-76. ISOPLETHS ON ^{90}Sr ACTIVITY IN pCi/g (AVERAGE IN TOP 40 CM) FOR NW QUADRANT OF ISLAND JANET

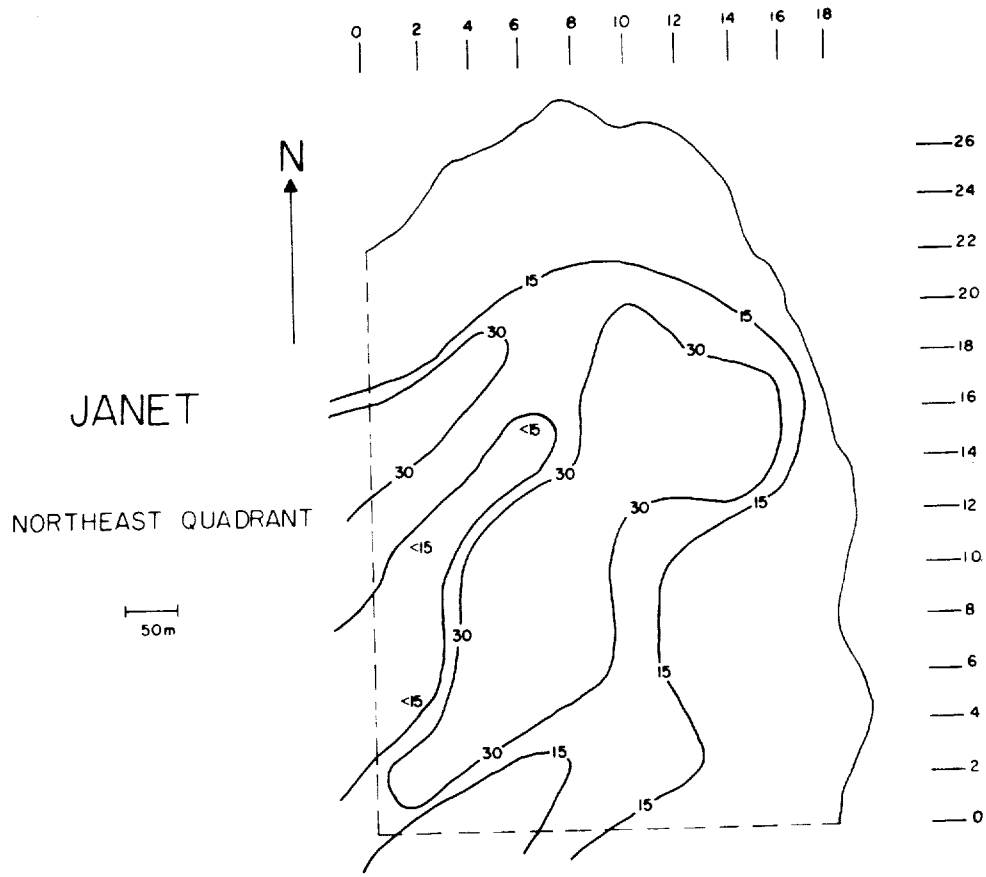

FIGURE 7-77. ISOPLETHS ON ^{90}Sr ACTIVITY IN pCi/g (AVERAGE IN TOP 40 CM) FOR NE QUADRANT OF ISLAND JANET

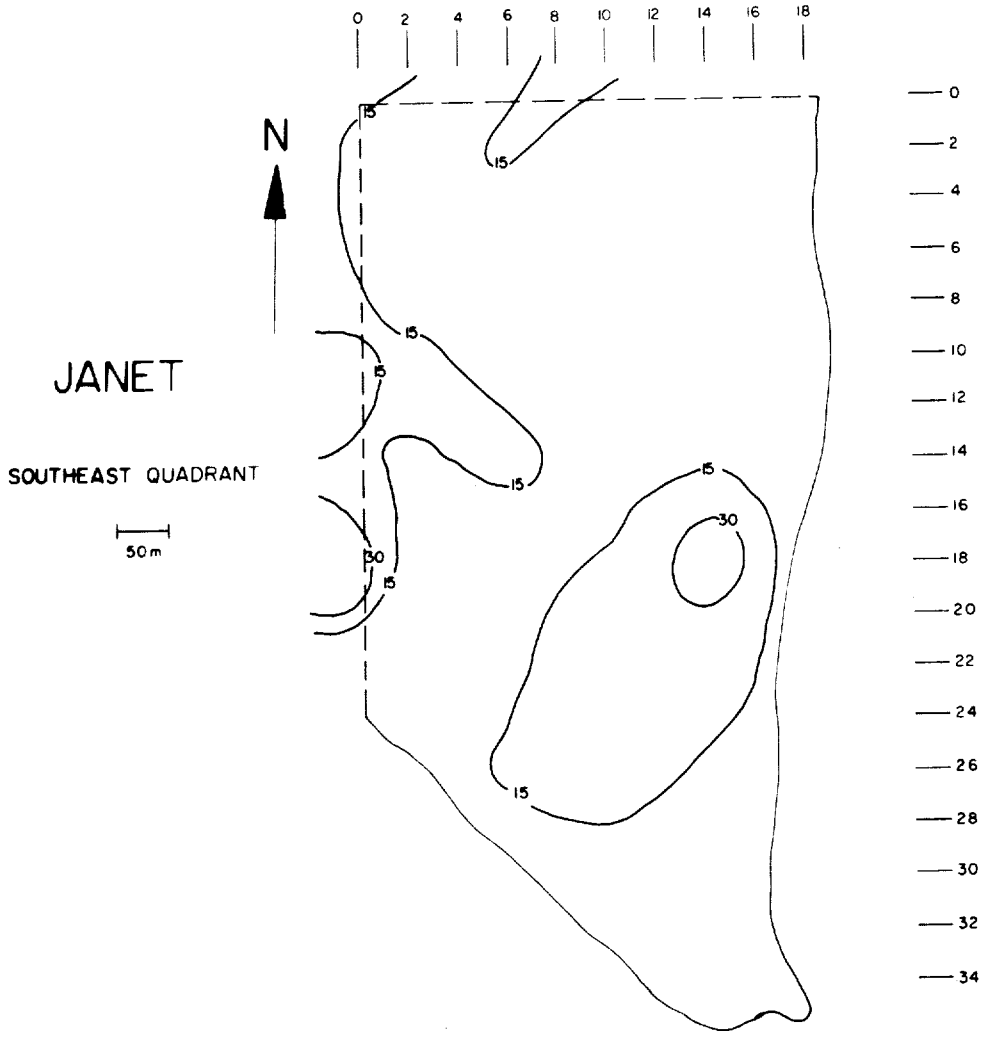

FIGURE 7-78. ISOPLETHS ON ^{90}Sr ACTIVITY IN pCi/g (AVERAGE IN TOP 40 CM) FOR SE QUADRANT OF ISLAND JANET

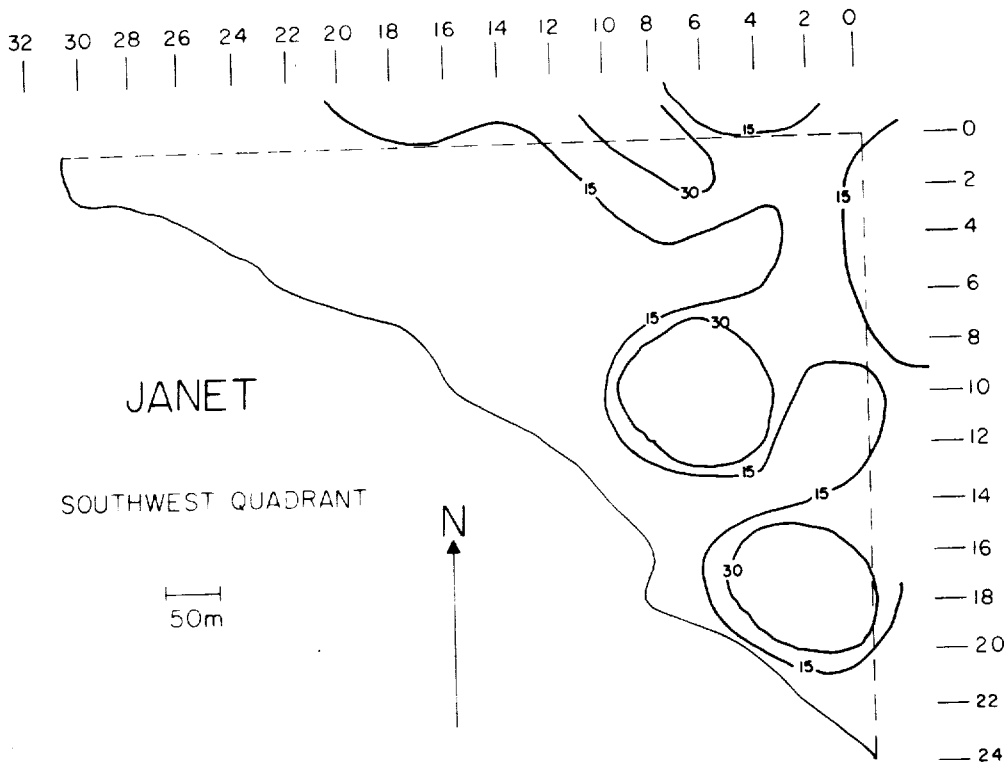

FIGURE 7-79. ISOPLETHS ON ^{90}Sr ACTIVITY IN pCi/g (AVERAGE IN TOP 40 CM) FOR SW QUADRANT OF ISLAND JANET

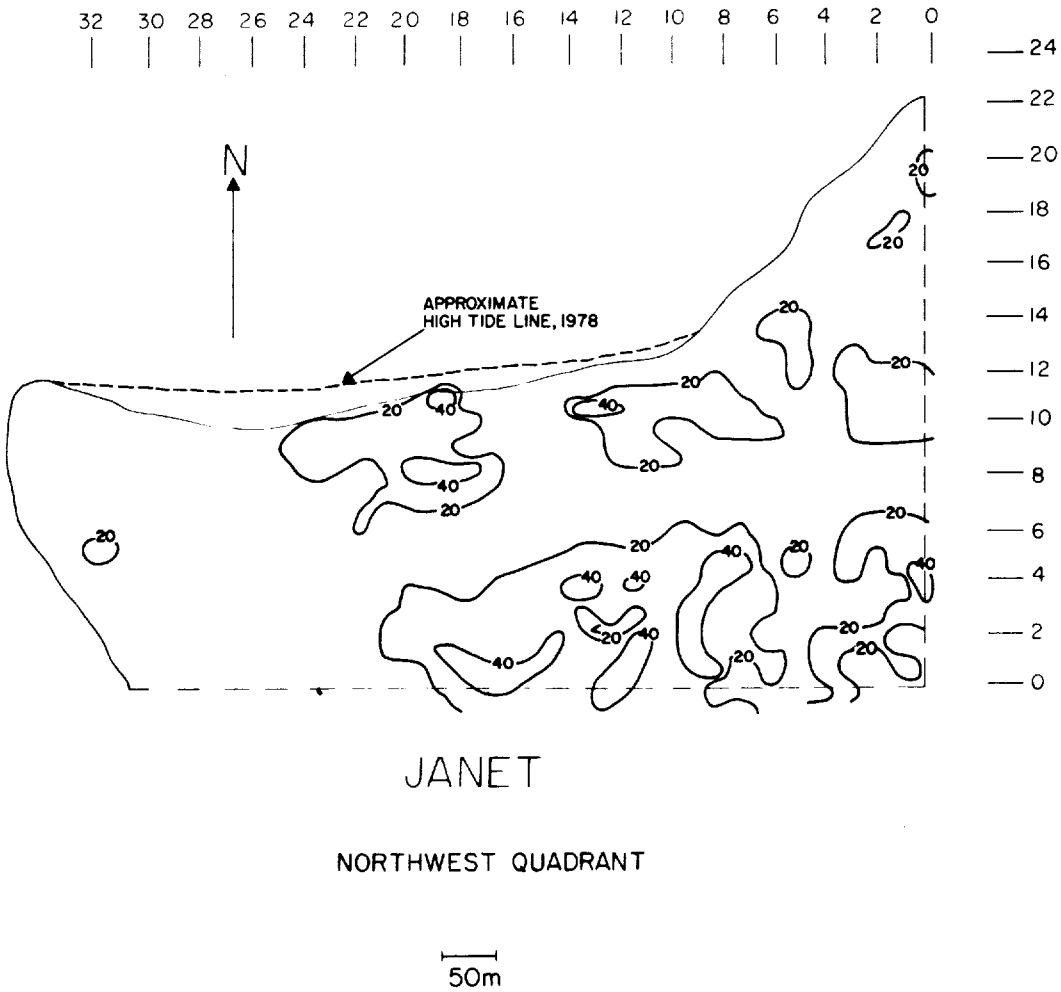

FIGURE 7-80. ISOPLETHS ON FINAL ESTIMATED SURFACE TRU ACTIVITY IN pCi/g FOR NEW QUADRANT OF ISLAND JANET

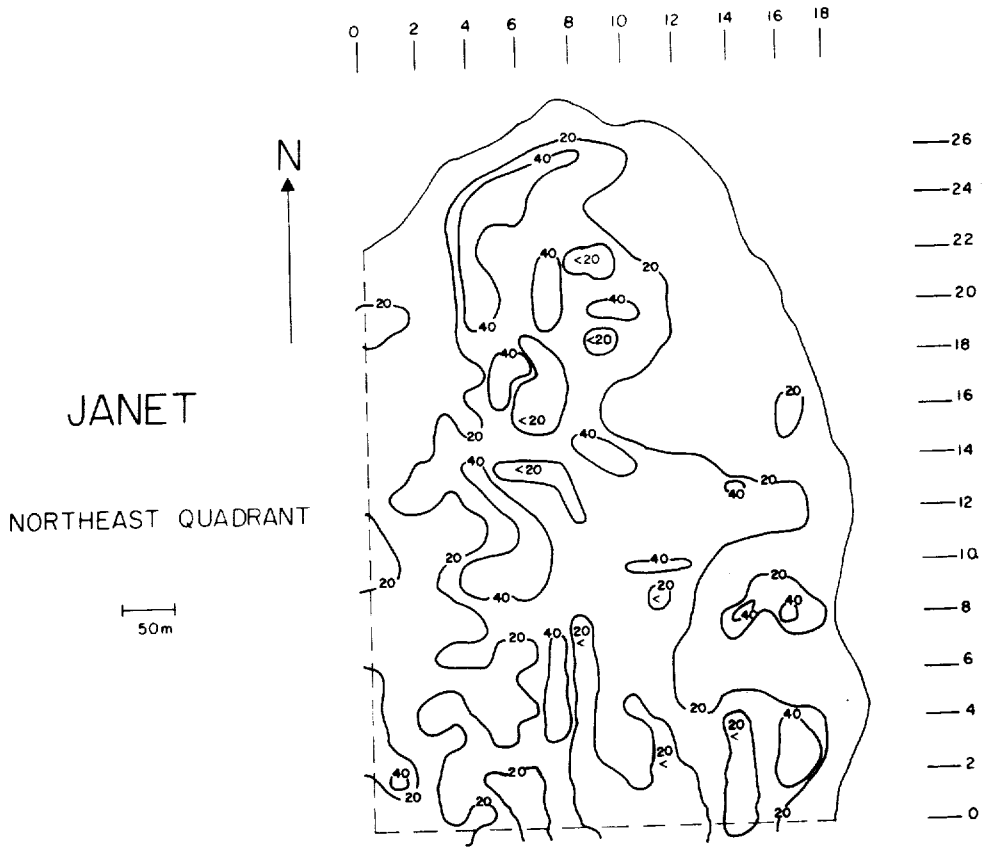

FIGURE 7-81. ISOPLETHS ON FINAL ESTIMATED SURFACE TRU ACTIVITY IN pCi/g FOR NE QUADRANT OF ISLAND JANET

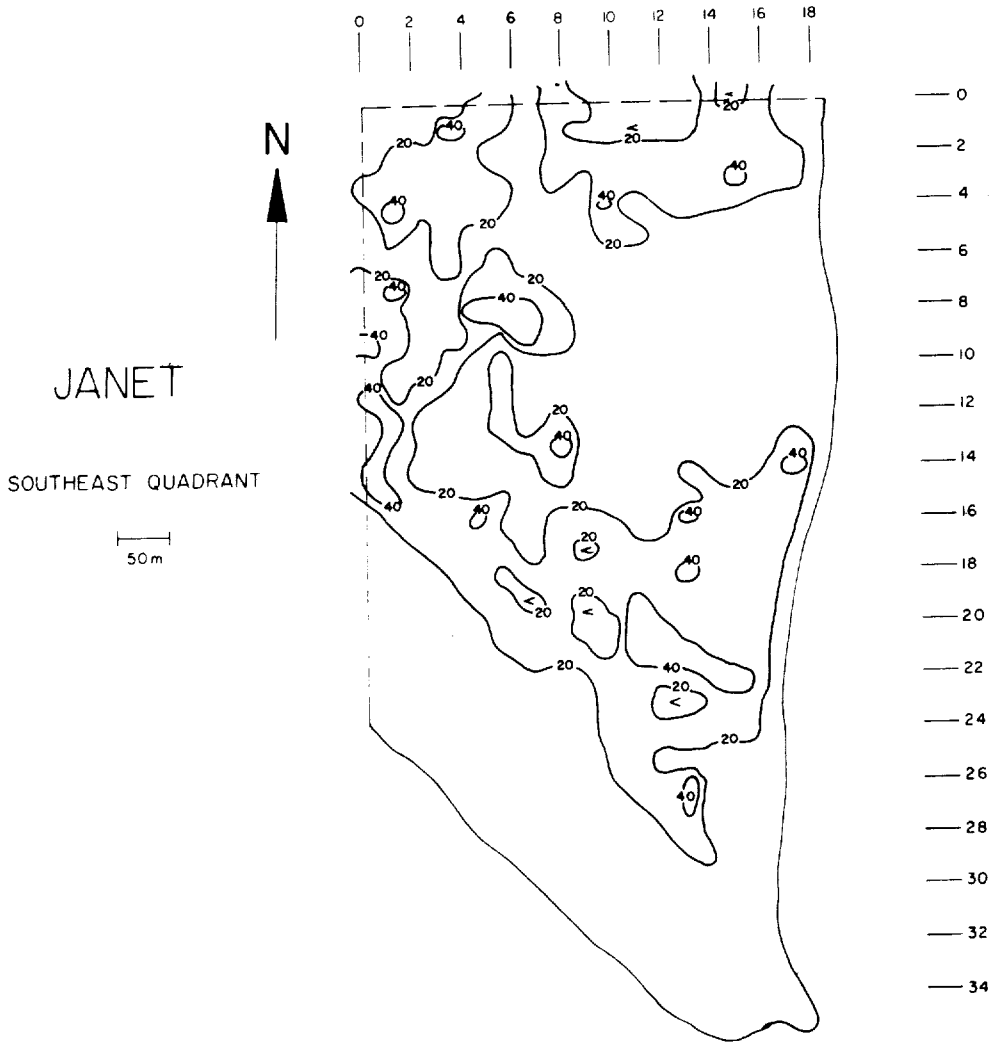

FIGURE 7-82. ISOPLETHS ON FINAL ESTIMATED SURFACE TRU ACTIVITY IN pCi/g FOR SE QUADRANT OF ISLAND JANET

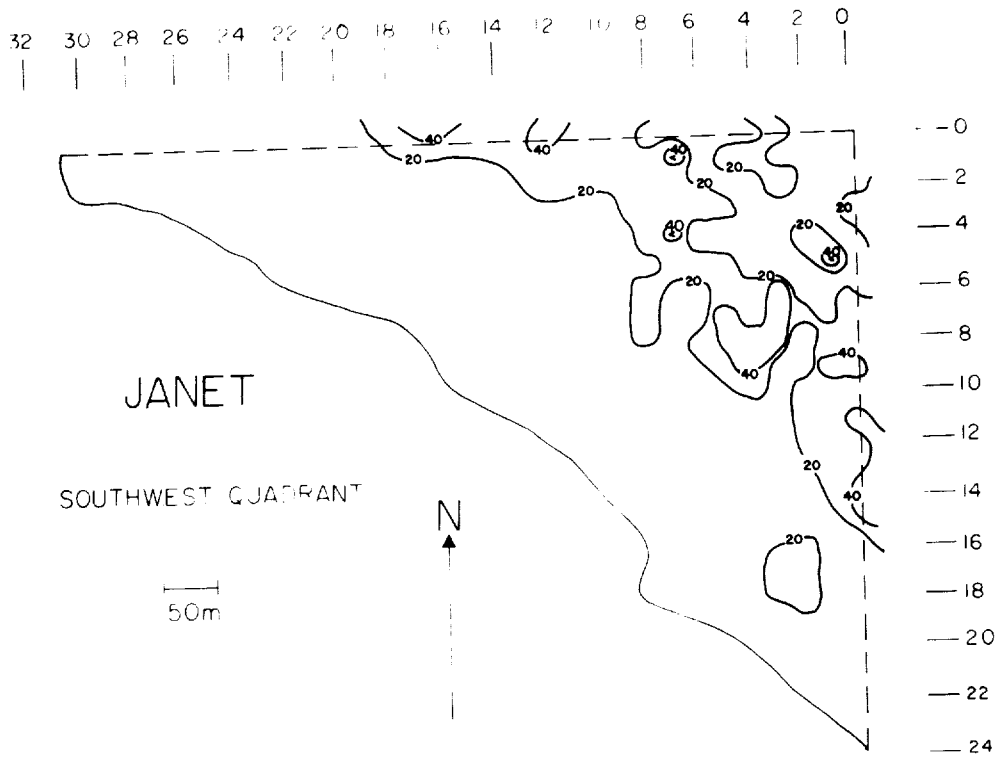

FIGURE 7-83. ISOPLETHS ON FINAL ESTIMATED SURFACE TRU ACTIVITY IN pCi/g FOR SW QUADRANT OF ISLAND JANET

7.5.3 Pearl

Background

Island Pearl (Marshallese: Lujor) is one of the larger of the northeastern islands with an area of 22 hectares (ha). The soil is very sandy and the plant cover was moderate to heavy before any cleanup. Pearl was the site for one nuclear test event, Inca, which was located in the middle of the western quarter of the island as shown in Figure 7-84. Because of this event plus 12 other surrounding events, Pearl ranks sixth among the islands in the Atoll in total H + 1 hour exposure rate with 4,329 R/h. A large quantity of debris including blocks of concrete remained on this island from the Inca event. There were no known or suspected burial sites on Pearl. However, because of the surface ground zero on the island, it was possible that some post-shot operations covered contaminated soil or debris.

1972 Survey Results

In the 1972 survey, soil samples were collected at 53 sites on Pearl along with a few vegetation and animal samples. Of these sites, 45 were 0-15 cm core samples, 5 were 0-35 cm samples, and 3 were 0-65 cm profiles. Most of the profiles showed either a steady or steep decrease in $^{239,240}Pu$, ^{137}Cs, and ^{90}Sr activities with increasing depth. The exception to this was a sample taken near the southeast end where the soil activities were more homogeneous with depth. The 0-15 cm core sample results at five sites indicated a hot spot in the northwestern part of Pearl. As shown by Table 7-3, $^{239,240}Pu$ concentrations on this island had a wide range of values and the highest values indicated that the agricultural criterion would not be met. Results for the ^{137}Cs and ^{90}Sr data collected in 1972 are shown in Tables 7-1 and 7-2, respectively.

Surface Characterization

Pearl was initially measured with the IMP on a 50 m grid in October 1977 as shown in Figure 7-84*. Some 25 m grid points were also measured in the same time period in areas of higher ^{241}Am concentration. These data were collected before any of the debris removal occurred and the only soil disturbance was due to the clearing of lanes for IMP access. Soil samples were first collected at five locations as shown in Figure 7-84 with two composites at three depths for a total of 30 samples. (See Section 4.2.1 for more information on soil sampling). Soil sample results from other islands showed very little ^{238}Pu. This was not the case for Pearl so the question arose whether this radioisotope would be included in the characterization of an island. Because of this uncertainty, two ratios were computed from the results of the initial five sampling locations for this island: $^{239,240}Pu$ to ^{241}Am and $^{238,\ 239,240}Pu$ to ^{241}Am (see Tech Note 2.0). It was decided (See Section 2.2.3) to use TRU activity for island characterization, and new ratios were calculated for Pearl.

These initial results indicated that there was more than one population of ratios on Pearl. Nine new locations were sampled and three old locations were resampled. The results from these additional samples yielded three distinct ratios of TRU to ^{241}Am based on a cluster analysis as detailed in Tech Note 2.0-B. The ratios used in the initial characterization were 9.1 $\pm$ 1.13 for locations within 150 m of Inca GZ, 7.80 $\pm$ 2.18 for locations between 150 m and 350 m from Inca and 4.10 $\pm$ 1.28 for locations more than 350 m from Inca. Figure 7-84 shows the boundaries for these ratios.

Pearl was also the site for a brush attenuation experiment where 10 locations were first measured with the IMP in an area with the brush undisturbed except for the bulldozed lane. These same 10 locations were remeasured by the IMP after the brush in the IMP's field of view was removed by hand. (The area was hand cleared to minimize soil disturbance.) A brush correction factor was determined from these data to be 1.15 $\pm$ 0.08. For the data used and a detailed write-up see Tech Note 1.0. This island also had some IMP measurements taken on a 25 m grid in two areas of higher ^{241}Am concentration. One such area in the northern part of the island was chosen because the aerial survey (Section 3.1) indicated elevated ^{241}Am concentrations and the other area in the southern part of the island showed high ^{241}Am activity in both IMP and soil sample results. This

*As map shows, the grid was not true north-south.

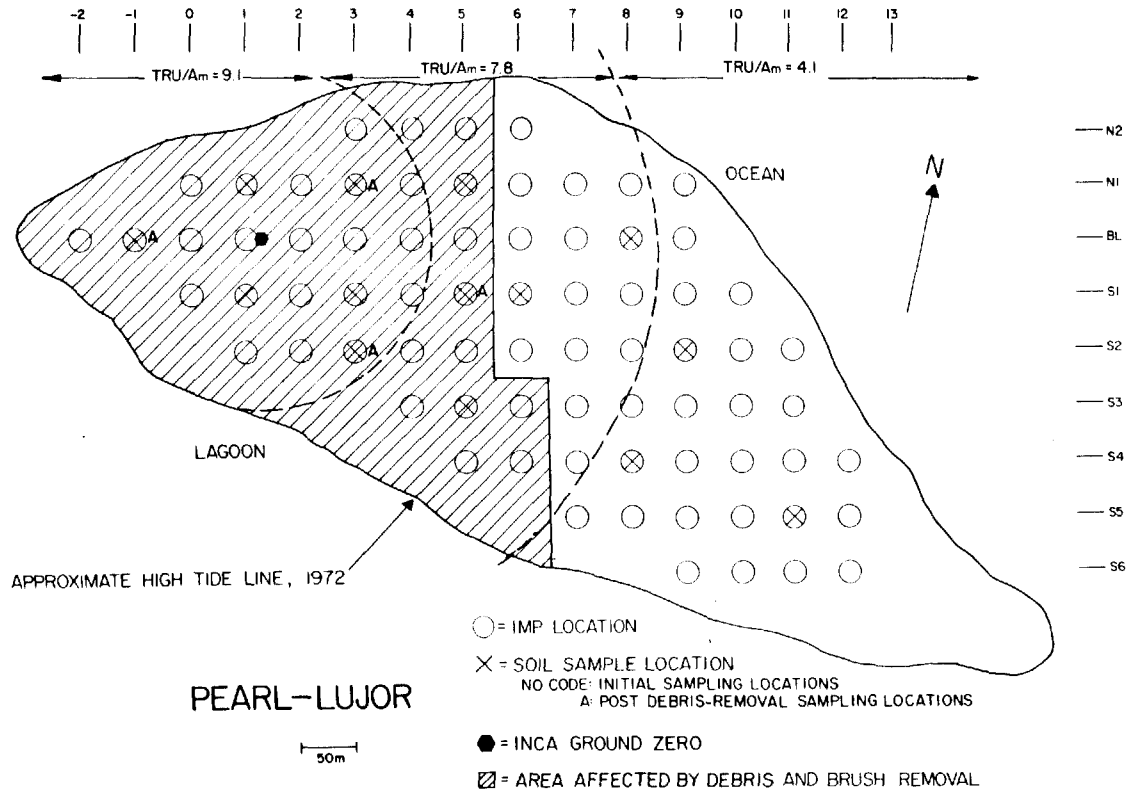

FIGURE 7-84. COASTLINE AND DATA COLLECTION LOCATIONS FOR ISLAND PEARL

latter area was centered at the grid node 5-S-3 and was an anomaly throughout the cleanup with respect to ratio computation and elevated levels of TRU activity for both subsurface and surface.

The initial TRU surface characterization used only the 50 m grid data and the ratios previously mentioned. The calculated TRU values were used to fit a variogram model necessary to make the kriging estimates and the 0.5 s upper bounds, where s is the standard deviation of the kriging error (see Section 5.1.1). The estimated model for Pearl did not follow the usual mathematical form of linearity seen on other islands but was a power function. The model was tested and found to fit the data quite well. Using this model and the 50 m grid TRU data, 0.25 hectare estimates were calculated based on original data. (See Tech Note 23 for discussion on original versus final data.) These results indicated that Pearl was one of the more highly contaminated islands with the highest 0.25 hectare TRU estimate being 281.6 pCi/g and the lowest being 10.1 pCi/g. Approximately 3/4 of the island was estimated to have TRU activity greater than 40 pCi/g based on the 0.5 s upper bound numbers, and approximately 2/3 of the island had TRU greater than 80 pCi/g based on the same upper bounds. Figure 7-85 shows the area with TRU estimated to be above 40 pCi/g for the initial data.

These estimates were based on data collected prior to any debris pickup. Because this island had a large quantitiy of debris and was also very sandy and heavily vegetated, the radiological condition of the island changed during debris removal. Remeasurement by the IMP and collection of soil samples were done to determine how much this heavy soil disturbance had altered the island's characterization.

The area of the island affected by the debris removal is shown in Figure 7-84. Only this area was remeasured by the IMP in July 1978 and four surface soil samples were collected concurrently at locations also shown in Figure 7-84. One ratio was calculated from these soil sample results whereas before two ratios were included in this area. It appeared that the disturbance homogenized the soil and one ratio of 6.91 $\pm$ 0.41 was appropriate. Five additional soil samples were collected to verify this ratio but were ballmilled with contaminated balls during sample preparation so more samples were collected. These additional results verified the ratio calculated after debris removal. For the area of no soil disturbance, the original ratios were used to calculate the TRU values.

Using this second set of data, a new variogram model was estimated. For these data, the model fit was linear with a smaller constant term than was estimated before. This model was tested and fit the raw data well. New kriged estimates were computed using this model and the new TRU values. These 0.25 hectare averages showed lower TRU concentrations as compared to the first estimates calculated. The highest 0.25 hectare TRU estimate based on original data was 167.1 pCi/g compared to 281.6 pCi/g prior to debris removal. However, the areas with TRU estimated to be greater than 40 pCi/g and 80 pCi/g were basically the same for both sets of data with the exception being one small area on the southwestern part of the island that was significantly lower after debris removal.

Because no actual soil removal occurred prior to the second iteration, it appeared that either the soil was mixed or the dirt and brush piles left on the island contained much of the original top soil. If substantial churning had occurred as a result of debris removal, it could mean the TRU activity would be distributed deeper and several soil lifts would be necessary to remove the contamination. Based on the surface soil samples that were collected at 0-, 10- and 20-cm intervals, it seemed some mixing did occur but did not go very deep. This conclusion was also based on subsurface sidewall samples (see Section 6.9) collected after debris removal to a depth of 120 cm. The results from these samples showed no ^{241}Am activity greater than 2 pCi/g below a depth of 20 cm. More will be said about the subsurface sampling later in this section.

The next sampling involved collecting soil from the dirt and brush piles remaining on Pearl following debris removal. The piles were first surveyed with a handheld instrument and areas with higher

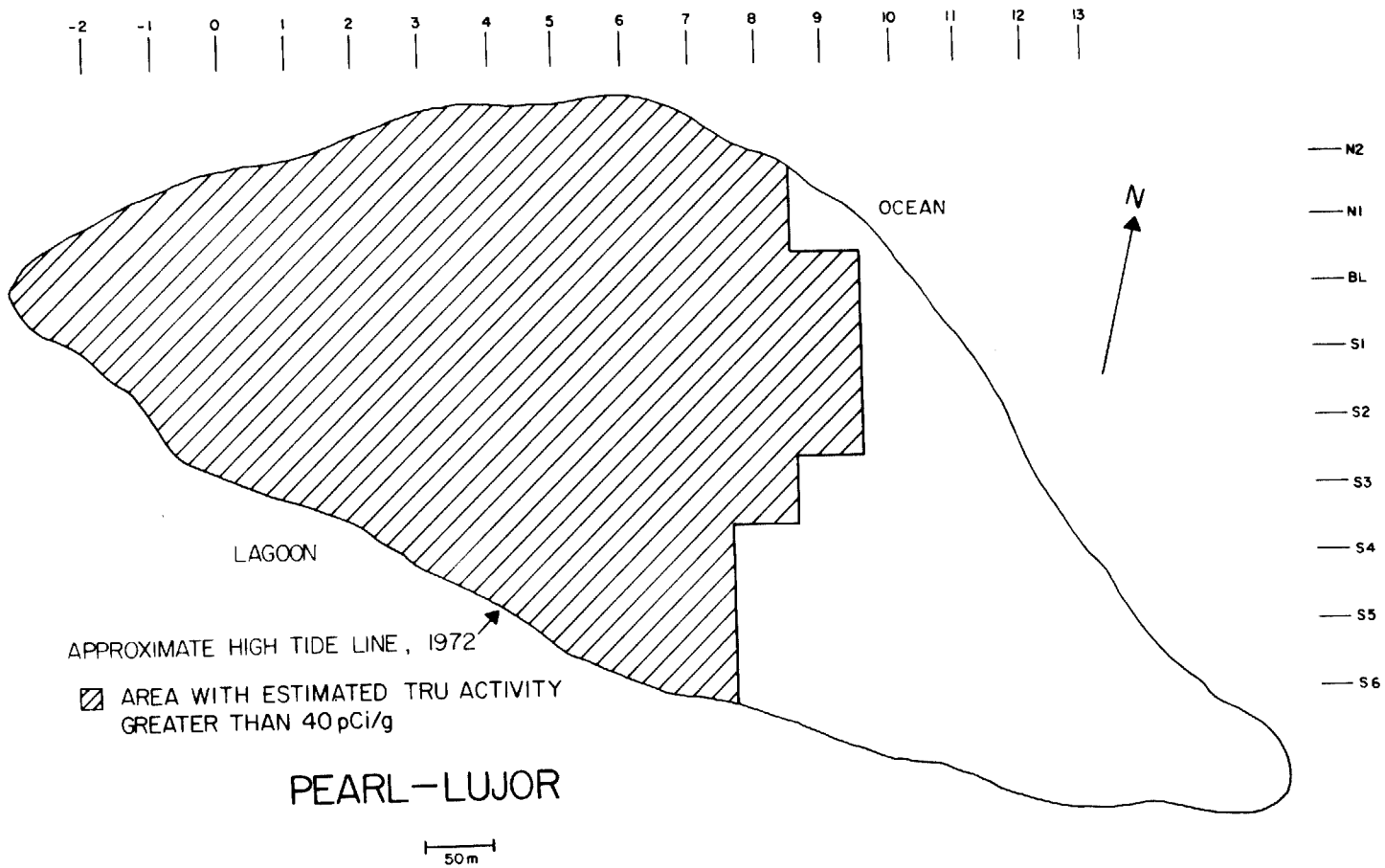

FIGURE 7-85. PRE-CLEANUP CHARACTERIZATION OF SURFACE TRU ACTIVITY FOR ISLAND PEARL BASED ON KRIGING ESTIMATES OF 0.25 HA AVERAGES (BEFORE DEBRIS REMOVAL)

readings were selected for soil sampling. Six samples were collected from different piles with each sample comprised of soil from the top, middle and bottom of the pile. The results from these samples showed a range of TRU activities from 101 pCi/g to 304 pCi/g indicating that it was possible a lot of the original top soil remained in the dirt and brush piles.

Subsurface Characterization

Because Pearl had one GZ, subsurface sampling was conducted in December 1977 and January 1978 to search for any pockets of contamination around Inca GZ and also the anomalous area around 5-S-3. Figures 7-86 and 7-87 show the locations and highest TRU result for each location for these two areas. Two iterations of sampling took place with the first being auger samples and the second being sidewall samples. (See Section 6.9.) Neither area showed any TRU activity greater than 160 pCi/g averaged over 0.0625 hectare below 20 cm. As previously mentioned, additional subsurface samples were collected after debris removal. Figure 7-88 shows the results and locations for this sampling.

Cleanup Activities

In March 1979, it was decided to clean Pearl to below 80 pCi/g based on the data collected after debris removal. IMP measurements were taken on some 25 m grid nodes to better define the boundaries for areas where TRU activity exceeded 80 pCi/g. The fine grid data were measured only around the original 50 m boundaries and not over the entire area because additional data in the interior would not change the 0.5 hectare average. (Originally 0.25 hectare estimates were made but the TRU criterion for an agricultural island is 80 pCi/g over 0.5 ha. Refer to Section 2.2.) The ratio of 6.91 determined from soil samples collected after debris removal was used on the fine grid data. Figure 7-89 shows the 7.75 hectare area where TRU was estimated to exceed 80 pCi/g averaged over 0.5 hectare based on all the data.

The areas requiring cleanup were excavated and all the soil stockpiled on the west end of Pearl for later removal to Yvonne. This was done so that the IMP could measure the areas where the soil had been removed and also in "no-lift" areas that were downwind or otherwise could be affected by soil removal. The IMP results indicated that three more small areas required a lift in order for the surface TRU to be below 80 pCi/g averaged over 0.5 ha. Two of the areas were on the fringes of the initial removal boundaries, therefore these removals were first lifts. The other lift was in an area where soil removal had already occurred. This was the only second lift necessary on Pearl.

After the removal of the stockpile and the three additional areas, these areas were remeasured by the IMP. In addition, twelve locations were soil sampled for ratio determination after cleanup. Two ratios were estimated for Pearl: 6.81 $\pm$ 0.30 for cleanup areas and 4.35 $\pm$ 0.50 for noncleanup areas. The highest 0.5 hectare average TRU after surface soil removal was 61 pCi/g (based on original data). The estimated amount of surface soil removed was 11,096 cubic meters (14,513 cubic yards) and the estimated curies of TRU activity removed was 1.64.

Fission Product Sampling

In support of the dose assessment, fission products sampling (Section 6.11) was done for the eastern part of Pearl (noncleanup area) in March 1979. The remainder of the island was sampled in May and June 1979 after surface soil removal was complete. This sampling was conducted on the 50 m grid already established with ^{90}Sr analysis done on 17 of 72 sampling locations. Using the nearest located TRU ratio based on the post-cleanup data rather than a mean value and the ^{241}Am gamma data from this additional sampling, some suspect pockets of subsurface contamination were revealed. Four locations showed a TRU value above 160 pCi/g at some depth. Because the initial subsurface sampling was 5 cm cuts at 20 cm intervals and the fission products sampling was at different increments, these four areas were not discovered in the initial subsurface investigations.

The first step in investigating these spots was to examine the validity of the ratio used in computing the TRU activity. The ratios did not change significantly so the areas were still suspect. The next step was to collect soil samples as described in Tech Note 18. Figures 7-90 through 7-93 show the results and sampling locations for the four areas on Pearl after sampling. As shown by Figures 7-90 through 7-92, no other elevated subsurface TRU activity was found for three of the areas and no

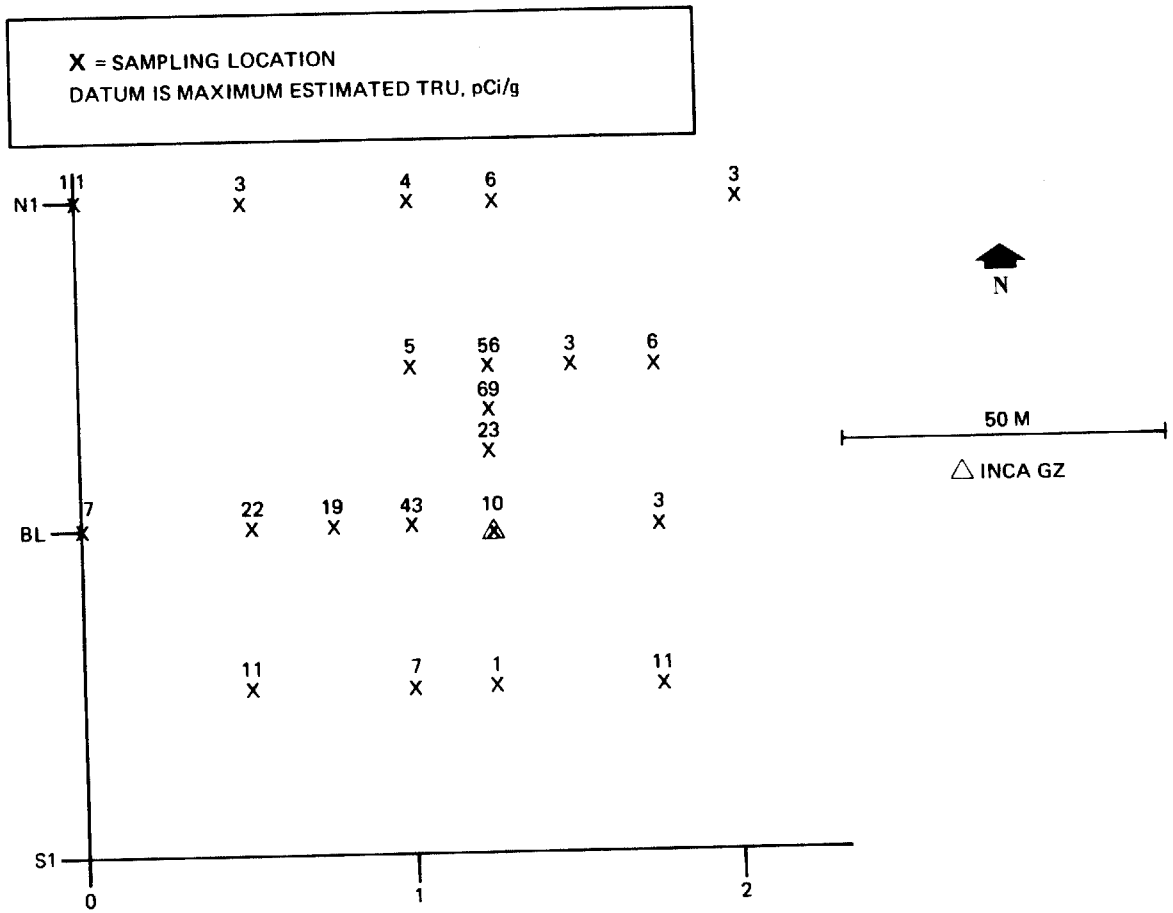

FIGURE 7-86. SUBSURFACE SAMPLING RESULTS, INCA GZ, ISLAND PEARL

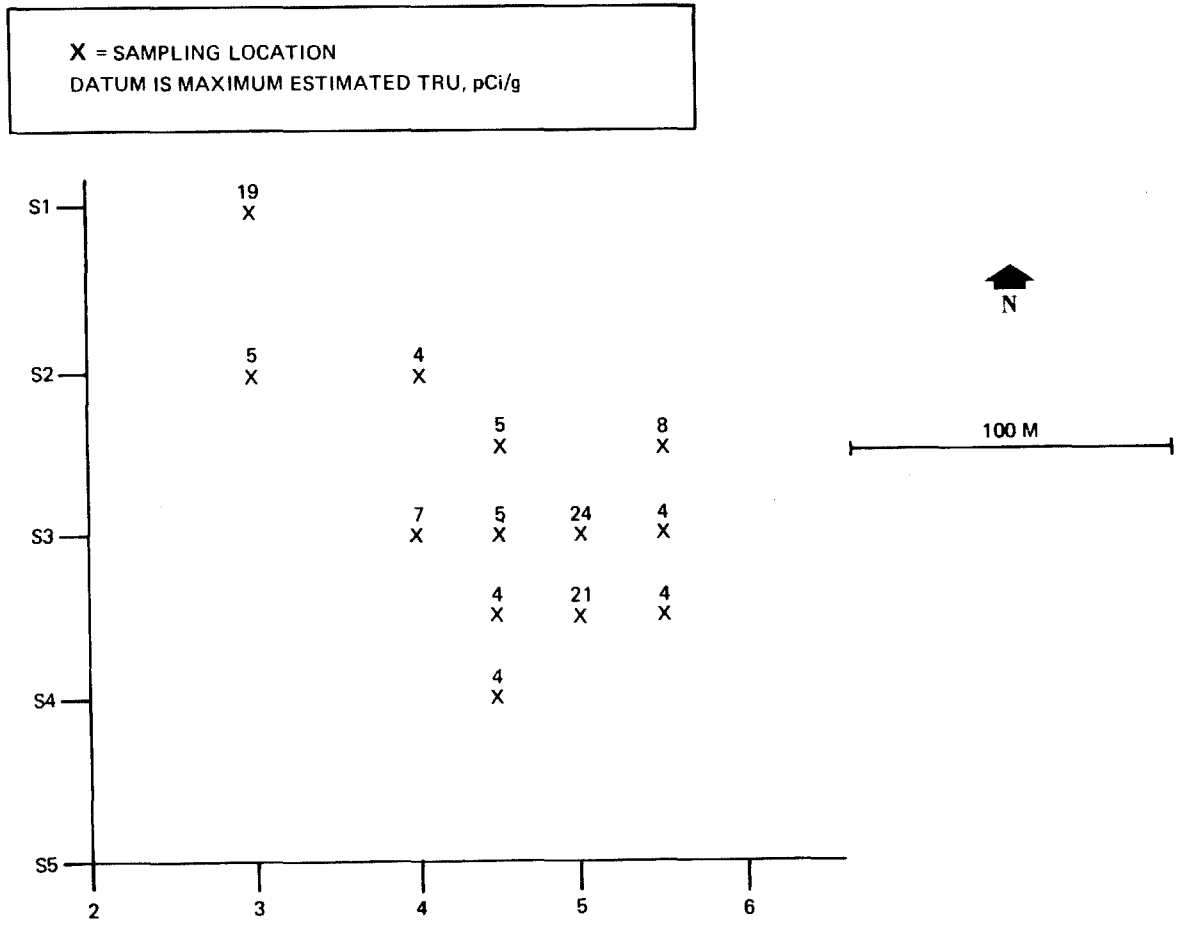

FIGURE 7-87. SUBSURFACE SAMPLING RESULTS, LOCATION 5S3, ISLAND PEARL

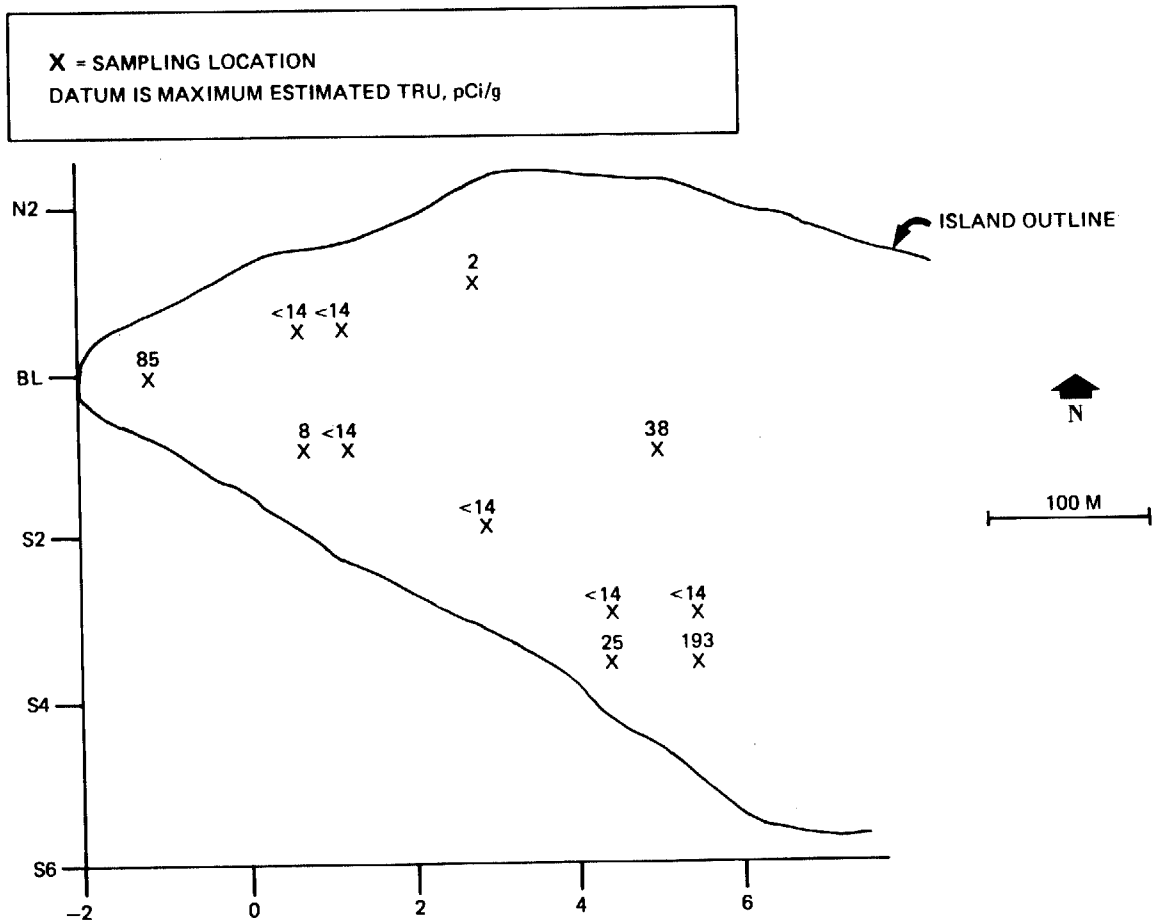

FIGURE 7-88. SUBSURFACE SAMPLING RESULTS, ISLAND PEARL

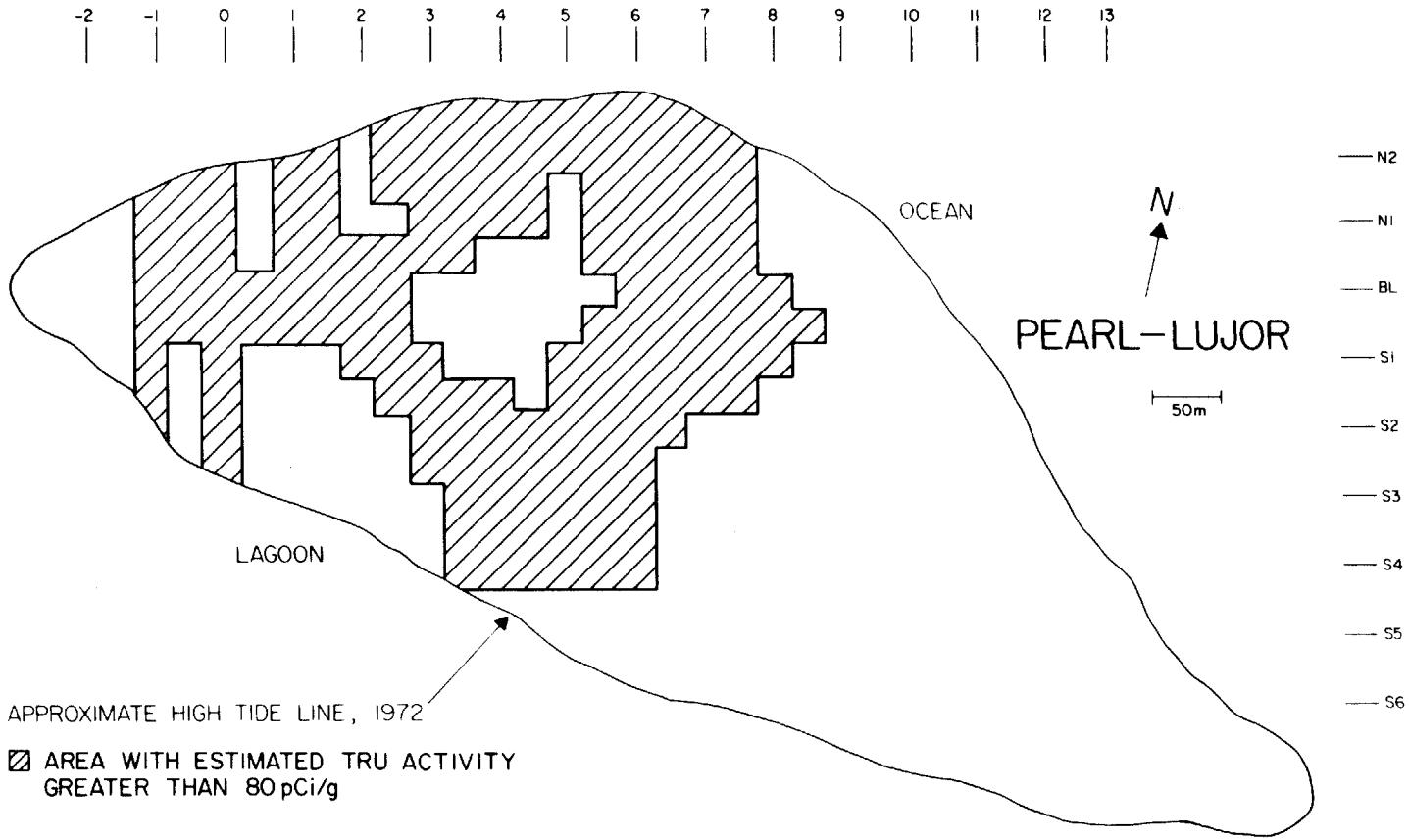

FIGURE 7-89. PRE-CLEANUP CHARACTERIZATION OF SURFACE TRU ACTIVITY FOR ISLAND PEARL BASED ON ESTIMATES OF 0.5 HA AVERAGES (AFTER DEBRIS REMOVAL)

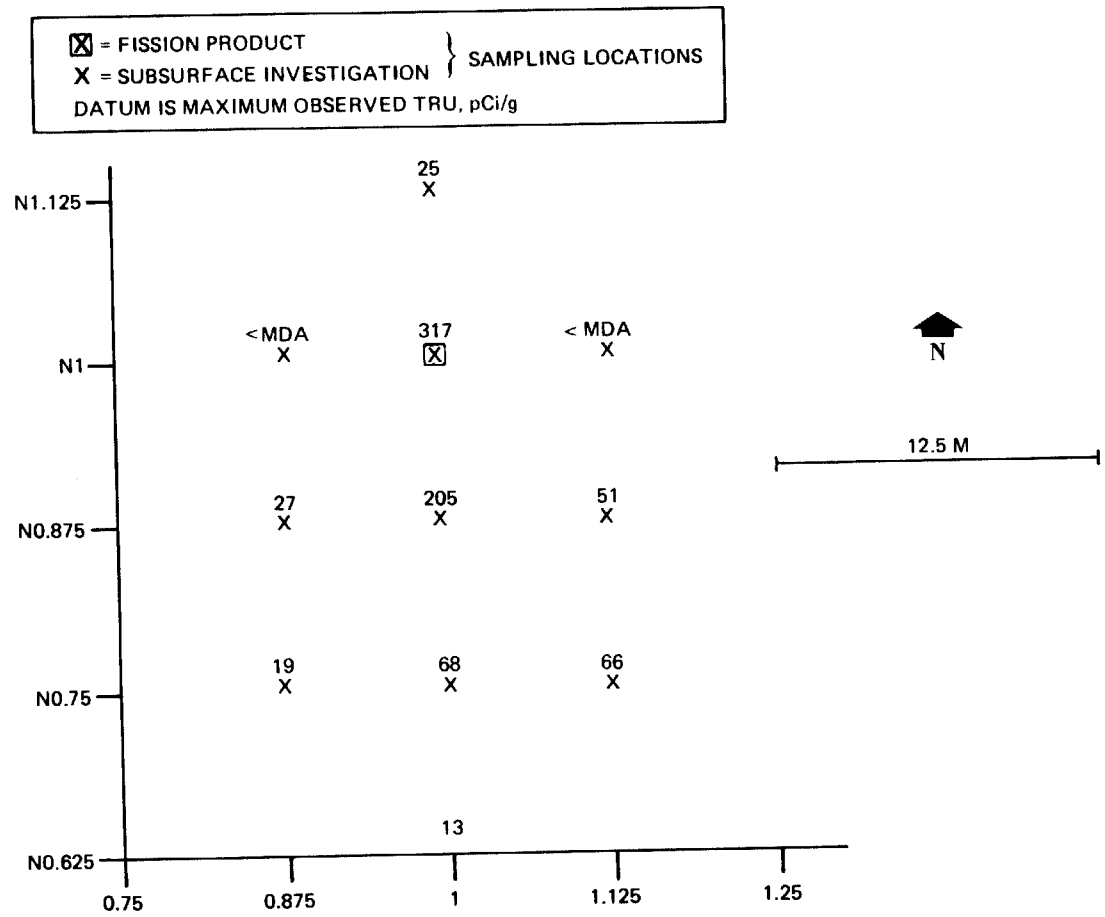

FIGURE 7-90. SUBSURFACE SAMPLING RESULTS , LOCATION INI, ISLAND PEARL

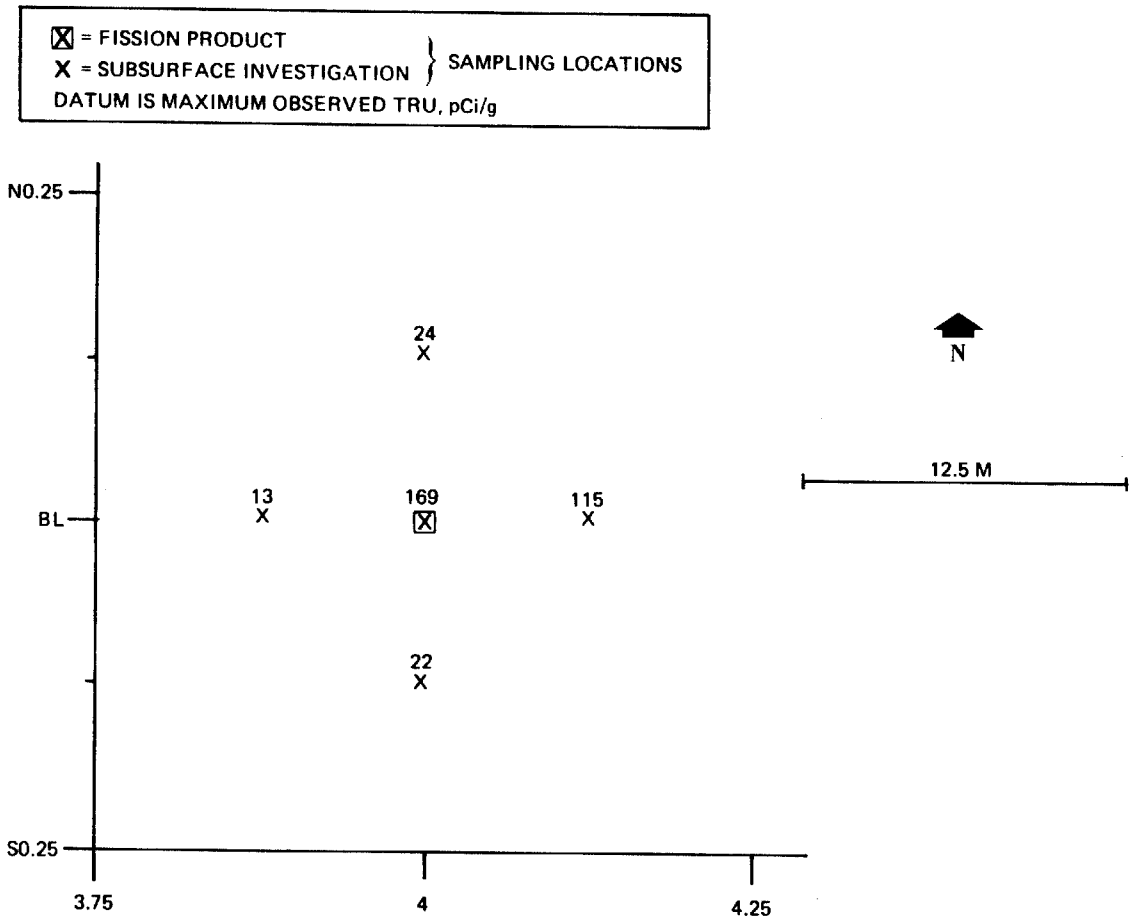

FIGURE 7-91. SUBSURFACE SAMPLING RESULTS, LOCATION 4BLO, ISLAND PEARL

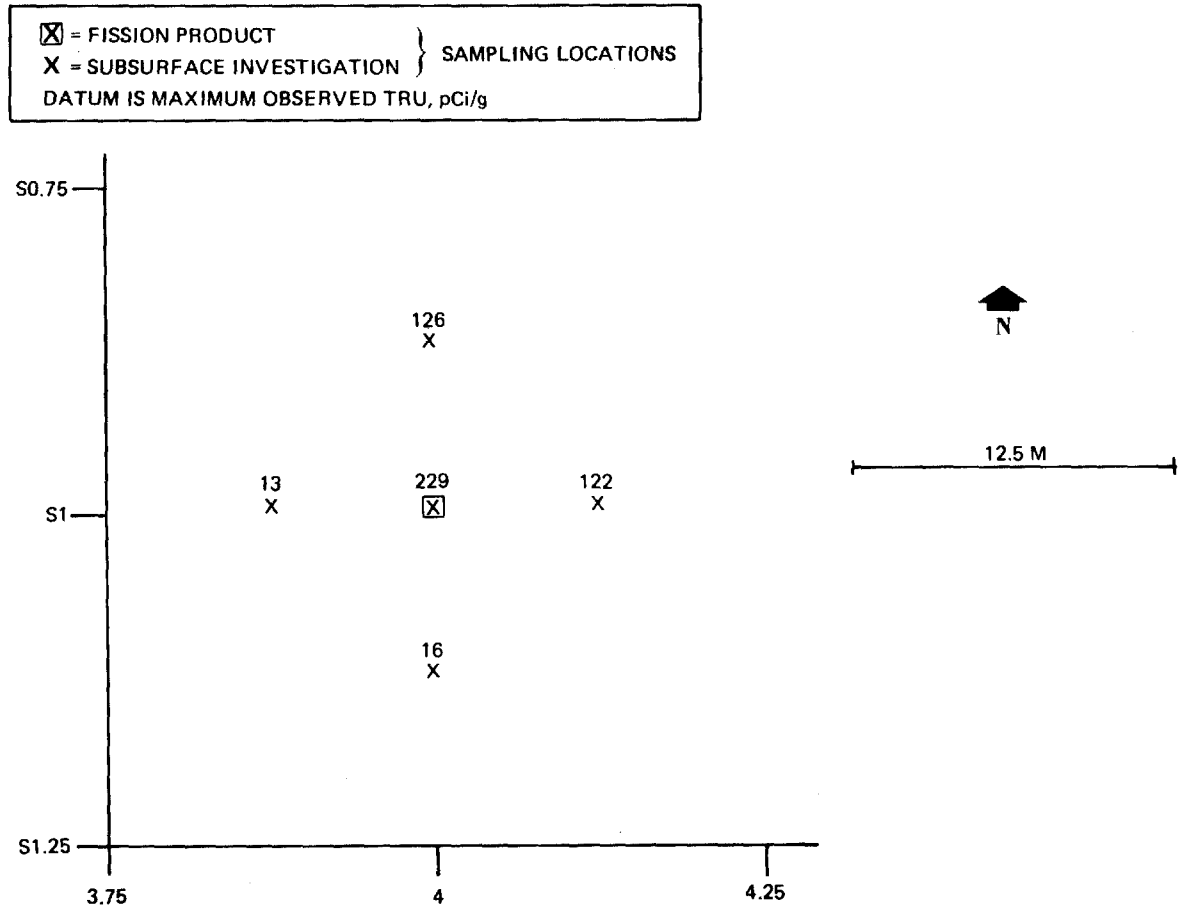

FIGURE 7-92. SUBSURFACE SAMPLING RESULTS , LOCATION 4S1, ISLAND PEARL

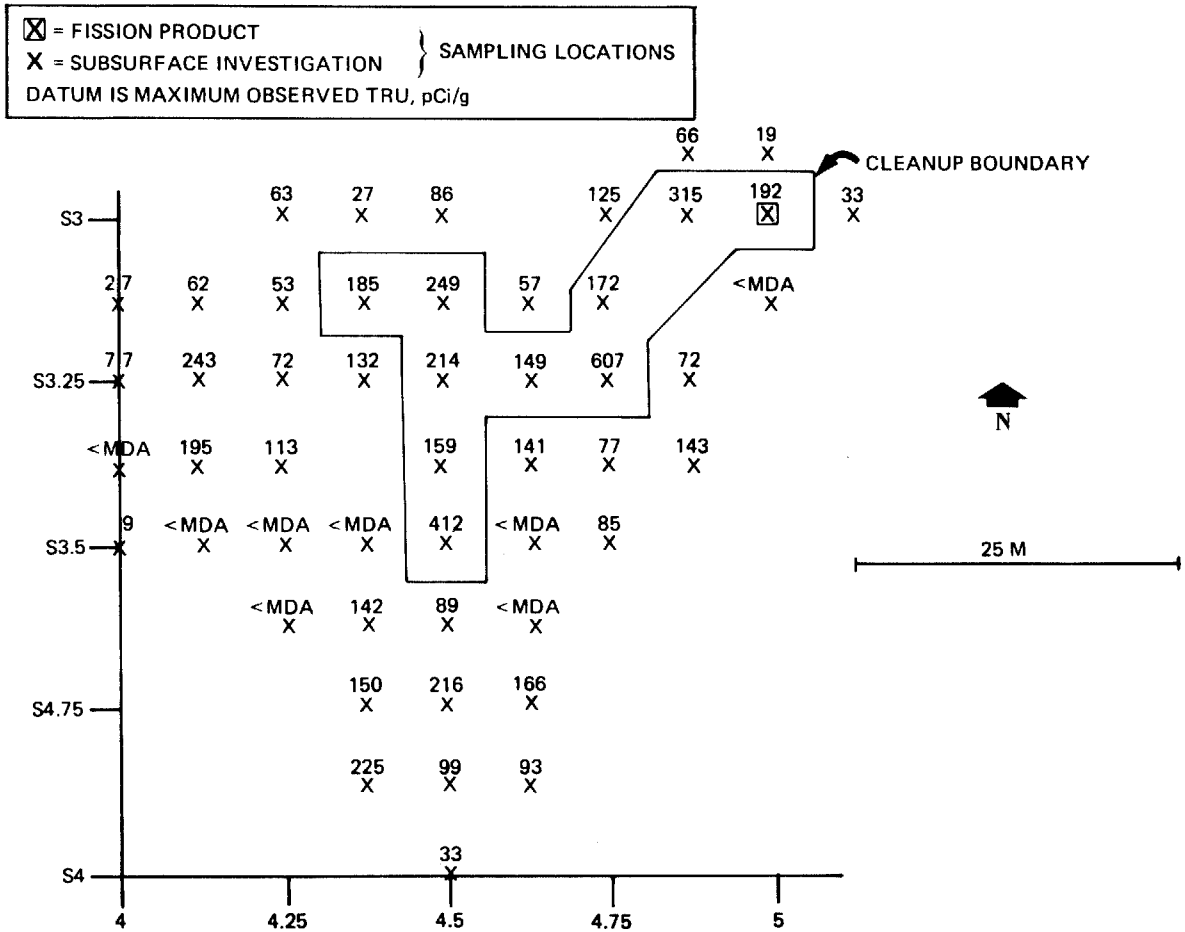

FIGURE 7-93. SUBSURFACE SAMPLING RESULTS, LOCATION 5S3, ISLAND PEARL

soil removal was necessary. The fourth area, 5-S-3, did show additional high TRU concentrations and soil removal was conducted. The boundary of the area with TRU activity above 160 pCi/g, is shown in Figure 7-93, although some soil outside this boundary was also removed.

Following the completion of subsurface soil removal, IMP measurements were taken and the results indicated no TRU concentrations greater than 80 pCi/g. The estimated amount of soil removed was 318 cubic meters (416 cubic yards) and the estimated curies of TRU activity removed (based on final data) was 0.07 for this subsurface soil removal.

The following table gives the arithmetic mean for selected depth intervals based on data from the fission product sampling program.

	0-5 cm	0-40 cm	0-60 cm	Total Samples
^{90}Sr, pCi/g	14.8	6.10	5.1	102
^{137}Cs, pCi/g	8.4	3.9	2.9	426

Tables 7-1, 7-2 and 7-3 give summary statistics for the 0-15 cm depths for the ^{137}Cs, ^{90}Sr and estimated $^{239,240}Pu$ results, respectively, and Figures 7-94 and 7-95 show isopleths for the 0-40 cm data over the entire island of Pearl for ^{137}Cs and ^{90}Sr, respectively.

Final Characterization

After the completion of the subsurface soil removal, the highest 0.5 hectare average TRU was 63.5 pCi/g based on final data. The previous highest 0.5 hectare estimate was at 5-S-3, but the subsurface soil removal reduced the surface average considerably. Table 7-5 gives the arithmetic means for the final IMP data for TRU, ^{137}Cs and ^{60}Co, and Figure 7-96 shows isopleths on the final TRU concentrations for Pearl.

The island average transuranics value reported in the Certification is 36 pCi/gm for surface soil, and the transuranics classification is Agricultural.

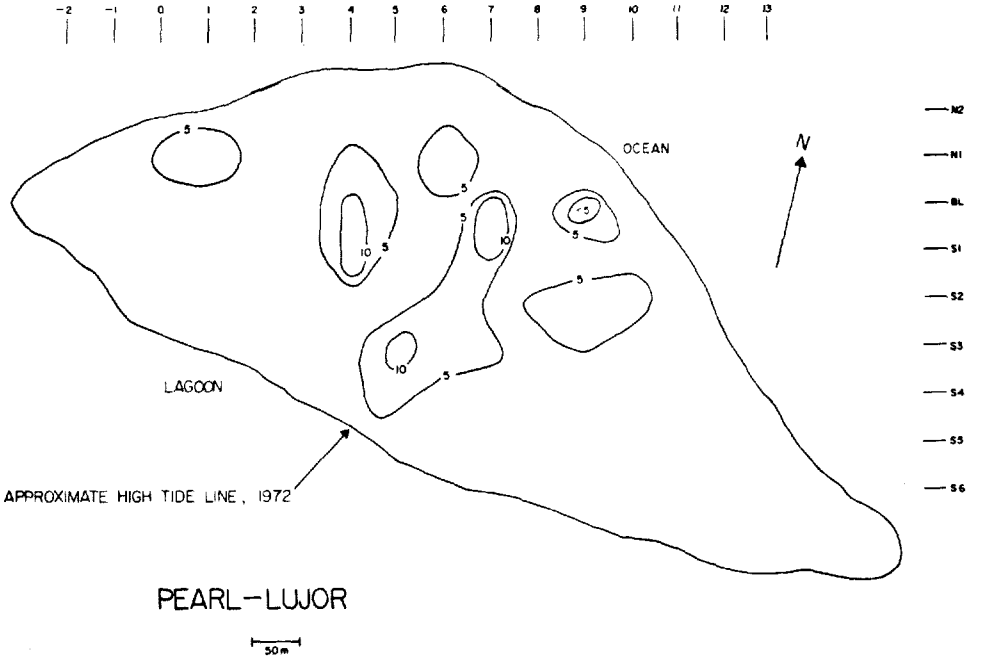

FIGURE 7-94. ISOPLETHS ON ^{137}Cs ACTIVITY IN pCi/g (AVERAGE IN TOP 40 CM) FOR ISLAND PEARL

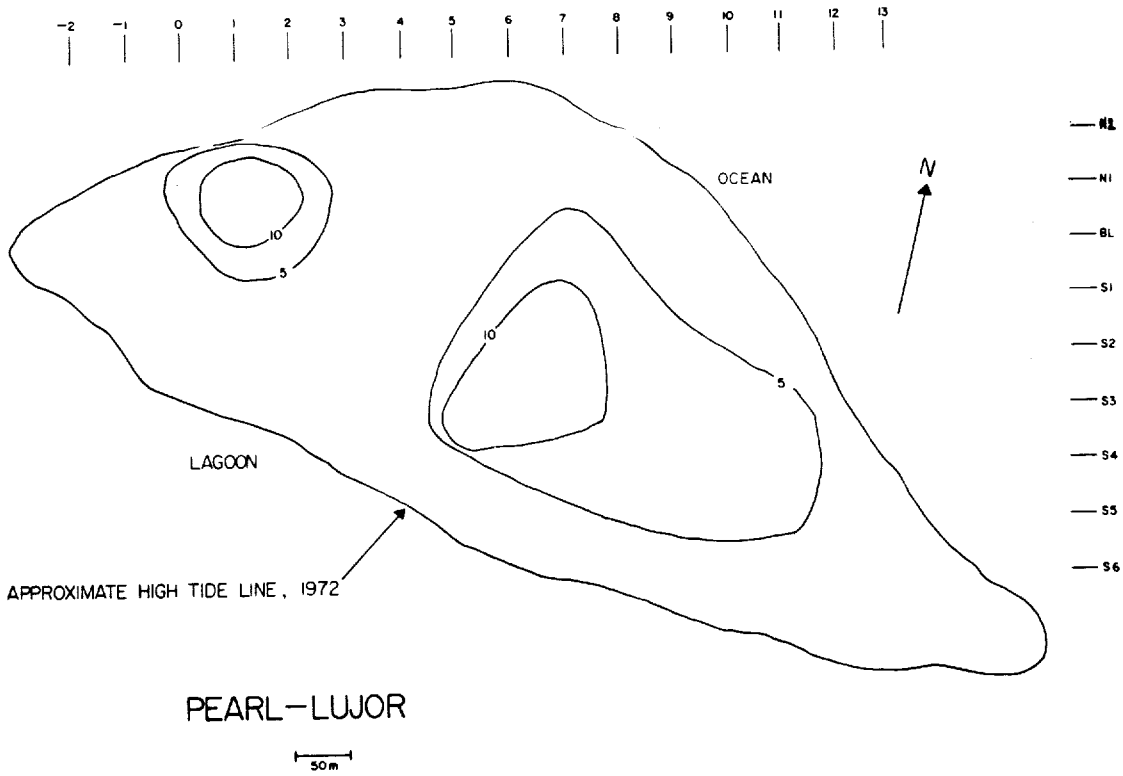

FIGURE 7-95. ISOPLETHS ON ^{90}Sr ACTIVITY IN pCi/g (AVERAGE IN TOP 40 CM) FOR ISLAND PEARL

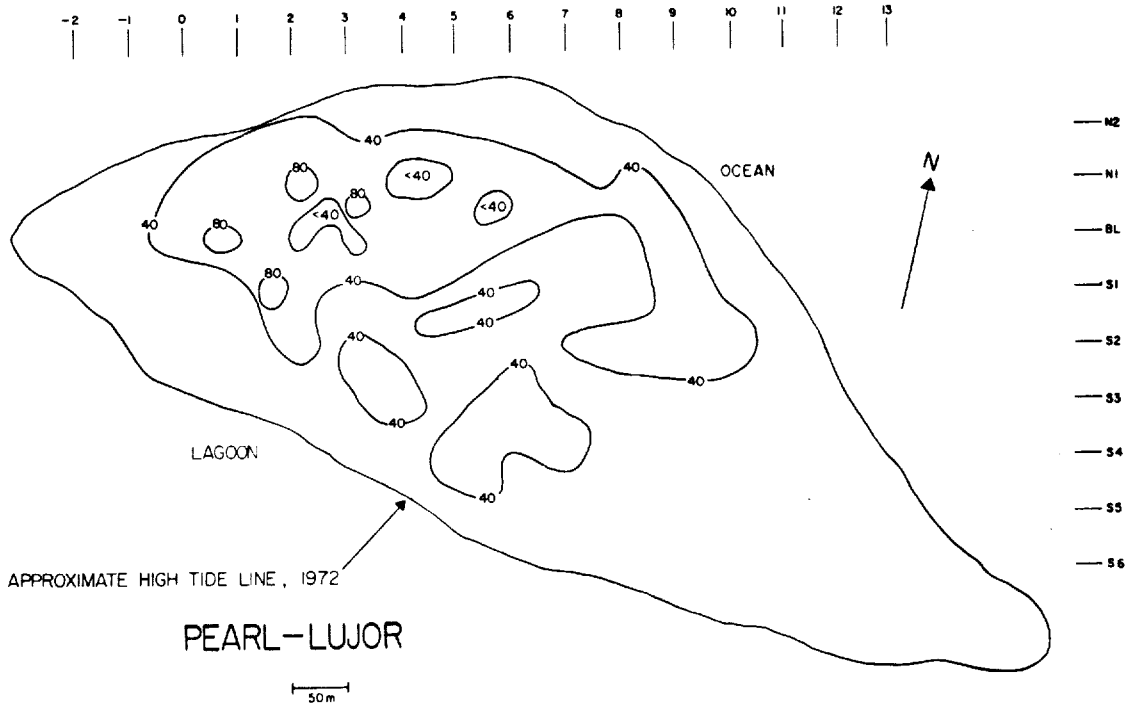

FIGURE 7-96. ISOPLETHS ON FINAL ESTIMATED SURFACE TRU ACTIVITY IN pCi/g FOR ISLAND PEARL

7.5.4 Sally

Background

Island Sally (Marshallese: Aomon) is the largest of the northeast islands in the Atoll with an area of 40 hectares (ha). It is the northernmost island in the Sally-Tilda-Ursula chain; these three islands are connected by causeways. The island is triangular in shape with sandy soil and heavy vegetation on the northern half of the island. The southern half of Sally is clear of vegetation and extremely sandy. On the western side of the island, a slender point of land juts out as a result of activities that took place after the testing program. Sally and the island Ruby were once connected by a land causeway but due to two nuclear events on Ruby, only two small parts of Ruby remained. One of these parts was still connected to Sally by the causeway and in 1972, a tidal pond beside the causeway was filled in during the Pacific Cratering Experiments (PACE). (See Section 1.5.2 for more information on PACE). This western tip, called Cape Mixan throughout the cleanup project, is considered part of Island Sally even though it was once part of Ruby. The second part is now a separate isle referred to as Ruby (see Section 7.4.9).

Sally was the site of three nuclear tests, all on towers. As Figure 7-97 indicates, one ground zero (GZ), Kickapoo, was located on the northern tip and the other two GZ's, Yoke and Yuma, were located on the lagoon side of the island. Because of these three tests, plus fallout from 13 other events, Sally ranks 13th in the Atoll in total H + 1 hour exposure rate with 1,981 R/h. One test bunker used for several operations remains on Sally and is located on the northwest ocean side of the island near the bend where Cape Mixan connects with the main body of the island. Other remnants from the testing years included several concrete slabs and blocks, a gamma shelter and a number of coaxial cable runs. The anchor blocks located around the GZ's were suspected to have some radioactive contamination underneath an added layer of uncontaminated concrete.

Both suspected and known plutonium burial sites existed on Sally prior to cleanup. The most obvious burial site, called the Aomon Crypt, was located on the manmade causeway connecting Sally and Tilda. The site was marked by a 6 inch square concrete post at each corner and a plaque stating that plutonium contaminated debris and soil were buried in that area. The characterization and cleanup of this burial site was a major part of the project and is discussed more fully in Section 6.8. Other suspected areas of subsurface contamination were the three event sites because burial of radioactive material was done routinely at or near the GZ's. The landfilled causeway between Sally and Ruby was also a suspect area because some of the fill was soil from the Yuma GZ.

1972 Survey

In 1972, soil samples were collected at 28 different sites on Sally along with some vegetation and animal samples. Except for two 0-15 cm core samples collected from the beach of the filled causeway between Sally and Ruby, all the soil samples were collected outside the PACE area. Out of the 28 samples, 20 were 0-15 cm core samples and 8 were profile samples down to a maximum depth of 200 cm.

Two of the soil sample profile results showed the $^{239,240}Pu$, ^{90}Sr, and ^{137}Cs activities to be increasing to a depth of 60-150 cm below the surface, while another profile showed almost homogeneous activities to a depth of 40 cm. These unusual distributions could be attributed to soil disturbance caused by a combination of post-shot activities around the event sites and the PACE operation. Other profiles showed the expected rapid decrease in activities with depth through the first 20 cm, with the rate of decrease leveling off below 20 cm. The highest concentrations for the radionuclides, $^{239,240}Pu$, ^{90}Sr, and ^{137}Cs, were found on the lagoon side of the western tip. Tables 7-1, 7-2, and 7-3 show the 0-15 cm island means and ranges for ^{137}Cs, ^{90}Sr and $^{239,240}Pu$, respectively, for the 1972 survey data.

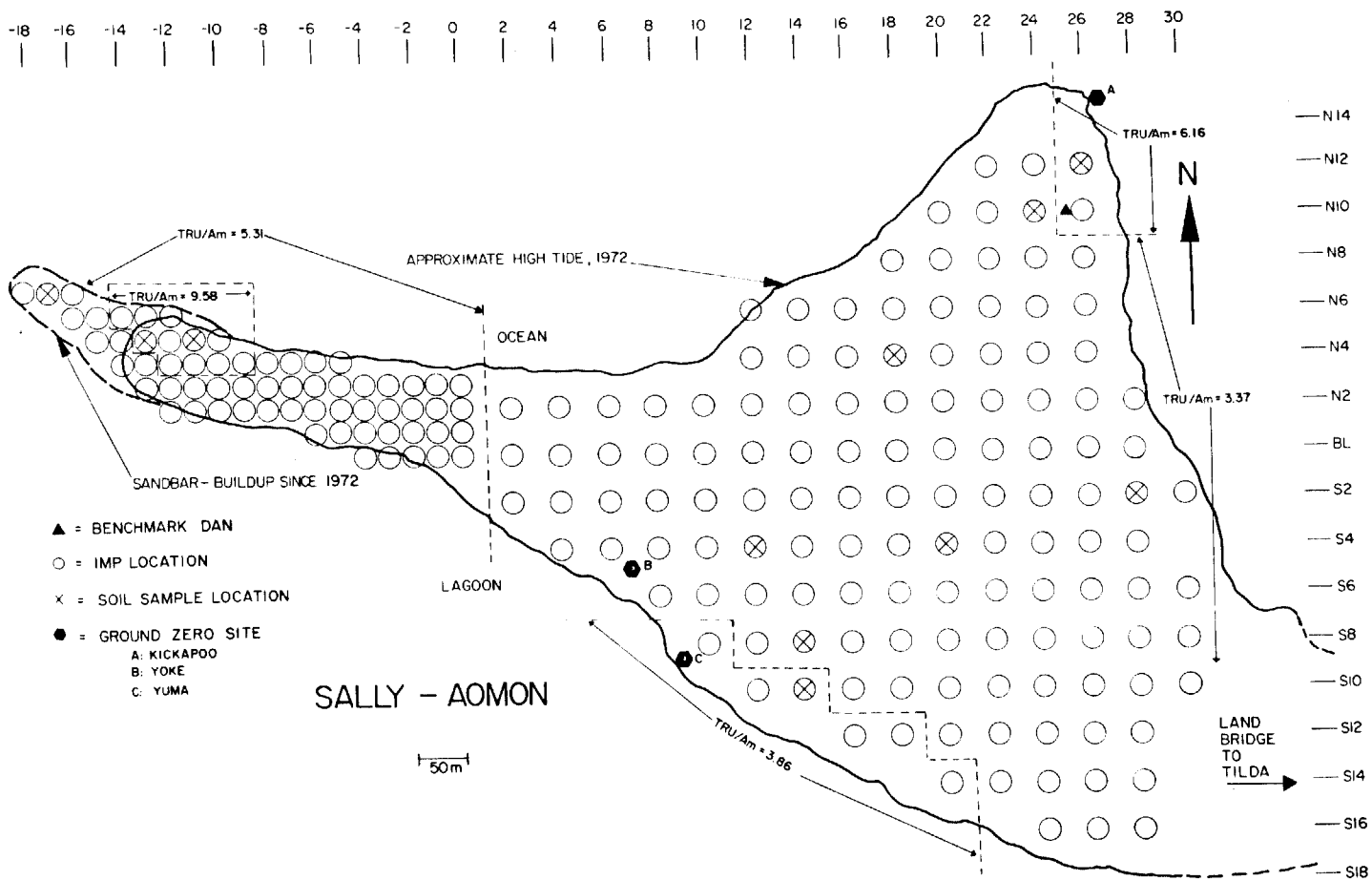

FIGURE 7-97. COASTLINE AND DATA COLLECTION LOCATIONS FOR ISLAND SALLY

Several sampling wells were drilled for groundwater studies in the 1972 survey in addition to the soil, plant and vegetation studies. Two pandanus trees were also a part of the long-term study of radionuclide uptake. Refer to Section 6.11 for more details on these studies.

Characterization - Surface

Sally was initially staked on a 50 m grid in the fall of 1977 except for Cape Mixan which was surveyed in the spring of 1978 on a 25 m grid. The 25 m grid was an extension of the 50 m grid but was staked later because of the confusion whether to consider that area Sally or Ruby. (The decision was made to call it a part of Sally.) The grid was tied in the Oscar coordinate system with the benchmark Dan, located in the northern part of the island (Figure 7-97). The benchmark Sally was also found after the surveyors began staking Sally. The grid on this island was erroneously laid 4 degrees west of true north.

The initial TRU characterization of Sally did not inlude Cape Mixan, which will be discussed later in this section. The main part of Sally was measured by the IMP from November 1977 through January 1978, and nine surface soil samples were collected in December 1977 for the same area. The IMP locations and soil sample locations are shown in Figure 7-97.

In order to calculate TRU values for Sally, the laboratory results from the soil samples were used to determine a TRU to ^{241}Am ratio. At each of the nine locations, soil samples were collected at 3 depths with 2 composites for a total of 54 samples (see Section 4.2.1). Because three of the ^{241}Am concentrations were below minimum detectable activity, they were not used in the calculation of the ratio. It was clear from the range of values for the ratio that more than one population of ratios existed on Sally. Three ratios were finally calculated and used for the first TRU characterization of Sally with 3.86 $\pm$ 2.72 for Yuma GZ, 6.16 $\pm$ 1.73 for Kickapoo GZ and 3.37 $\pm$ 1.08 for the rest of the island except Cape Mixan. (For more information on the computation of these ratios and data used, see Tech Note 2.5). The boundaries between the three ratio populations are shown in Figure 7-97.

After the initial 50 m grid was measured with the IMP, the appropriate ratio was applied and TRU values calculated. Using these TRU data and the kriging statistical technique (Section 5.1.1), 0.25 ha estimates were calculated based on original data. (See Tech Note 23 for discussion of original versus final data.)

The variogram model estimated from the data was linear in mathematical form. An apparent anisotropy seen in the east and southeast directions was mainly caused by insufficient data outside the PACE area in those directions. The PACE area was very low in ^{241}Am activity and homogeneous, therefore showing little change over distance in those directions. In the other directions, the wide range of TRU activity in the Kickapoo, Yuma and PACE area produced great change over distance in the raw variogram. On the average, however, the linear model was a good estimate of the variogram.

Figure 7-98 shows the initial TRU characterization of the main part of Sally and indicates the areas with TRU activity exceeding 40 pCi/g with a 0.5 s upper bound, where s is the standard deviation of the kriging error. These areas were "cleaned up" during the project. Because these areas were frequently referred to, each area had a code name: the area on the north tip was called Kickapoo, the area along the beach on the lagoon side was Yuma, and the area near the northwestern beach was known as Hustead.

The area known as Cape Mixan was surveyed on a 25 m grid and IMP measurements taken in March 1978. Initially, only three locations were soil sampled with two composites at three different depths for each site for a total of 18 samples. The results from these soil samples indicated that two distinct ratios were present as shown in Figure 7-97. The data from one location showed a ratio similar to the Yuma area while the other two locations indicated a new ratio entirely. It appeared that the new ratio was applicable to the region with higher ^{241}Am concentrations whereas the Yuma ratio seemed appropriate for the lower activity areas. Six more locations in the higher activity area were sampled in May 1978 with only one sample collected from each site. A ratio of

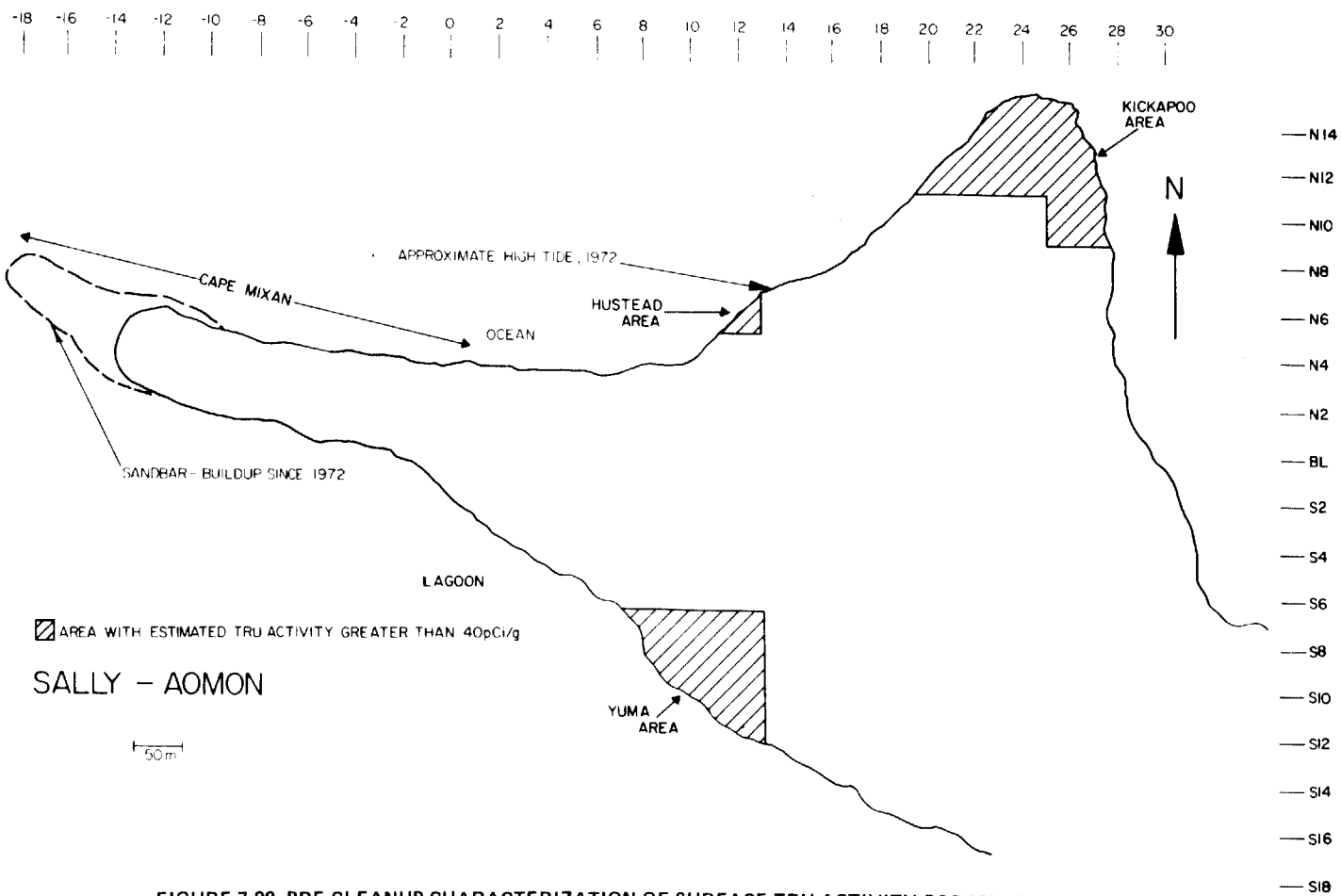

FIGURE 7-98. PRE-CLEANUP CHARACTERIZATION OF SURFACE TRU ACTIVITY FOR ISLAND SALLY BASED ON KRIGING ESTIMATES OF 0.25 HA AVERAGES

9.6 ± 0.22 was computed for this area. (Refer to Tech Note 2.21 for more information on this ratio). The other ratio used for Cape Mixan, 5.3 ± 0.2, was the ratio used for Yuma cleanup. (The cleanup ratio was different than the ratio used for characterization because more data were available for the later effort.)

Using these ratios and the IMP data, TRU values were calculated. To get a 0.25 hectare estimate, the average of four IMP readings forming a square was calculated since the IMP field-of-view includes most of the surface. Using original data no 0.25 hectare average was estimated with TRU activity greater than 40 pCi/g but based on final data, one 0.25 hectare was estimated to have a TRU activity of 41 pCi/g. The final isopleths for the final TRU values for Cape Mixan are shown on Figure 7-107 on the map of Sally.

Characterization - Subsurface

Subsurface investigation, as described in Section 6.9, was conducted in five different parts of the island - Kickapoo, Yuma, Hustead, Yoke and Cape Mixan. The results will be discussed more fully later in this section. Figures 7-99 through 7-102 show the sampling locations for these five regions and also give the highest TRU value in each profile.

Cleanup Activities

The pilot soil removal for the cleanup project was done in the Kickapoo area (Section 6.6). The initial results from the characterization analysis showed three 0.25 hectare to have greater than 40 pCi/g average TRU activity. To better define the surface boundary exceeding 40 pCi/g, a 12.5 m grid was surveyed and additional IMP measuremets were taken in February 1978 for the area in Kickapoo that had TRU activity estimated to be greater than 40 pCi/g. Isopleths of TRU activity exceeding the 40 pCi/g level are shown in Figure 7-103 for both 12.5 m and 25 m grids, along with the boundary resulting from the kriged estimates done on the 50 m grid data. Because the isopleths shown for the 25 m grid and the 12.5 m grid were not significantly different, the isopleth for the 25 m grid was used to outline the area where soil removal was necessary.

In addition to more IMP measurements, more surface soil samples were collected prior to any earth moving activities. This was done to verify that the ratio first calculated for Kickapoo was appropriate since the original number was based on one soil sample location. The additional results did justify using the 6.16 TRU to ^{241}Am ratio, and therefore the fine grid TRU values were calculated using this ratio.

The subsurface data collected earlier indicated that more than one "6-inch" lift would be necessary in certain spots. Figure 7-103 also shows the outlines of subsurface contamination.

Before any soil lifts were made, the vegetation in the cleanup area was removed in mid-March 1978. Surface soil samples were again collected and the TRU to ^{241}Am ratio verified. After this vegetation removal activity, different methods for soil removal were tried to compare their effectiveness. As a result of this experimentation, the soil was greatly disturbed. The area was then measured by the IMP to determine how this disturbance affected the surface TRU activity. The mean TRU concentrations before any soil disturbance was 146 pCi/g and after soil disturbance was 154 pCi/g; both calculations are based on data from the same sixteen locations. These results reflect no significant change in surface TRU activity due to soil disturbance.

After the first actual soil lift was complete, IMP measurements on a 25 m grid were taken and more surface and subsurface soil samples were collected during the first part of April 1978. The surface soil samples again verified the initial ratio and the subsurface soil results corroborated earlier results and also indicated another pocket of high activity along the northwest beach line. The IMP data showed that the majority of the area with TRU activity estimated above 40 pCi/g initially was still above 40 pCi/g.

After the next soil lift, very little soil was left at Kickapoo so that the surface was mainly beach rock. Only IMP data were collected in June 1978, following this lift, and these results showed two areas still with high TRU activity, the same two areas that had shown high subsurface activity. One

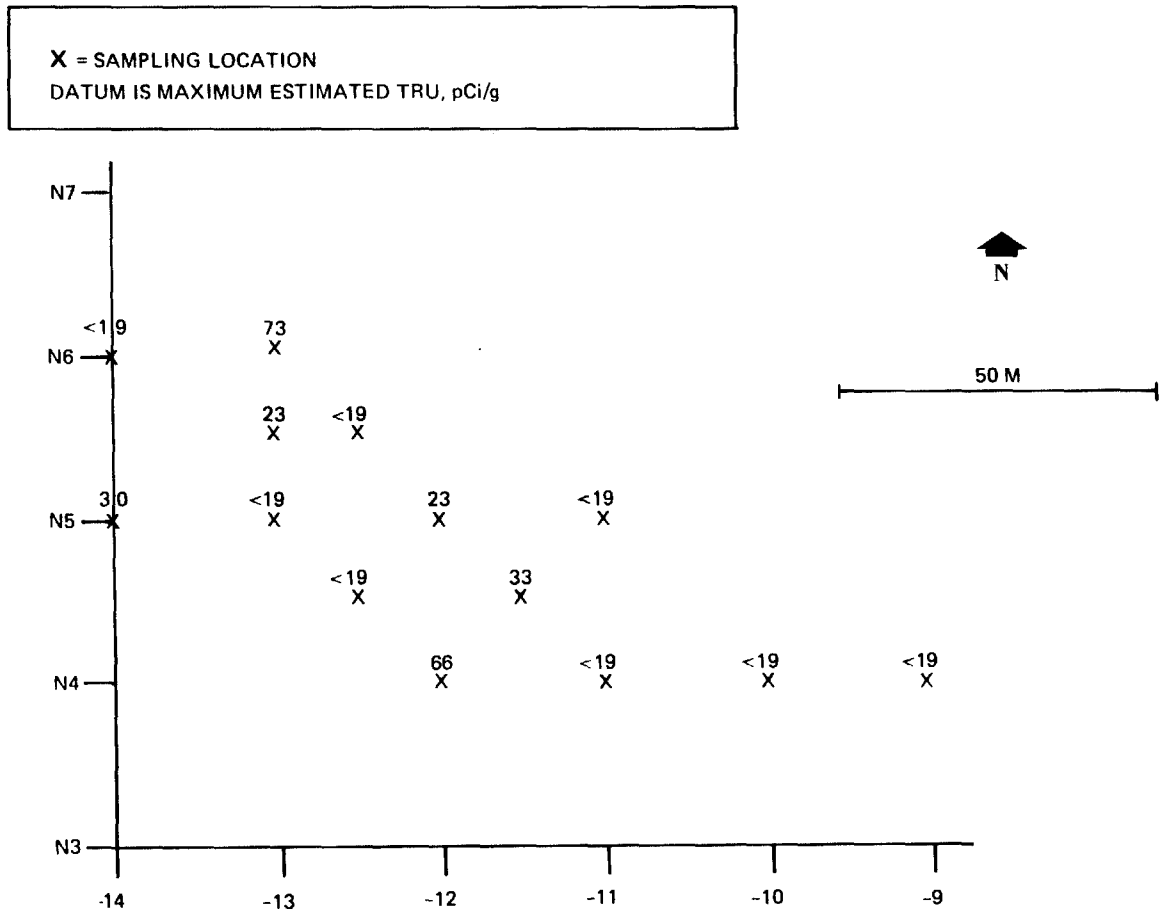

FIGURE 7-99. SUBSURFACE SAMPLING RESULTS, CAPE MIXAN AREA, ISLAND SALLY

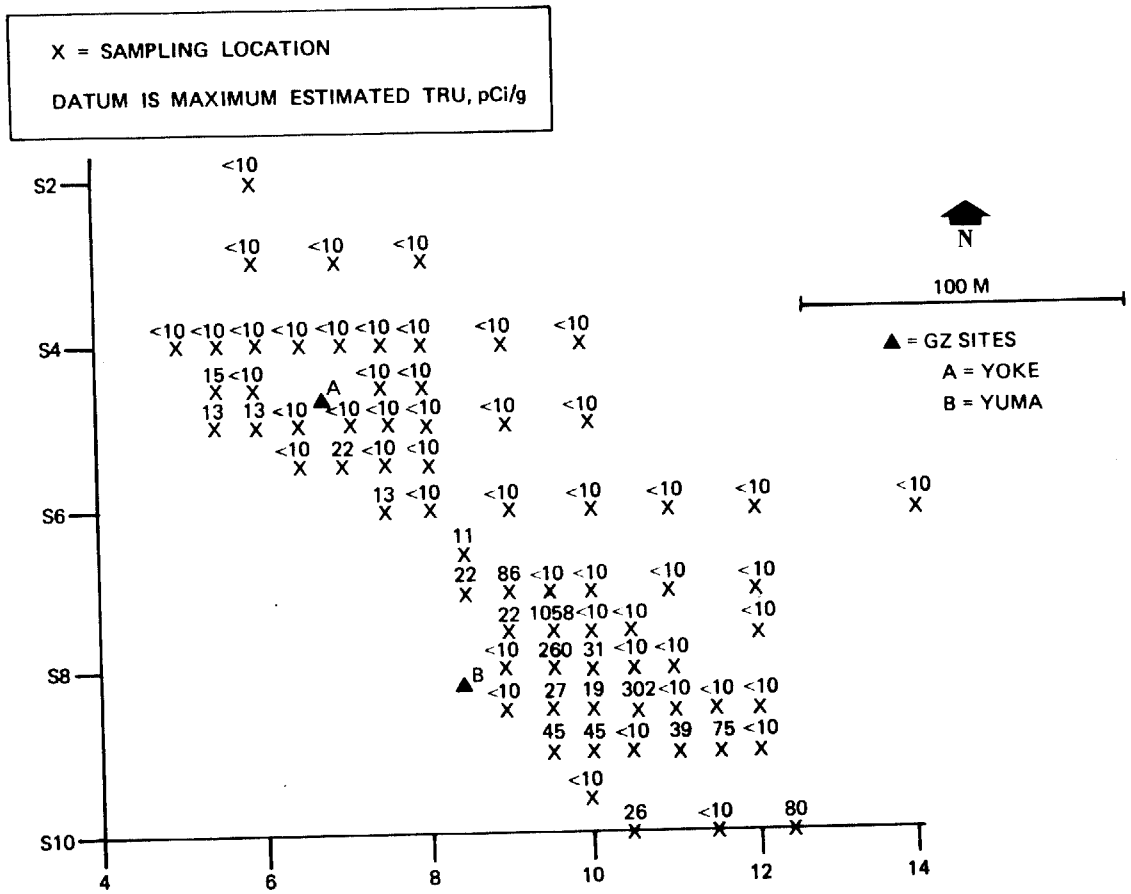

FIGURE 7-100. SUBSURFACE SAMPLING RESULTS, YOKE GZ AND YUMA GZ, ISLAND SALLY

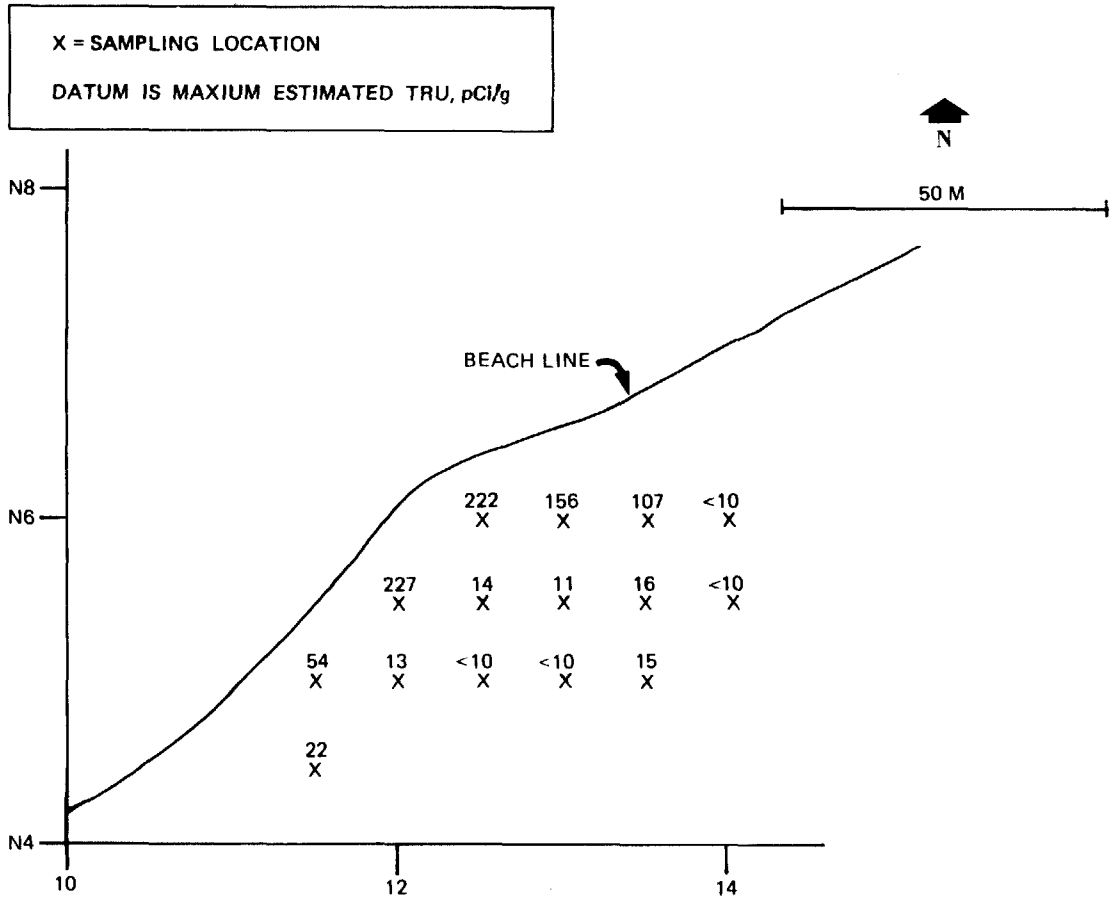

FIGURE 7-101. SUBSURFACE SAMPLING RESULTS, HUSTEAD AREA, ISLAND SALLY

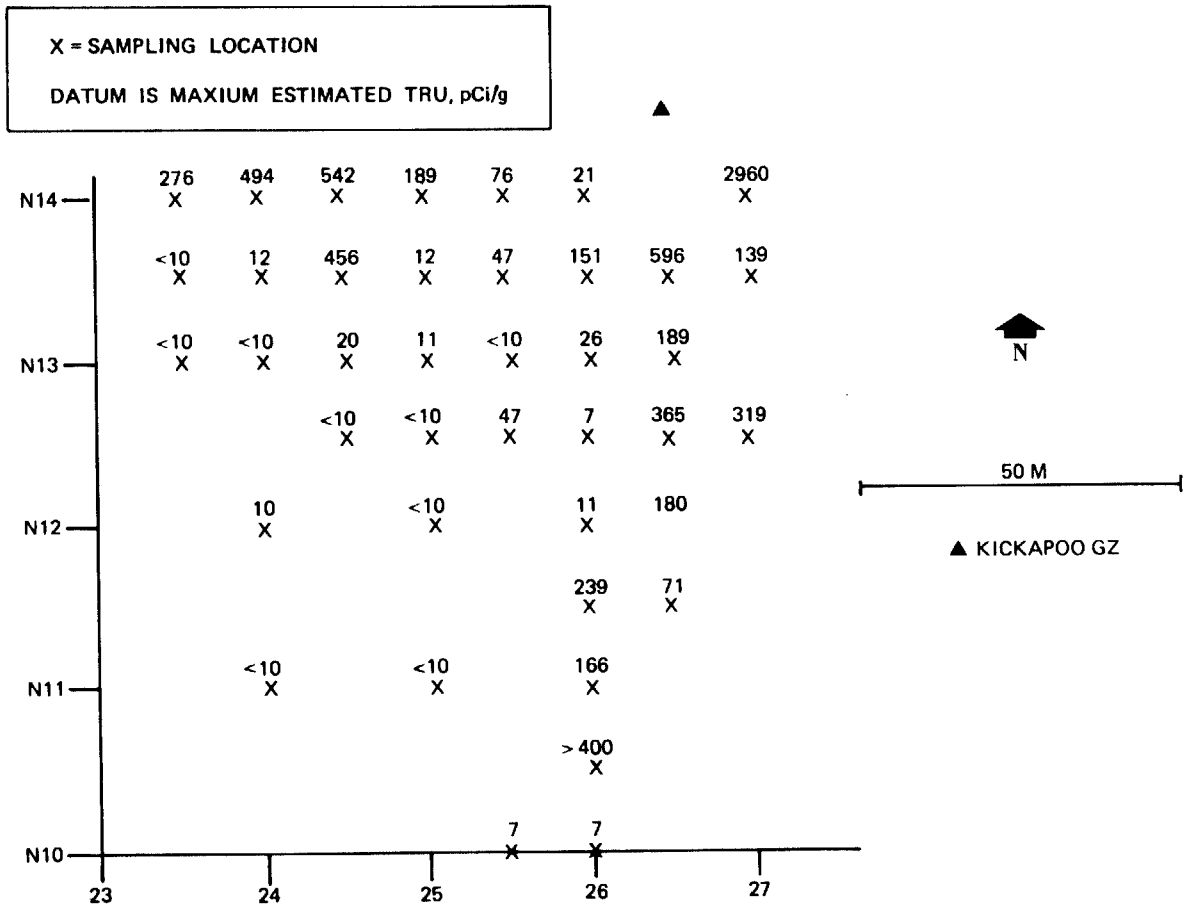

FIGURE 7-102. SUBSURFACE SAMPLING RESULTS, KICKAPOO GZ, ISLAND SALLY

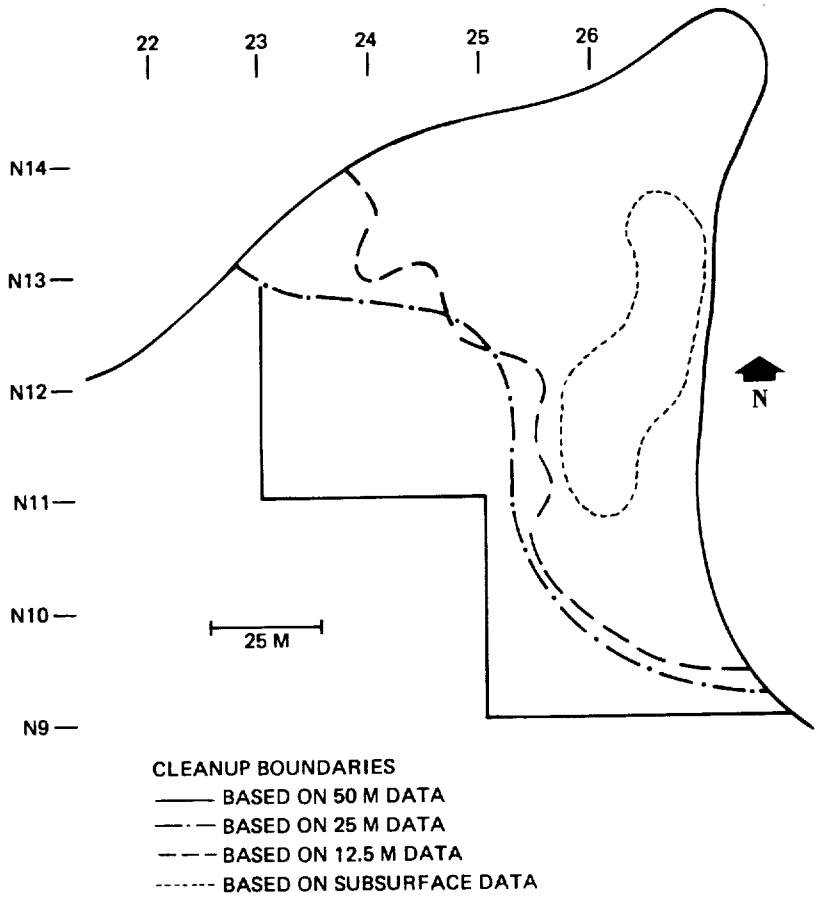

FIGURE 7-103. CLEANUP BOUNDARIES FOR KICKAPOO

area was a strip approximately 1.5 m wide and 65 m long parallel to the east beach line while the other was approximately a 15 x 8-m rectangle located on the northwest beach line of Kickapoo. These boundaries were determined using portable instruments. A beach rock sample was collected and analyzed which verified that the ratio had not changed.

Some data in these areas still indicate high TRU concentrations even after a diligent effort was made to remove the TRU activity, including hand sweeping and washing with high pressure water. After an attempt to scrape the activity from a piece of coral from one of these areas failed, it was determined the contamination left was fixed and the surface soil criteria no longer applied. In addition to this "Kickapoo hot strip" problem, small pieces of contaminated metal fragments still remain along the beach and are continually washed ashore. Periodic efforts were made to pick up these pieces of metal but more are likely to continue to wash ashore.

The total TRU activity removed from the Kickapoo area was estimated to be 0.85 curies based on final data with 4207 cubic meters (5503 cubic yards) of soil removed. The method for calculating activity removed is shown in Tech Note 10.0.

The second area where soil removal occurred was Yuma. IMP measurements were taken on a fine grid of 25 m, along with some at 12.5-m, in March 1978. Additional surface soil samples were collected to check the ratio of 3.37 which was not verified. After analysis of the data, the new ratio computed was 5.31 $\pm$ 0.20 with this ratio being consistent throughout the cleanup of Yuma. Like the cleanup of Kickapoo, a debris/brush removal occurred before any soil lifts were taken and the area was measured by the IMP on a 12.5 m grid with the detector at half-mast.

Two distinct lifts were made following this debris/brush removal, apparently based on the boundaries first drawn on the 50 m grid data, with the second lift overlapping the first in some places. These lifts did not encompass the whole area that was initially estimated to be over 40 pCi/g. IMP measurements were taken after each of these two lifts in April and May 1978 along with subsurface soil samples collected in these areas.

Cleanup boundaries had been based on 40 pCi/g average TRU activity up to this point but it was decided to clean up only the areas with TRU activity greater than 80 pCi/g. Using this criterion, new boundaries were drawn on the IMP data and subsurface data were collected after the first two lifts to indicate surface and subsurface TRU contamination greater than 80 pCi/g.

After the third lift was complete, the area was measured by the IMP in June 1978 with the data showing a fourth lift was necessary to get below 80 pCi/g. After the completion of this lift, IMP measurements were taken in July 1978. These results indicated all 0.25 hectare average TRU to be less than 80 pCi/g, though not less than 40 pCi/g. To achieve the 40 pCi/g level, only one small area would have to be removed. Following the excavation of this area, more data were taken around the area which still showed TRU concentrations greater than 40 pCi/g, thus another lift was done. IMP measurements collected following this lift showed no 0.25 hectare average TRU activity greater than 40 pCi/g.

The final estimate of TRU activity removed from the Yuma site is 0.28 curies and the estimated cubic meters removed is 2523 (3330 cubic yards). This area is not in the same radiological condition as it was immediately following the soil removal. A PACE restoration effort that was undertaken later in the project changed the appearance and the radiological condition of this area.

The third area on Sally requiring soil removal was Hustead. Some fine grid IMP measurements were taken in February 1978 with additional IMP data collected in May 1978. No soil samples had been collected in this area for characterization but in March and May of 1978, surface and subsurface soil samples were collected. A ratio of 5.16 $\pm$ 0.22 was computed for this area and boundaries were drawn showing the surface and subsurface areas with TRU activity greater than 80 pCi/g.

Following the first lift, the area was measured by the IMP and the results indicated another lift was necessary to get the TRU activity below 80 pCi/g. After the completion of this second lift, the area was measured by the IMP with the original results indicating no 0.25 hectare average TRU greater than 40 pCi/g. Based on the final data though, the highest 0.25 hectare average TRU was

estimated to be 41 pCi/g. An estimated 1375 cubic meters (1800 cubic yards) of soil containing an estimated 0.16 curies of TRU activity were removed from the Hustead area based on final data.

Other Activities

In February 1978 detector SN:496 was installed on one of the IMPs. This detector was mistakenly operated at a bias voltage of -2000 v rather than -3000 v from 3 February to 25 February 1978. To correct the IMP data already collected, remeasurements were taken at nine different locations in the Kickapoo area with the correct bias voltage. Data had already been taken at these locations with the lower voltage. A comparison was made of these results and a correction factor of 1.16 $\pm$ 0.25 was determined. (See Tech Note 5 series for more information on this experiment and others connected with detector SN:496.)

In order to determine total TRU activity removed in the Kickapoo and Yuma areas, a method using truck samples was attempted. Soil samples were taken from each truck loading from the cleanup area and analyzed by gamma spectroscopy to determine the ^{241}Am. After reviewing this method and comparing it to the method which used the IMP results, it appeared that the truck sampling was not a feasible technique for determining curies of TRU removed. (See Tech Note 10.0.)

Because the PACE area on Sally was swampy and in poor shape for agriculture, a restoration project was conducted. In order to ascertain that no high TRU concentrations would be exposed during this operation, subsurface soil samples from potential borrow areas were taken in June and August 1978. Figure 7-104 indicates locations sampled and also the areas the fill came from. The results from these samples showed no elevated TRU concentrations in the subsurface but two surface results showed high activity. These areas were then measured by the IMP and showed TRU concentrations of 30-35 pCi/g.

Fission Product Sampling

In support of the dose assessment (see Section 6.11), a fission products sampling program was conducted on Sally during March 1979 on the 50 m grid already established. Out of the 139 locations sampled, ^{90}Sr analysis was done on 39. The following table gives the arithmetic mean for ^{90}Sr and ^{137}Cs for certain profile ranges.

	0-5 cm	0-40 cm	0-60 cm	Total Samples
^{90}Sr, pCi/g	5.6	3.0	2.9	232
^{137}Cs, pCi/g	4.2	2.5	2.2	809

Tables 7-1, 7-2, and 7-3 give some summary statistics for the 0-15 cm depths for the ^{137}Cs, ^{90}Sr and estimated ^{239,240}Pu results respectively, and Figures 7-105 and 7-106 show isopleths for 0-40 cm profile mean data over the entire island for ^{137}Cs and ^{90}Sr, respectively.

Another major project associated with Sally was the Aomon Crypt mentioned previously. (For complete details, see Section 6.8.) Because this crypt was along the causeway, most of the soil and debris was stockpiled on Sally. After the stockpile was hauled away, the area was measured by the IMP to verify that no elevated TRU activity remained.

Final Characterization

Following recontouring of the PACE area, surface soil samples and IMP measurements were taken in the areas affected. The soil sample results yielded a TRU to ^{241}Am ratio of 3.2 with all IMP ^{241}Am values less than 2.5 pCi/g; therefore, all TRU activity was less than 8.0 pCi/g. Figure 7-107 shows the isopleths for the final Sally data and Table 7-5 shows the mean of the IMP results for the calculated TRU, ^{137}Cs and ^{60}Co for this island.

The island average transuranics value reported in the Certification is 7.5 pCi/gm for surface soil, and the transuranics classification is Residence.

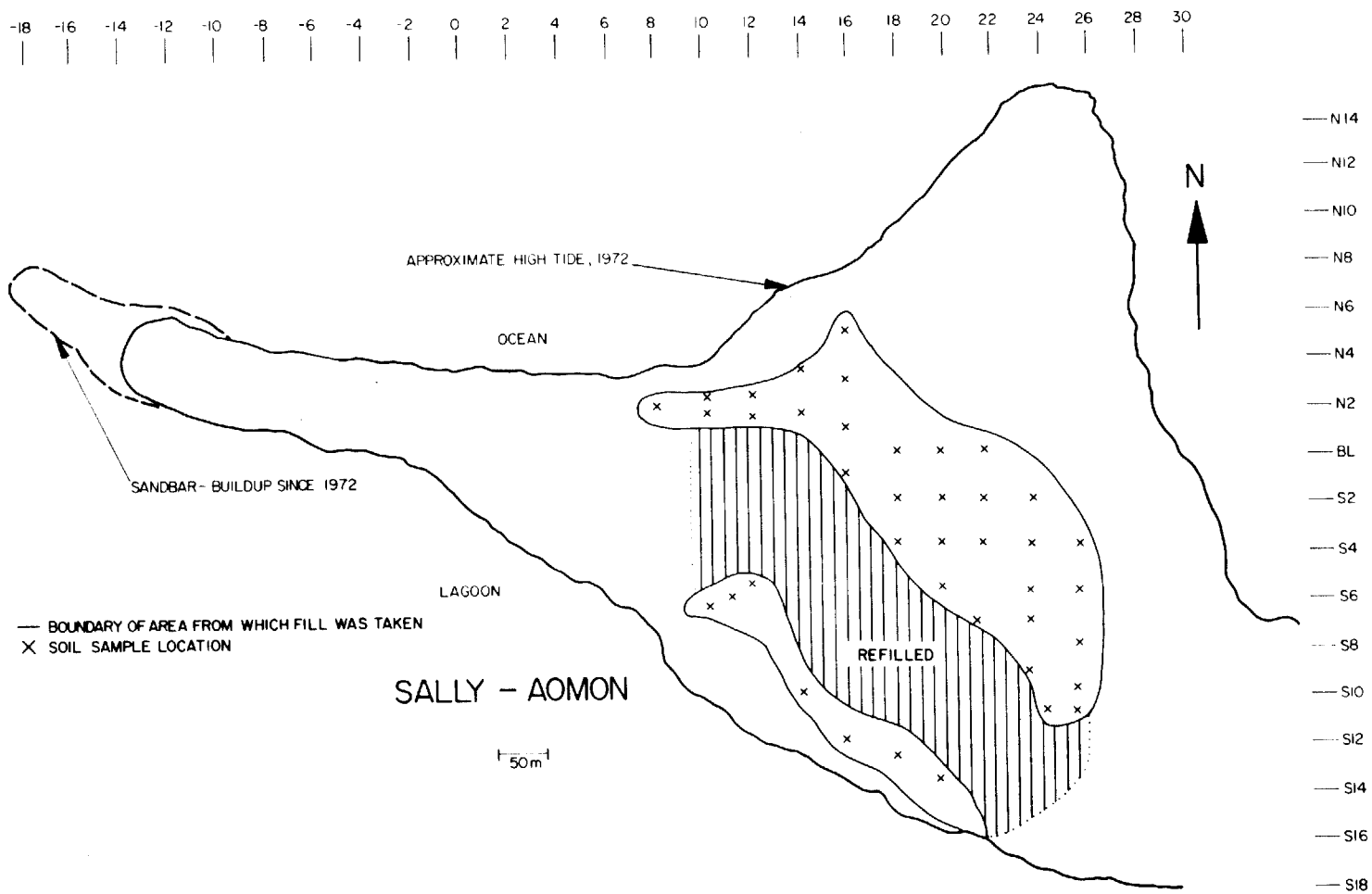

FIGURE 7-104. SAMPLING ON ISLAND SALLY FOR PACE RECONTOURING

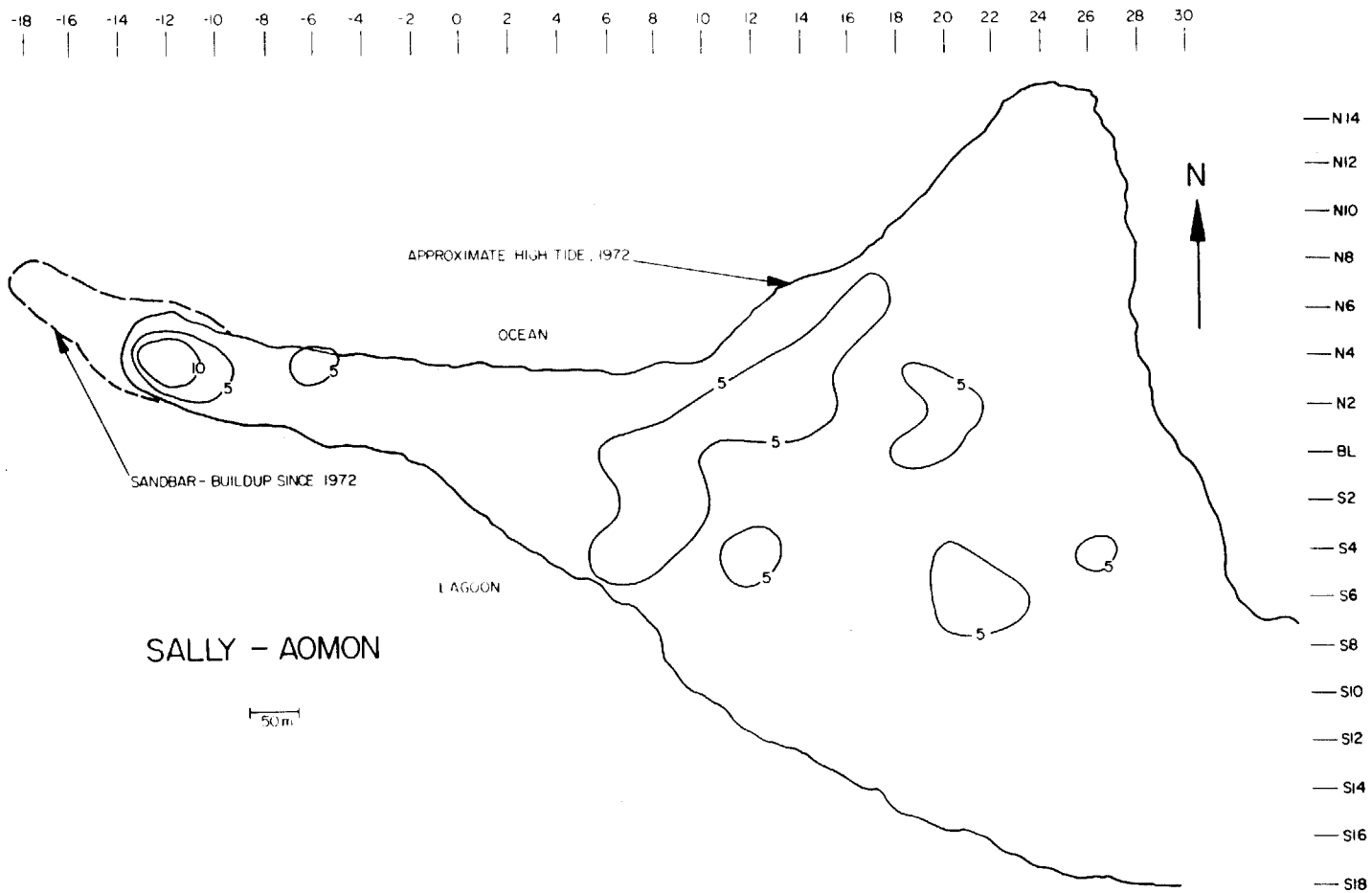

FIGURE 7-105. ISOPLETHS ON ^{137}Cs ACTIVITY IN pCi/g (AVERAGE IN TOP 40 CM) FOR ISLAND SALLY

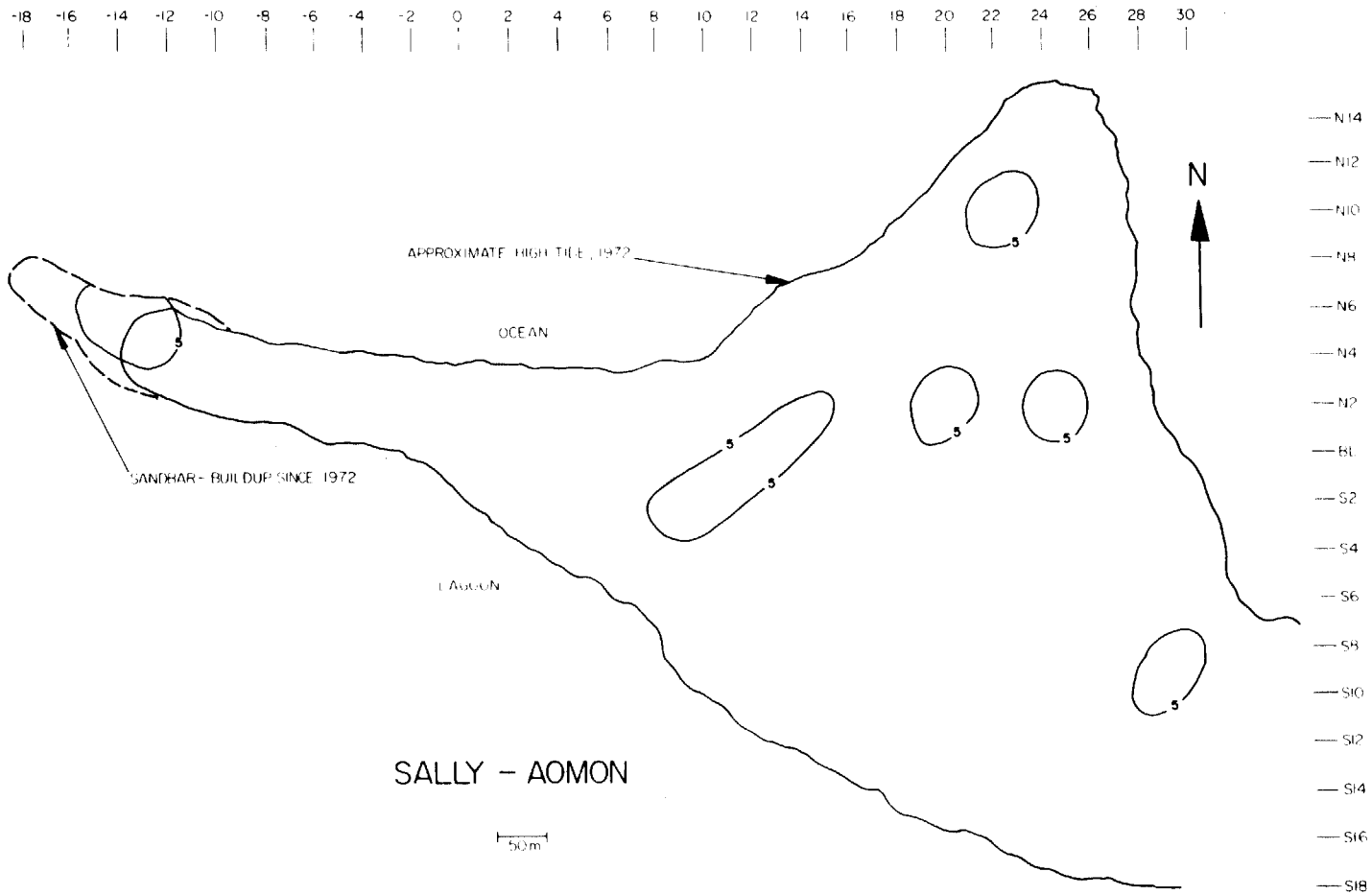

FIGURE 7-106. ISOPLETHS ON ^{90}Sr ACITIVTY IN pCi/g (AVERAGE IN TOP 40 CM) FOR ISLAND SALLY

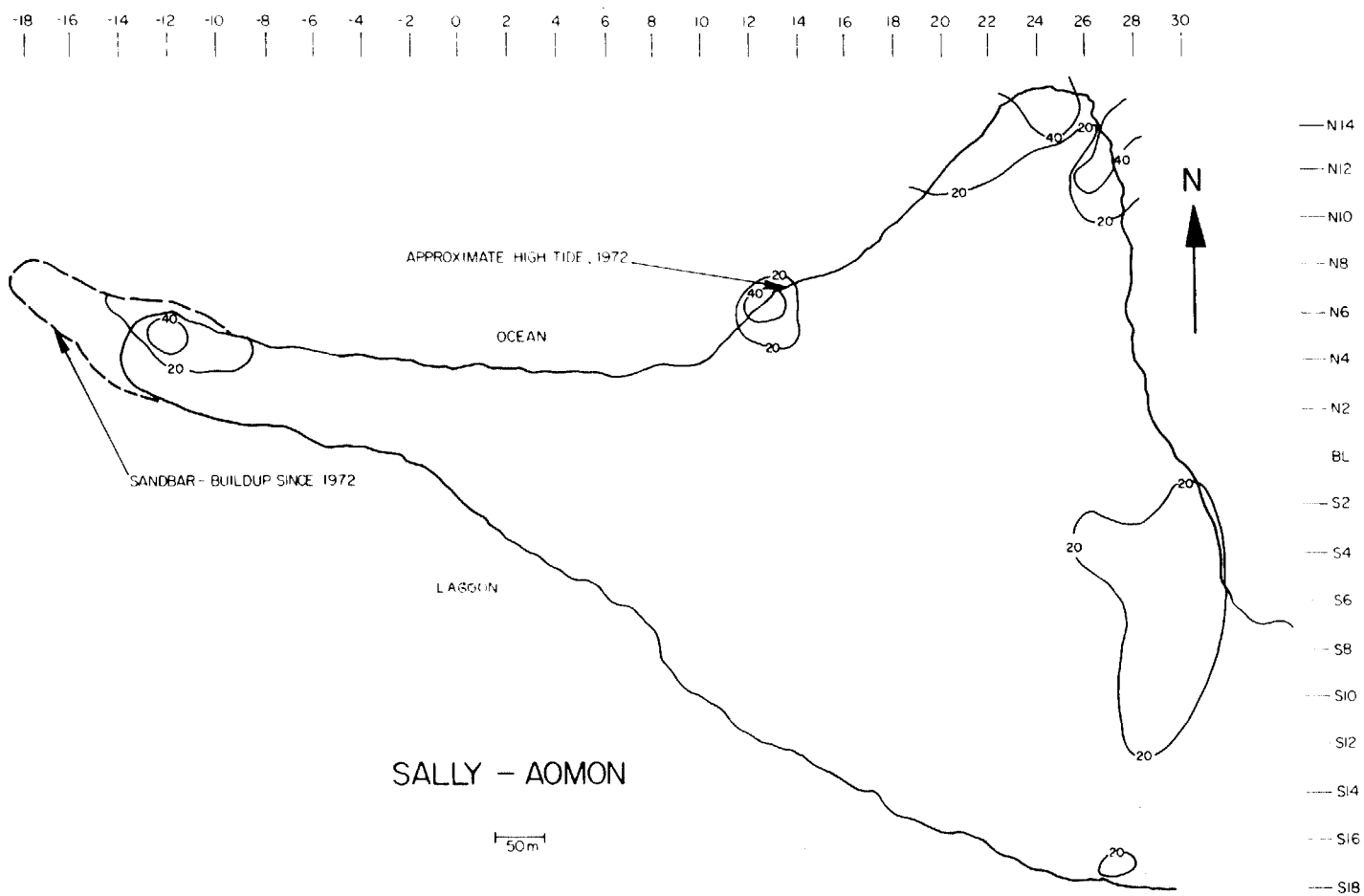

FIGURE 7-107. ISOPLETHS ON FINAL ESTIMATED SURFACE TRU ACTIVITY IN pCi/g FOR ISLAND SALLY

7.5.5 Yvonne

Background

Island Yvonne (Marshallese: Runit), the most northerly of the southern island grouping, is one of the largest islands in the Atoll, having an area of 37.0 hectares (ha). Yvonne is a long, slender island with mostly firm soil, and was once moderately to heavily vegetated. However, nuclear testing activities denuded it and regrowth has been limited by subsequent activities.

The northern and southern parts of the island have quite different histories of contamination from nuclear tests. Because of this, and the size and shape of Yvonne, the island has been divided into two sections at Hardtack Station 1310, a large bunker near the center of the island (see Figures 7-108 and 7-109).

Yvonne was the site for more nuclear events and other test-related activities than any other island in the Atoll, and has therefore suffered the most extensive damage. There were eight surface ground zeros (GZ's) on Yvonne, all but one being on northern Yvonne. Yvonne was also the target for one airdropped bomb, and was affected by another airdrop bomb and by eight barge shots in the lagoon near the island. Yvonne was also subjected to extensive soil movement, excavation and construction related to the numerous buildings and scientific stations on the island. Several areas were also known or suspected to contain buried radioactive materials, and there was a large amount of contaminated scrap on the island and adjacent reef.

The GZ's for both of the first two nuclear events on Yvonne, Zebra and Dog, were at the north end of the island, east of the location that was to become the Cactus event crater. Throwout from the Cactus event later covered the contamination from these two events and also covered possible sites of contaminated debris burials for these events. Lacrosse, the next event, was on the reef at the north end of Yvonne on an artificial island. The artificial island was destroyed by the event, leaving a waterfilled crater. There were large arrays of instrumentation associated with the Lacrosse event, and these left behind a large quantity of contaminated and activated rubble on the reef.

The fourth event, Erie, was a tower shot on southern Yvonne. This event left heavy contamination on the island, although much of it had decayed or eroded away by the time of cleanup. Also, there were a number of scientific test packages for Erie that were mounted in such a way that the event would cause them to impact on the island. In order to recover these packages, the impact area was extensively plowed, and thousands of cubic meters of soil were removed and sifted. The soil was eventually replaced in the impact area and regraded, and this resulted in a relatively constant distribution of radioactivity with depth to about 15 cm below the surface in the Erie area. Some contaminated debris might also have been buried near the GZ during these postshot operations.

After the Erie event, the soil in the central part of Yvonne was turned under with bulldozers to reduce the radiation exposure of personnel preparing for the next event, Blackfoot. Blackfoot was a tower shot near the center of Yvonne which heavily contaminated the area near the GZ. A few days later, the Osage device was airdropped over central Yvonne, but did not add significant contamination to the island.

Cactus, the sixth event on Yvonne, took place at the north end of the island. The event created a crater and produced large quantities of contaminated ejecta. The highest gamma exposure rates in Atoll soil were found in the Cactus crater lip material. The Cactus event crater was selected as the repository for contaminated soil and debris in the 1977-80 radiological cleanup of the Atoll.

The primary source of the present plutonium contamination on Yvonne was the final two events, Quince and Fig, especially the former. The Quince event had no nuclear yield, so the high explosives in the device simply scattered the plutonium fuel over the area near the GZ. Because Fig was scheduled for the same GZ, decontamination procedures were implemented immediately. These procedures included removing some soil and contaminated debris, and scraping soil to the side and covering it with uncontaminated soil. There were some inconsistencies in the reports about where the soil was pushed when it was scraped aside. Official reports state that the material was pushed

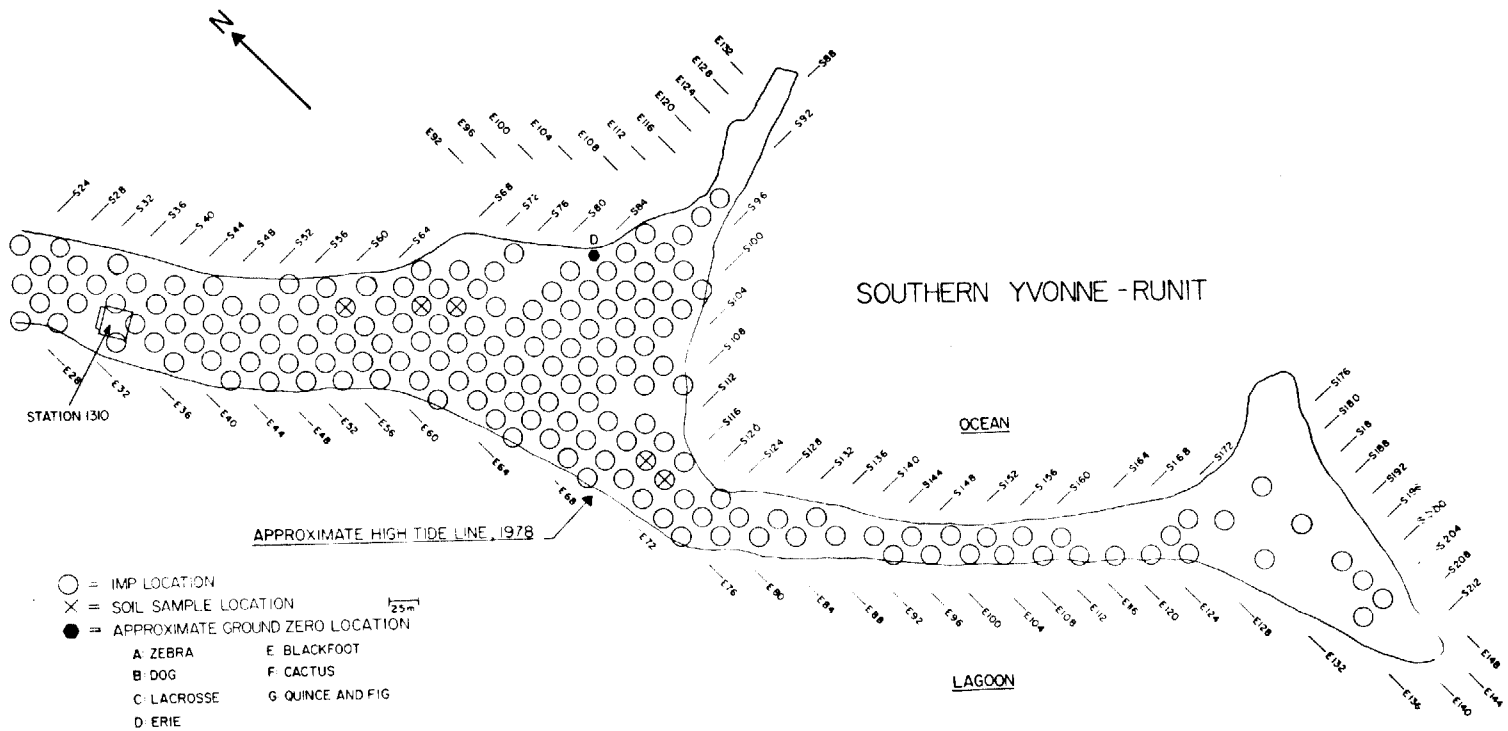

FIGURE 7-108. COASTLINE AND DATA COLLECTION LOCATIONS FOR SOUTHER HALF OF ISLAND YVONNE

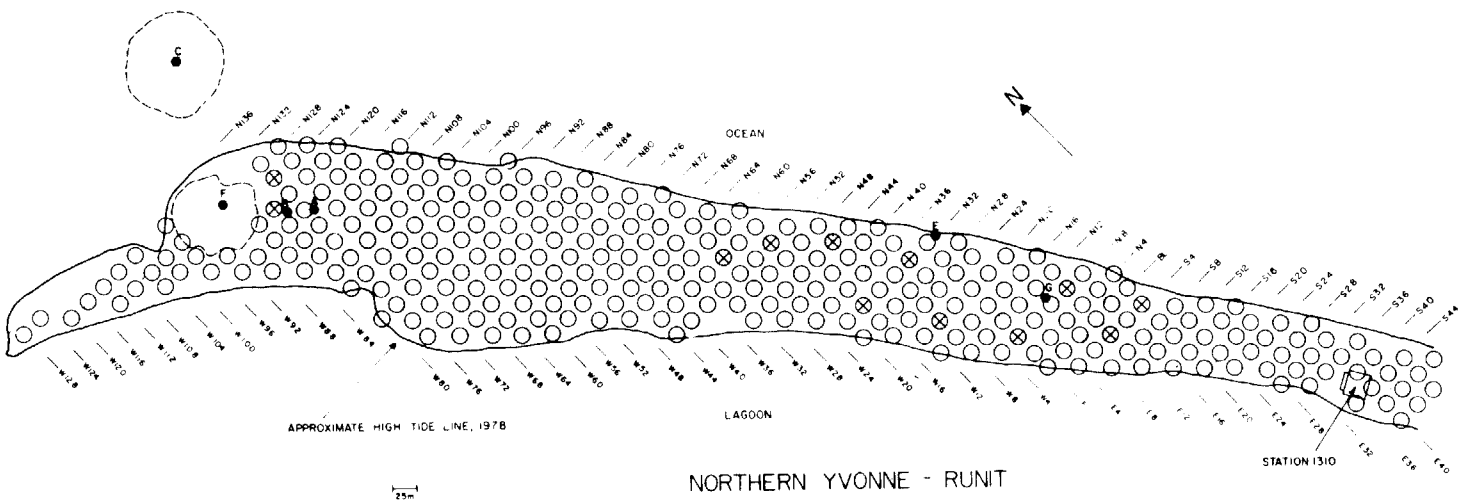

FIGURE 7-109. COASTLINE AND DATA COLLECTION LOCATIONS FOR NORTHERN HALF OF ISLAND YVONNE

only towards the lagoon, while unofficial eyewitness accounts mention that some soil was also moved toward the ocean. (The latter reports were supported by the fact that milligram-size particles of plutonium were found on both ocean and lagoon sides in 1972 and again during the cleanup.) There was also some indication in the reports that the contaminated soil was covered with plastic sheeting under the clean fill to warn that contamination was present.

After the decontamination operation, the Fig event took place at the same GZ, further disturbing the soil and dispersing the contamination. As a result of Fig, Quince and the earlier events, the horizontal and vertical distribution of contamination, especially plutonium, was extremely heterogeneous in central Yvonne. All the GZ sites on Yvonne are shown in Figures 7-108 and 7-109.

Other activities during test operations also contributed to the heterogeneity of the pattern of contamination on Yvonne. For example, soil was often levelled off or pushed into the ocean between nuclear tests, and fill was moved from one area to another during various construction operations. Numerous test stations, bunkers, concrete pads, and buildings were constructed on Yvonne; many still remained even after the cleanup. Most of the large quantity of debris on the island or the adjacent reef was north of the 1310 bunker, and some of it had exposure rates as high as 3mR/h at 1m in 1972. As a result of the 24 events that directly affected Yvonne, the island received by far the highest accumulated H + 1 hour exposure rate in the Atoll, with 62,849 R/h.

After the cessation of nuclear testing at Enewetak Atoll, Yvonne was sampled during the site selection process for the Pacific Cratering Experiments (PACE). (Details of the PACE program are in Sections 1.5 and 7.5.4.) Soil samples were taken in September 1971 near the Cactus, Lacrosse and Fig-Quince GZ's. Later, during the PACE operations, more samples were taken in one-foot increments to a depth of about ten feet during rotary drilling activities. Both sets of PACE-related samples were analyzed to obtain radiological data which were incorporated in cleanup decision-making.

1972 Survey Results

The standard sampling procedures of the 1972 survey were modified for northern Yvonne because of the known heterogeneity of the radioactive contamination on the island. Instead of the usual random sampling design, soil samples were taken on a regular grid with approximately 200-foot spacing in the Fig-Quince area. Samples were also taken at 200-foot intervals along a line down the center of the island from the edge of the Fig-Quince area to the Cactus crater and south from there for about 200 m along the lagoon side. There were 45 locations in this group, and each was sampled in 10 cm increments to a depth of 120 cm.

The situation on southern Yvonne was much less complex, so the standard procedures were used for the 51 locations sampled in the south half. One of these 51 was a 0-125 cm profile, two were 0-165 cm profiles, two were 0-185 cm profiles, and the other 46 were 0-15 cm cores. A number of plant and animal samples were also taken on Yvonne.

The 1972 survey results verified the heterogeneity of the contamination on Yvonne, particularly in depth distributions. Also, several areas were shown to have high TRU activity. For example, there were several locations in the Fig-Quince area with $^{239,240}Pu$ activity exceeding 100 pCi/g on the surface or at depths to 130 cm. Most of these locations were along the ocean and lagoon edges of the island. As might be expected in light of the post-Quince decontamination operations, the depth distribution of activity was very erratic. Elevated $^{239,240}Pu$ activity was also found at several locations near the Cactus crater, but at only one was the activity in excess of 100 pCi/g. Near Cactus, the $^{239,240}Pu$ activity tended to be homogeneous to about 60-80 cm or to fall slowly with depth; in several cases, the activity rose again below 80 cm.

The depth distribution of ^{137}Cs and ^{90}Sr was similar to the pattern for $^{239,240}Pu$ but less erratic. There was also less activity from these two isotopes, with the highest values in the Fig-Quince area being on the order of 10 pCi/g. Near the Cactus crater, the ^{137}Cs and ^{90}Sr activities were higher, although most of the values were less than 50 pCi/g except for two locations with ^{90}Sr activity greater than 100 pCi/g. Tables 7-1, 7-2 and 7-3 summarize the 1972 results for ^{137}Cs, ^{90}Sr and $^{239,240}Pu$, respectively.

Several areas were noted as possible sites of buried contamination based on the 1972 results and prior knowledge. At the Fig-Quince area, strips along both ocean and lagoon sides were suspect, as well as an inland area at the GZ itself. There was also elevated subsurface activity in the lip of the Cactus crater and in the area just south of the crater. Because of the earth-moving activities after the Erie event and the fact that the 1972 data showed some evidence of elevated subsurface activity near Erie GZ, this area also was suspect. Also, during the 1972 survey a jar containing sand with high plutonium activity was reported near the 1310 bunker and a box of contaminated material was reported near the old runway.

Initial Characterization and Cleanup

During the cleanup, much of Yvonne was covered with roads, buildings, storage yards, and other structures associated with the contaminated soil confinement operations. Therefore no complete initial surface characterization of Yvonne could be done. Instead, IMP measurements were made on the accessible areas of the island as time permitted. Part of northern Yvonne was measured in February 1978, and the undisturbed sections of southern Yvonne were measured in early February 1979. The rest of the accessible areas of northern Yvonne were also measured in February and early March 1979.

The ratios of TRU to ^{241}Am that were used to estimate TRU activity from IMP ^{241}Am data were based on both data from the 1972 survey and data taken during the cleanup. Soil samples were taken in February 1978 on northern Yvonne, at the locations shown in Figure 7-109. Southern Yvonne was soil sampled in February 1979, as shown in Figure 7-108. The 1978 samples were analyzed only for gross alpha activity and for ^{241}Am activity by gamma scan, not for plutonium, so only a rough estimate could be made. The ratio, which was estimated to be 9.5, was applicable only to the Cactus crater area. For the Fig-Quince area, 1972 data were used to estimate a ratio of 14.42 ± 0.67. For southern Yvonne, data from the 1979 samples were used to estimate a ratio of 8.16 ± 0.26. (See Tech Note 2.24 for details.) For the final characterization after cleanup, more soil samples were taken in August 1979 on northern Yvonne, and a ratio of 9.10 ± 1.08, applicable to all the north half, was estimated.

The Field Radiation Support Team (FRST) conducted several subsurface sampling efforts during the cleanup. In the first effort, an investigation of the Erie GZ area, samples were taken at several depths along several radials from the GZ in July 1977. No significant concentrations of elevated subsurface TRU activity were found. The Fig-Quince area was sampled by FRST between November 1977 and January 1978 using the auger coring method combined with logging of the holes for gamma activity. The purpose of this latter effort was to define, if possible, the boundaries of the area containing buried Quince material. Although a number of locations with very high subsurface TRU activity were found, no continuous boundary could be established. Auger core samples were also taken by the FRST on the Cactus crater lip.

As the Cactus crater was filled with contaminated soil, it became necessary to move the crater lip material. A set of samples was taken in May 1979 by ERSP personnel, to characterize this material. The sampling and results are described in Tech Note 15.0.

A final set of subsurface samples was taken in August 1979 in the area southeast of Fig-Quince. The soil from this area was later used as fill to reduce the surface TRU activity after the Fig-Quince area cleanup was terminated (see Section 6.10). These samples were also used to estimate the final TRU to ^{241}Am ratio for northern Yvonne.

Most of the cleanup effort on Yvonne was concentrated on the Fig-Quince GZ area. The FRST made periodic efforts throughout the cleanup project to pick up the milligram-size and larger pieces of plutonium from the Quince event. The usual method involved using handheld instruments to narrowly define the location of a particle, then removing small amounts of soil until the remaining activity dropped abruptly. In some cases, the actual particle could be isolated and removed. All the soil that was picked up in these efforts was bagged and later placed in the Cactus dome, as reported in Tech Note 14.

In June and July of 1979, soil was selectively removed with earth-moving equipment from the locations in the Fig-Quince area with highest TRU activity based on original data. (See Tech Note 23 for discussion of original versus final data.) After each soil lift, the locations involved were remeasured with the IMP, and more soil lifted, again from the locations with highest TRU activity. In the Fig-Quince cleanup, a total of approximately 8,200 cubic meters (10,735 cubic yards) of soil, containing an estimated 7.2 curies of TRU activity, was removed.

After the soil excisions, a layer of soil with relatively low TRU activity was spread over the locations in the Fig-Quince area which still had TRU activity, based on original data, in excess of 160 pCi/g (see Section 6.10).

Fission Products Sampling and Final Characterization

Because the numerous structures and soil confinement operations made sampling very difficult on northern Yvonne, only southern Yvonne was sampled in the Fission Product Data Base Program. Samples were taken at 14 locations, and soil from 5 of these was analyzed for ^{90}Sr. Tables 7-1, 7-2 and 7-3 summarize the results for 0-15 cm data for ^{137}Cs, ^{90}Sr and $^{239,240}Pu$, respectively. Island averages for other depth ranges are given below for ^{137}Cs and ^{90}Sr.

	0-5 cm	0-40 cm	0-60 cm	Total Samples
^{90}Sr, pCi/g	1.3	1.1	1.2	27
^{137}Cs, pCi/g	1.6	1.4	1.5	81

Following completion of the cleanup, soil confinement operations and dismantling of structures on Yvonne, the entire island was measured with the IMP at 25 m spacing. Figures 7-108 and 7-109 show the sampling locations, and Figures 7-110 and 7-111 show isopleths on the final post-cleanup surface TRU on Yvonne. Table 7-5 summarizes island average data for ^{137}Cs, ^{60}Co and TRU activity from IMP readings.

The overall TRU average for southern Yvonne is 7.8 pCi/gm and for northern Yvonne is 41 pCi/gm. Although the surface of Yvonne is technically within the numerical standard for the Food Gathering classification, the complex and unique radiological condition of the northern portion of the island leads to the conclusion that Yvonne should not be so classified. The island is currently quarantined.

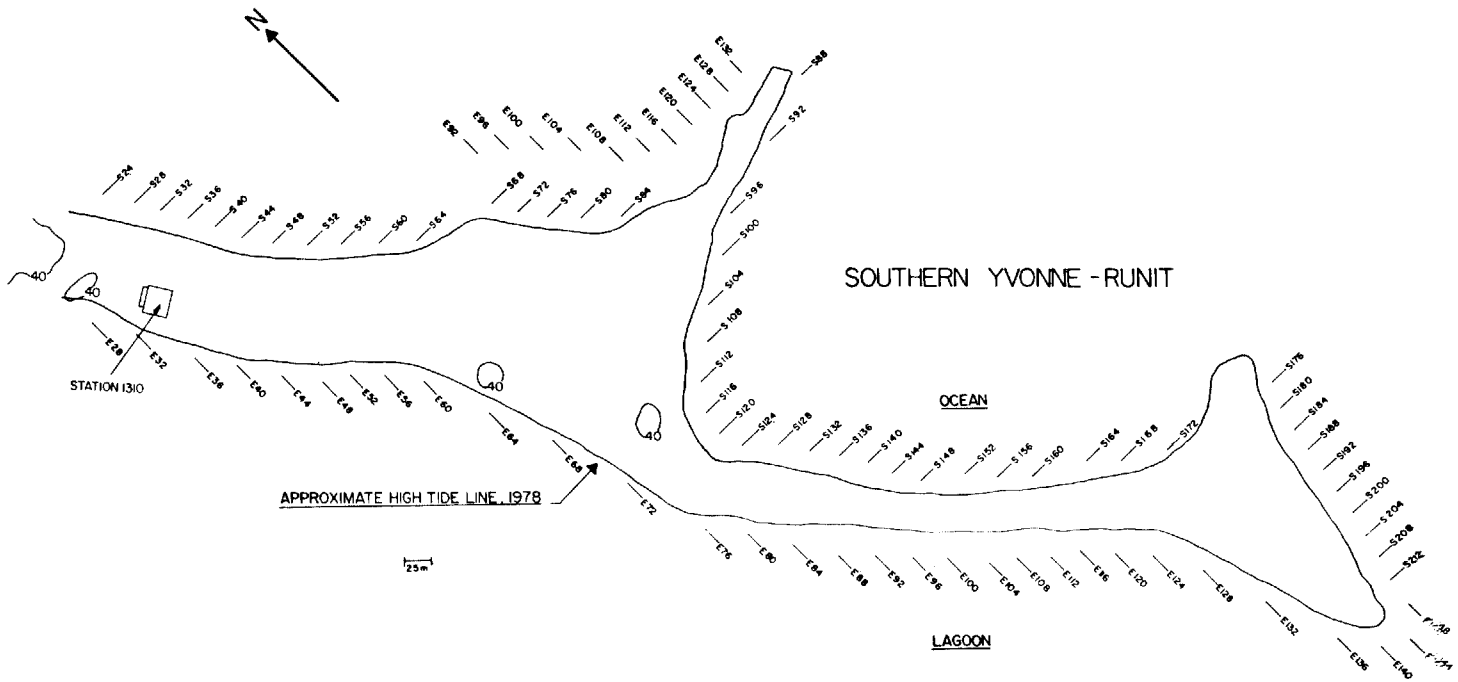

FIGURE 7-110. ISOPLETHS ON FINAL ESTIMATED SURFACE TRU ACTIVITY IN pCi/g FOR SOUTHERN HALF OF ISLAND YVONNE

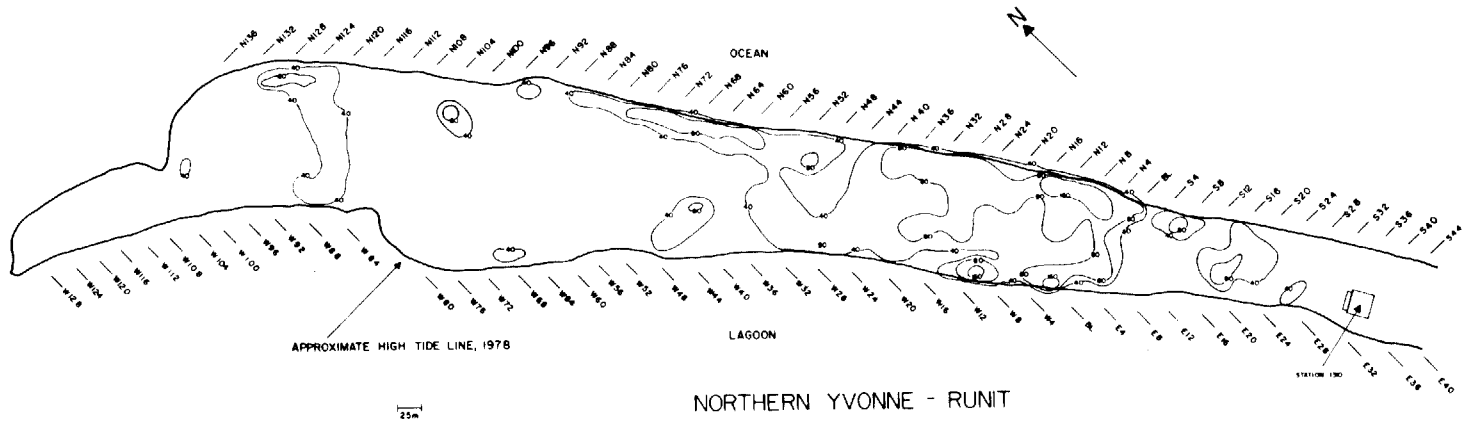

FIGURE 7-111. ISOPLETHS ON FINAL ESTIMATED SURFACE TRU ACTIVITY IN pCi/g FOR NORTHERN HALF OF ISLAND YVONNE

7.6 CERTIFICATION

7.6.1 Introduction

This section was originally intended to be a Chapter containing the island-by-island certificates of radiological condition prepared by DOE at the end of cleanup. However, the requirement that DOE provide DNA with island certificates at the completion of cleanup prompted early distribution of these documents (Enewetak Radiological Support Project, Island Certifications, March, 1980 reproduced in the microfiche). Rather than reproduce all 43 certificates (totalling 92 pages) only two have been included here to illustrate the two general formats utilized. Distribution of the certificates was made to concerned offices of participating agencies.

All of the information contained in the individual certification documents is incorporated in this report. The characterizations by island maximum and average concentrations of transuranics appear in Tables 7-3 and 7-5. Statements about special considerations summarize materials presented in Chapters 6 and 7 and appear only for islands Irene, Janet, Sally, Ursula and Yvonne. The certificates for islands Belle, with no special considerations, and Sally, with special considerations, are reproduced in Figures 7-112 and 7-113.

7.6.2 Post Certification Actions

The rehabilitation phase of the Enewetak Cleanup Project was begun in June 1978, and conducted concurrently over the last 21 months of cleanup. With completion of debris cleanup and island characterization in the summer of 1979, rehabilitation effort was stepped up and directed toward planting of coconut seedlings on selected islands in the northeast segment of the atoll. By 15 March 1980, planting of 10,690 seedlings was completed on the northeast islands of Olive, Pearl, Sally, Tilda, Ursula, and Vera. (Coconut seedlings and cuttings of breadfruit and pandanus were planted on southern islands Bruce, David, Elmer and Fred; however, these islands were of lesser radiological concern than the northeast islands, so are not included in the discussion that follows.)

Preparation for planting of the northeast islands included clearing, grading, and leveling. These tasks were accomplished by bulldozing all brush to the seaward side of the island, then grading and leveling only as required to achieve a relatively uniform surface. Hummocks and hollows were not entirely leveled, but enough soil was moved to create a different surface than existed at the time radiological characterization measurements were made. Analytical results of soil samples collected from various depths for both the TRU and FPDB programs; in situ gamma measurements made in connection with brush removal experiments on Janet, Pearl and Sally; and comparison of data related to soil disturbance due to lane clearing on several islands, all support the belief that the soil surface at planting time contained lower concentrations of radionuclides than were measured during characterization. The reduction would be attributed to vertical mixing and horizontal transport with no net change in total inventory. A fraction, perhaps up to 10 percent, of the total soil radioisotope inventory has been relocated to the oceanside beach in the native vegetation cleared prior to planting. This fraction may represent a significant portion of the soluble radionuclides. Future measurements should provide additional information on how effective vegetation removal has been in relocating some of the radionuclides available to food crops.

In conclusion, researchers should not expect future in situ gamma measurements or soil analyses to yield the same results as reported herein for the northeast islands where coconuts have been planted. The average radionuclide concentration should be lower (near the surface) because of the mixing inherent in grading and leveling. Future research and measurement programs should provide more information on the effect of clearing and planting on the distribution and availability of radionuclides to food plants.

Department of Energy
Enewetak Radiological
Support Project
APO San Francisco 96333

March 28, 1980

CERTIFICATION

Based on an evaluation of radiological conditions generally described below, the radiological cleanup of Bokombako/Belle, Enewetak Atoll, Marshall Islands, has been completed substantially in accordance with the radiological guidance contained in the report by the Atomic Energy Commission (AEC) Task Group entitled "Recommendations for Cleanup and Rehabilitation of Enewetak Atoll," June 19, 1974, as approved by the Commissioners of the AEC on August 12, 1974, and as amplified by Department of Energy guidance provided for field use which is contained in Section 4, Tab E, Appendix 2, Annex C of FC DNA OPLAN 600-77, April 29, 1977, and subsequent correspondence.

I. RADIOACTIVE DEBRIS

The Commander, Joint Task Group, Enewetak, has reported (Letter, HQ JTG, subject: Contaminated Debris Cleanup, dated August 20, 1979) that a diligent effort has been made to locate all radioactive debris. Disposition of all such debris has been in accordance with OPLAN 600-77 or other appropriate guidance.

II. BURIAL SITES

Based upon a study of the history of test operations, interviews with former test participants, evaluation of the results of the Fission Product Data Base Program, and an examination of markers, tablets, and monuments, it was determined that no known or suspected radiological burial sites exist on this island.

3-1

FIGURE 7-112. CERTIFICATION FOR ISLAND BELLE

III. TRANSURANICS* IN SURFACE** SOIL

Based upon a study of the history of test operations, upon the data reported in NVO-140, and upon radiological measurements made during the cleanup project, it was concluded that no 1/4 hectare average is greater than 125 pCi/gm. The island average is determined to be 95 pCi/gm. It is therefore concluded that the transuranics classification should be Food Gathering.

IV. TRANSURANICS IN SUBSURFACE SOIL

Based upon a study of the history of test operations, upon soil profile data reported in NVO-140, and upon the results of the Fission Product Data Base Program, a gridded subsurface sampling plan was implemented to delineate the boundary of each area exceeding 160 pCi/gm. No such area exceeds 1/16 hectare.

Roger Ray
Project Manager
Authorized Department of Energy
Representative

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*For the purpose of this certification, the term "transuranics" is defined as those radionuclides measured and calculated by the ERSP to guide the Enewetak cleanup, i.e., ^{238}Pu, ^{239}Pu, ^{240}Pu, and ^{241}Am.

**Surface, in this context, refers to the layer of soil observed by the in situ detector in its normal measuring position. It is generally taken as approximately 3 cm in depth.

3-2

FIGURE 7-112. CERTIFICATION FOR ISLAND BELLE (Continued)

Department of Energy
Enewetak Radiological
Support Project
APO San Francisco 96333

March 28, 1980

CERTIFICATION

Based on an evaluation of radiological conditions generally described below, the radiological cleanup of Aomon/Sally, Enewetak Atoll, Marshall Islands, has been completed substantially in accordance with the radiological guidance contained in the report by the Atomic Energy Commission (AEC) Task Group entitled "Recommendations for Cleanup and Rehabilitation of Enewetak Atoll," June 19, 1974, as approved by the Commissioners of the AEC on August 12, 1974, and as amplified by Department of Energy guidance provided for field use which is contained in Section 4, Tab E, Appendix 2, Annex C of FC DNA OPLAN 600-77, April 29, 1977, and subsequent correspondence.

I. RADIOACTIVE DEBRIS

The Commander, Joint Task Group, Enewetak, has reported (Letter, HQ JTG, subject: Contaminated Debris Cleanup, dated August 20, 1979) that a diligent effort has been made to locate all radioactive debris. Disposition of all such debris has been in accordance with OPLAN 600-77 or other appropriate guidance.

II. BURIAL SITES

Based upon a study of the history of test operations, interviews with former test participants, evaluation of the results of the Fission Product Data Base Program, and an examination of markers, tablets, and monuments, it was determined that no known or suspected radiological burial sites exist on this island. However, a burial site adjacent to Aomon/Sally is discussed in Section V, Special Considerations.

32-1

FIGURE 7-113. CERTIFICATION FOR ISLAND SALLY

III. TRANSURANICS* IN SURFACE** SOIL

Postcleanup surface soil concentrations were determined by the in situ detection method, supported by radiochemical ratio determination. Based upon 1/4 hectare averaging, more than 99 percent of the island is below the 40 pCi/gm residence island criterion. The two 1/4-hectare areas which exceed the standard are below 42 pCi/gm. The island average is determined to be 7.5 pCi/gm. It is therefore concluded that the transuranics classification of Aomon should be Residence.

IV. TRANSURANICS IN SUBSURFACE SOIL

Based upon a study of the history of test operations, upon soil profile data reported in NVO-140, and upon the results of the Fission Product Data Base Program, a gridded subsurface sampling plan was implemented to delineate the boundary of each area exceeding 160 pCi/gm. Areas exceeding 1/16 hectare were excised and resampled to confirm successful removal.

V. SPECIAL CONSIDERATIONS

High transuranic concentrations are known to exist on the north tip of this island along the high tide line near the Kickapoo ground zero. The highest value recorded for any assay area following cleanup is 110 pCi/gm. The remaining activity is fixed to the coral surface. A diligent effort was made to remove the activity, including sweeping and washing with high-pressure water. In addition, small pieces of contaminated metal debris remain along the beach. Debris from the Kickapoo tower was deposited over the reef and has been consolidated in the beach rock. Metal fragments have been removed periodically throughout the cleanup; however, it is likely metal debris will continue to be washed ashore.

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*For the purpose of this certification, the term "transuranics" is defined as those radionuclides measured and calculated by the ERSP to guide the Enewetak cleanup, i.e., ^{238}Pu, ^{239}Pu, ^{240}Pu, and ^{241}Am.

**Surface, in this context, refers to the layer of soil observed by the in situ detector in its normal measuring position. It is generally taken as approximately 3 cm in depth.

32-2

FIGURE 7-113. CERTIFICATION FOR ISLAND SALLY (Continued)

One known burial site, located between Aomon/Sally and Bijire/Tilda, was excavated during the cleanup for the removal of contaminated debris and sand. The criterion used for this removal was 400 pCi/gm rather than 160 pCi/gm used for other subsurface explorations.* The criterion was met and the excavation backfilled with a dry mixture of soil and cement followed by clean beach sand.

The southwestern 1/2 of Sally was excavated for the Pacific Atoll Cratering Experiments (PACE). The surface material was added to the lagoon side of the causeway which connected Sally and Eleleron/Ruby, and some was pushed to the interior of the island. The depression was recontoured using the soil from the middle of the island. In situ measurements were made prior to and following recontouring. No significant difference in the TRU levels was noted.

Roger Ray
Project Manager
Authorized Department of Energy
Representative

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*Plan for Aomon Crypt Excavation Project, November 8, 1978--product of a joint agency meeting held at Fort Shafter, Hawaii, November 6-8, 1978.

32-3

FIGURE 7-113. CERTIFICATION FOR ISLAND SALLY (Continued)

PREFACE TO APPENDIX A: DOE/ERSP PROCEDURES

Preparation of site-specific procedures applicable to the Enewetak Radiological Support Project began on atoll during July 1977. Each Procedure shows the date drafted, which was the date of first typing rather than the date the author began writing. Prior to first typing, rough drafts were reviewed by lead contractor staff. Once typed, the Tech Advisor performed critical review to ensure accuracy and clarity. When the Tech Advisor was satisfied, the draft was presented to the ERSP Manager or the Deputy on island for additional review. Procedures usually passed through several iterations of review and correction prior to final approval. In most cases, the procedures described or explained functions that were already being performed, or delineated responsibilities that were already recognized and implemented. No task or function was delayed by waiting for approval of a Procedure, but some functions were improved as a result of having to write a step-by-step description of what was being done.

Acting in an advisory role to the DNA, the ERSP Manager and Tech Advisor sat in on all meetings of the JTG's Radiation Control Committee, and were included in the review cycle for all procedures related to health physics presented to that Committee by members of the military Radiation Control (RADCON) staff. In areas of overlap or similarity, close coordination was required to reduce conflict between the two sets of procedures. Bearing full responsibility for health physics aspects, the RADCON staff prepared procedures for such things as Hotline setup and operation, implementation of face mask and protective foot covering requirements, administration of a film badge or dosimeter program, etc. Thus, these topics do not appear in this Appendix.

For ease of reference, the Procedure number follows the A in the pagination. For example, page A-4-6 refers to Appendix A, Procedure 4, page 6 of procedure 4.

CONTENTS

APPENDIX A: DOE/ERSP PROCEDURES

NO.	TITLE
1	Island Surface Contamination Evaluation
2	In Situ Van Function
3	Statistical Procedures
4	Soil Sampling Procedure
4a	Soil Sampling Procedure - Southern Enewetak
5	Quality Control Procedure
6	Radiation Safety
7	Disposal of Radioactive Waste Material from the RADLAB
8	Laboratory Soil Sample Preparation
9	Direct Alpha Counting of Soil Samples
10	Plutonium in Coral Soil
11	Am in Coral Soil
11.1	Coral Sample Analysis for Am
12	Uranium in Coral Soil
13	Counting of Nose Swipes
14	Plutonium in Urine
15	Y-90 in Coral Soil
16	High Level Sample Preparation
17	Sample Preparation Laboratory HEPA Filter Change
18	Instrument Calibration Range
19	Radio-Chemistry Laboratory Priority Operations
20	Soil Preparation for Library Storage
21	Soil Sample Screening by IMP
22	Interlaboratory Quality Assurance for Enewetak Soil Analysis
23	Sr-90 in Coral Soil
24	Water Safety During Island Landing and Exiting Operations
25	Data Reporting Procedure
26	FRST Air Filter Composite Sample Analysis for Plutonium
27	Archiving Procedures and/or Notes Concerning Soil Samples for the Enewetak TRU Program
28	Enewetak Fission Product Data Base Program
29	Portable Instrument Maintenance Manual

ISLAND SURFACE CONTAMINATION EVALUATION

DOE/ERSP PROCEDURE NO. 1 DATE DRAFTED: 27 September 1977

APPROVED: 3 October 1977 by Paul B. Dunaway (ERSP Manager)

I. ERSP Manager

A. Is responsible for the overall program.

B. Shall, with the concurrence of the JTG Commander, select the islands to be in situ surveyed.

C. Shall assure that the survey reference points are established for the island(s).

D. Shall approve the grid size and orientation to the reference points as performed by the Army or FRST surveyors. The initial grid size will depend on closeness of the particular island criteria to expected activity. The ERSP Manager should approve these criteria because operational needs may dictate approach (e.g., coarse grid for early part of survey with finer grid required depending on need).

E. Shall recommend to the DNA as to where soil should be removed based on the measured activity.

II. Tech Advisor

A. Coordinate with EG&G scientist and DRI statistician to establish grid size.

B. Review estimate plots (will be similar to Figures A-1-1, -2 and -3*), conversion factors (ratios, van calibration, etc.), soil sampling results and error terms and advise ERSP Manager on believability. Recommend to the ERSP Manager as to where soil should be removed.

C. Select 4-hectare parcels to be soil sampled from the island grid (see Procedure No. 4).

D. Assure that the high level sample (4000 cpm FIDLER) are field evaluated and the data recorded/reported.

E. Audit quality of van measurements, lab processing, soil sampling techniques, and advise ERSP Manager on quality of in situ survey program.

III. EG&G Functions

A. Provide scientist to direct operation of in situ vans and perform technical duties listed below.

B. Operate and maintain in situ vans.

C. Make in situ measurements and certify their quality, listing limitations.

D. Document the physical environment in the vicinity of each measurement.

E. Transmit the in situ data to DRI, including the printout of each spectrum** and isotopes detected. (DOE will audit this printout. Figure A-1-4 is a specimen of the final portion of a spectrum.)

* Original procedure contained 7 pages of output specimens.
**Spectrum printouts were all retained by EG&G.

F. Review DRI estimate plots, conversion factors (ratios, van calibration, etc.) and error terms and comment to ERSP Manager on believability.

G. Assist the Tech Advisor, when requested, in selecting the in situ locations to be soil sampled.

H. Obtain additional data as requested by DRI or DOE.

IV. DRI

A. Provide statistician for data evaluation who will:

1. Receive in situ data from EG&G.

2. Receive soil data from EIC (ground truth-Am, Pu, Pu/Am ratios).

3. Determine Van to Am, Am to Pu or Van to Pu ratios and errors to be used at each in situ location.

4. Receive EG&G, EIC and DOE comments on the believability of these factors. Return personal rebuttal comments to ERSP Manager or take action to correct situation commented on if required.

5. Request and/or comment on usefulness of taking additional data by EG&G or EIC.

6. Construct estimate plots including errors.

7. Comment on estimate maps and their usefulness.

V. EIC

A. Provide manager for overall laboratory and equipment maintenance direction.

B. Provide Soil Sampling Supervisor to direct the actual collection of soil samples.

C. Arrange for screening,* on island storage or transport of soil samples to laboratory.

D. Receive soil samples from boat at Enewetak Island and transport to laboratory.

E. Screen and prep samples, then gamma scan for Am and fission products.

F. Determine by appropriate methods ^{238}Pu and ^{239,240}Pu content of samples. Determine by gamma spectroscopy ^{241}Am content of samples as well as analyze a statistically valid number of samples for ^{241}Am by chemical methods.

G. Establish and perform quality analyses in laboratory.

H. Transmit data to DRI.

I. Comment on conditions of each soil sample.

J. Review DRI estimate plots, conversion factors (ratios, van calibration, etc.), and error terms and comment on believability.

K. Obtain additional data as requested by DRI, EG&G or DOE.

*As used herein, the word screen means to perform preliminary evaluation of the level of radioactive contamination. Screening in the sense of passing material through a sieve was not done.

For a grid of data points distance "d" apart, the programs can estimate the average over two sizes of area:

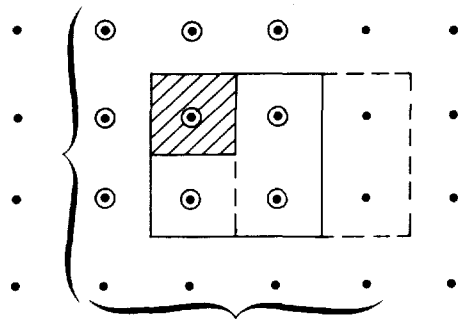
1. The "16-point" estimate averages over a square of side 2d using a 4x4 array of data points (see diagram below).

2. The "9-point" estimate averages over a square of side d (shaded area below), using a 3x3 array of data points (circled points below).

Any two adjacent 16-point estimates are averages on overlapping squares, e.g., compare areas enclosed by solid and dashed lines below. Adjacent 9-point estimates are averages on non-overlapping squares which are exactly one-fourth the area of the 16-point square. The four small square averages in each large square are estimated using the same 16 points as for the large square average, 9 at a time.

Data points are represented by dots on the 16-point estimate printout, and by the decimal points in the printout of 9-point estimates. The physical scales on the two printouts for a particular set of data are identical, so that the dots on the one exactly match the decimal points on the other.

The solid intensity plots indicate areas above an action level by darker blocks of color (see page A-1-5). Due to the overlap on the 16-point estimates, only the small square enclosed by the four data points in the center of an estimated square is darker when the average is above the action level. The blocks on the 9-point estimates represent the true areas estimated. The intensity plots can be matched up by exactly aligning the row of asterisks (*'s) above the plot, with the first asterisk on the 16-point plot lined up on the fourth asterisk of the 9-point plot.



Anywhere that two diagonally adjacent data points are missing, the area actually averaged over is a square with the appropriate corner knocked off (see illustration below). The purpose of this is to approximate the true shape of the island as closely as possible.

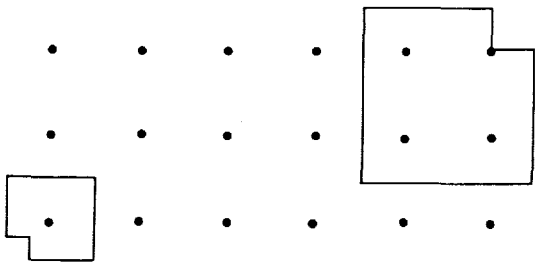


FIGURE A-1-1. GRID ESTIMATES AND PLOTS

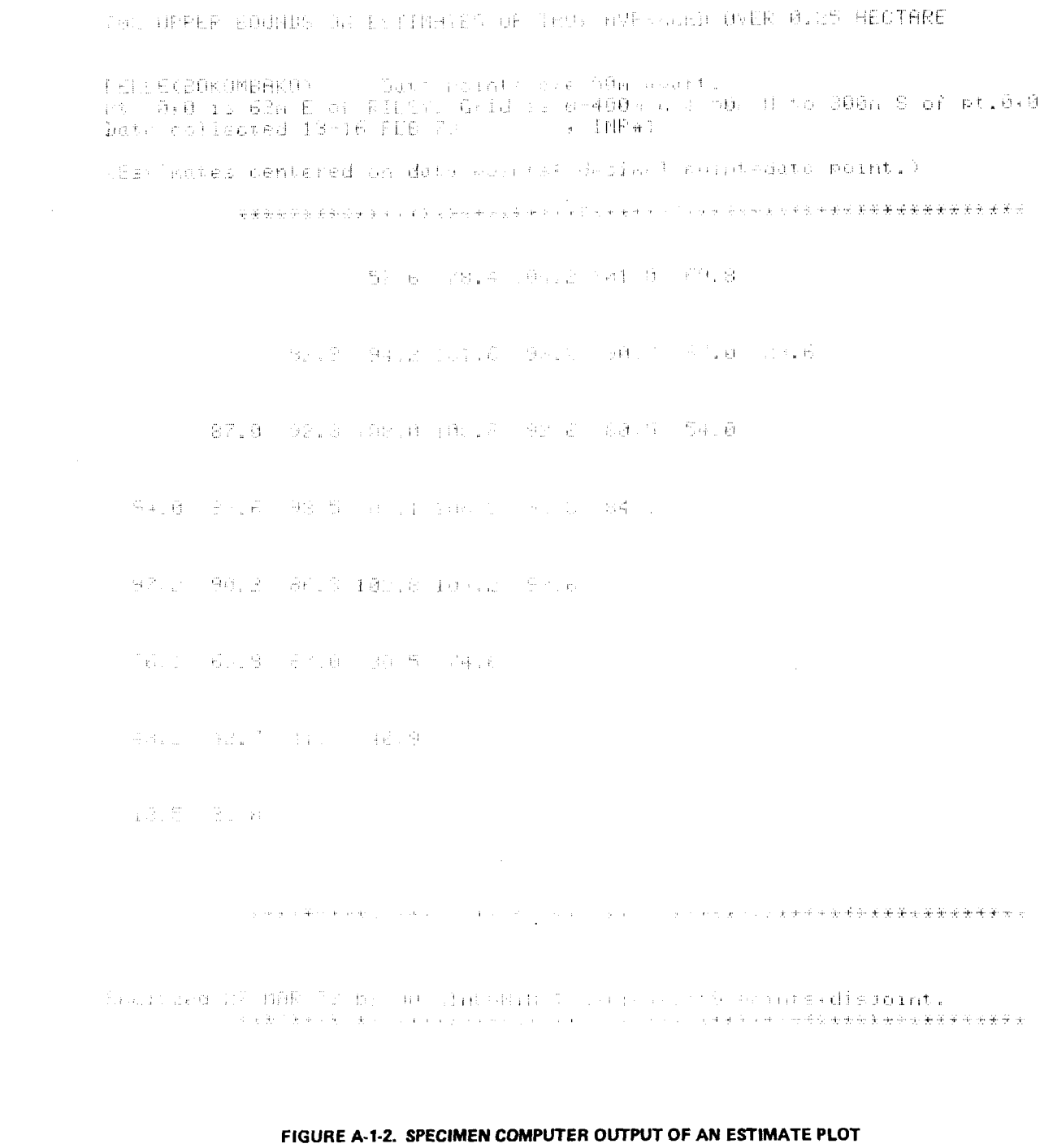
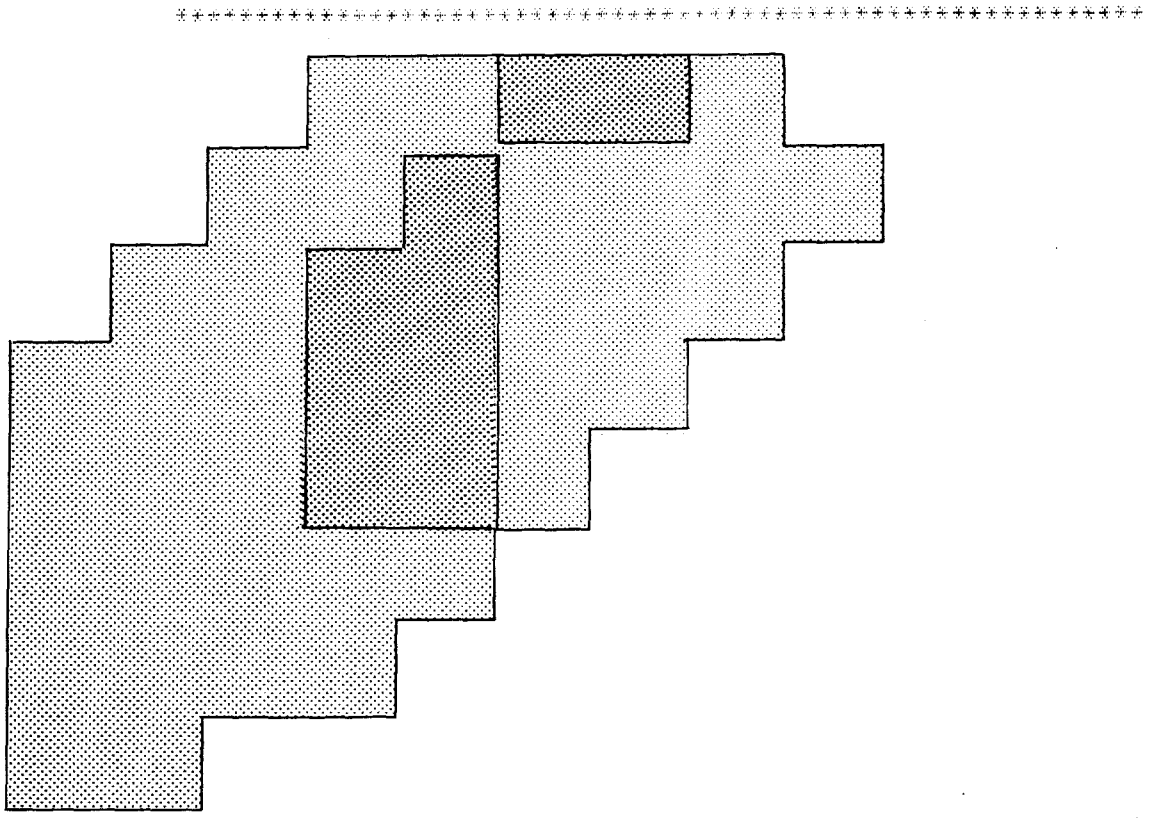


FIGURE A-1-2. SPECIMEN COMPUTER OUTPUT OF AN ESTIMATE PLOT

70% UPPER BOUNDS ON ESTIMATES OF TRU, AVERAGED OVER 0.25 HECTARE.

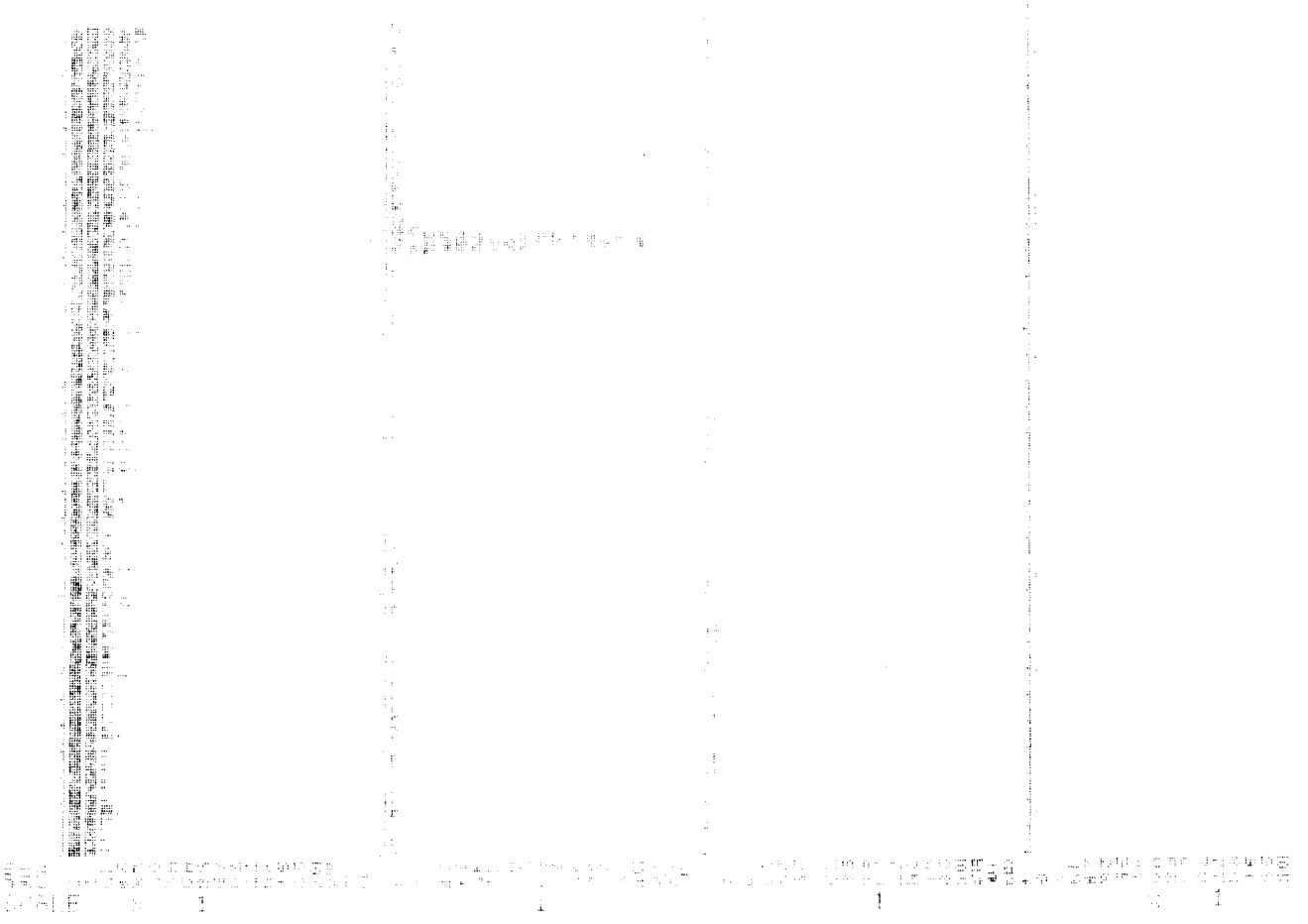
BELLE(BOKOMBAKO) Large block of 6x6 small blocks is 50mx50m.
Pt. 0,0 is 62m E of RILEY. Grid is 0-400m W & 50m N to 300m S of pt.0,0.
Data collected 13-16 FEB 78 , IMP#1

LIGHT AREA=UPPER BOUNDS ARE < 100 pCi/g AT 70 % CONFIDENCE



Analyzed 22 MAR 78 by JO GIACOMINI Estimates:9 points,disjoint.

FIGURE A-1-3. SPECIMEN COMPUTER OUTPUT OF AN INTENSITY PLOT OF ESTIMATES



Channel Number	Energy (keV)	Net Counts	Sigma	Net Sigma	Nuclide	Energy (keV) Peak	Others	(--=)	Activity (pCi/g)
37.9	14.2	112	37	8					
62.3	23.4	156	227	6					
133.8	50.2	139	249	7					
159.0	59.6	235	319	10	AM241	59.5	-45.0	-103.0	2.1
					EU155	60.0	86.5	105.3	0.2
160.4	63.3	149	252	7					
199.6	74.9	168	407	7					
526.9	198.3	53	134	4	RU103	497.9	127.2	-325.1	0.3
571.9	214.5	72	110	6					
595.6	223.4	64	175	5					
1517.0	569.2	33	7	5	CS134	564.1	601.7	795.8	2.2
					RU207	569.1	1363.7	-1770.2	0.0
1763.9	661.5	942	33	30	CS137	661.6	0.0	0.0	13.2
1127.4	1173.0	45	4	6	CO 60	1173.2	-1332.5	0.0	0.9
3552.1	1332.0	35	2	6	CO 60	1332.5	1171.2	0.0	0.7

FIGURE A-1-4. SPECIMEN OF THE FINAL PORTION OF A SPECTRUM PRINTOUT

IN SITU VAN FUNCTION

DOE/ERSP PROCEDURE NO. 2 DATE DRAFTED: 27 September 1977

APPROVED: 3 October 1977 by Paul B. Dunaway (ERSP Manager)

I. Introduction

The in situ van's primary function during the Enewetak cleanup operation is the determination of plutonium concentration within the top few centimeters of soil. This is done by measuring the 60 keV gamma ray from ^{241}Am (a daughter of ^{241}Pu). Conversion factors have been established to convert the ^{241}Am photopeak count rate data into ^{241}Am concentration in the ground. These data are then converted into plutonium concentrations using plutonium to americium ratios established from soil sample data. Since the free path for 60 keV gamma rays in soil is approximately 2.5 cm, the detector only "sees" down through the top 3 to 5 centimeters. Other techniques must be used to look for Pu contamination buried below the top few centimeters.

II. Instrumentation

The in situ van itself is a Thiokol "IMP" which is a small, lightweight, tracked vehicle purchased especially for its ability to operate in soft sand. The IMP has been modified and equipped to be a fully self-contained mobile data acquisition and reduction laboratory. Power is provided by a 4 kW Onan generator mounted in front of the vehicle. The back part (rear cabin) of the IMP contains the electronics and is air conditioned to provide the required temperature and humidity controls. Gamma radiation from the ground is detected by a planar intrinsic germanium detector mounted on the end of a retractable boom located at the rear of the IMP. The detector has a surface area of 19 square centimeters, is 1.6 cm thick and has a gausian resolution of 840 eV FWHM (i.e., full width, half maximum of the gausian photo peak curve) at 122 keV. In its normal operating position the detector face is 740 cm above the ground. A thin 1/2" lead collimating cone mounted on the detector limits the field of view for 60 keV gamma rays to a 21 meter diameter circle. Signals from the preamplifier (mounted on the detector) are fed inside the IMP to a 4096 multichannel analyzer. Data from the analyzer can be stored on a cassette tape for future data reduction or can be transferred into a Hewlett Packard 9831 calculator for immediate processing. A printer is available for hard copy output.

III. Operational Procedures

Prior to making any measurements the detector system is calibrated to 375 eV per channel (approximately 1500 keV full scale) using a combination ^{60}Co, ^{137}Cs and ^{241}Am calibration source. The calibration is checked periodically and any gain shift is corrected. (Maintaining power to the preamplifier and amplifier on a 24-hour-a-day basis has minimized gain shift problems.) The IMP is moved from location to location with the boom fully retracted and the detector securely fastened. At a measurement point the boom is extended to its full length and then inclined at an angle of 20 degrees away from the IMP. After completing the measurement (a typical acquisition time of 900 seconds) the boom is retracted and the detector secured for movement to the next measurement location. The total time required for each measurement sequence is typically 25 to 30 minutes.

IV. Data Reduction

While the detector is being secured and the IMP moves to the next location, data from the previous measurement is normally processed on the HP-9831 calculator. The calculator has several software options available. The data from any portion of the spectrum can be printed or plotted - normally the first 200 channels are printed and the ^{241}Am, ^{137}Cs and ^{60}Co portions of the spectrum plotted out. An automatic peak search routine identifies the ^{241}Am, ^{137}Cs and ^{60}Co photopeaks within the spectrum, and then calculates the concentration (in pCi/g) for each isotope. The entire spectrum may be plotted and a large number of isotopes identified and quantified using another software routine at the

discretion of the EG&G scientist and as the need exists. After the data is processed in the IMP, it is stored on a cassette tape and sent to Enewetak. The data are transferred to a floppy disk for use in data evaluation. The cassettes of raw data are stored as a permanent record.*

V. Typical Operating Sequence

Figure A-2-1 shows a block diagram of the typical operating sequence for detection and removal of contaminated soil. Initially the heavy vegetation is removed** to allow the IMP to maneuver between measurement locations. A regular grid pattern is then surveyed (typically a square 25 or 50 meters on a side). The in situ van makes a measurement at each location and determines the ^{241}Am concentration. The americium data are converted to plutonium concentration and then processed through a statistical routine which provides area-averaged concentration values. In areas where the concentration exceeds the cleanup criteria, the top layer of soil is to be removed. The grid pattern is then reestablished. Those locations within and immediately adjacent to the areas where soil has been removed are remeasured. These new data are processed and the new area averages computed. If they still exceed the cleanup criteria additional soil will be removed. This process continues until the entire island complies with the established cleanup criteria.

VI. Technique to Locate Contamination Boundaries

It is sometimes of value to establish more accurately the location of high concentrations of ^{241}Am. One technique readily accomplished is to limit the radiation detector's field-of-view by simply lowering the detector from the standard 7.4 to 4.5 meter height (half mast). Although there are greater errors in this position (from van shadowing), the data are useful to determine contamination boundaries, i.e., the ground surface diameter field of view is decreased from 25.6 to 15.6 meters. In the half mast position, the 12.5 meter grid survey is preferred over the normal 50 or 25 meter grid.

*Cassettes were erased and reused after the data thereon had been transferred to magnetic tape in Las Vegas.
**Brush removal prior to grid survey was limited to Janet.

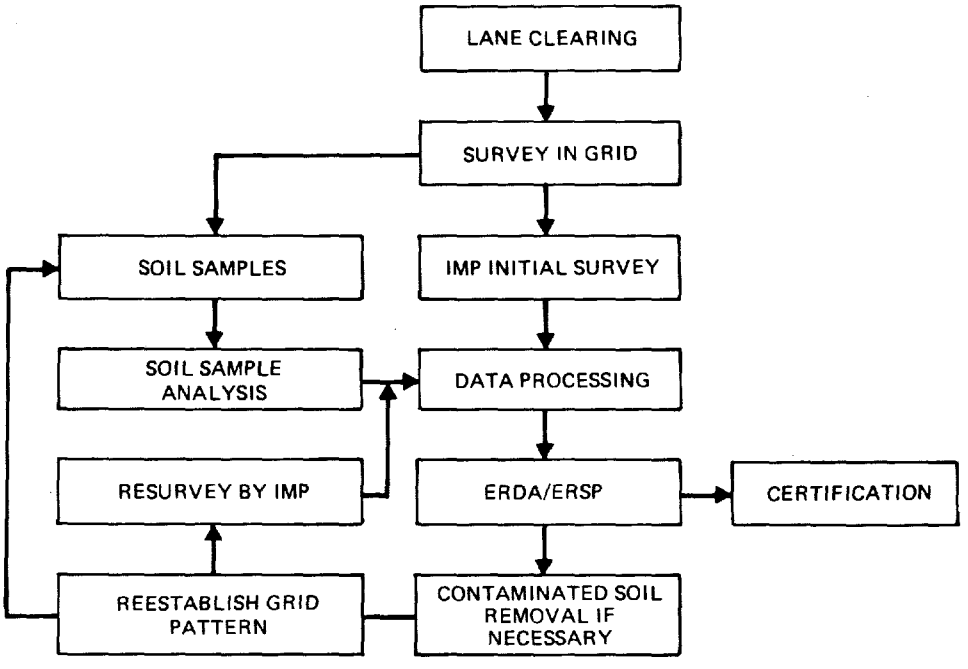


FIGURE A-2-1. TYPICAL OPERATING SEQUENCE FOR DETECTION AND EVALUATION OF CONTAMINATED SOIL

STATISTICAL PROCEDURES

DOE/ERSP PROCEDURE NO. 3 DATE DRAFTED: 27 September 1977

APPROVED: 6 October 1977 by Paul B. Dunaway (ERSP Manager)

I. Introduction

The duties of the Statistician fall into two general categories: Statistical analysis of data related to in situ sampling, and maintenance of a base of sampling, health physics and other data. The Statistician might be expected to extract specific subsets of data from the base, and present them in a particular format. Results of statistical analysis of in situ sampling will be presented in form useful to the DOE Technical Advisor, ERSP Manager, and JTG staff.

The Statistician is responsible for estimating average plutonium concentrations using the kriging technique, and for performing required preliminary work such as data verification and covariance structure fits. Concise, accurate, understandable display of results is the Statistician's responsibility, but decisions about actions based on those results are not. The Statistician is also responsible for the accuracy and completeness of the data bases, and for assuring the capability to accurately retrieve requested data.

The Statistician will provide the ERSP Manager an informal weekly written report on the status of statistical analyses and data storage.

II. In-Situ Data Procedures

(All program file numbers refer to track Ø of the Enewetak programs tape, all program names to the Enewetak programs disk.)

The in situ spectra and the log sheets containing additional information are brought from the sampled island approximately once a week. This data will be put on the in situ data base (tape file 23, IMPDB on disk). The spectrum for each sample point is contained in an integer array of 4096 elements. The first 31 channels* are used for location, date, comments, results, and other information. The remainder are total gamma counts per channel from the pulse height analyzer. The data are transferred to a string for disk storage on 33-record files, one sample per file. No hand input is necessary unless there are additional remarks. The file names indicate the island sampled and a sequence number. Each disk will be labeled (PRINT LABEL) with the absolute coordinates of the reference point**, the detector height, island name, and other information. A hard copy of the label and a catalogue (CAT) of the contents will be stored with each disk.

The tape data will be spot-checked for accuracy as necessary, and the disk data corrected or updated if errors or changes are found in the tape data. A note of such revisions will be made in the disk label and in the "additional comments" section of each affected file. Specifications for file names and disk labels, exact format of the data array, and examples of data retrieval are in the in situ data base program documentation.

After the data have been stored on disks and verified, a duplicate set of disks will be made. This set will be sent back to Las Vegas periodically and the data spectra stored on the big system there. The disks will then be erased and reused.

The storage of tapes and disks on Enewetak will be in separate areas to insure against loss due to fire, etc.

*Increased to 35 channels during the project to accommodate entry of additional identifying parameters.
**Reference points were not recovered or established on some islands so the disk labels do not all contain absolute coordinates.

It is currently anticipated that the spectrum tapes, data base disks, and hard copy spectrum printouts will be archived somewhere in Las Vegas.

The in situ samples are taken on a regular grid, at stakes identified by the four digits of their coordinates north and east relative to the Oscar triangulation platform*. The full coordinate is not necessary because knowing the island gives the first two digits. Americium-241 concentrations and counting errors will be stored on tape in arrays so that relative matrix positions are identical to relative ground positions. Matrix positions beyond the edge of an island will be set to zero, and there will always be at least one array row or column beyond any edge. If the data array must be broken into subsets to meet the estimation routine's limitation of 400 data points, the entire array will also be available in a single file for reference. When the Pu/Am ratio has been established (see "Soil Sample Data Procedures"), similar arrays of Pu concentrations will be calculated and stored.

The data matrix is used by the Gamma and Gamtst programs (files Ø, 1) to plot the raw semi-variogram and test model fits. If a drift is present, GenCov (File 2) fits the generalized covariance. The model chosen should fit the raw variogram reasonably well, and should make sense in light of the support of the data, the sampling method, and previous experience.

Printouts of the raw data and numerical results of model fitting, along with plots of the raw variogram and the fitted model, will be maintained in the results notebook. Written comments on the data and the model will appear in the daily log.

The covariance structure will be used to make kriging estimates of average Am and Pu concentrations (KrigIn, 16Krig, 9Krig on disk; tape files 2, 3, and 22). Estimates and standard deviations of kriging errors will be stored on tape for averages over two different areas. Printed outputs of the estimates, $1/2\sigma$ upper bounds (16prt, 9prt on disk; tape files 6, 14), and contour intensity plots (CnfBnd; file 16) will be reviewed by the Technical Advisor, EG&G and Eberline, then submitted to the ERSP Manager and JTG for action. Copies will also be kept in the result notebook.

When excavated and adjacent areas are resurveyed, the new data will be placed in the proper matrix position and stored on tape without altering the original data (i.e., in a new file). New estimates of averages and errors will be made and stored, and the printouts submitted for review and action.

Upon completion of cleanup for an island, a certification run will be made to estimate residual concentrations on the entire island with the most current data. The printed outputs will be prominently marked "Certification Estimates"**.

III. Soil Sample Data Procedures

The Eberline laboratory will store the soil sample results on magnetic tape in the form of two descriptive strings and a 2048 word integer spectrum array for each data point. The data can be stored directly on disk from tape (EICDB1 on disk; tape file 25), except for coded quality assurance samples, which require manual input to decode. The results for a data point will be stored logically as strings on a single 21-record file. Procedures for file names, disk labels and cataloging are similar to the in situ data base; details are in the soil sample data base program documentation, along with exact data format. The program documentation also includes examples of data retrieval. Update and correction procedures are the same as the in situ data base***.

The physical soil samples consist of two six-sample composites from each selected in situ survey location. The randomly-oriented pattern samples the field of view of the detector with a density approximately corresponding to the weighting function of the detector geometry.****

*Stake locations and identifiers followed the grid numbering systems established by the surveyors. Attempts to tie in to the Oscar system failed.

**Certification Estimates, as such, were not produced. However, final data maps were produced for islands from which soil was removed.

***EIC has extensively modified the procedure described. Details may be found in Chapter 4.

****The pattern was based on misinformation about detector response; as a result it does not correspond even roughly to the correct weighting function.

One purpose of the soil samples is to determine the Pu/Am ratio in order to calculate Pu concentrations from ^{241}Am concentrations. The total concentrations will include all Pu isotopes for which Eberline determines values. Preliminary data indicates that, for most islands, the set of ratios is distributed symmetrically and unimodally, with small variance; the mean of the distribution is therefore the desired ratio value. Histogram plots, goodness-of-fit tests, or other analyses will be used to verify the shape of the distribution and estimate the mean.

On a few islands, the ratio distribution has a large variance, or is a mixture of two or more distributions with different means. If possible, the island will be divided into subsections so that each contains ratios from a pure distribution. Statistical analyses will be performed to verify the appropriateness of the subdivision, and additional samples requested as necessary to assure accurate results. If this proves impossible, soil samples would, as a last resort, have to be taken at every survey location.

Documentation concerning the ratios used, the areas each ratio applies to, and justification for each will appear in the daily log and the results notebook. The chosen ratios will be used to calculate Pu concentrations, on which the covariance structure will be refitted if necessary.

Another objective of the soil sampling is to confirm the calibration factor on the in situ detector. The average ^{241}Am from soil samples should roughly equal the in situ value; since the actual area of measurement of the two methods is much different, exact equality is unlikely. If, however, the two values are totally inconsistent, EG&G and Eberline will be informed immediately so that the soil samples and in situ data can be checked. It is imperative that such discrepancies be resolved before any additional sampling is done.

IV. Procedures for Other Data Bases

For the health physics data base, Eberline will produce data stored on tape as two strings, which will be written logically to disk, one sample per two-record file (EICDB2 on disk; tape file 26). File name, disk label and catalog procedures are similar to the in situ data base. Details, along with data formats and sample retrievals, are in the health physics data base documentation.

Source documents of data collected by the FRST are maintained by the JTG staff, and will be used to input that data by hand to a separate FRST data base*. The data, two strings per sample, will be stored logically on one-record files, one sample per file. Field data from contaminated islands and environmental data from clean islands will be stored in the same format, but on separate disks.

Because of the increased probability of error due to hand input, a printed copy of the input data will be made, checked against the source document, and retained permanently. Details on file names, disk labels, catalogs, and sample retrievals are in the FRST data base program documentation.

V. Other Analyses, Documentation and Maintenance Procedure

Statistical analysis may be required on other types of data (e.g., water consumption patterns); the type of analysis appropriate to the situation is a matter of judgment for the Statistician. The plotter should prove an effective tool for presenting data and results, and for producing special format reports.

Complete, accurate documentation will be maintained continually. For example, permanent alterations in a program will be stored on the tape and disk copies and the program listing and documentation and the tape and disk catalogs updated. New programs in the repertory will be stored, listed and documented, and placed in the program documentation notebook.

Originals or copies of results of covariance fits, estimates, or other analysis will be stored in the results notebook, along with explanatory documentation as required. The daily log will contain notes on work accomplished, programs written or revised, problems encountered, approaches and suggestions for the other statistician.

*Responsibility for entry of FRST data was transferred to a military base in the U.S. in the fall of 1977; thus, DRI had no further contact with the FRST data after October 1977.

In addition to the individual reference coordinates on the disk labels, a complete hard copy list will be maintained. A running catalog will be maintained on incomplete disks, and a final catalog printed for complete, updated, verified disks, from which the WRITE tab will be removed. Tapes containing verified Am and Pu data or final estimates will also be write-protected.

Procedures documentation will also be kept current, and running commentary made in the daily log until procedures are well-established.

The owner's manuals for the H-P equipment list required and recommended maintenance on the calculator and peripherals. Tapes and disks will be stored properly and safely, away from strong magnetic fields. External tape and disk labels will indicate clearly, with indelible ink (use only felt tip on disks), the tape or disk contents.

SOIL SAMPLING PROCEDURE

DOE/ERSP PROCEDURE NO. 4 DATE DRAFTED: 18 August 1977

APPROVED: 1 March 1978 by Don R. Martin (ERSP Manager)

I. Purpose

To establish a standard soil sampling procedure to confirm the ^{241}Am concentration and to determine the TRU-to-Am ratio; to support the in situ van measurements; and to provide effective guidance for exploratory soil sampling intended to examine selected areas for profile radioactivity information.

II. General

A. The in situ van measurements program requires that representative surface samples be analyzed using wet chemistry techniques. The number and location of the sampled areas must satisfy the statistical requirements of the program, and the sampling design must be of a standard repeatable pattern oriented in a random manner.

B. Known or suspected burial areas, and possible SGZ areas, require subsurface investigation. Since no two situations will be alike, procedures will be developed on a case-by-case basis. However, guidance for acceptable approaches and practices will be discussed.

III. Responsibility

A. The DOE Technical Advisor will select the 4-hectare parcels and the grid location within each parcel for surface sampling.

B. The ERSP Manager, with the assistance of the Technical Advisor and the Eberline Laboratory Manager, will develop procedures on a case-by-case basis for subsurface soil sampling after the ERSP Manager has coordinated the need for profile information with the JTG.

C. The Eberline Laboratory Manager will train and supervise personnel designated as soil samplers.

D. The Eberline Laboratory Manager will provide containers for collecting soil samples, will receive and analyze the samples, will furnish analytical data to the Statistician, and will store samples by their approved identification numbers in the sample library. Further disposal instructions are reserved for the ERSP Manager.

IV. Surface Soil Samples

The criteria listed below apply when soil samples are taken from the surface to support in situ van operations after a grid of measurement locations has been established.

A. One location in every 4-hectare parcel of land will be soil sampled. However, no island will be sampled in less than four locations.

B. The selection of a location to be sampled will be based on visual inspection, in situ survey, and portable instrument (FIDLER or PG-2) survey. The location must be visually typical of the parcel and must not contain a "hot spot" of radiation near the 60 keV energy level. It should be close to the center of the parcel.

D. Before collecting soil from a collection point, remove any above-surface debris such as sticks, stones, organic or other materials that are not part of the surface soil.

E. Include all material (rocks and organic) excised in the 300 cm^3 sampling tool with the composite sample.

F. Each composite sample will contain six individual samples—one taken from each of six points within the selected location at the depth of interest. The procedure for physically sampling a given location will be as follows:

1. Spin a freely rotating pointer at the center of the location to determine a random direction. Record on sample label this direction in degrees from a magnetic north.

2. Place a prepared meter-square piece of plywood at the center of the location with the arrow on the plywood oriented in the direction of the pointer. This square piece of plywood has a bolt in its center and six hexagonal head screws located on azimuths bearing in the direction of the six individual sampling points of the "A" composite sample and six slot-head screws for the "B" composite sample (See Figure A-4-1).

3. A piece of nylon line with a loop on one end is marked at 1.8, 5.3 and 8.8 meters from that end. Place the loop over the center bolt in the oriented plywood platform and, using the marked line, extend the line in the direction of each of the six hexagonal screws (Composite "A") to determine the individual sampling point at the appropriate indicated distances.

4. Use the square sampling tool, "cookie-cutter" (10 cm on a side and 3 cm deep), to delineate the area and depth of each individual sample making up the composite. This tool is made of steel. It is sharp on the bottom edge with a shoulder 3 cm up from the bottom, and with one side open below the shoulder. When used to collect a sample, the tool is forced into the soil until its shoulder rests on the surface. A steel shovel-like companion tool is then used to cut soil from the open side and to enter that side to remove the 300 cm^3 of surface soil contained by the tool. Remove soil to repeat the sampling procedure at 10 cm depth and then at the 20 cm depth.

5. Without changing the plywood platform used to collect the "A" composite sample proceed to align the line to the slot-head screws to collect the "B" composite sample. Collect the "B" composite in the same manner as "A" was collected.

G. An individual sampling point will be sampled exactly where located unless that point is not representative of the selected in situ location. In such a case, the point will be moved to the closest acceptable point. The direction and distance of the move will be recorded on the sample label; e.g., if the located point should fall on a 1000 cm^3 rock in a sand area, the point would be moved off the rock onto the sand.

H. Decontaminate the sampling tools after completing a selected in situ location by scouring them with soil from the location to be sampled or by washing them with clean water (fresh or sea). It is not necessary to decontaminate these tools while the samples are being composited at one location.

I. After samples are collected and identified, surveyed (see below), and deviations have been noted, deliver them to the Eberline Sample Preparation Trailer on Enewetak Island for processing and radiochemistry analyses.

V. Subsurface Soil Sampling

A. When it has been determined that subsurface samples are required to evaluate an area in profile, the area will be located on a map and a procedure for the specific case will be written including the location and depths of the sampling points and the criteria for extending areas or depths.

B. One of two methods will normally be used to explore the subsurface. Either the area will be ditched with a backhoe so that trenches can be entered for sidewall samples, or it will be probed with a core-type earth auger according to an area and depth design pattern. Each method has advantages that depend on the situation. The auger is less physically disturbing to the area, but if metal or other buried objects are discovered, a backhoe or other substitute method may have to be employed.

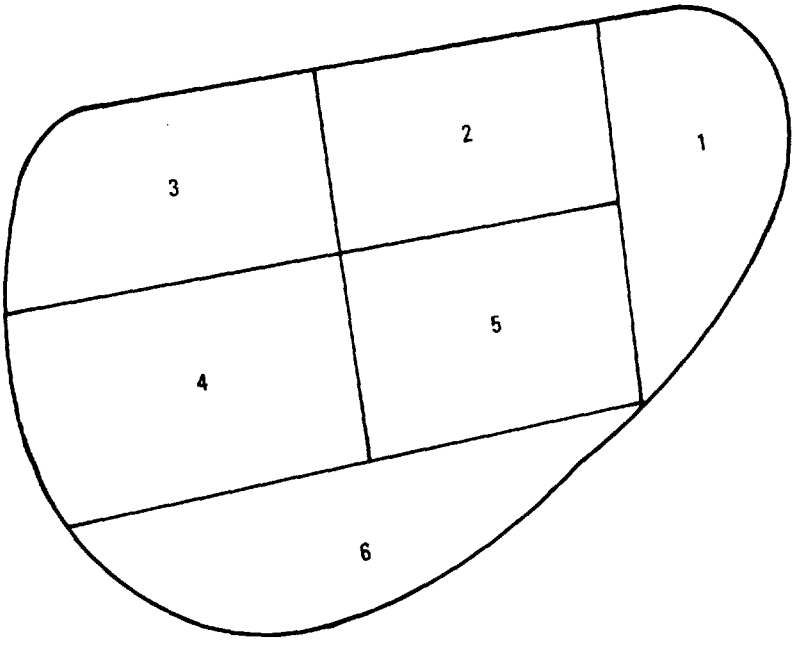
C. Subsurface soil samples will be identified with their grid location and depth measured in centimeters from the surface of the ground to the top of the soil removal point. The nominal sample size will be about 500 cm^3.

D. Sidewall samples from a trench or core samples from an auger will be analyzed in a fixed calibrated geometry using an intrinsic Ge detector and multichannel analyzer.

E. It is emphasized that subsurface sampling is exploratory and may require a change in direction during an operation. The important ingredients are planning, flexibility, and experienced supervision. Under certain conditions, the FIDLER or PG-2 detectors may be used effectively to facilitate searches for contaminated soil areas.

VI. Soil Sampling Area Selection

A soil sample (for in situ van calibration purposes) shall be taken in each 4-hectare parcel. For a 24-hectare island, this would call for 6 sample locations. Islands smaller than 16-hectare will still require 4 areas to be sampled. For example:



24-Hectare Island

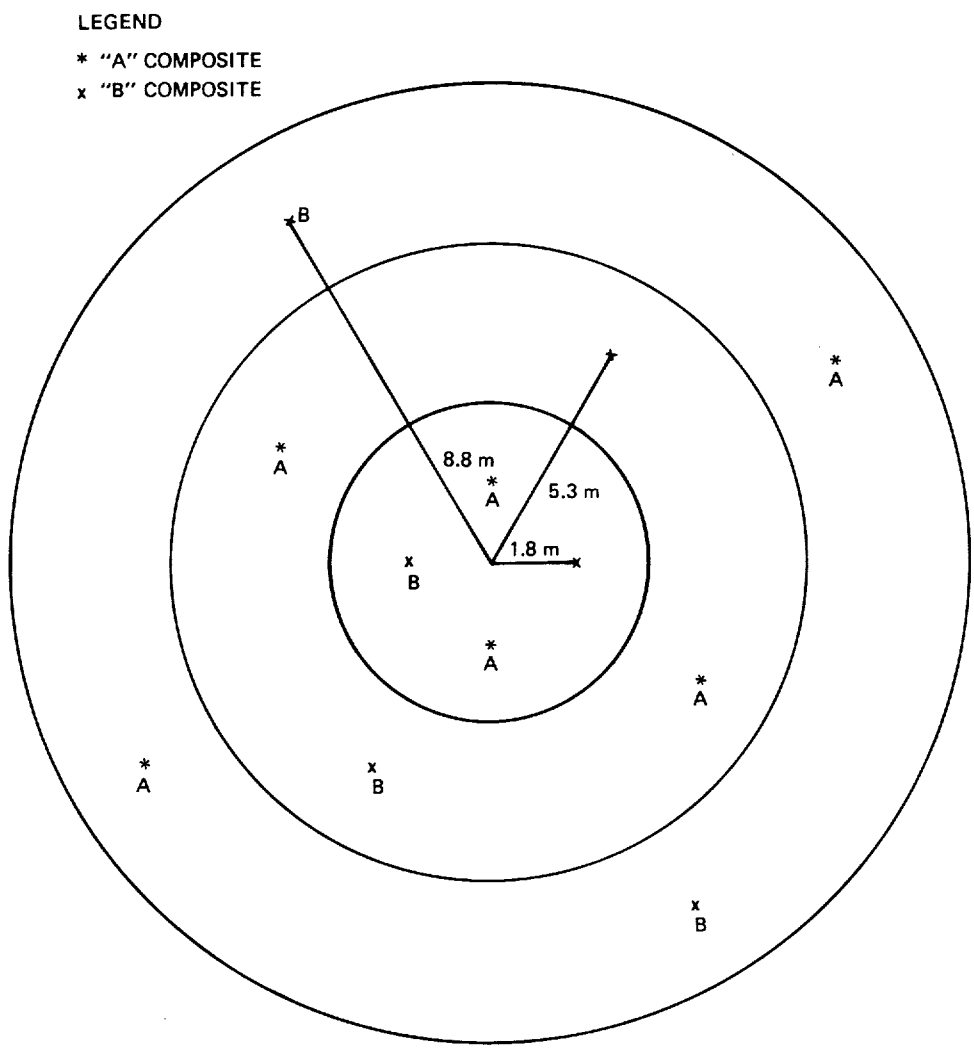


FIGURE A-4-1. LAYOUT OF SOIL SAMPLES FOR BACKUP OF IN SITU DETECTOR

Changes to Soil Sampling Procedure (ERSP No. 4), 20 April 1978.

IV. Surface Soil Samples

C. Replace with:

Four composite samples called A, B, C and D (each of which will contain soil from six points around the selected location as explained in F. below) will be taken from the surface of each selected location and shall be identified by grid location, composite and bearing.

F.6. Add:

After composites A and B have been taken, rotate the plywood platform 45° clockwise and collect the C composite in the same manner as the A composite was collected. Then collect the D composite just as the B composite was collected.

Add to end of:

I. The C and D composites are to be analyzed only if so directed by the DOE Technical Adviser after his review of the A and B composite data.

Signed by Bruce Church, ERSP Manager.

Changes to Soil Sampling Procedure (ERSP No. 4) and Letter to "All ERSP Elements & Project Managers" dated 20 April 1978.

IV. Surface Soil Samples

Add to end of:

I. The C and D composites are to be analyzed only if so directed by the DOE Technical Adviser after his review of the A and B composite data.

Delete the above sentence (IV.I) as revised by letter dated 20 April 1978.

Insert in its place the following sentence:

The C composite is to be analyzed in the same manner as the A composite sample, and the D composite treated in the same manner as the B composite sample.

Signed by Paul J. Mudra, ERSP Manager, 2 May 1978.

SOIL SAMPLING PROCEDURE - SOUTHERN ENEWETAK

DOE/ERSP PROCEDURE NO. 4a DATE DRAFTED: 10 September 1978

APPROVED: 10 October 1978 by Bruce W. Church (ERSP Manager)

I. Background

In joint session and considering Procedure No. 4, the ERSP Manager, ERSP Technical Advisor, and Element Managers for DRI, EIC and EG&G agreed on 8 September 1978 that the following soil sampling procedure would be preferred for documenting the final cleanup condition of the southern or uncontrolled islands of Enewetak Atoll. Additional background may be found in the Element Managers' and Technical Advisor's log books for September 1978.

II. Purpose

To establish a standard soil sampling procedure for use in documenting ^{241}Am, ^{238}Pu, $^{239,240}Pu$, ^{137}Cs, and ^{60}Co in soil for the smaller islands of Enewetak Atoll; i.e., Sam through Leroy excepting Elmer which will be measured by the IMP.

III. General

NVO-140 yields informative data for the above islands useful in establishing radiological condition and designing further sampling.

A. NVO-140 information will be used to guide the DRI in selecting 4 or more soil sampling locations from an island.

B. EIC soil sampling teams will collect from each location composites A and B as defined in ERSP Procedure No. 4.

C. EIC will stake and flag the location for future reference.

D. Analyses will include the isotopes listed in II above.

E. Samples from all locations will be archived.

IV. Specific

A. Procedure No. 4 specifies that vegetation and other organic litter should be removed and only the underlying soil sampled. For some of the southern islands this organic layer may be of significant depth and may contain materials of interest. Therefore, in locations where the organic layer exceeds 5 cm in average thickness above mineral soil at the sampling location, A and B composite samples of the organic layer will be taken. The "cookie cutter" tool will be used to define the area of the sample and the sample depth will be the total depth to mineral soil.

B. A and B composite samples of surface mineral soil will be taken according to Procedure No. 4 regardless of the thickness of the organic layer.

QUALITY CONTROL PROCEDURE

DOE/ERSP PROCEDURE NO. 5 DATE DRAFTED: 30 January 1978

APPROVED: 7 February 1978 by Don R. Martin (ERSP Manager)

I. Purpose

To assure quality of results.

II. Applicability

This procedure applies to the Pacific Laboratory (DOE Element) on Enewetak Atoll.

III. Responsibility

The Pacific Laboratory chemist is responsible for the conduct of the Quality Control program. He will prepare blind spikes that will be processed in the normal procedure. At completion of processing the letters "QC" will be suffixed to the assigned sample number, and a comparison will be made between the known and obtained values.

IV. Procedure

A. Plutonium and americium by alpha spectroscopy.

1. Tracers:

a. Appropriate tracers will be added to determine the chemical recovery of plutonium and americium.

b. The plutonium tracer will be cross-checked by alpha counting against an NBS standard, at time of preparation. The americium tracer will be an NBS standard.

c. Purity of tracer will be determined by alpha spectrometry at time of preparation.

2. Duplicate analyses:

a. A duplicate field sample will be run using the normal procedure once a week.

3. A reagent and glassware blank will be run after a high level (this to be determined by the chemist) sample has been processed.

4. Background soil:

a. Soil from Enewetak Island will be used as "background" soil.

b. A sample of this background soil will be run once a week using the normal procedure.

c. The same soil will be used to prepare the blind spikes.

5. Spiked soil samples:

a. A blind spike will be analyzed each week. This blind spike will have a known amount of Pu and/or americium comparable to amounts found in soil and the amounts of each will vary from week to week.

6. Results:

   a. Quality control data will be evaluated each month.

B. Radiation Detection Instruments.

1. All gross alpha counters will be calibrated daily with a plutonium standard and a background determined daily.

2. All gross beta counters will be calibrated daily with a strontium-yttrium standard and a background determined daily.

3. The liquid scintillation counter will have the background determined as well as a calibration run daily when in use.

4. The alpha spectrometer(s) will have a background, energy and efficiency determination weekly using sources traceable to National Bureau of Standards values or The Radiochemical Center, Amersham, England values.

5. The gamma spectrometer(s) will have a background, energy and efficiency determined weekly, using solution traceable to NBS or AS.

V. Reports

All calibration data will be recorded and filed. Logged QC results will be available each month.

A monthly quality control report will be compiled and reported to DOE/ERSP Manager with a carbon copy to Eberline Instrument Corporation, Santa Fe, New Mexico.

RADIATION SAFETY

DOE/ERSP PROCEDURE NO. 6 DATE DRAFTED: 30 January 1978

APPROVED: 9 February 1978 by Don R. Martin (ERSP Manager)

Sample Preparation Lab

All work on open soil samples will be carried out under a hood.

The operator will wear a disposable dust mask.

When the screening of a sample indicates gross alpha activity concentration of between 100 and 400 pCi/g, the sample will be opened and processed under the high velocity hood with the operator wearing gloves, protective clothing and a half face mask. Upon completion of processing, protective apparel will be disposed of or monitored; immediate area and personnel will be surveyed; and the pertinent employees will wash their hands.

If the screening indicates a concentration exceeding 400 pCi/g, the sample will be returned to the presenting organization with accompanying warnings and disposal recommendations or handled in accordance with DOE/ERSP Procedure No. 16.

DISPOSAL OF RADIOACTIVE WASTE MATERIAL FROM THE RADLAB

DOE/ERSP PROCEDURE NO. 7 DATE DRAFTED: 31 January 1978

APPROVED: 4 March 1978 by John D. Stewart (ERSP Manager)

I. Purpose

To establish a standard procedure for disposal of radioactive waste material from the RADLAB.

II. Applicability

This standard operating procedure applies to radioactive materials that are required to be used in the lab during its normal course of performing laboratory support for the Enewetak cleanup.

III. Responsibility

The Eberline laboratory manager is responsible to the ERSP to ensure that the lab personnel comply with this SOP.

IV. General

Radioactive waste materials are generated in the laboratory during the normal course of sample processing. These waste materials must be disposed of in a safe manner. The radioactive waste will be in two forms (solutions & solids), each requiring a different consideration for disposal.

V. Procedure

A. Radioactive Solutions. Small amounts of radioactive solutions will be generated by:

1. Remaining portions of samples after chemistry.

2. Materials used as tracers.

3. Organic materials used in sample processing.

All radioactive materials in solutions except organics will be washed out the drain system. The amount of water (approximately 100 gallons/day) that is used will dilute the concentrations to levels that are well below MPCs for drinking water. See following text for calculation of level. Periodic samples will be taken from the acid neutralizing tank to verify this assumption.

Organic liquid waste will be transferred to a 55-gallon drum and vermiculite added as an absorbent material.

B. Solid Material.

1. All disposable materials generated from the preparation lab will be disposed of in a yellow 55-gallon drum marked RAD WASTE.

2. All glassware pipette tips and other disposable materials will be collected in a 55-gallon drum marked RAD WASTE.

3. These drums will then be handed over to FRST Rad Control for disposal.

C. Concentraton of Waste Water.

1. Assumptions:

a. Sixteen samples per day through laboratory with 8 Pu and 8 Am analyses.

b. Sample levels do not exceed 400 pCi/g which is to be considered ^{239}Pu, with a public MPC in water of 5×10^{-6} Ci/cc or 5 pCi/cc.

c. Water usage in laboratory is 100 gal/day.

2. Calculations:

a. Pu Analysis.

Sample Loss (25% of 5 g) (8 samples) (400 pCi/g)	=	4,000 pCi.
Tracer Loss (25% of 72 dpm) (8 samples) (.45 pCi/dpm)	=	65 pCi.

b. Am Analysis.

Sample Loss (85% of 5 g) (8 samples) (400 pCi/g)	=	13,600 pCi
Tracer Loss (85% of 80 dpm) (8 samples) (.45 pCi/dpm)	=	245 pCi
Total pCi/day	=	17,910

$$\left(\frac{17{,}910 \text{ pCi/day}}{100 \text{ Gal/day}}\right)\left(\frac{1 \text{ gal}}{3{,}785 \text{ cc}}\right) = 0.05 \text{ pCi/cc}$$

This value is 1/100 of MPC for public water based on ^{239}Pu.

LABORATORY SOIL SAMPLE PREPARATION

DOE/ERSP PROCEDURE NO. 8 DATE DRAFTED: 30 January 1978

APPROVED: 2 March 1978 by Don R. Martin (ERSP Manager)

I. Purpose

To provide uniform analysis and preparation procedures for soil samples.

II. Applicability

This procedure applies to all soil samples received at the Enewetak Sample Preparation Trailer.

III. Responsibility

The Laboratory Chemist is responsible to the EIC Manager for implementation of this procedure within the sample preparation facility on Enewetak.

IV. Analysis and Reports

Samples are generated from three principal sources and require the following analysis and reports. Other samples will be handled on a case-by-case basis. Sample handling is shown graphically in Figure A-8-1.

A. DOE In Situ Van Soil Samples.

In situ samples are collected using DOE/ERSP Procedure No. 4. Samples are taken in two composites, A and B, at the depths of 0, 10 and 20 cm.

1. Analysis:

a. Total wet weight, wet volume and total dry weight will be recorded.

b. All samples will be dried and ballmilled.

c. Gross alpha, Pu-chemistry and gamma scan will be done on all A and B composites.

d. Am-chemistry will be done on 0 cm, A composite only.

2. Report (To DOE/Data Reduction):

a. Wet weight, wet density and dry weights, gross alpha, ^{238}Pu, $^{239,240}Pu$, ^{241}Am by gamma, and ^{241}Am by chemistry.

b. Data from the label, gamma spectrums, results, raw data and calibration data used to generate results will be stored on magnetic tape files and sent to DOE Data Reduction for permanent storage at NV. No alpha spectrum data other than peak totals will be stored.

B. DOE Ground Zero and Subsurface Investigations.

DOE GZ and subsurface samples are collected using DOE/ERSP Procedure No. 4. Samples from a specific grid location are collected from the surface and at 20-cm intervals to a depth of 120 cm.

1. Analysis:

a. Gross alpha on dry rough soil will be done on all samples.

b. The Chemist will pick 10% of the samples and the following analysis will be performed. Where GZ samples are involved, one shall be a surface sample.

(1) Record total wet weights, wet volume and total dry weight.

(2) Dry and ballmill all samples selected.

(3) Run gross alpha, Pu-chemistry, and gamma scan on all selected samples. Run Am-chemistry on one sample out of group.

(4) If samples are from GZ areas, run one surface sample for isotopic uranium.

2. Report (DOE/Data Reduction):

a. Gross alpha on dry rough soil will be done on all samples.

b. Wet weight, dry weight, wet density, gross alpha, ^{238}Pu, $^{239,240}Pu$, ^{241}Am by gamma and ^{241}Am by chemistry on 10% selected.

c. Isotopic uranium on surface GZ sample.

d. Data from the label, raw data, results, calibration data and all gamma spectrums generated will be stored on magnetic tape and sent to DOE/Data Reduction for permanent storage.

C. FRST Team Samples.

FRST samples are collected by FRST field crews in support of FCDNA operations.

1. FRST samples are not ballmilled and typically will not be analyzed for more than dry gross alpha. Additional analysis will be requested by FRST on a case-by-case basis after gross alpha data is received.

2. Report (FRST Team with copy to DOE/Data Reduction):

a. All gross alpha and other data as required.

V. Procedure

A. Soil samples are received in 1/2- and 1-gallon cans furnished to field crews by EIC supply. As sample cans are received at the sample preparation facility, they should be checked to assure that metal labels are affixed and complete field data is written in.

B. The sample is screened on the FIDLER to estimate its ^{241}Am content.

1. If pCi/g of ^{241}Am is <60, proceed to Step C.

2. If pCi/g ^{241}Am is ≥ 60, do not open can. Notify chemist who will estimate gross alpha based on previous samples or other island data. If his estimate indicates gross alpha to be less than 400 pCi/g, proceed to Step C.

3. If sample gross alpha estimate is greater than 400 pCi/g, then handle by high level procedure (DOE/ERSP Procedure No. 16), after obtaining DOE/ERSP Project Manager's approval.

C. Homogenize sample by stirring with a disposable spoon and take a random portion of rough soil and dry. Spread approximately 50 grams of dry soil evenly in an AC-3 plastic cover, place a spacer on top and take a gross alpha reading.

1. If gross alpha count >400 pCi/g, handle as per high level procedure (DOE/ERSP Procedure No. 16), after obtaining DOE/ERSP Project Manager's approval.

2. If gross alpha count ≤400 pCi/g, proceed.

D. Wet weight and volume are recorded and total sample is dried and ballmilled.

E. Dry weight is recorded and 50 grams of ballmilled soil is spread in an AC-3 cover and counted for gross alpha.

1. If gross alpha count >400 pCi/g, handle as per high level procedure (DOE/ERSP Procedure No. 16), after obtaining DOE/ERSP Project Manager's approval.

2. If gross alpha count is ≤400 pCi/g, proceed.

F. Sample aliquots taken for Pu and Am chemistry analyses are muffled at 700°C for 4 hours.

1. Five grams for gross alpha levels <100 pCi/g.

2. One gram for gross alpha levels ≥100 but <400 pCi/g.

G. A standard petri dish (100 x 20 mm size) is filled with approximately 100 g of dry soil, weighed and covered with a dish lid, sealed with 1/2-in. black vinyl tape and passed on to the counting laboratory for gamma analysis.

1. (Optional) If a beta count of the sample is required, seal the dish with a thin plastic sheet and count with an HP-210, then affix top and pass to counting laboratory for gamma analysis.

H. After completing analyses, return all portions of soil to sample collection can for storage at warehouse or as directed by chemist.

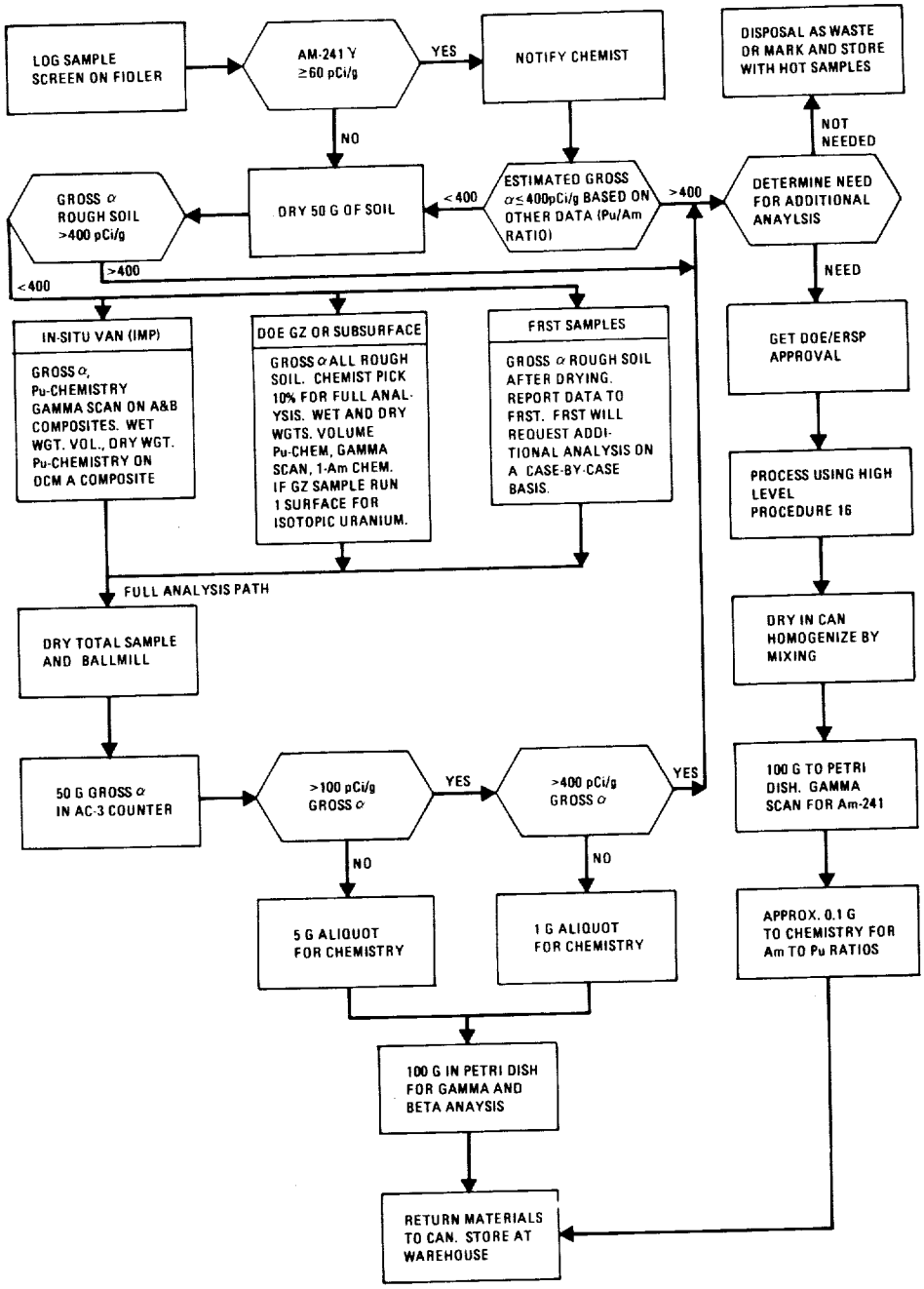


FIGURE A-8-1. SOIL SAMPLE FLOW CHART

DIRECT ALPHA COUNTING OF SOIL SAMPLES

DOE/ERSP PROCEDURE NO. 9 DATE DRAFTED: 30 January 1978

APPROVED: 8 February 1978 by Don R. Martin (ERSP Manager)

I. General

The purpose of this procedure is to provide a method of determining the plutonium activity in soil by counting the alpha activity present. This procedure provides for only an estimate of the plutonium activity.

Several variables interact which could cause significant error in the interpretation of direct alpha counting, such as the ^{238}Pu to $^{239,240}Pu$ ratio and the $^{239,240}Pu$ to ^{241}Am ratio. When an accurate determination of the concentration is desired alpha spectrometry should be used.

II. Sample Preparation

After logging in the sample, an aliquot of soil is transferred to an AC-3 probe face plastic cover. The volume of the aliquot should fill the bottom of the cover to a depth of approximately 0.5 cm. Remove organic debris and rocks with diameters larger than 0.25 cm. Spread the sample evenly over the bottom of the cover and break larger chunks of soil into granules to homogenize the sample.

Dry sample for several hours to remove all moisture. Water entrapped in the sample will shield the alphas emitted from the soil and cause as much as a 50% reduction in the gross alpha counts detected. To dry the sample at higher temperatures an aluminum foil drying pan may be substituted for the plastic face cover.

III. Sampling Counting

Prior to counting, place an open AC-3 probe face, with webbing removed, on the sample to prevent the probe from resting directly on the soil. The spacer thickness should be kept to a minimum, thick enough only to prevent contamination of the probe face. Care should be taken when placing the AC-3 probe on the spacer so that the mylar window of the probe is not punctured; then count the sample for 10 minutes with the AC-3 probe on the spacer above the sample. The concentration of plutonium in soil is calculated by dividing the net counts (gross 10-minute count minus the 10-minute background count) by 1.07. This is an empirically derived conversion factor obtained by Dr. Bramlitt, of DNA, while he was at Enewetak.

PLUTONIUM IN CORAL SOIL

DOE/ERSP PROCEDURE NO. 10 DATE DRAFTED: 30 January 1978

APPROVED: 15 February 1978 by Don R. Martin (ERSP Manager)

Plutonium in Coral

1. Dissolve ashed residue with 30 ml of 8N HNO_3. Place in ultrasonic cleaner, if necessary, to dissolve sample. (HF treatment is necessary on all samples containing silicates.) Plutonium-236 is added as internal tracer.

2. Add 5 ml of 25% w/v $NaNO_2$; place on hot plate for 5-10 minutes to expel NO_2 fumes. Cool sample at room temperature.

3. Transfer to 125 ml separatory funnel, add 40 ml of 30% v/v Aliquat-336 in xylene, shake for 5 minutes, allow phases to separate for 15 minutes. Save aqueous phase for americium analyses.

4. Add 30 ml of 8N HNO_3 to Aliquat-336, shake for two minutes. Allow phases to separate for five minutes and reserve aqueous phase for americium anaylsis.

5. Back extract plutonium from Aliquat-336 with 50 ml of $HClO_4$ + oxalic acid solution. Shake for 5 minutes. Collect plutonium in 150 ml beaker.

6. Add 1 ml of 5% $NaHSO_4$ and evaporate sample in perchloric fraction hood.

7. Rinse the wall of beaker with HNO_3 and evaporate to incipient dryness.

8. Dissolve sample in 75 ml 8N HNO_3.

9. Pass through an ion column containing AG1X8 (50-100 mesh) or AG1X2 (50-100 mesh) ion exchange resin previously treated with 50 ml of 8N HNO_3. After the sample has passed through the resin column, rinse column with 70 ml of 8N HNO_3, follow with 80 ml of 9M HCl.

10. Elute the plutonium into a 150 ml beaker with 3 x 20 ml of a solution of 9M HCl and 1M NH_4I at a 20 to 1 ratio.

11. Add 10 ml HNO_3 to the eluate, evaporate to near dryness and rinse sides of beaker with HNO_3 and HCl, dropwise.

12. Add 50 ml 8N HNO_3 and repeat steps 9-11 if visible residue remains.

13. Continue heating the sample to dryness, removing the beaker just before the last of the liquid evaporates.

14. Convert the residue to the chloride form by adding 1 ml of concentrated HCl and evaporate to dryness.

15. Electrodeposit the sample as follows:

    a. Add 2 ml of 0.4N HCl to the beaker. Swirl.

    b. Add 3 ml of 4% ammonium oxalate solution. Swirl.

    c. Transfer the electrolyte sample mixture into a numbered plating cell with deionized water. Add rinse to cell. Continue rinse and addition to cell until cell (1/8" from top) is full. Electrodeposit at 210 ma.

16. After 2.5 hours and with current still on, add two drops of phenolphthalein indicator and make basic with 1% NH_4OH.

17. Remove the plating cells and wash them with two 10 ml washes of deionized water.

18. Remove the disc from the cell and allow the disc to air dry.

19. Cool and count 400 minutes on the alpha spectrometer.

20. Calculate dpm of ^{239}Pu per sample as follows:

    a. Add the net counts within the ^{239}Pu channels to obtain total ^{239}Pu counts.

    b. Add the net counts within the ^{236}Pu channels to obtain total ^{236}Pu counts.

    c. Divide total ^{239}Pu counts by total ^{236}Pu counts and multiply this ratio by the total dpm ^{236}Pu added in step 1:

$$\frac{^{239}\text{Pu counts}}{^{236}\text{Pu counts}} \times \text{dpm } ^{236}\text{Pu added} = \text{dpm } ^{239}\text{Pu}$$

AM IN CORAL SOIL

DOE/ERSP PROCEDURE NO. 11 DATE DRAFTED: 30 January 1978

APPROVED: 11 February 1978 by Don R. Martin (ERSP Manager)

I. Introduction

Americium-243 tracer must be added to the sample during the initial dissolution, prior to the plutonium extraction. If no plutonium analysis is to be performed, the sample may be diluted immediately following the initial dissolution.

Reagents

NH_4OH	1.5M HNO_3
Fe Cl_3 solution	2M HNO_3
HCl	6M HNO_3
0.5M HNO_3	8M HNO_3
50Wx8 Dowex Resin (50-100 mesh)	

II. Procedure

1. Dilute the 8M HNO_3 from the plutonium extraction to 100 ml. Aliquot 20 ml into a 40 ml centrifuge tube.

2. Add approximately 10 mg Fe carrier and stir. Precipitate $Fe(OH)_3$ with NH_4OH. Digest the sample in hot bath for 5 minutes. Centrifuge sample and discard the supernate.

3. Dissolve the sample in 5 ml HNO_3. Digest in a hot bath for 5 minutes. Dilute the sample to 20 ml with deionized water. Add NH_4OH to precipitate $Fe(OH)_3$. Centrifuge sample and discard supernate.

4. Dissolve the sample with 15 ml concentrated HCl and 1 drop concentrated HNO_3 and pass the sample through an ion exchange column pretreated with concentrated HCl. (The resin is BioRad 1x2 50-100 mesh, resin bed is 10 cm x 12 mm.) Collect the load solution and one 10 ml wash of concentrated HCl.

5. Evaporate the sample to dryness. Add 5 ml HNO_3, and 5 ml HCl. Evaporate the sample to incipient dryness. Dissolve the sample with 25 ml of 0.5M HNO_3.

6. Pass the sample through a cation exchange resin column (Note 1). Wash the column with 25 ml 0.5M HNO_3. Wash the column with 100 ml 1.5M HNO_3. Wash the column with 20 ml of 2M HNO_3.

7. Elute the americium into a 250 ml beaker with 100 ml 6M HNO_3. Evaporate the sample to dryness.

8. Transfer the sample to a 40 ml centrifuge tube with 5 ml HNO_3 and deionized water. Add approximately 10 mg Fe carrier. Precipitate $Fe(OH)_3$ by adding NH_4OH. Centrifuge the sample and discard the supernate.

9. Repeat step 4.

10. Add 5 ml conc HNO_3, evaporate to dryness and prepare the sample for electrodeposition.

11. Electrodeposit sample for 4 hours at 180 ma.

12. After 4 hours and with current still on, add two drops of phenolphthalein indicator and make basic with 1% NH_4OH. Empty cell and wash twice with 10 ml of deionized water.

13. Remove disc and rinse with water, followed by an alcohol rinse. Allow to air dry.

14. Flame disc at low heat until disc turns a gold color; cool.

15. Count in alpha spectrometer for 400 minutes.

NOTE 1: The resin bed is Dowex 50Wx8 50-100 mesh 12mmx18cm. The column is pretreated by pouring through 20 ml 8M HNO_3, followed by 25 ml deionized water. 25 ml of 0.5M HNO_3 completes the pretreatment.

CORAL SAMPLE ANALYSIS FOR AM

DOE/ERSP PROCEDURE NO. 11.1 DATE DRAFTED: 19 January 1979

APPROVED: 29 January 1979 by Ernie Campbell (ERSP Manager)

I. Introduction

This procedure supersedes DOE/ERSP Procedure No. 11. This procedure guarantees the complete separation and purification of the americium isotopes from other interfering radionuclides. Americium-243 tracer must be added to the sample during the initial dissolution prior to the plutonium extraction. If no plutonium analysis is to be performed, the sample may be diluted immediately following the initial dissolution.

II. Procedure

1. Adjust the volume of the 8M HNO_3 fraction from the plutonium extraction step to 100 ml with 8M HNO_3. Transfer a 20 ml aliquot into a 40 ml centrifuge tube.

2. Add approximately 10 mg of Fe carrier and stir. Adjust the pH to 9-11 with conc NH_4OH. Place sample in a hot water bath and digest for 5 minutes. Cool sample, centrifuge and discard the supernatant.

3. Dissolve the precipitate in 5 ml of conc HNO_3. Digest in a hot water bath for 5 minutes. Add 20 ml of deionized water. Adjust the pH to 9-11 with 12M NaOH and allow to digest in hot water bath for another 5 minutes. Cool sample, centrifuge and discard supernatant.

4. Wash the precipitate with 10 ml of deionized water, centrifuge and discard the supernatant.

5. Dissolve the precipitate in 5 ml of conc HNO_3 and three drops of conc HCl. Place in a hot water bath and digest for 5 minutes. Add 20 ml of deionized water. Adjust pH to 9-11 with conc NH_4OH and allow to digest for another 5 minutes. Cool sample, centrifuge and discard the supernatant.

6. Dissolve the precipitate in 15 ml conc HCl and 1 drop conc HNO_3.

7. Prepare an anion exchange column with a 12mm x 10cm bed of BioRad AG1X2, 50-100 mesh resin. Wash the column with 50 ml conc HCl.

8. Pass sample through resin column and collect the eluate in a 250 ml beaker. Wash the column with two 10 ml portions of conc HCl. Collect the HCl washes in the same beaker.

9. Evaporate the sample to near dryness. Add 5 ml conc HNO_3 and 5 ml conc HCl. Evaporate to near dryness. Dissolve sample in 25 ml of 0.5M HNO_3.

10. Prepare a cation exchange column with a 12mm X 18cm bed of BioRad 50WX8, 50-100 mesh resin. Wash the column with 20 ml 8M HNO_3 followed by 25 ml of deionized water. Rinse column with 25 ml of 0.5M HNO_3.

11. Pass sample through resin column. Wash column with 25 ml of 0.5M HNO_3, then with 100 ml of 1.5M HNO_3 followed by 20 ml of 2M HNO_3.

12. Elute the americium into a 250 ml beaker with 80 ml of 6M HNO_3 followed by 20 ml of 8M HNO_3. Evaporate the sample to near dryness.

13. Dissolve the sample in 5 ml of 8M HNO_3 and transfer into a 40 ml centrifuge tube. Rinse the beaker with two 5 ml portions of deionized water and add rinse to centrifuge tube. Add approximately 10 mg of Fe carrier.

14. Adjust pH to 9-11 with 12M NaOH and digest in a hot water bath for 5 minutes. Cool sample, centrifuge and discard supernatant (Note 1).

15. Dissolve the precipitate in 5 ml conc HNO_3 and a few drops of conc HCl. Digest in a hot water bath for 5 minutes. Add 20 ml of deionized water and repeat Steps 14 and 15.

16. Adjust pH to 9-11 with conc NH_4OH and digest in a hot water bath for 5 minutes. Cool sample, centrifuge and discard supernatant. Dissolve the sample in 15 ml of conc HCl and 1 drop conc HNO_3.

17. Repeat Steps 7 and 8.

18. Add 5 ml of conc HNO_3 and evaporate to near dryness. DO NOT BAKE.

19. Electrodeposit sample as follows:

    a. Add 2 ml of 0.4 N HCl to the beaker.

    b. Add 3 ml of 4% ammonium oxalate solution. Swirl.

    c. Transfer the electrolyte sample mixture into a numbered plating cell with deionized water. Add rinses to cell until cell is full (1/8" from top).

    d. Electrodeposit at 210 ma for 2.5 hours.

20. After 2.5 hours of electrodeposition and with current still on, add two drops of phenolphthalein indicator and make basic with 1% NH_4OH until pink color appears.

21. Remove the plating cell and wash with two 10 ml washes of deionized water. Remove the disc from the plating cell, rinse once with alcohol and flame over a Bunsen burner.

22. Allow disc to cool and count 400 minutes on the alpha spectrometer.

23. Calculate dpm of ^{241}Am per sample as follows:

    a. Add the net counts within the ^{241}Am channels to obtain total net counts.

b. Add the net counts within the ^{243}Am channels to obtain total net counts.

c. Divide total ^{241}Am counts by total ^{243}Am counts and multiply this ratio by the total dpm ^{243}Am added:

$$\frac{^{241}Am \text{ counts}}{^{243}Am \text{ counts}} \times \text{dpm } ^{243}Am \text{ added} = \text{dpm } ^{241}Am$$

NOTE 1: If there is a substantial amount of residue after evaporating the eluate from the cation resin column (Step 12) and if the first hydroxide precipitate after the cation resin column is a light tan in color and further hydroxide precipitates don't darken (Step 14), repeat the cation resin column (Step 10).

URANIUM IN CORAL SOIL

DOE/ERSP PROCEDURE NO. 12 DATE DRAFTED: 1 February 1978

APPROVED: 4 March 1978 by John D. Stewart (ERSP Manager)

1. Ash a 2-5 gram sample at 700°C for 10-16 hrs. Dissolve the residue in 30 ml of 8N HNO_3 and 2-3 ml of 25% $NaNO_2$. Use ^{232}U as the internal tracer.

2. Transfer the sample to a 125 ml separatory funnel and add 40 ml of 30% Aliquat-336 in xylene. Shake for 5 minutes and allow phases to separate for 10-15 minutes. Drain and discard the aqueous phase.

3. Wash the organic phase with 30 ml of 8N HNO_3. Shake for 2 minutes and allow phases to separate for 5 minutes. Drain and discard aqueous phase.

4. Back extract the uranium from the organic phase with 50 ml of (400 ml deionized water + 16 grams oxalic acid + 80 ml $HClO_4$) solution. Shake for 5 minutes; allow phases to separate for 10-15 minutes. Drain the aqueous phase into a 150 ml beaker. Discard organic phase.

5. Add 1 ml of 5% $NaHSO_4$ to the beaker containing the uranium and evaporate to near dryness.

6. Dissolve sample with 75 ml of 9M HCl. Add 1 ml of conc HNO_3 and stir.

7. Prepare anion exchange column as follows:

   a. To a glass column with 8-inch stem, 5/8-inch inner diameter, add a piece of glass wool to plug the stem opening.

   b. Make a slurry of anion resin (AG1X8 or AG1X2) in a beaker with deionized water and load on column to a height of approximately 8 cm.

   c. Pretreat the column with 50 ml of 9M HCl.

8. Pass sample through the column. Rinse beaker with 20 ml 9M HCl and add to column. Repeat rinse one more time.

9. Elute the uranium into 150 ml beaker with 50 ml of 1M HCl followed by a warm deionized water rinse.

10. Evaporate the solution to near dryness.

11. Electrodeposit as follows:

    a. Dissolve sample with 10 ml of uranium electrolyte (18 ml HNO_3 + 16 ml NH_4OH + 900 ml deionized water adjusted to pH 1.5).

    b. Agitate sample in ultrasonic cleaner.

    c. Transfer to a marked plating cell using the uranium electrolyte to complete the transfer.

    d. Electrodeposit at 300 ma for 2 hours.

12. After electrodeposition is complete, add 2 drops of phenolphthalein and neutralize using 1% NH_4OH until pink color appears.

    a. Rinse and allow disc to air dry.

    b. Flame sample disc and transfer to counting room.

13. Count on alpha spectrometer for 400 minutes.

14. Calculate dpm of U as follows:

$$\frac{\text{U counts}}{^{232}\text{U counts}} \times \text{dpm } ^{232}\text{U added} = \text{dpm U}$$

COUNTING OF NOSE SWIPES

DOE/ERSP PROCEDURE NO. 13 DATE DRAFTED: 30 January 1978

APPROVED: 7 February 1978 by Don R. Martin (ERSP Manager)

The Liquid Scintillation Counter (Beckman LS 100C) should be set up in window 3. The lower level discriminator should be set to 300. The upper level discriminator should be set to 1000.

Procedure

1. The entire end of the nose swab (cotton swab, enclosing piece of wood) is put into a scintillation vial. Four ml of deionized water is added, capped and shook vigorously for 1 minute.

2. Open and add 12 ml of scintillation cocktail. Cap.

3. Shake vigorously for one minute.

4. Label and enter sample number on counting sheet.

5. Wipe sides of vial clean with tissue dampened with ethanol.

6. Put vial into liquid scintillation counter, close cover to allow for adaptation to darkness, about 30 mintes, and count.

   Note: An ^{241}Am standard and blank sample should be prepared in the same manner to determine the counting efficiency and background.

PLUTONIUM IN URINE

DOE/ERSP PROCEDURE NO. 14 DATE DRAFTED: 30 January 1978

APPROVED: 16 February 1978 by Don R. Martin (ERSP Manager)

1. Transfer the sample into a 2 liter graduated cylinder. Make certain the entire sample is transferred.

2. Check acidity of sample using pH paper. If the sample is not acidic (at least pH 2.) cautiously add with a swirling motion 4 ml of conc HNO_3 per 100 ml of sample. N-octyl alcohol may be added if excessive foaming occurs. Mix sample well.

3. Record the acidified volume on sample sheet.

4. Pour 700 ml of urine into a 1000 ml graduate tall form beaker.

   a. If sample is < 700 ml transfer entire sample into a 1000 ml tall form beaker.

5. Record the aliquot used on the sample sheet.

6. Add ten drops of calcium carrier (111 g $Ca(NO_3)_2$ in 200 ml deionized water).

7. Add ^{236}Pu internal tracer and 1 ml of 85% H_3PO_4 .

8. Place sample on hot plate and stir continuously. When temperature of sample is between 70 - 80°C add approximately 200 ml of conc NH_4OH to pH of 9-10.

9. Allow sample to digest for 30 minutes with continuous stirring.

10. Allow sample to stand at least 16 hours, decant and discard liquid.

11. Dissolve the precipitate with 20 ml of 8N HNO_3. Evaporate sample to incipient dryness.

12. Continue wet ashing sample with conc HNO_3 and H_2O_2 until a white residue is obtained (muffle may be used at low temperature to speed up ashing).

13. Dissolve sample in 30 ml of 8N HNO_3; add 2-3 ml of 25% $NaNO_2$. Heat sample and allow to cool.

14. Transfer to a 125 ml separatory funnel and rinse beaker with 8N HNO_3. Transfer rinse to separatory funnel.

    a. Add 40 ml of 30% Aliquat-336 in xylene.

    b. Shake for 5 minutes and let the sample stand for 10 minutes. Discard the aqueous phase (bottom layer).

    c. Add 30 ml of 8N HNO_3 and shake for 2 minutes. Let stand for 5 minutes. Discard the aqueous phase.

    d. Backextract the plutonium from the organic phase with 50 ml portion of $HClO_4$ - oxalic acid solution (400 ml water and 80 ml conc $HClO_4$ to 16 grams of oxalic acid). Collect the backextract in a 100 ml beaker. Discard the organic waste.

15. Add 1 ml 5% $NaHSO_4$ solution to sample and evaporate to dryness in the perchloric acid fume hood.

16. Dissolve the sample with 50 ml of 8N HNO_3.

17. Process sample through an ion exchange column as follows:

    a. Use a column tube with 8-inch stem by 5/8-inch inside diameter. Place glass wool plug in column.

    b. Prepare a slurry of Bio-Rad AG1X2 ion exchange resin with deionized water and transfer the slurry into the column until the resin bed is 8 cm high.

18. Wash the resin bed three times with 20 ml 8N HNO_3. The resin will shrink.

19. Transfer the sample solution to the column and allow to flow through the resin bed.

20. Rinse the beaker with 20 ml 8N HNO_3 and transfer to column. Repeat twice more.

21. Wash column with 20 ml 9M HCl. Repeat twice more.

22. Elute the plutonium with 3x20 ml of 1M NH_4I and 1 ml (20 ml 9M HCl + 1 ml NH_4I). Collect plutonium in 100 ml beaker, add 10 ml HNO_3 and evaporate to dryness.

23. Add 10 ml HNO_3, rinse walls of container and evaporate to dryness.

24. Convert the residue to the chloride form by adding 1 ml of conc. HCl and evaporate to dryness.

25. Electroplate as follows:

    a. Add 2 ml of 0.4N HCl.

    b. Add 3 ml of 4% ammonium oxalate.

    c. Agitate sample in ultrasonic cleaner.

    d. Transfer to a numbered plating cell with deionized water. Rinse beaker with deionized water. Add rinse to cell. Electroplate at 210 ma for 2 hours.

26. After plating for 2 hours, add phenolphthalein indicator and make basic with 1% NH_4OH.

27. Remove plating disc, allow to air dry and flame to blue color.

28. Cool and count on the alpha spectrometer.

Y-90 IN CORAL SOIL

DOE/ERSP PROCEDURE NO. 15 DATE DRAFTED: 30 January 1978

APPROVED: 15 February 1978 by Don R. Martin (ERSP Manager)

I. Introduction

The method used to arrive at a ^{90}Sr value is derived by assuming that secular equilibrium of the ^{90}Y daughter has been achieved and remains in the coral soil. Strontium recovery is assumed to be 100 percent. The only separation time the chemist need be concerned with is the SrY separation during the extraction (T_2).

Reagents

8M HNO_3	NH_4OH (carbonate free)
Yttrium carrier	9M HCl
0.08M HCl	Saturated $(NH_4)_2C_2O_4$
5% HDEHP in toluene	Methyl red indicator
3M HNO_3	Ethanol

II. Procedure

A. Ash 1 to 2 g of coral soil in a muffle furnace at 700°C for 4 hours.

B. Transfer the sample into a 250 ml beaker with 25 ml of 8M HNO_3. Add the desired amount of yttrium carrier (normally 20 mg).

C. Dissolve the sample by boiling, then evaporate to near dryness.

NOTE: Excess residual acid should be avoided. The extraction of yttrium into HDEHP is dependent on a low acid concentration.

D. Allow the sample to cool. Dissolve the sample with 25 ml of 0.08M HCl by warming gently. Transfer the sample to a 125 ml separatory funnel. Rinse the beaker with 5 ml of 0.08M HCl and add the rinse to the funnel.

E. Add 30 ml of 5% HDEHP in toluene to the separatory funnel and shake for 2 minutes. Record the extraction time and date as T_2. Drain the 0.08M HCl from the funnel and discard.

F. Add 30 ml of 3M HNO_3 to the sample. Shake the sample for 2 minutes and allow the phases to separate.

G. Drain the 3M HNO_3 into a 40 ml centrifuge tube. Add conc NH_4OH to the sample while stirring to precipitate $Y(OH)_3$. Digest the sample in a hot water bath until the precipitate coagulates.

H. Centrifuge the sample and discard the supernate.

I. Dissolve the $Y(OH)_3$ in 2-3 ml of 9M HCl. Dilute the sample to 10 ml with deionized water and filter the sample into a clean 40 ml centrifuge tube.

J. Add methyl red indicator to the sample and neutralize the sample to the end point by the addition of NH_4OH. Make the solution just barely acid with 9M HCl. Add 2 drops excess 9M HCl.

K. Add 3-4 ml saturated $(NH_4)_2C_2O_4$ to the sample and stir. Digest the sample in a hot water bath for 5 minutes to coagulate the precipitate. Centrifuge the sample and discard the supernate.

L. Filter the sample into a tarred filter disc (Glass fiber or Whatman 42). Wash the sample once with deionized water and once with ethanol. Dry and weigh the sample and submit it for counting. A completed EIC ^{90}Sr data sheet must accompany the sample.

HIGH LEVEL SAMPLE PREPARATION

DOE/ERSP PROCEDURE NO. 16 DATE DRAFTED: 30 January 1978

APPROVED: 11 February 1978 by Don R. Martin (ERSP Manager)

1. Samples with ≥400 pCi/g gross alpha will fall in this category.

2. These samples will not be ballmilled but merely homogenized.

3. The samples will be dried in sample can and homogenized in special hood area.

4. An aliquot of approximately 100 grams will be transferred to a petri dish (100 x 20 mm) and sealed under special hood area and taken to count room for gamma determination of ^{241}Am.

5. Depending on ^{241}Am activity:

   a. A small portion of soil is transferred to a beaker (approximately 0.1 grams) under a hood area; no weights are needed.

   b. Add ^{243}Am and ^{236}Pu as internal tracers.

   c. Sample is then processed through chemistry to determine ratios of ^{241}Am to ^{238}Pu and to $^{239,240}Pu$.

   Note: While working with high level samples, respirator, gloves, and lab coat must always be worn. All materials used to process these samples, such as glassware, drying pan, gloves, crucible, etc., shall be discarded into container marked "RAD WASTE".

SAMPLE PREPARATION LABORATORY HEPA FILTER CHANGE

DOE/ERSP PROCEDURE NO. 17 DATE DRAFTED: 30 January 1978

APPROVED: 7 February 1978 by Don R. Martin (ERSP Manager)

I. Introduction

By the end of six months of operations about 6000 soil samples will have been processed in this facility, and 10% are ballmilled. Assume that each averages 100 grams and that 0.1% of the material is trapped in one or the other of the 4 HEPA filters. One can further assume then that each filter will accumulate about 15 grams of potentially radioactive material.

The average activity ($^{238, 239}Pu$) for the samples is 10 pCi/g. Therefore one could expect a total of no more than 150 pCi of $^{238, 239}Pu$ to accumulate on each filter in a 6-month period.

Due to the inherent difficulties of determining the levels of alpha radionuclides imbedded deep within filter material, the loaded filters should be treated as though they contain significant levels of Pu, Am and U.

II. Procedure

When the Dwyer Model 25 manometers indicate, in inches of water, that the red lined partial pressure levels have been reached for a hood, filter and blower combination, the HEPA filters are to be changed.

The drying oven hood red line is set at 0.75 inch of water;
The ballmill hood red line is set at 0.80 inch of water;
The muffle oven hood red line is set at 0.75 inch of water; and
The grinding hood red line is set at 0.45 inch of water.

A. Erect wind screen.

B. Don mask and protective clothing.

C. Disconnect the downstream flex pipe from the filter opening.

D. Seal in plastic the downstream pipe opening and the filter opening.

E. Disconnect the upstream flex pipe from the filter.

F. Seal in plastic the upstream pipe opening and the filter opening.

G. Double bag the loaded filter and box.

H. Dispose of as low level radioactive waste.

I. Install new HEPA filter and establish new manometer cut off setting.

J. Survey the personnel and roof area to verify that they are free of contamination.

INSTRUMENT CALIBRATION RANGE

DOE/ERSP PROCEDURE NO. 18 DATE DRAFTED: 1 February 1978

APPROVED: 28 February 1978 by Don R. Martin (ERSP Manager)

I. Purpose

To establish a standard procedure for operating the cesium-137 gamma source ranges for calibration of field instruments.

II. Applicability

This procedure applies to the 100 mCi and 10 mCi cesium-137 sources used at the Enewetak instrument trailer and to the 1 mCi cesium-137 source used at the Ursula instrument trailer.

III. Responsibility

The Eberline Laboratory Manager is responsible to the ERSP to ensure that PMEL and other DOE personnel comply with this procedure.

IV. General

The cesium-137 test sources are to be used for the calibration of gamma and beta-gamma radiation detectors used by the FRST and DOE personnel. A test source consists of a cesium-137 source, a shielded container and a padlock for locking the shield plug in place. The 100 mCi and 10 mCi sources are to be used in conjunction with the external lead shield and source handler system installed on the ocean side of RADLAB bunker on Enewetak.

V. Precautionary Measures

A. The radioactive sources are to be used only under the direct supervision of persons designated by the EIC Manager. Personnel designated shall be limited to the following: EIC Manager, EIC Engineer, Air Force PMEL Supervisor at Ursula, and Air Force Technician.

B. Film badge is required for all personnel using these sources.

C. "Caution Radiation Area" signs shall be placed around calibration area and shall be clearly visible to anyone approaching the area.

D. Operating personnel shall wash their hands before eating or smoking after working with the sources.

E. The source shields shall be locked at all times when calibration is not being accomplished.

F. Sources shall remain in their shielded containers except for the time actual calibration is being done. Personnel exposure shall be maintained as low as practical.

VI. Procedure

Prior to calibration of instruments, establish a rope around the range area with placards reading "Caution - Radiation Area." Calibration is accomplished as follows:

A. Place the source in its shielded container at the required location. Make the necessary calculations to determine the present intensity of the source and distance

required using the equations shown in Section VIII. These data are available in tabular form from the EIC computer.

B. Unlock the shield plug padlock and attach the source handling tool. Proceed to calibrate probe as specified in the instrument procedure manual.

C. During calibration be watchful of personnel entering the field. Immediately, on completion of calibration, lower the source into its shielded container.

D. When calibration operations have been completed remove the source handling tool, lock the shield, place the shielded container in the bunker, and place a weatherproof cover over the shield.

E. Remove the rope barrier from the area and lock the storage bunker.

VII. Source Testing

All sources shall be leak tested in accordance with the current FRST Source Testing SOP 608-06 at least every six months. A copy of the SOP is attached for reference. The source should be leak tested whenever rust is evident on the shield or if it is difficult to return and remove the source from the shield, or when damage to the source is suspected.

VIII. Source Handler

Care should be used during setup of bunker source handling system to assure that source capsule does not drag during removal from and insertion into shield. Shim or align shield and/or bearing unit to prevent any detectable drag. Spacers on shield plug shall be installed to prevent source from impacting on pig bottom during insertion.

Decay of dose rate listed will be as follows:

$$I = I_0 e^{-((0.693)(T))/361.2}$$

I = Intensity at Time T
I_0 = Intensity at calibration date T_0
T = Months from T_0 to present date (measure to nearest 1/10 month)

Intensity values for the Enewetak cesium-137 calibration source are listed below:

Source	Intensity(mR/h @ 100 cm)(I_0)	Date(T_0)
100 mCi (CS-352)	29.9	6/28/77
10 mCi (Future Source)		
1 mCi (CS-818A)	0.35	8/31/77

The following equation can be used to calculate the field intensity-distance relationship:

$$d = 39.37 \sqrt{I1/I2}$$

Where

I1 = Present intensity of field in mR/h at 1 meter after correction factor is applied.

I2 = Intensity of field mR/h at distance d.

d = Distance in inches between source and test point (2.54 cm = 1 inch).

ENCLOSURE TO DOE/ERSP PROCEDURE NO. 18, FCRR SOP 608-06, 12 October 1977.

RADIOACTIVE SOURCE TEST PROCEDURES

1. Reference: None

2. Purpose: To establish serviceability standards and test procedures for radioactive sources, both sealed and unsealed.

3. General:

   a. All radioactive sources will be given initial leak tests by the possessing organization upon receipt.

   b. All radioactive sources will be leak tested at intervals of 6 months by the possessing organization.

4. Leak Test Procedures:

   a. Sources containing alpha emitters:

      1) Use a Whatman filter paper #1 or equivalent material cut to a 4.25 cm diameter circle.

      2) Dampen the paper disc with distilled water.

      3) Thoroughly wipe all surfaces (except active surfaces) of the radioactive sources with the moistened paper. The paper should have sufficient wet strength to prevent it from falling apart when wet. Moderate pressure should be used while wiping the test source.

      4) Allow the paper to dry with the contact face up.

      5) Count the wipe sample using a laboratory proportional counter.

      6) Requirement: If 200 or more counts per minute (cpm) are registered, the test source is unserviceable and should be disposed of as unwanted radioactive material. If leakage of a source is indicated, the general area in which the source set was stored or used should be checked for contamination.

   b. Sources containing beta-gamma emitters:

      1) Use a Whatman filter paper #1 or equivalent material cut to a 4.25 cm diameter circle.

      2) Dampen the paper disc with distilled water.

      3) Thoroughly wipe all surfaces (except active surfaces) of the radioactive sources with the moistened paper. The paper should have sufficient wet strength to prevent it from falling apart when wet. Moderate pressure should be used while wiping the test source.

      4) Allow the paper to dry. Using a beta counter, determine the beta-gamma activity on the paper in terms of disintegrations per minute (dpm).

      5) Wipe test sources showing removable activity of 11,100 dpm (0.005 μci) or more indicate the source is unserviceable and should be disposed of as unwanted radioactive material.

6) If leakage of a test source is indicated, the immediate area in which the test source has been used or stored should be checked for contamination.

c. Shielding of sources while in storage:

1) Radioactive test sources, as packed in their shipping containers, are taken to an area previously checked and found to have a background not exceeding 1 mr/hr. Using a calibrated meter, determine the maximum dose rate at the surface of each container.

2) The dose rate at the surface of the outer container shall not exceed 200 mr/hr. The dose rate 1 meter from the surface shall not exceed 10 mr/hr.

3) If either of the above requirements is exceeded, it is an indication of faulty or insufficient shielding. The items must be repacked, using additional shielding or less items per container. After repacking, the shielding test must be repeated.

d. Records of results will be maintained by the RPO using the Army Functional Filing System.

e. A source wipe test label will be used on the source assembly or on the source container to readily indicate wipe test dates. The following information will be incorporated on the label:

Source Wipe Test Date

Type	_____	Activity	_____
Date	_____	Serial No.	_____
Model	_____	Due Date	_____
By	_____ (orgn)	By	_____ (person)

5. Safety Precautions: In addition to the standard precautions for handling radioactive material, the following are extremely important:

a. Wear surgical type rubber gloves when handling the source. Do not handle the source except with tongs or forceps. Exercise extreme care to avoid dropping the source as this may cause microscopic flaking of the radioactive deposit or other damage.

b. Do not touch the active surface of a test source.

c. Wear a film badge.

d. Wash hands thoroughly after handling sources.

e. Do not eat, drink, or smoke in a storage area containing radioactive material. All personnel participating in the surveillance testing of radioactive material must be monitored for contamination before leaving the area or before eating, drinking or smoking.

RADIO-CHEMISTRY LABORATORY PRIORITY OPERATIONS

DOE/ERSP PROCEDURE NO. 19 DATE DRAFTED: 22 April 1978

APPROVED: 27 April 1978 by Bruce W. Church (ERSP Manager)

Samples submitted to the Radio-Chemistry Laboratory will be analyzed on a routine basis unless otherwise specified by the ERSP Technical Adviser or the ERSP Manager.

Sample analyses may be processed within a different time schedule depending on the degree of priority.

Priority #1 (Routine)

The samples will enter the system at the end of the line of samples and analyses currently in process. The analyses on these samples will be completed within six (6) days. (Notes 1 and 2).

Priority #2 (Facilitate)

Priority assigned by the Technical Adviser.

The samples will enter the system ahead of the line of samples and analyses currently in process. Results on these samples will be available within six (6) days. (Note 2).

Priority #3 (Rush)

Priority assigned by the ERSP Manager.

The samples will enter the system immediately and pre-empt all samples and analyses in process. Laboratory operations will be assigned to a 24 hour work shcedule. Results will be available within three (3) days. (Note 2).

Priority #4 (Super Rush)

Priority assigned by ERSP Manager.

The samples will enter the system immediately and pre-empt all samples and analyses in process. Laboratory operations will be assigned to a 24-hour work schedule. Results will be available in one (1) to three (3) days. In order to obtain results in such a short time, accuracy and reliability will be sacrificed. Other laboratory operations such as drying, ballmilling, muffling, counting, etc., will be limited to meet the above reporting period.

Note #1: Allow one (1) additional day for each ten (10) plutonium and americium chemical analyses and/or fifteen (15) gamma or alpha analyses in process of samples submitted.

Note #2: Allow one (1) additional day for each ten (10) plutonium and americium chemical analyses and/or fifteen (15) gamma or alpha analyses.

In all the above cases except for routine analyses, the request is to be directed to the Laboratory Manager in a written form.

SOIL PREPARATION FOR LIBRARY STORAGE

DOE/ERSP PROCEDURE NO. 20 DATE DRAFTED: 13 July 1978

APPROVED: 1 August 1978 by Roger Ray (ERSP Manager)

I. Purpose

To provide a uniform sterilization and packaging procedure for Enewetak Cleanup Project soil samples to be archived by DOE.

II. Applicability

This procedure applies to soil samples selected for Library Storage and processed by the Eberline Instrument Laboratory (DOE Element) on Enewetak Atoll.

III. Responsibility

The Eberline Enewetak Laboratory Manager is responsible for the preparation of soil samples in accordance with this procedure.

IV. General

During the Enewetak Cleanup Project approximately 8,000 to 12,000 soil samples will be analyzed by the Eberline Laboratory Facility, and representative portions of those samples selected by DOE for long term retention will be processed so that the samples may be returned to the DOE sample library at the Nevada Test Site, Mercury, Nevada. All samples returned will be packaged in 16 oz. (500 ml) Nalgene LPE wide mouth bottles Cat. #2104-0016 with Cat. #53 screw caps. Bottles will be packaged in a single transportainer (CONEX container) for shipment to NTS.

Sample location grid sheets will be provided with the shipment. The grid sheets will be located inside the transportainer in an envelope labeled "sample locator." The location of each sample in the transportainer will be indicated on the appropriate grid sheet. The grid sheets will also include the following information: island (name or symbol), sample coordinates and the EIC laboratory number or other DNA number if the samples were not processed by EIC. A copy of the grid sheet will be retained by EIC with a copy also sent to the ERSP Manager. A Department of Agriculture permit or other authorization will be obtained and maintained by Eberline Instrument Corporation to cover samples shipped into the United States.

V. Procedure

A. Remove sample from storage location and take to the sample preparation facility or process as part of the normal sample routine after laboratory analysis is completed.

1. Any samples that have not been processed by EIC will be ballmilled according to the standard ballmilling procedure.

2. Spread 550-600 ml of soil in 4x6-in. aluminum pan. Use a new aluminum pan for each sample.

3. Mark pan with EIC sample number to avoid mixing up samples. Fill in EIC sample number and other info on the grid sheet.

4. Dry in soil oven for 4 hours. Start time after loaded oven stabilizes at 300°F as determined by the oven thermometer embedded in one of the soil samples.

5. Allow pans to cool and fill Nalgene bottles full. Vibrate bottle by tapping on table to compact soil and then cap.

6. After filling storage bottle with soil sample dispose of remainder of sample and can in accordance with procedures to be developed.

7. Place filled bottle in shipping transportainer and designate its location on the grid sheet.

Changes to Soil Preparation for Library Storage
Procedure (DOE/ERSP No. 20), 7 August 1978.

Delete V.A.1.

Insert at V.A.1.:

1. Samples that have not been ballmilled will not be ballmilled. All samples will be turned on the ballmilling machine, without balls, for 10 minutes to allow some mixing.

Signed by Roger Ray, ERSP Manager

SOIL SAMPLE SCREENING BY IMP

DOE/ERSP PROCEDURE NO. 21 DATE DRAFTED: 19 May 1978

APPROVED: 2 June 1978 by Paul B. Dunaway (ERSP Manager)

I. Introduction

There were several considerations that brought about the need for screening* soil samples. Some of these were:

A. Many subsurface soil samples are required to define the extent of contamination beneath the surface in specific areas of concern.

B. Large portions of these samples have low activity (84 out of 113 Yuma subsurface samples showed less than detectable activities by lab analysis).

C. Laboratory results are currently the pacing item for DOE activities.

D. Processing large quantities of soil samples containing negligible radioactivity is not the best utilization of lab time for current DOE activities.

E. Sample screening also allows near to real-time decisionmaking capability in determining the need for additonal samples to adequately define areas of contamination.

II. Screening Location

There are some advantages of screening the soil samples at or near the sampling locations rather than at the lab on Enewetak. Screening can be done by IMP equipment in the field or on Ursula. A screening site with low background is preferred.

III. Procedures

A. Soil samples sealed in petri dishes with black plastic tape should be prepared (and labeled properly) at, or near, the field location. Corresponding sample cans should be saved until after screening.

B. Each sample container and corresponding data sheet should include island, stake number, depth, date and other useful information (e.g., special "site" designation such as Yuma, Hustead, Plowing Experimental Area 1, etc.).

C. Petri dishes should be counted (gamma scanned) in numerical order and in order of depth of sample.

D. Counting time should be 5 minutes (300 seconds).

E. The net count from ^{241}Am and ^{137}Cs from all samples should be recorded on the provided data sheet (see specimen attachment).

F. Print results from calculator for all samples. This short form printout will be the only future reference for any sample with less than 20 net counts.**

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*As used throughout, screening does not mean passing the sample through any type of particle size separator. Instead, screening means performing a preliminary gamma scan to determine a relative level of radioactivity.

**A net count of 20 corresponds to about 1-1/2 to 2 pCi/g ^{241}Am.

G. After counting, the petri dishes should be separated into two piles, above and below 20 net counts ^{241}Am.

H. The weight of each sample reading above 20 net counts ^{241}Am should be determined and recorded.

I. Save for lab processing the following:

1. Cans from which the screening sample reads 20 counts ^{241}Am and above.

2. Petri dishes which read 20 counts ^{241}Am and above.

3. One tenth of soil samples (cans and petri dishes) reading less than 20 counts ^{241}Am.

J. Discard (in contaminated area) remainder of soil samples reading less than 20 counts ^{241}Am. Reuse of cans and petri dishes of this category is optional.

IMP SOIL SAMPLE COUNTING RESULTS

IMP ____ Detector _____ Operator _____

Counting Date _____ Island _____ Area _____ Counting Time ___

Sampling Date _____ Percent Moisture Assumed _____

Stake No.	Depth (cm)	^{137}Cs Net Count	^{241}Am Net Count	Wet Weight (g)	^{241}Am Activity (pCi)	(pCi/g)	Run No.	Comments

Additional Comments

Distribution: ERSP MGR
Tech. Adv.
EIC
DRI
EG&G

(This specimen reduced from full page original)

INTERLABORATORY QUALITY ASSURANCE
FOR ENEWETAK SOIL ANALYSIS

DOE/ERSP PROCEDURE NO. 22 DATE DRAFTED: 2 August 1978

APPROVED: 20 September 1978 by Bruce W. Church (ERSP Manager)

I. Purpose

To provide a cross laboratory check on actual soil samples analyzed in the EIC field laboratory.

II. Applicability

This procedure applies to all types of analysis performed in the field.

III. Responsibility

The Eberline Laboratory Manager is responsible for the selection of appropriate numbers of samples on a quarterly basis and the packaging and shipment of same to REECo.

IV. Procedure

A. A portion of those surface samples containing 10 to 100 pCi/g total transuranics which have had chemistry analysis performed and have been scanned by IMP will be selected and further homogenized.

B. Sterilize as per soil preparation for Library Storage Procedure and ship under that permit.

C. The sample is placed on a clean plastic sheet for cone and quartering.

D.* Divide into four aliquots of at least 100 g dry weight, one will be analyzed on site as an original or rerun and three will be placed in 500 cc Nalgene bottles. Bottles to be labeled with lab sample number only. At this time analyze only for $^{239,240}Pu$, ^{238}Pu and ^{241}Pu. Cesium-137 and ^{90}Sr-^{90}Y may be of interest in the future.

E. Record all information available such as sample date, location, and laboratory results and forward to Bruce Church, DOE, Las Vegas.

F. The samples selected for each quarter are to be packaged and shipped to REECo where DOE will instruct them as to distribution to three independent laboratories.

G. All results will be reported to Bruce Church, DOE, Las Vegas, approximately two weeks after the receipt of the samples.

*It may be necessary to collect some extra large samples for this procedure.

SR-90 IN CORAL SOIL

DOE/ERSP PROCEDURE NO. 23 DATE DRAFTED: 17 January 1979

APPROVED: 20 January 1979 by Ernie Campbell (ERSP Manager)

I. Introduction

This procedure does not depend on secular equilibrium between ^{90}Sr and ^{90}Y in the soil sample. Yttrium-90, ^{152}Eu, ^{154}Eu, ^{155}Eu, and ^{137}Cs are stripped away from the ^{90}Sr. After a two week period to allow ^{90}Y ingrowth, the ^{90}Y will have reached 97% of its equilibrium value. At this point, the ^{90}Y is again stripped away and counted. Because the secular equilibrium is essentially complete, the ^{90}Sr activity can be calculated from the measured ^{90}Y activity. The second separation of ^{90}Y from ^{90}Sr can be done after a shorter ingrowth period if a correction is made for incomplete ^{90}Y ingrowth.

II. Procedure

A. Sample Preparation

1. Samples must be screened to select the proper aliquot size for chemistry. All samples to be analyzed for ^{90}Sr will be counted for gross beta after ballmilling. A 10 g aliquot will be used for samples which contain 200 pCi/g or less. For samples between 200 and 500 pCi/g, a 5 g aliquot will be used. For samples which contain greater than 500 pCi/g of activity, consult the EIC chemist for further instructions.

2. Weigh out the appropriate aliquot in a porcelain crucible and place in a muffle furnace and ash for 8 hours at 800°C.

3. Remove from furnace and allow to cool. The sample is now ready for chemistry.

B. T_1 Separation (First Milking)

1. Transfer the sample into a 150 ml beaker with deionized water. Rinse the crucible three times with 10 ml portions of conc HNO_3, and transfer each rinse to the beaker with swirling. Add 10,000 dpm ^{85}Sr tracer. Evaporate volume to about 5 ml. Add 20 ml conc HCl and evaporate sample to dryness.

2. Cool sample and dissolve in 10 ml of 0.08M HCl.

3. Transfer sample into a 40 ml conical centrifuge tube. Rinse beaker with two 10 ml portions of 0.08M HCl and transfer each rinse to the centrifuge tube.

4. Centrifuge for 10 minutes at 1800 rpm.

5. Transfer supernatant to a 125 ml separatory funnel. If a residue is present, wash with 5 ml of 0.08M HCl, recentrifuge and transfer supernatant to separatory funnel.

6. Add 30 ml of 20% HDEHP (v/v in toluene) and shake for two minutes. Allow the phases to separate and drain the aqueous layer into a second 125 ml separatory funnel. Discard the organic layer and rinse the first separatory funnel with 5 ml of toluene.

7. Add 30 ml of 20% HDEHP to the second separatory funnel, shake for two minutes and allow the phases to separate. Drain the aqueous layer into the first separatory funnel and discard the organic layer.

8. Add 30 ml of 20% HDEHP to the first separatory funnel. Shake for two minutes and allow the phases to separate. Record the date and time of this last separation as T_1 on data sheet.

9. Drain the aqueous phase into a bottle containing a known amount of yttrium carrier (10 - 20 mg). Discard the organic layer.

10. Count the sample for ^{85}Sr with the gamma spectrometer. Compute the ^{85}Sr recovery by taking the ratio of the number of net counts in the sample to the number of net counts in the standard. The standard is prepared by adding the same amount of ^{85}Sr as was added to the sample to a bottle containing yttrium carrier and 30 ml of 0.08M HCl.

11. Store the sample for two weeks.

C. T_2 Separation (Second Milking)

1. Transfer the sample to a 125 ml separatory funnel. Rinse the bottle with two 15 ml portions of 5% HDEHP (v/v in toluene) and add each rinse to the separatory funnel. Shake for two minutes and allow phases to separate. Record the date and time of separation as T_2 on data sheet.

2. Drain off aqueous layer into original bottle and record T_2 time as T_1 on this bottle. This portion will be saved in case a rerun or verification is necessary.

3. Add 30 ml of 3N HNO_3 to the 5% HDEHP in the separatory funnel and shake for two minutes. Allow phases to separate and drain aqueous phase into a 40 ml conical centrifuge tube.

4. Adjust to pH 9 with conc NH_4OH, centrifuge for 10 minutes at 1800 rpm and discard the supernatant. Dissolve the precipitate in 20 ml of 3N HNO_3 and repeat the NH_4OH precipitation twice. Dissolve the final precipitate in 2 - 4 ml of 1M HCl.

5. Add 25 - 30 ml of deionized water and place in a water bath at 90°C for 15 minutes. Add 3 - 4 ml of saturated $(NH_4)_2C_2O_4$ and digest in a water bath for 10 minutes.

6. Filter the sample with a millipore filter apparatus collecting the precipitate on a dried, tarred glass fiber filter paper. Wash sample once with deionized water followed by an alcohol wash. Do not draw excess air through the filter.

7. Carefully remove the filtered sample and dry in oven for one hour at 100°C. Remove from oven and allow to cool in a dessicator for 20 minutes.

8. Weigh sample and record weight. Calculate yttrium yield from the net weight of the precipitate.

9. Count the sample in the low background beta counter and compute the ^{90}Sr activity present in the sample from the measured ^{90}Y activity.

WATER SAFETY
DURING ISLAND LANDING AND EXITING OPERATIONS

DOE/ERSP PROCEDURE NO. 24 DATE DRAFTED: 16 October 1978

APPROVED: 25 October 1978 by Bruce W. Church (ERSP Manager)

I. Purpose

To provide guidance and policy whereby the ERSP party chief will understand the management philosophy applied to the importance of personnel and equipment safety.

II. General

The ERSP work party chief is delegated the responsibility to assess each landing and exiting situation such that personnel and equipment safety will not be jeopardized. The party chief has the authority to abort the mission at any time that in his judgment a compromise will put personnel and equipment at increased risk. All missions aborted are to be reported to the ERSP Manager through the contractor management with recommended remedial operational procedures.

III. Specific Instructions

A. No work party will leave base of operations without adequate off-island radio communications.

B. Tide schedule and weather conditions are to be reviewed to achieve best operational opportunities.

C. All equipment is to be packaged appropriately to prevent salt water damage.

D. Personnel should dress according to need and planned mission to minimize exposure to expected element conditions which may compromise health.

E. Personnel are not to exceed water greater than waist deep at any time during planned operations.

F. Personnel are not to exceed travel distances through water of approximately 75 yards during landing from or approaching water craft.

G. When landing from a boat onto a beach, party chief is to instruct boat coxswain to remain in position until all personnel have safely landed on shore.

H. If instructions E and F are likely to be compromised by existing conditions the party chief is to make radio contact (thru radio relay if necessary) with the ERSP Coordinator/Manager for further instruction.

DATA REPORTING PROCEDURE

DOE/ERSP PROCEDURE NO. 25

DATE DRAFTED: 24 October 1978
DATE REVISED: 27 June 1979
by Jack Aeby, EIC Lab Manager

APPROVED: 11 July 1979 by Ernie Campbell (ERSP Manager)

I. Purpose

To standardize the method of reporting data from the DOE/ERSP laboratory.

II. Responsibility

The Eberline chemist is responsible for the preparation of the data report sheets in accordance with this procedure. The Eberline Lab Manager will be responsible for the review of the reports prior to their being submitted to the ERSP Technical Advisor and/or the DRI Statistician.

III. Procedure

A. Some low level samples may have a negative net count. In this case the sample activity will be reported as zero.

B. There will be no routine reporting of minimum detectable activity (MDA) or lower limit of detection (LLD). Results will be reported with three significant figures plus a two sigma error term, except for activities less than one pCi per appropriate unit, which will be reported to two decimal places plus a two sigma error term.

C. Each sample analysis result will include a two sigma counting error term. Results will be reported as: sample activity in pCi per appropriate unit (grams, cubic meters, etc.) $\pm 2\sigma$ (in pCi per approppriate unit).

For all analysis results, except those from the alpha spectrometer, the two sigma error term will be of the form:

$$2\sigma = \frac{2}{C.F.} \sqrt{\frac{\text{gross counts}}{(T_c)^2} + \frac{\text{background counts}}{(T_c)^2}}$$

where C.F. = a conversion factor to convert the 2 sigma term into pCi per appropriate unit (grams, cubic meters, etc.)

T_c = count time

For alpha spectrometer results, the two sigma error term will be:

$$2\sigma = 2 \times \text{sample activity in pCi/g} \times \sqrt{\frac{1}{\text{sample counts}} + \frac{1}{\text{spike counts}}}$$

FRST AIR FILTER COMPOSITE SAMPLE ANALYSIS
FOR PLUTONIUM

DOE/ERSP PROCEDURE NO. 26 DATE DRAFTED: 26 October 1978

APPROVED: 10 November 1978 by Paul J. Mudra (ERSP Manager)

I. Introduction

Air filter composites from selected FRST air filters will be analyzed for plutonium. The composites will be of two types: Those composited monthly and those composited weekly.

The monthly composites will be:

A. Yvonne batch plant composite.

B. Maggie 7 composite.

C. Maggie 8 composite.

D. Maggie 9 composite.

E. Mesh I composite.

F. Mesh II composite.

G. Mesh III composite.

Monthly composite samples will be processed at the end of the month if at that time there are only 25 air filter samples or less represented in that month's composite. If during the course of a given month more than 25 air filter samples have been received for compositing in any group (e.g., Mesh II), those 25 samples will be composited and analyzed for plutonium immediately.

The weekly composites will be:

A. Yvonne screen (shaker) plant composite.

B. Janet soil stockpile composite.

C. Irene soil lift composite.

II. Procedure

A. Sample Preparation - for each air filter composite.

1. Set up a work area in which no cross contamination can occur between other samples in the Sample Prep Trailer.

2. Remove 1/4 of each air filter and place in a clean 250 ml Pyrex beaker.

3. Cover the beaker with aluminum foil, place in a muffle furnace and ash at 400°C for about 12 hours.

4. Remove the sample from the furnace and allow to cool.

5. Take the sample to the Chemistry Trailer.

DATA REPORTING PROCEDURE

DOE/ERSP PROCEDURE NO. 25

DATE DRAFTED: 24 October 1978
DATE REVISED: 27 June 1979
by Jack Aeby, EIC Lab Manager

APPROVED: 11 July 1979 by Ernie Campbell (ERSP Manager)

I. Purpose

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II. Responsibility

The Eberline chemist is responsible for the preparation of the data report sheets in accordance with this procedure. The Eberline Lab Manager will be responsible for the review of the reports prior to their being submitted to the ERSP Technical Advisor and/or the DRI Statistician.

III. Procedure

A. Some low level samples may have a negative net count. In this case the sample activity will be reported as zero.

B. There will be no routine reporting of minimum detectable activity (MDA) or lower limit of detection (LLD). Results will be reported with three significant figures plus a two sigma error term, except for activities less than one pCi per appropriate unit, which will be reported to two decimal places plus a two sigma error term.

C. Each sample analysis result will include a two sigma counting error term. Results will be reported as: sample activity in pCi per appropriate unit (grams, cubic meters, etc.) $\pm 2\sigma$ (in pCi per approppriate unit).

For all analysis results, except those from the alpha spectrometer, the two sigma error term will be of the form:

$$2\sigma = \frac{2}{C.F.} \sqrt{\frac{\text{gross counts}}{(T_c)^2} + \frac{\text{background counts}}{(T_c)^2}}$$

where C.F. = a conversion factor to convert the 2 sigma term into pCi per appropriate unit (grams, cubic meters, etc.)

T_c = count time

For alpha spectrometer results, the two sigma error term will be:

$$2\sigma = 2 \times \text{sample activity in pCi/g} \times \sqrt{\frac{1}{\text{sample counts}} + \frac{1}{\text{spike counts}}}$$

FRST AIR FILTER COMPOSITE SAMPLE ANALYSIS
FOR PLUTONIUM

DOE/ERSP PROCEDURE NO. 26 DATE DRAFTED: 26 October 1978

APPROVED: 10 November 1978 by Paul J. Mudra (ERSP Manager)

I. Introduction

Air filter composites from selected FRST air filters will be analyzed for plutonium. The composites will be of two types: Those composited monthly and those composited weekly.

The monthly composites will be:

A. Yvonne batch plant composite.

B. Maggie 7 composite.

C. Maggie 8 composite.

D. Maggie 9 composite.

E. Mesh I composite.

F. Mesh II composite.

G. Mesh III composite.

Monthly composite samples will be processed at the end of the month if at that time there are only 25 air filter samples or less represented in that month's composite. If during the course of a given month more than 25 air filter samples have been received for compositing in any group (e.g., Mesh II), those 25 samples will be composited and analyzed for plutonium immediately.

The weekly composites will be:

A. Yvonne screen (shaker) plant composite.

B. Janet soil stockpile composite.

C. Irene soil lift composite.

II. Procedure

A. Sample Preparation - for each air filter composite.

1. Set up a work area in which no cross contamination can occur between other samples in the Sample Prep Trailer.

2. Remove 1/4 of each air filter and place in a clean 250 ml Pyrex beaker.

3. Cover the beaker with aluminum foil, place in a muffle furnace and ash at 400°C for about 12 hours.

4. Remove the sample from the furnace and allow to cool.

5. Take the sample to the Chemistry Trailer.

B. Chemistry on each air filter composite which contains only paper filters.

1. Proceed with the Plutonium In Coral Soil (DOE/ERSP Procedure No. 10) starting at Step No. 1.

C. Chemistry on each air filter composite which contains glass fiber filters.

1. Transfer the filter quarters to a 250 ml Teflon beaker containing 8M HNO_3 and a Teflon stirring rod. Add ^{236}Pu tracer.

2. Transfer the sample from the Chemistry Trailer to the outside perchloric acid hood.

3. Add: 20 ml $HClO_4$, 50 ml 1M HF and 10 ml 8M HNO_3.

4. Place on Corning hotphate (setting 5) and reduce volume until dense white $HClO_4$ fumes are given off.

5. Remove from hotplate and cool. Dilute with 10 ml of 8M HNO_3. Add 5 - 10 ml $HClO_4$ and 50 ml HF and again reduce volume until $HClO_4$ fumes appear.

6. Repeat Step 5 until all silica appears to have been destroyed.

7. Transfer sample back into original 250 ml Pyrex beaker using 8M HNO_3 as needed.

8. Take sample to dryness and continue heating carefully to avoid spattering. Heat until most of the dense white $HClO_4$ fumes are no longer present.

9. Rinse the sides of the beaker with 8M HNO_3 and repeat Step 8 until $HClO_4$ fumes are no longer given off.

10. Remove sample from perchloric hood and return it to the Chemistry Trailer. Add 30 ml of 8M HNO_3 and proceed with Step 2 of the Plutonium In Coral Soil (DOE/ERSP Procedure No. 10).

ARCHIVING PROCEDURES AND/OR NOTES CONCERNING
SOIL SAMPLES FOR THE ENEWETAK TRU PROGRAM

DOE/ERSP PROCEDURE NO. 27 DATE DRAFTED: 10 February 1979

APPROVED: 13 February 1979 by Don R. Martin (ERSP Manager)

I. After samples have been ballmilled, prepared by sterilization and placed in plastic sample bottles, they will be:

A. Identified with Eberline Identification Number sequentially.

B. Stored in a CONEX container in the following manner:

1. Left side of container upon entry will be the A side and the right side will be the B side.

2. Shelves will be numbered 1 through 8 starting at the top shelf and going to the lower shelf.

3. Samples will be placed on the shelves in numerical sequence starting with the lowest EIC number.

4. When a sequential number is not followed, a blank (bottle with tape to identify it as a blank) will be placed in that numbered slot. (This will allow a position for a missing sample bottle if found at a later date.)

5. If a sample is removed for further analysis a blank with tape will be placed in its slot to identify that the sample has been removed after cataloging.

6. An entry in the archive log will be made to identify the reason for removal of the sample.

7. Numerical sequence changes drastically, i.e., samples 625 to 681 are not present because they were swipes or air samples. Any data that are necessary to explain why the samples are not sequential should be entered in archiving log and inventory sheet.

8. When CONEX container is full, it will be prepared for shipment as follows:

a. All samples must be made secure to preclude them from falling off the shelves.

b. CONEX container will have a numerical listing of samples in the container.

c. CONEX container will be locked to prevent entry without proper authority.

d. CONEX container's serial number or assigned identification will be placed in the master archiving log for future reference.

e. Shipping instructions follow.

This procedure is to be used as a guideline only and will be followed until changes are authorized.

See the attached Eberline Locator Procedure. (Ed Note: Attachment deleted.)

ENEWETAK FISSION PRODUCT DATA BASE PROGRAM

DOE/ERSP PROCEDURE NO. 28 DATE DRAFTED: 14 March 1979

APPROVED: 20 March 1979 by John D. Stewart (ERSP Manager)

I. General

This procedure details a uniform method of taking soil profiles for LLL dose assessment of the fission products present on Enewetak Atoll.

II. Responsibility

The Eberline Laboratory Manager is respnsible to the DOE/ERSP Site Representative for implementing these procedures to assure soil data quality equal to that previously taken by LLL in the Pacific Islands.

III. Procedure

A. Tools and equipment

1. One gallon or 1/2-gallon cans with standard sample aluminum labels and lids (6 per profile).
2. Scoops
3. Shovels
4. Hatchets
5. Tape measure or calibrated stick marked in centimeters - 100 cm long.
6. Backhoe to dig 36-inch deep trench
7. Soil samplers field notebook
8. Short pointing trowel
9. Personnel: 1 sampler, 1 data logger, and 1 packer
10. Glass filament tapes
11. PRS-1 and SPA-2 Probe (μr/h meter)

B. Method

1. Offset from survey stake location upwind to avoid disturbing stake.
2. Dig trench to a depth of 100 cm minimum unless solid rock or water is encountered. Have backhoe operator use care to prevent major disturbance of the side wall to be sampled.
3. Use shovel and square up side wall to be sampled to at least 70 cm deep.
4. Log the hole at each sample level with the μr/h meter and record in field notes.
5. Starting at top of soil column take 6 samples of at least 1000 cc of soil at each of the following levels: 0-5 cm, 5-10 cm, 10-15 cm, 15-25 cm, 25-40 cm, and

40-60 cm. Adjust area of each layer taken to include sufficient volume for 1000 cc of sample. Clear vegetation on top of soil column to expose soil. Exclude all rocks and roots greater than 3/8-inch in sample layers. As the 1st layer is taken, expand area of level to extend about 1 foot beyond the edge of next area to avoid cross-contamination of next layer due to falling side walls.

6. To assure correct site location on can, do not premark cans or labels before arriving at site location.

7. Data logger will be responsible to mark labels with the following site data:

   a. Island identifier: FJ (for example).

   b. Island stake location: 24N16 (e.g.).

   c. Date of sample: 2/4/79 (e.g.).

   d. Cm depth: 0-5 (e.g.).

   e. Short note of site condition: (e.g., raining, water level 90 cm, rock at 40 cm, windrows or other information that may be pertinent).

8. Data logger will be responsible to record in Soil Sampler's Log on a daily basis:

   a. Islands sampled.

   b. Stakes sampled.

   c. General notes about weather and conditions of sites.

   d. Disposition of cans shipped to Enewetak for processing.

   e. Names of soil sampling crew.

9. Do not let backhoe operator get more than a few holes ahead of soil sampling teams.

10. The holes will be backfilled prior to completing the island.*

11. All samples taken will be transported to a holding area for shipment to laboratory on Enewetak for processing as soon as possible.

C. Analysis - EIC

1. On-Site Sample Preparation. The sample preparation at Enewetak Laboratory will include recording all important information such as location, date, sample size, weights, drying, homogenizing and ballmilling.

   Initially the 100-meter profiles will be processed for full analysis to provide expedient data for LLL for dose assessment, then the 50-meter samples will be processed for future analysis if required.

*Constraints of time and tides made this step difficult. All islands were visited later and open holes backfilled.

2. On-Site Analysis. The samples are then transferred to an approximate 700 g geometry for gamma counting for ^{241}Am, ^{152}Eu, ^{155}Eu, ^{137}Cs and ^{40}K. After gamma counting has been completed, the samples are split. One portion shipped to EIC, Albuquerque Laboratory, and the other portion stored in the Soil Library. The shipping box will have a packing list with EIC Laboratory number and hard copy of gamma results with island location information. On-site gamma sensitivity for ^{137}Cs will be approximately 1 pCi/g. Pu/Am chemical analysis will be done on island as laboratory load permits working to the goal of chemical analysis of 10% of all 100-meter samples. The sample locations to be processed for Pu/Am will be specified by the DOE/ERSP representative.

3. Off-Site Analysis. EIC offsite analysis will include processing coral sample for ^{90}Sr and all other Pu/Am not completed on Enewetak.

   DOE/ERSP Procedure No. 15 assumes secular equilibrium of ^{90}Sr and ^{90}Y has been attained. The ^{90}Y is separated and used to quantify the ^{90}Sr. Americium and plutonium analyses offsite include isolation of plutonium from americium and electrodeposition. Tracers will be used to quantify plutonium and americium activity based on the ratio of the tracer to isotope of interest.

PORTABLE INSTRUMENT MAINTENANCE MANUAL

DOE/ERSP PROCEDURE NO. 29

APPROVED: 21 March 1978 by Eberline Instrument Corporation

I. GENERAL

A. The PRS-1 digital ratemeter scaler is compatible with all alpha, beta and gamma probes discussed in the Portable Instrument Maintenance Manual (PIMM). In the scaler mode the instrument counts pulses for a present time and displays the detected counts per minute (cpm). In the ratemeter mode the instrument detects a predetermined number of pulses and divides that number by the time that was required to detect the pulses. The resultant number is displayed. A "calibration factor" (which is discussed later) is available in the ratemeter mode which converts the resultant number to units more useful than detected cpm. The PRS-1 can be used for gross counting or pulse height analysis (PHA) in energy spectrum analyses.

B. The three-month calibration interval specified in this manual for all instruments is based on past Eberline experience plus consideration of the extremely corrosive environments encountered. Any future adjustments of this calibration interval will be limited to decreasing the interval only. Any adjustment will be made only after a thorough review of the instrument history cards by the Eberline Engineer and Instrument Equipment Technician. The Eberline Engineer has the final authority for making any change in the calibration interval.

C. The following documentation will be maintained on all instruments and associated probes.

1. Instrument History Cards (5x7-inch)

a. Information entered on these cards will be: model number, serial number, date due calibration, calibration factor (when appropriate) and high voltage setting (when appropriate). In addition, all actions taken on the instrument, i.e., repair, calibration, operational check, cleaning, date dispatched to field, discrepancies, etc., will be entered on this card. All entries, with the exception of the date dispatched, will be handscribed. The date dispatched will be entered by using a date stamp.

2. Calibration Scheduling Card (5x7-inch)

a. This card will be maintained on all instruments and associated probes in date due calibration sequence. Entries on this card will be limited to model number, serial number and date due calibration. When an instrument is calibrated, the new date due calibration will be entered on this card and the card placed in the proper sequence for the new date.

II. OPERATIONAL CHECK PROCEDURES

Instruments should be checked daily for correct operation, with the following procedures, prior to their usage in the RADLAB and prior to their issue for usage in the field. These operational checks should also be made before performing the three-month instrument calibration.

A. PRS-1

1. Visual check for external dirt, corrosion and damage. Clean and repair as needed.

2. Open and make visual check for internal dirt, corrosion, loose connections and excessive humidity (check desiccant). Clean, repair and change desiccant as needed.

3. Battery check: Turn function switch to "A" ratemode, turn speaker on, reduce threshold to zero for maximum speaker noise and turn light on, then check for "error" legend ON and "Batt. OK" legend OFF; replace batteries if this condition exists.

4. Check reset function.

5. Check time base on one scaler mode preset time.

6. Put function switch in high voltage (HV) position. As the HV potentiometer is varied, the HV reading should vary from 400 to 1400.

7. Turn function switch to OFF and close PRS-1.

B. Probe Operational Check

1. Make visual check of probe, probe cable and cable connector for dirt, corrosion, or damage. Clean and repair as needed.

2. Connect probe to PRS-1 and perform appropriate operational check procedure in the condensed instrument procedures at the rear of this report.

   a. Calibration factor pots located on rate multiples board.

   b. "Hot," "Medium" and "Cool" check sources:

      1) "Hot" ^{90}Sr-Y: 10,000-20,000 cpm (2π).

      2) "Hot" ^{241}Am: 300,000-400,000 dpm.

      3) "Med." ^{241}Am: 20,000-40,000 dpm.

      4) "Cool" ^{241}Am: 3,000-5,000 dpm.

3. Check for noisy probe cable. Repair as needed.

4. Check for light leaks in AC-3, RASP-1 and SPA-1 probes. If necessary repair or replace mylar face and recalibrate probe.

5. Any probe that fails, during the operational check, to give the current reading (+ 20%), or whose efficiency is not within 20% of the efficiency listed on the calibration sticker, must be recalibrated or repaired.

III. CALIBRATION PROCEDURE

Instrument should be calibrated at three-month intervals using the procedures which follow:

Each probe should have a calibration sticker affixed showing: (1) the name of the technician who calibrated the probe, (2) date of last calibration, (3) the calibration due date (three months after the last calibration), and (4) other data as specified in the calibration procedure for each probe type. In these procedures "Hot" and "Medium" sources mean the following:

"Hot" ^{90}Sr-Y: 10,000-20,000 cpm (2π)
"Hot" ^{241}Am or ^{239}Pu: 300,000-400,000 dpm
"Med." ^{241}Am or ^{239}Pu: 20,000-40,000 dpm

A. PRS-1

When the PRS-1 is operated in the ratemeter mode with the calibration factor enabled the dpm detected by the probe will be multiplied by a Calibration Factor. This process allows cpm detected to be converted to and displayed in more useful units such as mR/h, dpm or 2π dpm (impinging cpm).

It is important to understand the unit's disintegration per minute (dpm) and counts per minute (cpm). An activity level is measured in pCi or dpm. One dpm equals 2.22 times the number of pCi. The amount of radiation emitted in the 2π direction is labeled the impinging cpm. The number of counts detected by a given probe is labeled "Detected cpm." Detected cpm divided by impinging cpm is the probe efficiency. The reciprocal of probe efficiency is the PRS-1 Calibration Factor (CF).

Perform the following procedure at three-month intervals (using the MP-1 Mini Pulser):

1. Inspect and clean the input connector as necessary and put calibration switch to OUT.

2. Using an electrostatic voltmeter verify that the PRS-1 HV is within $\pm 5\%$ of the indicated value at 500, 1000 and 1400 volts.

3. Check the Battery OK circuit. Battery OK must be ON at 5.75 volts and OFF at 5.6 volts.

4. Check for proper operation of all display legend switches.

5. In the PHA mode with the threshold and window both set to 1.00 and HV set to minimum, check that pulse amplitudes between approximately 12 and 24 mV are detected.

6. Check the A, B, C and D ratemeter scales at 1000 cpm.

7. Check the 0.5-, 1-, 2- and 5-minute scaler pre-set times.

8. Check the Manual, Stop and Reset functions for operation.

Note on Probe Calibration:

The HV indications of the PRS-1 used for calibrating probes must be calibrated immediately prior to use. Unless otherwise noted, set PRS-1 controls as follows for the calibration of probes:

PHA—Gross	Gross
Threshold	1.00
Window	1.00
Calib.	Out

It is assumed that rate multiplier boards will be installed in all PRS-1's.

B. AC-3

General:

The AC-3 probe is a large area alpha scintillation probe that is useful as a personnel and equipment survey instrument and for obtaining a preliminary estimate of alpha activity in soil.

Calibration:

Perform the following procedure at three-month intervals. (Calibrate the HV indication of the PRS-1 used prior to probe calculation.):

1. Inspect and clean or repair the probe face and connector as necessary. (If the mylar is removed, allow several hours for photomultiplier (PM) tube stabilization before proceeding.)

2. Run an alpha plateau using a "medium" or "hot" ^{239}Pu or ^{241}Am standard. Start at 800 volts and take reading every 50 volts. Use the 1-minute scaler range. The operating voltage will be located on the flat portion of the curve and should be at least 75 volts higher than the knee of the curve.

3. Run a 30-minute background check at the operating voltage. If the background is greater than 1 cpm, decontaminate the probe face.

4. Check that the beta response (R_s-R_b) at the operating voltage is not more than 1 cpm using the procedure:

   a. Determine R_s (source + background cpm) over a 30-minute interval (6 five-minute measurements) using a "hot" ^{90}Sr-Y source.

   b. Determine R_b (background cpm) over a 30-minute interval (6 five-minute measurements) in the same geometry that R_s was determined.

5. Using a "medium" ^{239}Pu or ^{241}Am standard compute probe efficiency and calibration factor. Use the 1-minute scaler range. Assume a 2π counting geometry so that efficiency and calibration factor will be cpm/cpm. (Eff. = cpm/(source dpm/2).)

6. List the operating voltage, efficiency and calibration factor on the calibration label. (C.F. = 1/eff.)

C. RASP-1

General:

The RASP-1 alpha scintillation probe uses a cartridge type replaceable detector and a shock-mounted PM tube to provide a survey instrument more rugged than the AC-3 probe. Due to its smaller active face area, the RASP-1 is a less sensitive survey detector, but is useful in confined areas or where an AC-3 probe might be damaged.

Calibration:

Perform the same procedure as the AC-3 except start the plateau at 700 volts. The calibration interval is three months.

D. SPA-1

General:

The SPA-1 is a windowless alpha scintillation probe with a built-in sample holder. It is designed to count small diameter swipe papers. It is useful for monitoring nose swipes and for removable contamination.

Calibration:

At three-month intervals perform the same procedure as the AC-3 except start the plateau at 700 volts (use ^{239}Pu standard).

E. HP-210

General:

The HP-210 is a rugged, pancake geometry Geiger tube, principally designed for detecting beta radiation. The HP-210 probes have been modified by the addition of aluminized mylar resulting in a total window thickness of approximately 5 mg/cm^2. This approximates the 7 mg/cm^2 dead skin layer and gives a more accurate estimate of the hazard to humans.

Calibration:

Perform the following procedure at three-month intervals:

1. Inspect and clean or repair as necessary.

2. Set PRS-1 HV to 900V.

3. Using a ^{90}Sr-Y standard and the 1-minute scaler range, measure the cpm detected. Divide the cpm detected by the dpm of the standard, the result is the probe efficiency. The reciprocal of probe efficiency is the calibration factor.

4. List the efficiency and calibration factor on the calibration label.

F. HP-177C and HP-270

General:

The HP-177C is a thin wall standard geometry Geiger tube with a rotating beta shield. It is capable of detecting gamma radiation alone or beta and gamma together. The HP-270 uses an energy-compensating shield to limit the characteristic over-response of Geiger tubes in the lower energy range.

Calibration:

Perform the following procedure at three-month intervals:

1. Inspect and clean or repair as necessary.

2. Set the PRS-1 HV to 900 volts.

3. Position the probe at the 1 mR/h distance on the calibration range with the beta shield closed. Using the 1-minute scaler range, measure the detected counts. Divide 1000 by the detected counts. The result is the calibration factor for μR/h.

4. Input the calibration factor into the rate multiplier board.

5. Position the probe on the range at the 10 mR/h and 0.1 mR/h distances. The PRS-1 indication must be 10,000 and 100 μR/h $\pm$ 20%, respectively.

6. List the calibration factor on the calibration label.

G. SPA-2

General:

The SPA-2 gamma scintillation probe uses a one-inch diameter by one-inch thick NaI(Tl) crystal detector. It is a very sensitive gamma survey meter capable of monitoring in the μR/h range.

Calibration:

Perform the following procedure at three-month intervals:

1. Inspect and clean or repair the probe as necessary.

2. Set PHA-Gross switch to PHA and Speaker to ON.

3. Set Threshold at 2.50 and Window to 1.00.

4. Using a "hot" ^{241}Am source, adjust the HV for maximum noise from the speaker. The 60 keV ^{241}Am peak is now centered over the 3.0 channel.

5. Set Threshold to 1.00 and PHA-Gross switch to Gross.

6. Position the probe at the 0.1 mR/h distance on the calibration range. Using the 1-minute scaler, measure the detected counts. Divide 100 by the measured counts. The results is the calibration factor for μR/h.

7. Input the calibration factor into the range multiplier board. Turn on decimal point (D.P.) 2.

8. Position the probe at the 1.0 mR/h distance. The PRS-1 must indicate 1000.00 $\pm$ 20%.

9. List the calibration factor on the calibration label.

H. PG-2 and FIDLER

General:

The PG-2 and FIDLER are used to detect low energy gamma rays and X-rays associated with ^{241}Am and ^{239}Pu. The PG-2 detector is a thin (2mm) NaI(Tl) crystal coupled with a two-inch diameter PM tube. The FIDLER detector is a thin NaI(Tl) crystal coupled with a five-inch diameter PM tube.

Calibration:

The PG-2 and FIDLER are set up to search the 60 + 10 keV energy band.

Perform the following procedure at three-month intervals:

1. Inspect and clean or repair the probe as necessary.

2. Set the PHA-Gross switch to PHA, the Threshold to 5.80 and window to 0.40.

3. Using a "hot" ^{241}Am source, adjust the HV for maximum noise from the speaker. The 60 keV gamma ray is now centered over the 6.0 channel on the PRS-1.

   If maximum noise cannot be reached in Step 3 with the FIDLER probe, then use the following alternate procedure:

   a. Inspect and clean or repair the probe as necessary.

   b. Set the PHA-Gross switch to PHA, the Threshold to 1.9, and Window to 0.2.

   c. Using a "hot" ^{241}Am source, adjust the HV for maximum noise from the speaker. The 60 keV gamma ray is now centered over the 2.0 channel on the PRS-1.

d. Set the Threshold to 1.60 and the Window to 0.80. This broadens the search band to 60 $\pm$ 10 keV.

4. Set the Threshold to 5.00 and Window to 2.00. This broadens the search band to 60 $\pm$ 10 keV.

When set up in this manner, the PG-2 has a sensitivity of 3-5 cpm for each pCi/gm of ^{241}Am in soil when the sample measured is of infinite diameter and infinite depth. This may be checked by measuring the standard soil sample at the center of the bottom of the can. The value of the standard soil is approximately 20 pCi/g; therefore the reading should be about 60 cpm. For an ideal sample the reading expected would be about 80 cpm (60-100), but because the depth is only 5 cm and the diameter is not infinite the reading is somewhat low.

When set up in this manner, the FIDLER has a sensitivity of approximately 40-60 cpm for each pCi/gm of ^{241}Am in soil when the sample measured is of infinite diameter and infinite depth.

5. List the operating voltage (approximately), threshold and window on the calibration sticker.

TABLE 1. CONDENSED INSTRUMENT SETUP PROCEDURES

OPERATIONAL CHECK WITH PROBE		STEP 1 SET Cal. SW. to	STEP 1 SET Cal. Factor to	STEP 2 Turn Legend	STEP 3 SET PHA-Gross Switch to	STEP 4 SET Thresh. to	STEP 4 SET Window to	STEP 5 SET HV	STEP 6 Using Source	STEP 7 PRS-1 Reads
AC-3 & RASP-1 SPA-1		IN	Cal. label value	cpm on	Gross	1.00	—	at Cal. label value	Hot or Med ^{241}Am ^{239}Pu	Source cpm ±20%
HP-210		IN	Cal. label value	cpm on	Gross	1.00	—	at 900 v.	^{90}Sr-Y	Source cpm ±20%
HP-177C & HP-270		IN	Cal. label value	All legends off	Gross	1.00	—	at 900 v.	8μ Ci, ^{137}Cs check source at contact with beta shield closed	≅5,000 μR/h
SPA-2	Part I	IN	Cal. label value	D.P.2 ON	PHA	2.50	1.00	For max. spkr. noise	Hot ^{241}Am	—
	Part II								331,000 dpm ^{241}Am source at contact	
	Part III				Gross	1.00	—	—	8μ Ci, ^{137}Cs check source 3-3/4" from xtal housing side	

TABLE 1. CONDENSED INSTRUMENT SETUP PROCEDURES (Continued)

OPERATIONAL CHECK WITH PROBE		STEP 1 SET Cal. SW. to	STEP 1 SET Cal. Factor to	STEP 2 Turn Legend	STEP 3 SET PHA-Gross Switch to	STEP 4 SET Thresh. to	STEP 4 SET Window to	STEP 5 SET HV	STEP 6 Using Source	STEP 7 PRS-1 Reads
SPA-2	Part I	OUT	—	All legends off	PHA	5.80	0.40	For max. spkr. noise	Hot ^{241}Am	—
	Part II					5.00	2.00	—	331,000 dpm ^{241}Am	
Alter. FIDLER Calib.	Part I	OUT	—	All legends off	PHA	1.90	0.20	For max. spkr.	Hot ^{241}Am	—
	Part II					1.60	0.80	—	331,000 dpm ^{241}Am	
FIDLER Ludlum 204	Part I	OUT	—	All legends off	PHA	2.90	0.20	For max. spkr. noise	Hot ^{241}Am	—
205Hb63/ 5-0-21X	Part II					2.50	1.00	—	Hot ^{241}Am on one-minute scaler	———

PREFACE TO APPENDIX B: TECH NOTES

The Tech Notes in this Appendix are an accumulation of papers, each documenting how or why something was done, or the results of special investigations. Generation of Tech Notes was begun in November, 1977, at the suggestion of Phil Nyberg, EPA, who was serving in his first tour of duty as Technical Advisor to the DOE/ERSP Manager. This use of Tech Notes as a special form of documentation is patterned after a similar technique utilized by the EPA and some other organizations. The original intent was for each Tech Note to document actions and results at the time a task was performed so the basis for actions, and any decisions of consequence which might follow, would be available for review by staff members following later in the rotation schedule. While continuing to fulfill this purpose, preparation of a Tech Note also became a means of transmitting data results, or conclusions and recommendations of special investigations, to the Commander, Joint Task Group, and his staff.

Most Tech Notes were distributed to contractor agencies involved in the cleanup operation as well as to the JTG, but there were some exceptions to the usual pattern of distribution. In general, the Tech Notes prepared since August, 1979, have been reviewed only by members of the Editorial Committee working on this Final Report, and the DOE/ERSP Project Managers.

Tech Notes are numbered by subject matter. All Notes dealing with the same subject have the same number in front of the decimal point. Thus, Tech Notes numbered 2.n all deal with the determination of the ratio of total transuranics (TRU) to americium-241, while n takes on the values from 0 through 24 to include all islands for which this determination was made (with the exceptions noted in the Contents of this Appendix).

Each Tech Note in the 2 series describes the methods and results for estimating the ratio of TRU to ^{241}Am for a single island. At the start of the cleanup project the ratio and error were estimated by the sample mean and standard deviation of the ratios from individual samples. In those cases where more than one population of ratios was present on an island, a separate analysis was performed to determine the boundaries between the populations of ratios. The statistical assumption on which use of the sample mean is based is that the variance of the TRU value is proportional to the square of the ^{241}Am value. As more data were collected, it became clear that a more accurate assumption would be that the variance of the TRU is proportional to the ^{241}Am value. An estimator based on the latter assumption, described in Doctor and Gilbert (1978), was therefore used from February 1978 until the end of the project.

In the process of changing the computer programs on-island to use the new method, a typographical error was made on entering a program into the computer. Although the error did not affect the estimate of the ratio of TRU to ^{241}Am, it made the estimate of the standard deviation too large. This in turn caused the propagated standard deviation on the final TRU values to be too large. The 0.5 s upper bounds on the area average estimates, where s is the standard deviation of the kriging error, were therefore also too large. The standard deviation estimate on the ratio has been corrected in the text of the final report. The incorrect original estimate has been left intact in the Tech Notes, but an appropriate footnote has been added. While it is true that certain error terms were incorrectly computed on the high side, in no case was the magnitude of the difference between correct and incorrect numbers large enough to affect soil removal decisions or final categorization for certification purposes.

This approach is taken here because the Tech Notes present information upon which decisions were made at the time. While the standard deviation estimate on the ratio was alone not of great importance to decisionmakers, the situation represents the philosophy followed throughout the Tech Notes; namely, that a Tech Note written early in the cleanup program should not be modified by knowledge gained later in the program since this would give an improper picture of the information available at the time decisions were made. Knowledge gained later is, in a few instances, presented in a follow-up Tech Note bearing the same number in front of the decimal as the original Note.

For ease of reference, the Tech Note number follows the B in the pagination.

CONTENTS

APPENDIX B: TECH NOTES

NO.	TITLE
1.0	Brush Attenuation Factor
1.1	Additional Measurements of Brush Attentuation and Calculation of Brush Correction Factor.
	(Actual titles in the Tech Note 2 series differ from the abbreviated form used below; however, the intended meaning is unchanged. Significant exceptions to the general title are indicated in parentheses.)
2.	Determination of the Ratio of Total Transuranics to Americium in Soil on Island:
2.0	Pearl (Plutonium to Americium)
2.0-A	Pearl
2.0-B	Pearl
2.0-C	Pearl (After debris removal)
2.1	Irene (Plutonium to Americium)
2.1-A	Irene
2.1-B	Irene
2.2	Vera (Plutonium to Americium)
2.2-A	Vera
2.3	Olive
2.4	Janet
2.5	Sally
2.6	Lucy
2.7	Alice
2.8	Belle
2.9	Clara
2.10	Kate
2.11	Nancy
2.12	Daisy
2.13	Tilda

NO.	TITLE
2.14	Wilma
2.15	Mary
2.16	Ruby
2.17	Pearl's Daughter (No ratio computed)
2.18	Percy (No ratio computed)
2.19	Edna (No ratio computed)
2.19-A	Edna (No ratio computed)
2.20	Sally's Child (No ratio computed)
2.21	Sally, Cape Mixan Area
2.22	Mary's Daughter (No ratio computed)
2.23	Sally, Aomon Crypt
2.24	Southern Yvonne
3.0	Correction of ^{241}Am for Contribution of ^{155}Eu
3.1	Revision of ^{155}Eu Correction Factor for ^{241}Am
4.0	Soil Disturbance Experiment
5.0	Correction Factor for Detector (SN:496) Operating at Low Voltage
5.1	Correction Factor for Detector (SN:496) Operating at Low Voltage on Island Alice
5.2	Correction Factors for Detector SN 496
6.0	IMP Soil Sample Counting System
6.1	Comparison of IMP Screening and Lab Results
7.0	Estimation of Excision Volumes for Areas of Subsurface Contamination
8.0	Field Investigation of Soil Sample to IMP Results
9.0	Selection of Potential Soil Plowing Experimental Areas on the Island of Janet
9.1	Plowing Experiment: On-Site Report
10.0	Computation of Total TRU Activity Excised in the Kickapoo Area of Sally

NO.	TITLE
10.1	Computation of Total TRU Activity Removed from the Hustead Area of Island Sally
11.0	Effective Area Factor for Detector SN 483
12.0	IMP Measurement Characteristics
13.0	Surface Sampling of Concrete Bunkers
14.0	Estimated TRU Content and Recommended Disposition of Yvonne High-Grade Soil/Debris Stored in Hard-tack Station 1610 Bunker
15.0	Activity Levels in Soil Stockpile on Yvonne Near Southern Lip of Cactus Crater
16.0	Field Inspection of Grid Stakes and Portable Instrument (PG-2) Survey of Fig/Quince Area on Yvonne
17.0	Aomon Crypt IMP Measurement
18.0	Soil Sampling to Define the Boundaries of Subsurface Activity
19.0	Estimation of Average TRU Activity in Soil Subsurface Intervals Different From Those Sampled
20.0	Errors and Error Propagation in Computed TRU Activity
21.0	Reproducibility of IMP Measurements
22.0	Soil Density, Soil Moisture and Soil Composition
23.0	Correction Factor for the IMP ^{241}Am Data

BRUSH ATTENUATION FACTOR

DOE/ERSP TECH NOTE NO. 1.0 DATED: December 1977

AUTHOR: F. Tomnovec, EG&G

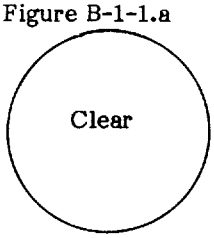
Both the in situ van and the aerial survey are designed to measure the characteristic 59.5 keV gamma-ray radiation from ^{241}Am. On the islands of Enewetak Atoll, the dense brush undergrowth provides significant attenuation for this low-energy radiation. In an effort to determine the degree of attenuation, an experiment was performed on Pearl. Ten sites were carefully chosen to get various average heights of brush and the in situ van (hereafter identified as the IMP) made a measurement at each of these points. The 84th Army Engineers then carefully cut by hand the brush in a seventy-foot circle, removed it, and the IMP remeasured these points. Table B-1-1 is a resume' of the IMP operator's impressions of each site.

It should be noted that several sites had some clear areas; Table B-1-2 indicates the magnitude of the clear area to the total effective area. The effective area is here defined as the actual area times the IMP's detector efficiency. This is an averaging method that allows us to disregard the exact location of each clear spot to the detector. To properly allow for the effect of the clear area seen by the IMP detector we must add all the clear areas together. Let us look at the logic and a sample calculation of one station, 6-S-1.

6-S-1 IMP measurement before clearing of brush = 14.8 pCi/gm

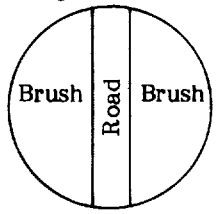
IMP measurement after clearing of brush = 16.2 pCi/gm

Figure B-1-1.a



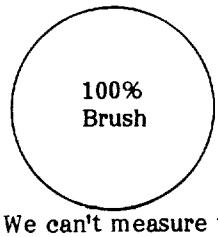
We measured this
= 16.2 pCi/gm

Figure B-1-1.b



We measured this
= 14.8 pCi/gm
Road = 17.4% clear area

Figure B-1-1.c



We can't measure this
but we can calculate it

$$\text{Ratio} = \frac{\text{clear area}}{100\%\ \text{Brush}} = \frac{16.2}{\dfrac{14.8 - 0.174\,(16.2)}{0.826}} = \frac{16.2}{\dfrac{11.9812}{0.826}} = \frac{16.2}{14.50508} = 1.11685$$

FIGURE B-1-1. MEASUREMENT OF ^{241}Am IN CLEAR AND BRUSHY AREAS

We would have liked to measure Figure B-1-1.a/Figure B-1-1.c directly but our IMP cannot negotiate the heavy brush so a road is cleared by a bulldozer and we can make the measurement in Figure B-1-1.b. We merely make a calculation of the radiation seen by the IMP detector of any clear area, and subtract it from the reading of Figure B-1-1.b.

The resultant is an IMP measurement of the remaining radiation attenuated by the brush. In this case 82.6% of the IMP measurement is from the brush covered area and 17.4% is from the clear area. When one divides the remaining radiation from the brush by the area of the brush we get 14.5 pCi/g, which is the measurement when there is 100% brush attenuation, the condition of Figure B-1-1.c. The ratio of Figure B-1-1.a to Figure B-1-1.c gives us our brush attenuation factor. This brush attenuation factor is 14.7% for a 100% brush covered area. Therefore, every IMP measurement point has a clear area, the road plus any other clear area. An example of its use is as follows:

5-S-4 22.3 pCi/g ^{241}Am Open area is 626 ft.^{2}

The effective area seen by the IMP is the area multiplied by the detector efficiency. Table B-1-3 is a computation of the value including the effect of the road.

$$\text{Clear area} = (626\ ft^2/3621\ ft^2) + 17.4\%\ (\text{Road}) = 0.173 + 0.174 = 0.347$$

$$\text{Corr. Factor} = \frac{1.147}{(0.347)(1.147) + 0.653} = \frac{1.147}{0.398 + 0.653} = \frac{1.147}{1.051} = 1.091$$

22.3 pCi/g x 1.091 = 24.3 pCi/g

The original concept of the experiment was that a common attenuation coefficient would be found and then one would multiply this coefficient by the average height of the brush. It was soon apparent that there is no common attenuation coefficient. Table B-1-4 shows the computation of the brush attenuation factor. Table B-1-5 shows the data and that the attenuation coefficient has a coefficient of variation of 65.6%, which is a broad distribution around the average.

It became clear on examining the data for ^{241}Am that regardless of the height of the brush the clear to brush ratio had a tight coefficient of variation.

Figure B-1-2 is the average data extracted from tables B-1-4,-6,-7 and -8. These averages are for ^{241}Am, ^{155}Eu, ^{137}Cs and ^{60}Co. The ^{60}Co data, because of the poor statistics, has the average value presented for both 1173.2 and 1332.5 keV and is given the average energy of 1252.8 keV. After the data had been compiled it was noted that the data was less than 1.0, which is a physical impossibility, but a statistical probability due to the low level of ^{60}Co and the small attenuation. The ^{60}Co data is therefore not used in Figure B-1-2. The data in Figure B-1-2 has a straight line fitted to the data points of the brush attenuation experiment. Wayne Bliss suggested that this indicated the brush attenuation was of the form of an umbrella effect or a canopy of leaves. Visual observation indicates that the canopy is real, for branches of the scaevola are relatively clean of intermediate branches, but branches out at the top exposing all of the leaves. Therefore, the height of the scaevola bush is not important.

An attempt was made to verify this idea by assuming the canopy of leaves to have an equivalent thickness of carbon (which it is largely composed of) to reduce the ^{241}Am by 1.147. The thickness necessary to reduce the 60 keV to what is observed experimentally is 0.343 cm. This thickness is then used to construct a curve (from the data in Table B-1-9) that is superimposed on Figure B-1-2 to show what effect a simple canopy of carbon would look like. The reasons that the curves are not superimposed at all energies are numerous:

1. The poor statistics of the experiment at high energies, as is evident from the ^{60}Co.

2. The poor geometry as compared to good geometry from which attenuation coefficients are derived, and which we used for carbon.

3. The resolution of the crystal eliminates even a slightly scattered gamma-ray out of the gamma-peak, measured by the intrinsic germanium crystal. A dose measurement with ion chambers would probably cause the two curves to become congruent.

In conclusion we find no difficulty in using a single attenuation coefficient of 1.147 and applying it to the data after allowing for the effect of any clear areas. The aerial survey would use the 1.147 correction to all data measured over brush covered areas.

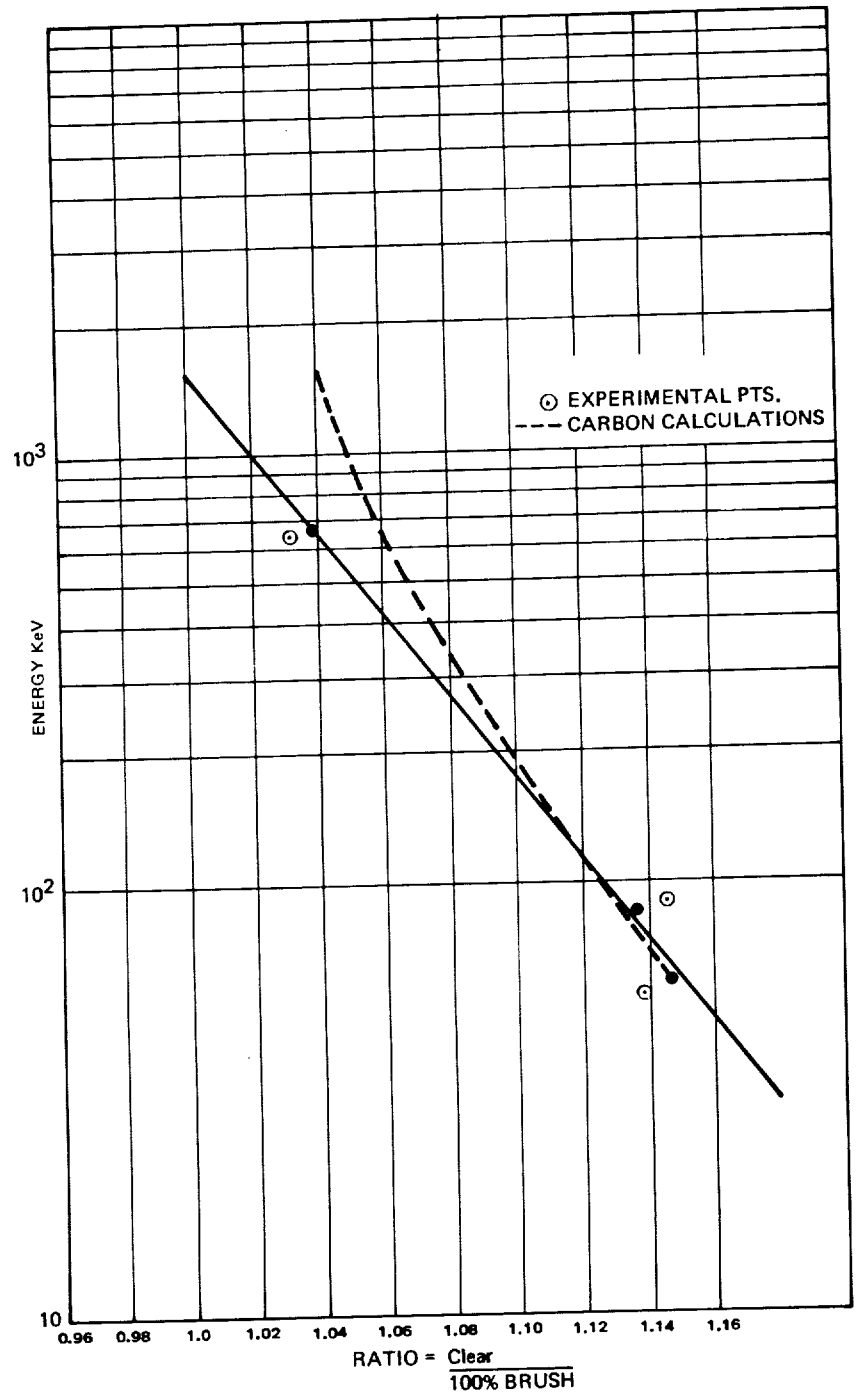


FIGURE B-1-2. BRUSH ATTENUATION FACTOR Y=A+E−BX WHERE A=4.16210E+12, B=21.70

TABLE B-1-1. IMP OPERATOR COMMENTS ON BRUSH ATTENUATION EXPERIMENT SITES

Stake No.	Operator's Comments
5-S-3	Average 7' brush 2 areas 18' diameter open grass, dead brush in road, stake under growth
	Extra 508.68 sq. ft. of cleared area*
5-S-2	Average 5' high brush, 2 areas clear grass 15' diameter each
	Extra 353.25 sq. ft. cleared area
6-S-2	Average 5' high brush numerous open spots, 7 ft^2 open areas, access road 12' wide
	Extra 125.2 sq. ft. of clear area
7-N-1	Average 8' high brush, 200 $ft.^2$ clear area
	Extra 200 ft^2 clear area
6-N-1	Average 8' high brush, center of a 15' wide track instead of a 10' wide track
	Extra 313 sq. ft. clear area
5-N-1	Average 10' high brush
6-S-1	Average 6' high brush, 5 ft. high pile of dirt and brush 12' SSE of stake
4-N-1	Average 10' brush
4-S-3	Average 10' brush dense no opening
7-S-1	Average 6' high brush

*Underlined comments were added by the author.

TABLE B-1-2. EFFECT OF CLEAR AREA IN PERCENT

Stake No.	Open Area, ft^2	$\frac{\text{Area}}{3621}$, percent
5-S-2	353	0.049
6-S-2	125	0.054
7-N-1	200	0.055
6-N-1	313	0.086
5-N-1	0	0.0
6-S-1	0	0.0
4-N-1	0	0.0
4-S-3	0	0.0
7-S-1	0	0.0

TABLE B-1-3.a. EFFECTIVE AREA SEEN BY THE IMP

Angle (θ) (degrees)	Eff. of detector at midpoint of θ	Tan θ	x(ft)	x^2 (ft^2)	Area of each interval (ft^2)	Area x eff. (ft^2)	Int. Area x Eff. / Total (Ratio)
10	0.99	0.17633	4.28	57.6	57.6	57.0	0.0157
20	0.955	0.36397	8.84	245.8	188.2	179.7	0.0496
30	0.89	0.57735	14.02	618.4	372.6	331.6	0.0916
40	0.805	0.83910	20.39	1306.1	687.7	553.6	0.153
50	0.69	1.19180	28.96	2634.7	1328.6	916.7	0.253
60	0.54	1.7321	42.08	5565.0	2930.3	1582.4	0.437
					Total	3621.0	0.9999

TABLE B-1-3.b. THE EFFECT OF A 10' WIDE ROAD

Angle (θ) (degrees)	Eff. of detector set mid-pt. of θ	Tan θ	x(ft)	Width of road=10' (ft^2)	Area of each interval (ft)	Total Area (ft^2)	Area x Eff. (ft^2)	Int. Area x Eff. / Total (Ratio)
10	0.99	0.17633	4.28	28.8	28.8	57.6	57.0	0.016
20	0.955	0.36397	8.84	88.4	59.6	119.2	118.6	0.033
30	0.89	0.57735	14.02	140.2	51.8	103.6	92.2	0.023
40	0.805	0.83910	20.39	203.70	63.5	127.0	102.2	0.028
50	0.69	1.1918	28.96	289.30	85.6	171.2	118.1	0.033
60	0.54	1.7321	42.08	420.50	131.2	262.4	141.7	0.039
						Total	629.8	0.174

TABLE B-1-4. COMPUTATION OF THE BRUSH ATTENUATION FACTOR FOR ^{241}Am

Stake No.	^{241}Am Cleared	^{241}Am Unclear	Clear Area, %	Road, %	Total Clear, %	Brush Radiation	100% Brush Radiation	Ratio = Clear / 100% Brus
7-N-1	18.9	17.2	0.055	0.174	0.229	12.872	16.695	1.132
6-N-1	20.3	18.1	0.086	0.174	0.260	12.822	17.327	1.172
5-N-1	20.6	17.3	0.0	0.174	0.174	13.716	16.605	1.240
5-S-2	13.3	11.8	0.049	0.174	0.223	8.834	11.369	1.170
6-S-2	16.2	13.5	0.054	0.174	0.228	9.806	12.703	1.275
6-S-1	16.2	14.8	0.0	0.174	0.174	11.981	14.505	1.117
4-N-1	18.57	17.8	0.0	0.174	0.174	14.569	17.638	1.053
4-S-3	22.4	21.0	0.0	0.174	0.174	17.102	20.705	1.082
7-S-1	13.2	12.4	0.0	0.174	0.174	10.103	12.231	1.079
5-S-3	45.1	35.9	0.140	0.174	0.315	21.693	31.667	1.424

Attenuation Factor, $\bar{x} = 1.147$; $\sigma = 0.075$; $\sigma/\bar{x} = 6.5\%$

TABLE B-1-5. COMPUTATION OF (ft^{-1}) AN ATTENUATION COEFFICIENT

Stake No.	I = 100% Brush (pCi/g)	Io = Clear (pCi/g)	I/Io	1-(I/Io)	t = ft	=
7-N-1	16.7	18.9	0.883	0.12405	8'	0.01
6-N-1	17.3	20.3	0.852	0.15836	8'	0.02
5-N-1	16.6	20.6	0.806	0.21560	10'	0.02
5-S-2	11.4	13.3	0.857	0.1568	5'	0.03
6-S-2	12.7	16.2	0.784	0.24320	5'	0.04
6-S-1	14.5	16.2	0.895	0.1105	6'	0.01
4-N-1	17.6	18.6	0.946	0.0515	10'	0.00
4-S-3	20.7	22.4	0.924	0.07869	10'	0.00
7-S-1	12.2	13.2	0.924	0.07620	6'	0.01

Average $\bar{\lambda} = 0.020$; $\sigma = 0.013$; $\sigma/\bar{x} = 65.6\%$

TABLE B-1-6. ^{155}Eu (86.550 keV) BRUSH ATTENUATION MEASUREMENTS

Stake No.	Cleared (pCi/g)	Uncleared (pCi/g)	Total Cleared (%)	Cleared / 100% Brush (Ratio)
7-N-1	6.0	5.4	0.229	1.149
6-N-1	7.7	6.9	0.260	1.163
5-N-1	7.8	6.3	0.174	1.303
5-S-2	7.8	7.6	0.223	1.034
6-S-2	8.8	7.2	0.228	1.308
6-S-1	6.6	5.4	0.174	1.282
4-N-1	8.23	7.9	0.174	1.051
4-S-3	13.13	12.3	0.174	1.083
7-S-1	4.7	5.5	0.174	0.829

Ratio Mean, $\bar{x}$ = 1.137
Standard Deviation, σ = 0.155
$\sigma/\bar{x}$ = 13.7%

TABLE B-1-7. ^{137}Cs (661.6 keV) BRUSH ATTENUATION MEASUREMENTS

Stake No.	Cleared (pCi/g)	Uncleared (pCi/g)	Total Cleared (%)	Cleared / 100% Brush (Ratio)
7-N-1	31.0	28.2	0.229	1.133
6-N-1	33.2	29.3	0.260	1.189
5-N-1	25.2	24.2	0.174	1.050
5-S-2	21.5	21.1	0.223	1.024
6-S-2	35.9	34.1	0.228	1.069
6-S-1	26.3	27.5	0.174	0.947
4-N-1	22.93	23.3	0.174	0.981
4-S-3	27.0	27.9	0.174	0.961
7-S-1	25.7	25.8	0.174	0.995

Ratio Mean, $\bar{x}$ = 1.039
Standard Deviation, σ = 0.08
$\sigma/\bar{x}$ = 7.8%

TABLE B-1-8. ^{60}Cs (1252.8 keV) BRUSH ATTENUATION MEASUREMENTS

Stake No.	Cleared (pCi/g)	Uncleared (pCi/g)	Total Cleared (%)	Cleared / 100% Brush (Ratio)
7-N-1	6.3	5.9	0.229	1.089
6-N-1	8.3	8.3	0.260	1.000
5-N-1	8.6	8.0	0.174	1.092
5-S-2	15.1	15.1	0.223	1.000
6-S-2	15.9	15.2	0.228	1.060
6-S-1	7.8	8.2	0.174	0.941
4-N-1	9.2	10.3	0.174	0.893
4-S-3	22.3	24.5	0.174	0.873
7-S-1	6.4	7.1	0.174	0.883

Ratio Mean, $\bar{x} = 0.981$
Standard Deviation, $\sigma = 0.088$
$\sigma/\bar{x} = 8.9\%$

TABLE B-1-9. CARBON ATTENUATION COMPUTATION

keV	cm^2/gm*	cm^{-1}	I0/I	where t = 0.343 cm
60	0.176	0.399	1.147	
80	0.161	0.365	1.133	
100	0.152	0.345	1.126	
200	0.123	0.279	1.100	
300	0.107	0.243	1.087	
500	0.0872	0.198	1.070	
800	0.0709	0.161	1.057	
1000	0.0637	0.144	1.051	
1500	0.0519	0.118	1.041	

*Page 137, Radiological Health Handbook

ADDITIONAL MEASUREMENTS OF
BRUSH ATTENUATION AND CALCULATION
OF BRUSH CORRECTION FACTOR

DOE/ERSP TECH NOTE NO. 1.1 DATED: 3 August 1979

AUTHOR: R. Jaffe, EG&G

There has recently been renewed interest in the question of the attenuation factor attributable to brush covering an IMP measurement area. Consequently, the original Tech Note 1 (undated, about November 1977, by F. Tomnovec) was examined, and two additional experiments were conducted. The purpose of this note is to discuss the original tech note and to present additional data. The first experiment to be discussed is a direct measurement of brush weight per unit area. The second experiment is placing a known ^{241}Am source under brush cover, and calculating brush attenuation, the reciprocal of which is the brush correction factor (BCF). These experiments confirm the original factor proposed for BCF of 1.15 for a high density brush cover.

Original Work and Analysis

The original work (in October-November 1977) was done on Pearl. IMP access lanes were cut through and ^{241}Am readings taken at ten locations. The 84th Army Engineers then carefully cut by hand the brush in a seventy foot circle, removed it, and the IMP remeasured these points. These data were analyzed, and the effect of brush determined. BCF is the ratio of clear-area readings to brush-covered-area readings. BCF was calculated as 1.147 for a 100% brush-covered area.

The concept proposed was to determine the total open area fraction and then calculate:

$$\text{BCF} = 1.147 / (\text{Open Fraction} \times 1.147 + (1 - \text{Open Fraction}))$$
$$= 1.147 / (1 + 0.147\ (\text{Open Fraction}))$$

which is rounded and simplified to:

$$= 1 + 0.15\,(1 - \text{Open Fraction}).$$

There was no correlation in the experimental data with brush height, which may be explained as a canopy of brush cover independent of brush height, which is reported to be characteristic of the dominant scaevola brush. The density of brush growth and fraction of brush-covered area are both included in the brush coverage observation recorded at each measurement location by the IMP operator.

An objection has been raised to the original tech note concerning the omission from the analysis of one of the ten experimental measurements. As the author is not available for consultation, it is necessary to speculate about the reasons for the omission. These may be: that for the location in question, the open area fraction is about a factor of two higher than for the next highest open-area location; or that in subsequent debris removal, an atypically large decrease in ^{241}Am was noted, implying a localized concentration pattern, which would be undesirable for BCF determination. For whatever reason, data from this location, 5-S-3, were not included. There were four measurements taken before debris removal at that point:

DATE	^{241}Am (pCi/g) READING	COMMENT
10-08-77	35.9	"Average 7' brush/two areas 18' dia open grass/dead brush in road/stake under growth."
10-13-77	45.1	Brush cleared.
10-20-77	43.3	300 second data acquisition time.
11-18-77	41.3	

The comment on original condition is copied from Tech Note #1 which checks exactly with the operator's log sheet. The open area ^{241}Am assay values may be averaged to give 43.2 pCi/g. Using the equations and open area data of Tech Note #1, BCF is 1.328. The following is an ordered list of BCF for all ten points:

5-S-3	1.328
6-S-2	1.275
5-N-1	1.241
6-N-1	1.172
5-S-2	1.170
7-N-1	1.132
6-S-1	1.117
4-S-3	1.082
7-S-1	1.080
4-N-1	1.053

The comparison of the nine-point and ten-point data mean and standard deviation (as percent of mean) is given below.

	TEN POINTS	ORIGINAL NINE POINTS
Mean	1.165 = 1.17	1.147 = 1.15
Standard Deviation	7.8%	6.5%

There is no practical difference between the data with or without 5-S-3.

Approach by Brush Weight Per Unit Area

Because of the high interest in BCF, a direct measure of the amount of brush coverage was made. An experienced IMP operator selected two typical areas of maximum brush density encountered in field operations. Both were on Tilda. One was at approximately 10-S-1, the other at 6-S-1. For both sites an area 9 x 10 feet wide was stripped of brush, deadwood and vines, and the vegetation placed in plastic bags. An approximate square cut was used so that the total weight of vegetation vertically covering the area was gathered. The samples weighed 126 and 147 pounds each. The average areal density was 1.52 lb/ft^2 or 0.742 g/cm^2. A representative sample was dried and the water fraction found to be 0.55. Combining these data and the assumption that the brush was composed of cellulose $(C_6H_{10}O_5)_n$, the attenuation coefficient at 60 keV was calculated at 0.148.* (This value is not much affected by composition except for large weight fractions of hydrogen. Even if the water content were grossly different, say 10%, the attenuation coefficient would be 0.144. If the material were pure carbon, the attenuation coefficient would be 0.131.)

*Mass attenuation coefficient used is: H = 0.326, C = 0.176 and O = 0.191 cm^2/g (Radiological Health Handbook).

To determine BCF, the effect of this assumed slab shield over the surface must be properly averaged for detector response geometry. The response given in EG&G Report RSSD 78-177 (August 1978) was used. The equation is:

$$BCF = \frac{\Sigma f(\theta) R(\theta)}{\Sigma f(\theta) R(\theta) \exp(-d / \cos\theta)}$$

where

$f(\theta)$ = $\tan\theta \exp(-\mu_a h \sec\theta) / (\alpha + \mu_s \sec\theta)$
= flux at angle θ
$R(\theta)$ = detector angular response
d = attenuation coefficient = $\Sigma \mu \rho t$ for brush
θ = detector view angle
μ_a = linear attenuation coefficient for air
h = height of detector
α = reciprocal of the relaxation length of the source logarithmic distribution in the soil
μ_s = linear attenuation coefficient for soil

For the last four factors, the reference value for the IMP calibration factor was used, as discussed in the reference report.

The calculation was done numerically considering five degree increments from 0 to 62.5 degrees. The resulting BCF is 1.22. It is worth noting that this is very close to the 1.20 value obtained by calculating BCF at 35 degrees, which is the angle at which 50% of the total detector counts are received, i.e., exp (0.148/cos 35) = 1.20.

Response to Source Under Brush

At the suggestion of J. J. Giacomini of DRI, an experiment was jointly designed by J. L. Pigg of EG&G and Giacomini. It utilized the on-atoll ^{241}Am source used to calibrate the IMP. Essentially, it involves placing the source under representative brush and determining the count response. Knowing the response obtained for the same geometry with no brush, the BCF can be calculated. The experiment was performed on the island of Kate, and the reference no-brush geometry was tested on Ursula, near the IMP garage. Data for the no-brush test are given in Table B-1-10 and Figure B-1-3.

Figure B-1-3 gives the experimental data, normalized to the count response observed with the source directly under the vertical axis of the detector. (The count rate agreed within 8% with that calculated from the inverse square law and the last calibration of that detector.) A calculation of the normalized detector response was made, using the detector angular sensitivity determined for a similar detector (during IMP calibration in July 1977 at EG&G, Las Vegas), and the inverse calculated response is high by about 8%. It is believed that this is due to the non-isotropic nature of the source, which was kept flat on the ground during the experiment, rather than angled toward the detector. (The source disc is recessed slightly inside an annular aluminum ring.)

Table B-1-11 gives the brush data and the results of the BCF calculation. The three valid runs taken with this technique give an average BCF of 1.12 for "Medium Dense" brush. In the experienced IMP operator's judgment, this area would be rated as about 60% brush covered. The BCF would thus be calculated as 1 + (0.12 / 0.6) = 1.20.

Summary and Recommendation

The original study gave 1.15 as BCF. Including the tenth point would give 1.17. The direct brush weighing gives 1.22. Placing a source under brush gives 1.20.

It is the author's judgment that all available present data show that 1.15 may continue to be used for BCF. The extensive experimental program that would be required to obtain a better value is judged to be not warranted.

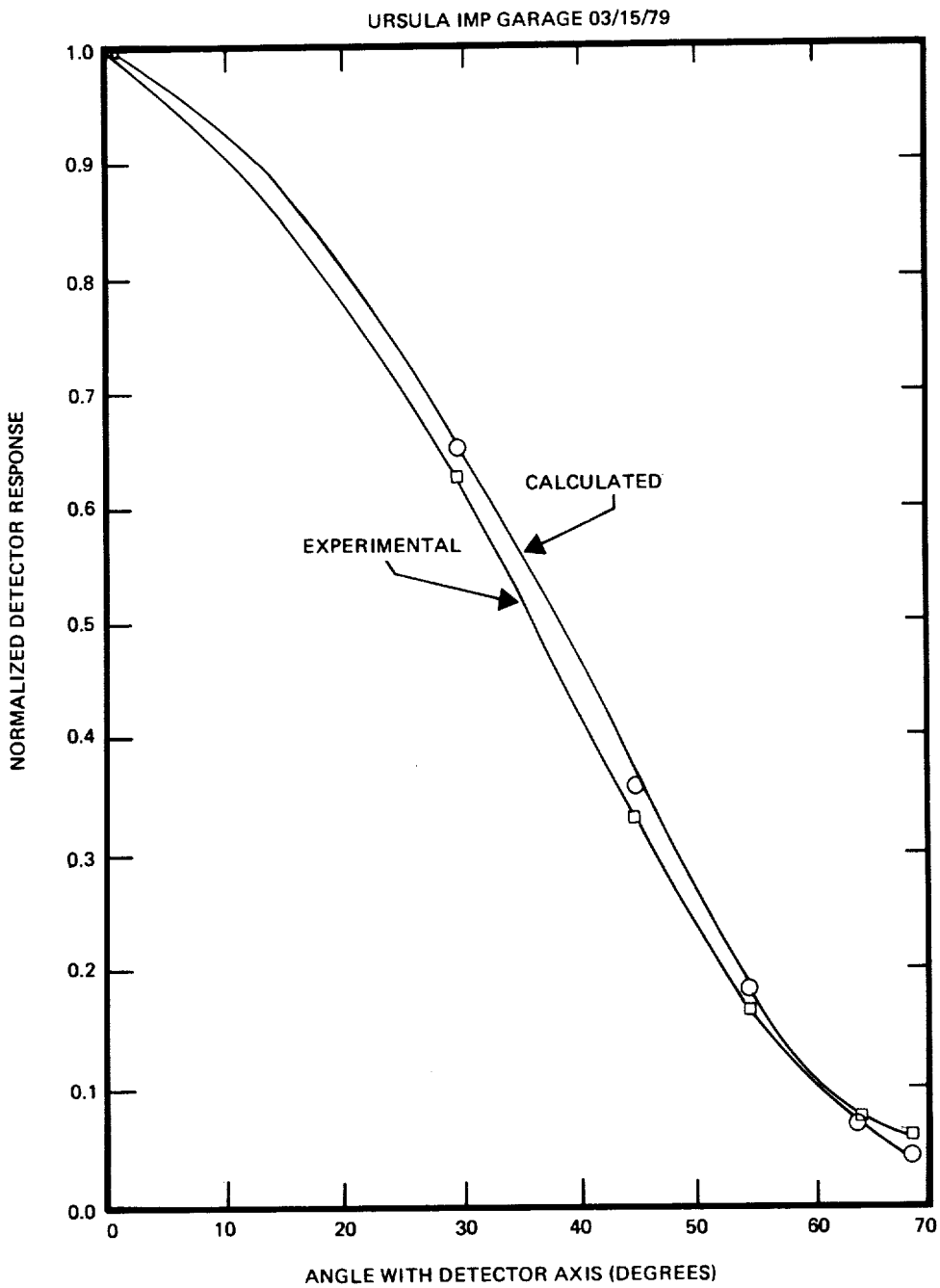


FIGURE B-1-3. DETECTOR RESPONSE WITH NO BRUSH

TABLE B-1-10. ANGULAR RESPONSE OF IMP to ^{241}Am SOURCE

HORIZONTAL DISTANCE (cm)	COUNTS (900 sec) ALONG MAST PROJECTION	NORMAL TO MAST	RELATIVE COUNTS	ANGLE w/DETECTOR AXIS (deg)	CALCULATED RESPONSE
0	3348	3308	1.000	0	1.000
395	2128	2027	0.624	29.9	0.649
700	1072	1109	0.328	44.6	0.356
1000	569	532	0.165	54.6	0.184
1420	226	229	0.068	63.4	0.069
1750	193	203	0.060	67.9	0.040

NOTES:

1. IMP II measurement, Detector 635, 3/15/79.
2. Detector height: 710 cm.
3. Collimator removed (measurements and response calculation different at angles greater than 55 degrees than corresponding values with collimator).
4. Relative counts corrected for measured background of 114 counts in 1800 seconds.

TABLE B-1-11. MEASUREMENTS THROUGH BRUSH

A. DATA*

STAKE	COUNTS (900 sec) W/SOURCE	NO SOURCE	SOURCE HORIZONTAL DISTANCE (cm)	ANGLE W/DETECTOR (DEGREES)	BRUSH DESCRIPTION
Unknown	2319	331	300	22.9	3 Ft. Scaevola
4-N-2	3226	1209	440	31.8	Morning Glories
4-S-6	1775	132	500	35.2	2 ft. Medium Dense Scaevola
4-S-4	1828	281	500	35.2	4 ft. Medium Dense Scaevola
8-S-2	1867	1588	600	40.2	8 ft. Medium Dense Scaevola
2-S-4	675	119	600	40.2	Medium Dense Scaevola with Deadwood
6-BL-0	1348	818	950	53.2	2 ft. Scaevola with Moss

* IMP II, detector 635, 3/19-20/1979

B. ANALYSIS

STAKE	ANGLE	RELATIVE COUNT W/BRUSH	NO BRUSH**	BCF	COMMENTS
Unknown	22.9	0.593	0.737	1.232	
4-N-2	31.8	0.606	0.590	0.974	Discard - Morning glories, not brush
4-S-6	35.2	0.494	0.510	1.032	
4-S-4	35.2	0.465	0.510	1.097	
8-S-2	40.2	0.084	0.410	4.88	Discard - Source and No Source counts too close together
2-S-4	40.2	0.167	0.410	2.46	Discard - Not physically believable
6-BL-0	53.2	0.159	0.176	1.107	Discard - Questionable - High sensitivity to detector angle
				1.12	Average of three valid runs

**From Figure B-1-3

DETERMINATION OF THE PLUTONIUM TO AMERICIUM RATIO IN SOIL SAMPLES FROM ISLAND PEARL

DOE/ERSP TECH NOTE NO. 2.0 DATED: 12 November 1977

AUTHOR: B. Friesen, DRI

Soil surface samples were collected on Island Pearl in accordance with documented guidelines. The samples were analyzed by wet chemistry methods as well as alpha and gamma spectroscopy techniques in the Eberline Instrument Corp. laboratory and the the results forwarded to DRI. The objective was to incorporate the Pu/Am ratio into computations required to make estimates of the Pu distribution on the island based on the ^{241}Am measurements made by the in situ van (IMP).

Use of the ratio is necessary because direct field measurements cannot be made of plutonium by the IMP but they can be made of ^{241}Am which bears a functional relationship to plutonium.

Analysis of the soil sample data involves two steps. First is the determination of a ratio, or if necessary, a set of ratios that can be used to characterize the Pu to Am relationship. The second is the determination of the error term(s) associated with the computed ratio(s). The remainder of this Technical Note will deal with these steps separately.

Determination of one mean ratio for Lujor was made first excluding the ^{238}Pu component, then later including ^{238}Pu along with $^{239,240}Pu$. Using $^{239,240}Pu$ and ^{241}Am laboratory results, the ratio was determined for each of 10 samples taken from 5 locations on the island. The arithmetic mean of these 10 numbers was 3.77 with a coefficient of variation of 35.93%.

Some concern was expressed over the magnitude of the spread between lowest and highest ratios; the range was from 1.78 to 6.00. Simple and weighted mean ratios of $^{239,240}Pu$ to ^{241}Am were computed for each of 6 arrangements of the data as shown below.

"A" Samples		"B" Samples	
Ratio No.	Ratio	Ratio No.	Ratio
1	1.78	2	1.78
3	3.10	4	4.64
5	3.99	6	3.80
7	3.73	8	3.59
9	6.00	10	5.30
Simple Mean	3.72		3.82
Weighted Mean	3.96		4.00

Set or Subset	Mean	
	Weighted	Simple
Nos. 1-10	3.98	3.77
1-8	3.43	3.30
3-8	3.83	3.80
3-10	4.36	4.26

Attention was then directed toward a comparison of surface soil ratios and subsurface ratios taken at 10 cm and 20 cm depths. All tests performed indicated that in the statistical sense all of the ratios came from the same population, i.e., there was no reason to discard or suspect any of the numbers, taking them at face value. It was recognized that some outside information not evident in the data could lead to later changes; however, the decision was made to proceed with available data for a first approximation. The ratio actually used in preparing the first estimates of $^{239,240}Pu$ for Pearl was $3.825 \pm .495$.

Instruction from Las Vegas indicated the need to incorporate ^{238}Pu into the ratio computations. This was done in the same manner as described above with the results being a total Pu/^{241}Am ratio of 5.63. The new ratio, computed several ways, still appears to be acceptable for application to the entire island.

"A" Samples		"B" Samples	
Ratio No.	Ratio	Ratio No.	Ratio
1	1.877	2	1.871
3	3.451	4	5.319
5	5.591	6	5.392
7	5.536	8	5.352
9	9.228	10	8.060

Set or Subset	Mean Weighted	Mean Simple
"A" Samples	5.70	5.13
"B" Samples	5.55	5.19
Nos. 1-10	5.63	5.16
1-8	4.56	4.29
3-8	5.16	5.16
3-10	6.22	5.99

Since it appears likely that more surface samples will be analyzed, and the resulting ratios used in final computations, the decision was made to proceed using a conservative value. Therefore, the ratio used to compute the second estimates was 6.0. If, in fact, different ratios are used on different parts of the island, the expectation is that the final distribution map would show lower values than are currently estimated for a significant portion of the island.

Determination of an error term to associate with the mean ratio of $^{238,239,240}Pu$ to ^{241}Am is accomplished by computing the low-to-high range in ratio for each sample, then take the square root of the sum of the square of one-half the range for each sample, all divided by the number of samples (prior to taking the square root). The Pearl data has a weighted mean ratio and error term of 5.66 $\pm$ .598. When the ^{238}Pu is excluded from the data the weighted mean and error term is 3.825 $\pm$ .495.

ADDENDUM TO TECH NOTE 2.0: DETERMINATION OF THE RATIO OF TOTAL TRANSURANICS TO AMERICIUM IN SOIL ON ISLAND PEARL

DOE/ERSP TECH NOTE NO. 2.0-A DATED: 13 February 1978

AUTHORS: M. Barnes, DRI
J. Giacomini, DRI

A re-examination of all the existing soil data on ratios of total transuranics ($^{238,239,240}Pu$ and ^{241}Am) to americium on Pearl indicated the existence of multiple distinct underlying populations.

The ratios of total transuranics to ^{241}Am at each soil sample location were plotted against distance from Inca ground zero (GZ) (Figure B-2-1). Three distinct clusters of ratios were apparent: Cluster 1, containing samples within 150 meters of Inca GZ; Cluster 2, containing samples further than 150 meters but less than 350 meters from Inca GZ; and Cluster 3, containing samples more than

350 meters from Inca GZ. The simple means and standard deviations of the ratios in each cluster are presented below.* The three means were compared using t-tests, and found to be statistically different at the 90% significance level.

The computed total transuranics values were used to derive estimates and upper bounds of quarter hectare and half hectare average concentrations.

Cluster	Mean Ratio	Standard Deviation
1	9.10	1.13
2	7.80	2.18
3	4.10	1.28

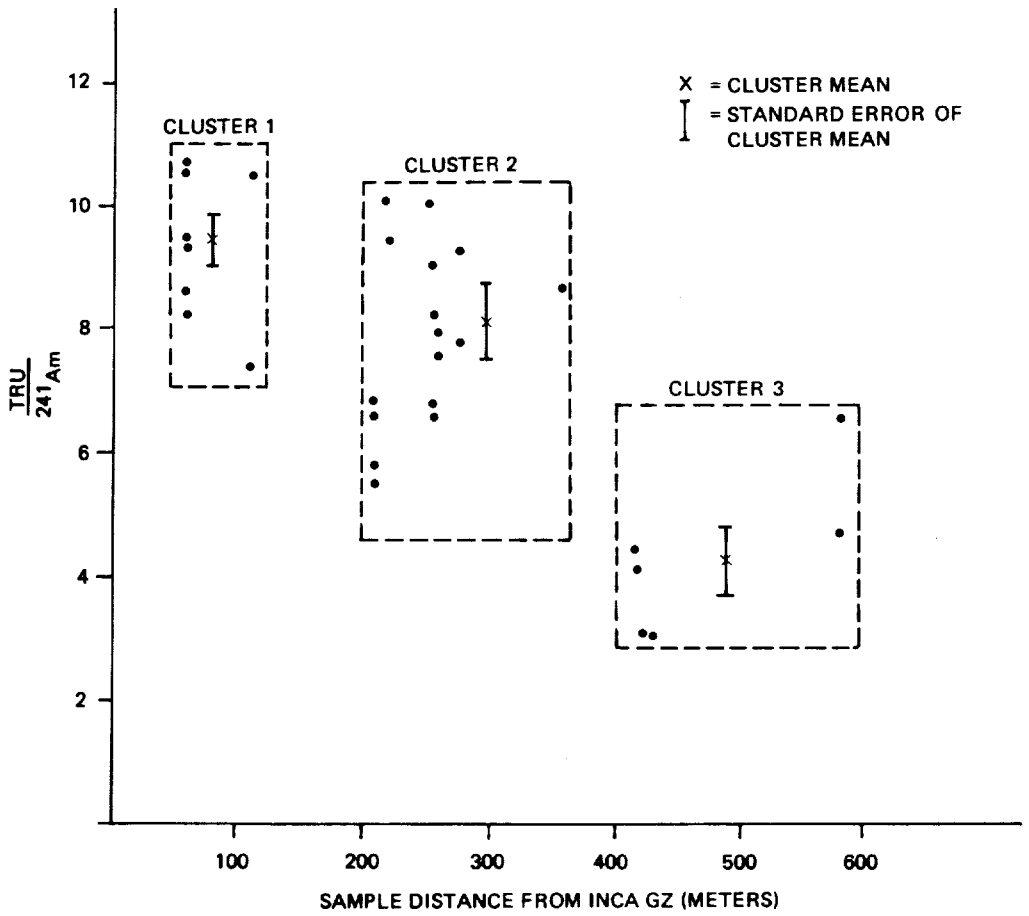


FIGURE B-2-1. PEARL SOIL SAMPLE DATA, TN 2.0-A

*This method of estimating the ratio and error was later replaced by a method based on more accurate assumptions as described in Tech Note 2.2-A.

ADDENDUM TO TECH NOTE 2.0: DETERMINATION OF THE RATIO OF TOTAL TRANSURANICS TO AMERICIUM IN SOIL ON ISLAND PEARL

DOE/ERSP TECH NOTE NO. 2.0-B* DATED: 15 March 1978

AUTHOR: M. Barnes, DRI

A re-examination of all the existing soil data on ratios of total transuranics ($^{238,239,240}Pu$ and ^{241}Am) to americium on Pearl indicated the existence of multiple distinct underlying populations.

The ratios of $^{239,240}Pu$ to ^{241}Am at each soil sample location were plotted against distance from Inca ground zero (GZ) (Figure B-2-2). Three distinct clusters of ratios were apparent: Cluster 1, containing samples within 150 meters of Inca GZ; Cluster 2, containing samples further than 150 meters but less than 350 meters from Inca GZ; and Cluster 3, containing samples more than 350 meters from Inca GZ. Simple means and standard deviations of the ratios in each cluster follow. The three means were compared using t-tests, and found to be statistically different at the 95% significance level.

Cluster	Mean Ratio	Standard Deviation
1	6.63	1.79
2	5.28	1.72
3	2.90	1.07

These results were used to draw boundaries around relatively homogeneous populations of ratios. Within each area so determined, the simple mean and standard deviation of the ratios of total transuranics to americium were calculated,** and those values used to compute total transuranics at each sample point in that area. Table B-2-1 shows the actual total transuranics to americium ratios at each soil sample location, and the mean and standard deviation for each area.

The computed total transuranics values were used to derive estimates and upper bounds of quarter hectare and half hectare average concentrations.

*This Tech Note supersedes Tech Note 2.0-A which is cancelled.
**This method of estimating the ratio and error was later replaced by a method based on more accurate assumptions as described in Tech Note 2.2-A.

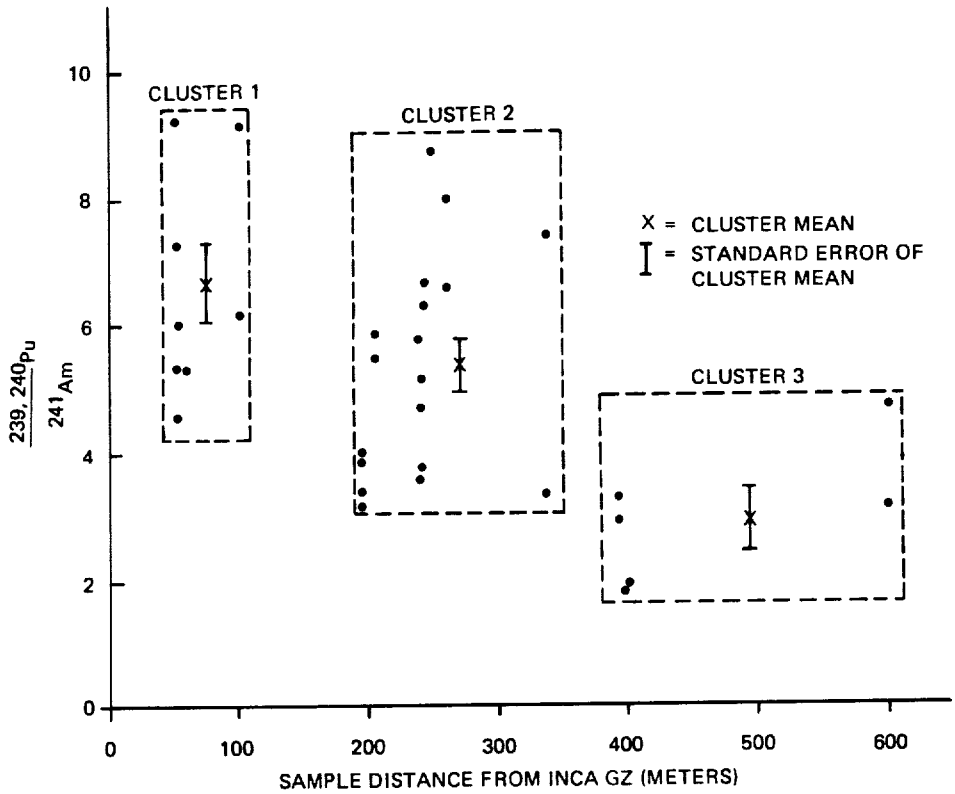


FIGURE B-2-2. PEARL SOIL SAMPLE DATA, TN 2.0-B

TABLE B-2-1. TRU/AM RATIOS AT IDENTIFIED SITES ON PEARL

Location	Cluster	"A" Composite	"B" Composite
11-S-5	3	4.45	6.32
8-S-4	3	4.23	3.87
9-S-2	3	2.87	2.87
5-N-1(160°)	2	6.59	6.39
5-N-1(150°)	2	5.57	5.29
6-S-1	2	7.27	7.61
8-BL-0	2	4.28	8.37
5-S-3(280°)	2	6.54	6.35
5-S-3(270°)	2	7.87	8.66
5.5-S-3	2	7.56	8.96
4.5-S-2.5	2	9.03	9.68
4.5-S-3.5	2	9.61	—
5.5-S-2.5	2	14.04	—
1-S-1(280°)	1	9.03	7.93
1-S-1(300°)	1	10.23	9.06
3-S-1	1	10.18	7.17
1-N-1	1	10.26	8.28

Cluster	Mean Ratio	Standard Deviation
1	9.10	1.13
2	7.80	2.18
3	4.10	1.28

ADDENDUM TO TECH NOTE 2.0: DETERMINATION OF THE RATIO OF TOTAL TRANSURANICS TO AMERICIUM IN SOIL ON ISLAND PEARL AFTER DEBRIS REMOVAL

DOE/ERSP TECH NOTE NO. 2.0-C DATED: 20 August 1978

AUTHOR: J. Giacomini, DRI

Pearl was first measured by the in situ van and soil was sampled in October-November 1977. Average concentrations of total transuranics (TRU) were computed based on these data. Debris removal has since taken place, which caused much soil disturbance. To determine the effect of the debris removal, the island was remeasured by the IMP and new soil samples were collected. Figure B-2-3 shows the area that was remeasured and the soil sample locations.

The new soil samples indicated a different ratio from that reported in Tech Note 2.0-B. Determination of one ratio for the disturbed area was made using laboratory results from soil samples taken at four locations with two composites at each location. (Reference Tech Note 2.2-A for assumptions made in computing the mean ratio and associated error.) The range of values is from 5.42 to 8.64. The ratios are:

Location	0 cm A	0 cm B
3-S-2	7.58	6.84
3-N-1	7.75	5.46
-1-BL-0	8.64	7.42
5-S-1	5.57	5.42

The Pearl data have a mean ratio of 6.91 with a standard deviation of 1.41;* these values were used in estimating total transuranics and upper bounds.

*Due to a programming error, the standard deviation reported here is overestimated.

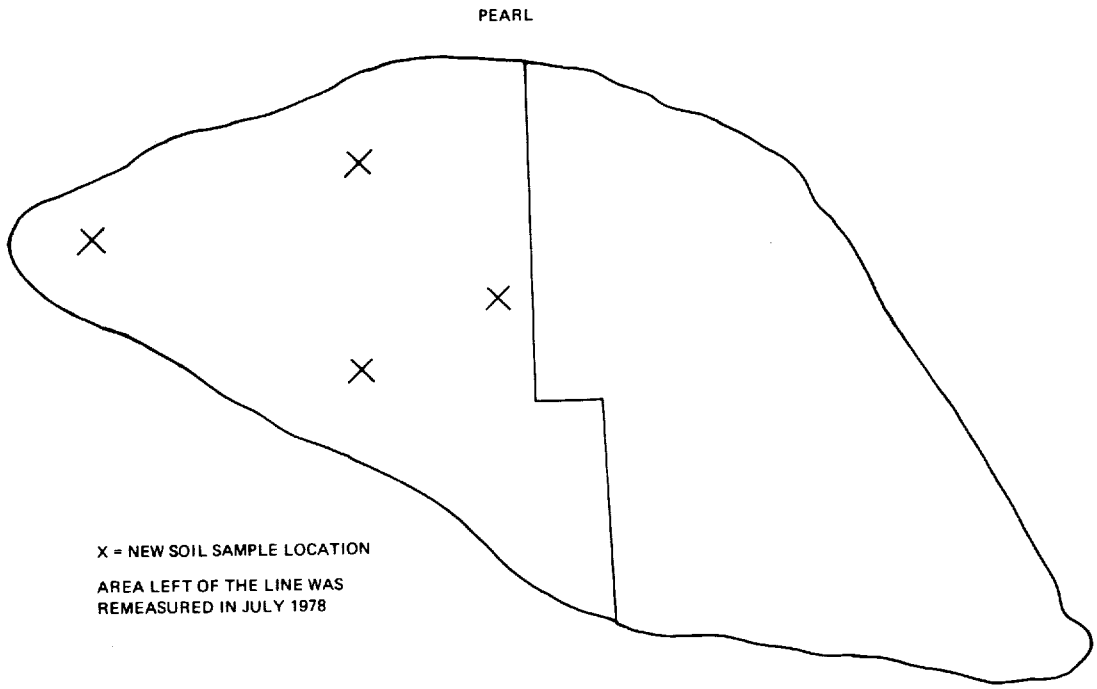


FIGURE B-2-3. PEARL SOIL SAMPLE LOCATIONS AFTER DEBRIS REMOVAL

DETERMINATION OF THE PLUTONIUM TO AMERICIUM RATIO IN SOIL SAMPLES FROM ISLAND IRENE

DOE/ERSP TECH NOTE NO. 2.1 DATED: 21 November 1977

AUTHOR: B. Friesen, DRI

Reference Tech Note 2.0 for introductory remarks.

Soil samples were collected from the surface and from 10 cm and 20 cm depths at 5 locations on the island of Irene. Results from the laboratory showed high variation in the $^{238,239,240}Pu$ to ^{241}Am ratio, with the lowest values on the east end of the island and the highest values on the west end. One intermediate value was observed in the north central portion. In order to derive first approximation estimates of total Pu distribution, three separate ratios were used and are shown below. Soil sample locations and the areas for which each ratio apply are shown on the map to which this Tech Note is appended.*

"A" Samples		"B" Samples	
Ratio No.	Ratio	Ratio No.	Ratio
1	2.85	2	2.54
3	4.67	4	5.64
5	9.43	6	11.63
7	9.21	8	7.59
9	12.45	10	10.60

Ratio Numbers	Mean Simple	Mean Weighted	Ratio Used
1 - 2	2.70	2.70	3.0 ± 0.72
3 - 4	5.16	5.18	6.0 ± 0.60
5 - 10	10.15	10.28	11.0 ± 1.60

ADDENDUM TO TECH NOTE 2.1: DETERMINATION OF THE RATIO OF TOTAL TRANSURANICS TO AMERICIUM IN SOIL ON ISLAND IRENE

DOE/ERSP TECH NOTE NO. 2.1-A DATED: 6 February 1978

AUTHOR: M. Barnes, DRI

For the purpose of computing values of total transuranics from americium values, Irene was divided into three distinct areas as described in Tech Note 2.1. In each area, using 0, 10, and 20 cm soil sample results, the simple mean and standard deviations of the ratios were computed.** These values were then used in estimating quarter hectare average concentrations of total transuranics.

Area	TRU/Am	Standard Deviation
Eastern End	4.12	0.53
Central Area	6.50	1.20
Western End	11.13	1.70

*Map omitted here.
**This method of estimating the ratio and error was later replaced by a method based on more accurate assumptions as described in Tech Note 2.2-A.

ADDENDUM TO TECH NOTE 2.1: DETERMINATION OF THE PLUTONIUM TO AMERICIUM RATIO IN SOIL SAMPLES FROM IRENE

DOE/ERSP TECH NOTE NO. 2.1-B DATED: 25 July 1979
AUTHOR: Madaline Barnes, DRI

In examining chemistry results for samples taken from soil more than 20 cm below the original surface of Irene it became clear the TRU/Am ratio was changing as a function of depth. Some of the samples were taken after recontouring of the excision area near 13-N-1 and 12-N-2; others were samples analyzed as part of the TRU subsurface investigation process triggered by FPDB sample results. (See Tech Note 18).

Accurate TRU/Am ratios were needed to determine whether or not cleanup criteria had been met on Irene. Ratio information was therefore checked for every area affected by excision, recontouring or backfill. Also, the original TRU/Am ratios were estimated by the means of sample ratios. The characteristics of the data, explained in Tech Note 2.2-A, are such that the ratio of sample means is a more appropriate estimator. The original soil sample data were used to compute the ratios of means, and these revised estimates were used for all areas not affected by soil moving. Table B-2-2 summarizes the original and revised ratio estimates and errors. Except as discussed below, the boundaries between areas with different ratios were not altered.

In the region around 13-N-1, 12-N-2 and 14-N-1, the post-cleanup ratio was clearly different than any of the values in Table B-2-2. There were sufficient samples from this area to estimate a separate ratio. The post-lift ratio at 9-S-3 was the same as this region, and was included in the estimate. The ratio from the corresponding depth at 9-S-1 could also have been included in this group of samples, but was not because no soil was excised from 9-S-1. (Ratios in this group were computed using ^{241}Am from chemistry because gamma results were erratic for 13-N-2 and 12-N-2 - an analyzer problem is suspected. All others use ^{241}Am from gamma scan.) Post-lift ratio data from 10-N-1 and 7-S-3 were about the same as the pre-lift west area ratio. The post-lift ratio at 6-S-2 was the same as the pre-lift central area ratio. Table B-2-3 summarizes the post-lift ratio information. The estimated ratio and error for the 14-N-1/13-N-1/12-N-2 region is 7.92 $\pm$ 1.34.

For the final post-cleanup TRU estimates, the boundaries between areas with different ratios were left basically the same. Corresponding revised ratios from Table B-2-2 were applied to data in each area. The new ratio estimated for the 14-N-1/13-N-1/12-N-2 region was applied to all data from the shaded area in Figure B-2-4. The shading includes all the area affected by lifting and recontouring in that vicinity. The new ratio was also applied to 9-S-3 post-lift, but was used at 14-N-1 only for post-lift data before backfilling. The backfill material came from the lagoon end of the 8-row, which is in the west region. Therefore, the west area ratio 11.27 was applied to post-backfill data at 14-N-1.

Table B-2-2. TRU/Am Ratios for Irene

	Original Estimates		Revised Estimates	
Area	Ratio	Error	Ratio	Error*
East	4.12	0.53	4.06	0.41
Central	6.50	1.20	6.41	1.03
West	11.13	1.70	11.27	1.09

*Due to a programming error, the standard deviation reported here is overestimated.

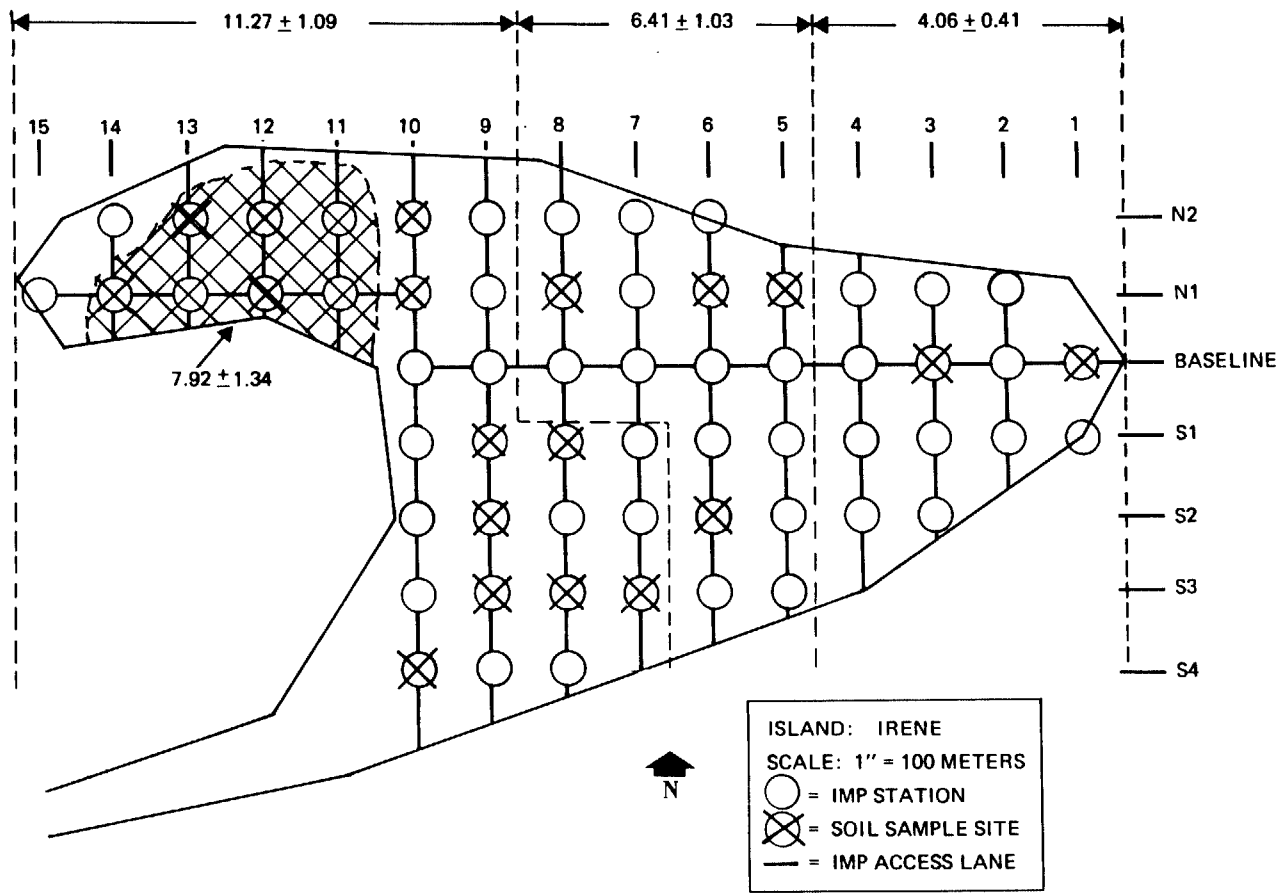


FIGURE B-2-4. TRU/Am RATIOS IN VARIOUS REGIONS OF IRENE

Table B-2-3. Post-Cleanup TRU/Am Ratios on Irene

Location	TRU/Am
13-N-2	8.48
12-N-2	6.57
9-S-3	7.70
12-N-1	7.34
14-N-1	9.36
10-N-1	10.23
7-S-3	11.39
6-S-2	6.06

DETERMINATION OF THE PLUTONIUM TO AMERICIUM RATIO IN SOIL SAMPLES FROM ISLAND VERA

DOE/ERSP TECH NOTE NO. 2.2 DATED: 21 November 1977

AUTHOR: B. Friesen, DRI

Reference Tech Note 2.0 for introductory remarks.

Determination of one mean ratio for Vera was made including $^{238,239,240}Pu$ and ^{241}Am. Laboratory results of eight soil samples taken from four locations on the island were used to compute a ratio for each sample. The weighted mean of these eight numbers was 1.55 with a coefficient of variation of 17.7%. The range in values was 1.26 to 2.09.

Determination of the error term to associate with the mean ratio was accomplished as described in Tech Note 2.0. The Vera data has a weighted mean ratio and error term of 1.572 ± 0.415, as presented below, and these were used in the computations to derive total plutonium estimates and upper bounds.

"A" Samples		"B" Samples	
Ratio No.	Ratio	Ratio No.	Ratio
1	2.09	2	1.26
3	1.73	4	1.32
5	1.62	6	1.33
7	1.60	8	1.45
Simple Mean	1.76		1.34
Weighted Mean	1.77		1.34
Weighted Mean (all samples)	1.572		

ADDENDUM TO TECH NOTE 2.2: DETERMINATION OF THE PLUTONIUM TO AMERICIUM RATIO IN SOIL SAMPLES FROM ISLAND VERA

DOE/ERSP TECH NOTE NO. 2.2-A DATED: 9 February 1978

AUTHOR: J. Giacomini, DRI

To determine a ratio for total transuranics (TRU) to ^{241}Am certain assumptions were made. One assumption is that the true ratio is constant at each value of ^{241}Am and that a plot of TRU against ^{241}Am is a straight line through the origin. The second assumption states that the variance of TRU increases proportionally to ^{241}Am as ^{241}Am increases. Both of these assumptions are met by the data from this island. Reference "Ratio Estimation Techniques in the Analysis of Environmental Transuranic Data" by Pamela Doctor and Richard Gilbert.

Data collected at four sample locations (two composites) were used in computing the mean ratio and associated error.

The Vera data has a mean ratio of 2.51 with a standard deviation of 0.22;* these values were used in estimating TRU and upper bounds.

	"A" Sample		"B" Sample	
Location	TRU	^{241}Am	TRU	^{241}Am
2-W-2	10.23	3.31	16.96	7.49
4-B-0	9.31	3.41	5.7	2.46
5-E-2	13.21	5.04	11.43	4.90
7-B-0	12.68	4.87	11.3	4.62

DETERMINATION OF THE TOTAL TRANSURANICS TO AMERICIUM RATIO IN SOIL SAMPLES FROM ISLAND OLIVE

DOE/ERSP TECH NOTE NO. 2.3 DATED: 17 January 1978

AUTHOR: M. Barnes, DRI

Determination of one mean ratio for Olive was made including $^{238, 239, 240}Pu$ and ^{241}Am. Laboratory results of 22 samples taken at four locations were used to compute a mean ratio. Ratios for 0, 10, and 20cm were from the same population, so all depths were included when computing the mean. The range in values is from 2.01 to 3.72.

The simple mean** is 2.74 and the standard deviation 0.46; these values were used to derive total transuranics estimates and upper bounds.

Location No.	Depth, cm					
	0		10		20	
	"A"	"B"	"A"	"B"	"A"	"B"
18-S-2	2.97	2.96	2.49	2.88	2.17	2.59
10-S-2	3.48	2.61	2.40	2.59	—	—
8-N-6	2.70	2.97	3.45	3.19	2.47	3.07
2-N-2	2.31	2.72	2.01	2.01	2.55	3.72

*Due to a programming error, the standard deviation reported here is overestimated.
**This method of estimating the ratio and error was later replaced by a method based on more accurate assumptions as described in Tech Note 2.2-A.

DETERMINATION OF THE TOTAL TRANSURANICS TO AMERICIUM RATIO ON ISLAND JANET

DOE/ERSP TECH NOTE NO. 2.4 DATED: 25 January 1978

AUTHOR: M. Barnes, DRI

Soil samples from 25 locations on Janet were analyzed in the laboratory for $^{238, 239, 240}Pu$ and ^{241}Am and used to compute ratios. The ratios of total transuranics to americium came from two distinct populations, one corresponding to the Easy/Xray ground zero, and the other to the remainder of the island. The abrupt boundary between these two regions had been located on the basis of aerial survey and IMP survey results.

Simple mean ratios and standard deviations were computed* for each area; the ratios are listed in Table B-2-4. The range in ratios for the Easy/X-ray area is from 4.63 to 6.67, with mean 5.34 and standard deviation 0.69. The range for the rest of the island is from 2.48 to 4.46, with mean 3.32 and standard deviation 0.42. These values were used to derive estimates and upper bounds of quarter hectare average concentrations of total transuranics.

TABLE B-2-4. TRU/AM RATIOS ON ISLAND JANET

Location	"A" Composite	"B" Composite
NW 29, 7	5.13	5.25
NW 21, 7	4.63	5.06
WB 22, 0	5.30	6.67
SW 14, 2	3.67	3.49
NW 14, 8	3.66	4.01
EB 10, 0	3.12	3.43
EB 2, 0	2.91	3.08
WB 6, 0	2.98	3.15
NE 14, 2	2.71	2.62
NE 14, 10	3.20	3.87
SW 2, 8	3.86	2.97
SW 4, 14	3.06	3.69
SE 4, 22	3.04	2.48
SE 6, 1	3.26	3.09
SE 6, 8	2.85	2.89
SE 6, 14	2.90	3.02
NW 2, 14	3.48	3.80
NW 6, 8	4.24	3.81
NE 2, 8	3.72	3.99
NE 6, 16	3.80	3.46
NE 6, 24	3.86	3.81
NE 10, 8	3.22	2.79
NE 10, 22	3.08	3.10
SE 12, 14	3.28	3.32
SE 14, 6	3.43	4.46

*This method of estimating the ratio and error was later replaced by a method based on more accurate assumptions as described in Tech Note 2.2-A.

DETERMINATION OF THE RATIO OF TOTAL TRANSURANICS TO AMERICIUM IN SOIL ON ISLAND SALLY

DOE/ERSP TECH NOTE NO. 2.5 DATED: 25 January 1978

AUTHOR: M. Barnes, DRI

A total of 51 soil samples from 9 locations on Sally were analyzed in the laboratory for $^{238,239,240}Pu$ and ^{241}Am. Fourteen of the samples had americium concentrations less than the lowest detectable level, hence were not usable for ratio computations.

The PACE excavation activities affected a large portion, but not all, of the island. The assumption was made that all areas of the island that were affected, either by being excavated or by having new material piled on top, had ratios of total transuranics to americium from a single population. The remaining small areas, one in the vicinity of Kickapoo ground zero and one in the vicinity of Yuma ground zero, were each considered to have a separate ratio. The area of Yoke ground zero was excavated during PACE operations and was considered as part of the affected area.

All usable samples, listed below, were considered in calculating simple mean ratios and standard deviations. Sample locations 14-S-8 and 12-S-4 had all depths and both composites with americium concentrations less than lowest detectable level so were unusable. Boundaries between ground zero areas and PACE-affected areas were based on the 1972 aerial photographs and the IMP survey measurements.

Location	Depth, cm					
	0		10		20	
	"A"	"B"	"A"	"B"	"A"	"B"
26-N-12	7.34	5.79	5.37	5.21	9.01	4.22
28-S-2	3.01	2.45	2.54	3.03	3.36	3.44
14-S-10	2.43	9.19	2.59	2.19	4.33	2.43
24-N-10	4.86	4.45	*	3.98	*	*
2-N-2	3.55	3.78	*	1.65	4.00	1.82
18-N-4	4.47	2.90	3.42	2.47	4.40	2.75
20-S-4	3.49	3.46	*	6.12	1.22	2.67

The mean ratios and standard deviations** were used to derive estimates of quarter hectare average concentrations of total transuranics.

Area	Mean Ratio	Standard Deviation
Yuma GZ	3.86	2.72
Kickapoo GZ	6.16	1.73
Rest of Island	3.37	1.08

*Americium concentrations were less than lowest detectable level.
**This method of estimating the ratio and error was later replaced by a method based on more accurate assumptions as described in Tech Note 2.2-A.

DETERMINATION OF THE RATIO OF TOTAL TRANSURANICS TO AMERICIUM IN SOIL ON ISLAND LUCY

DOE/ERSP TECH NOTE NO. 2.6 DATED: March 1978

AUTHOR: J. Giacomini, DRI

Determination of one mean ratio for Lucy was made using laboratory results from soil samples taken at five locations including two composites and three depths. Reference Tech Note 2.2-A for assumptions made in computing the mean ratio and associated error. The range of values is from 2.42 to 3.21. The ratios are as listed.

The Lucy data has a mean ratio of 2.6 with a standard deviation of 0.12*; these values were used in estimating total transuranics and upper bounds.

Location	Depth, cm					
	0		10		20	
	"A"	"B"	"A"	"B"	"A"	"B"
2-BL-0	2.57	2.50	2.70	2.76	2.61	2.42
0-E-4	2.58	2.44	2.85	2.80	2.41	2.88
6-W-2	2.51	2.74	2.46	2.48	2.54	2.69
6-E-2	2.44	2.53	2.64	2.78	2.80	3.21
8-W-6	2.65	2.53	2.92	2.66	2.51	2.89

DETERMINATION OF THE RATIO OF TOTAL TRANSURANICS TO AMERICIUM IN SOIL ON ISLAND ALICE

DOE/ERSP TECH NOTE NO. 2.7 DATED: March 1978

AUTHOR: J. Giacomini, DRI

Determination of one mean ratio for Alice was made using laboratory results from soil samples taken at five locations including two composites and three depths. Reference Tech Note 2.2-A for assumptions made in computing the mean ratio and associated error. The range of values is from 2.70 to 5.97. The ratios are listed below.

The Alice data has a mean ratio of 3.2 with a standard deviation of 0.40*; these values were used in estimating total transuranics and upper bounds.

Location	Depth, cm					
	0		10		20	
	"A"	"B"	"A"	"B"	"A"	"B"
2-BL-0	3.67	4.94	4.43	3.21	4.39	5.65
4-N-2	3.27	3.13	2.70	3.01	2.90	2.93
8-BL-0	4.20	3.28	4.00	2.99	3.00	3.36
12-S-4	3.14	3.30	3.24	3.31	3.21	3.26
16-S-2	2.77	3.20	3.48	2.98	5.97	5.02

*Due to a programming error, the standard deviation reported here is overestimated.

DETERMINATION OF THE RATIO OF TOTAL TRANSURANICS TO AMERICIUM IN SOIL ON ISLAND BELLE

DOE/ERSP TECH NOTE NO. 2.8 DATED: March 1978

AUTHOR: J. Giacomini, DRI

Determination of one mean ratio for Belle was made using laboratory results from soil samples taken at five locations including two composites and three depths. Reference Tech Note 2.2-A for assumptions made in computing the mean ratio and associated error. The range of values is from 3.09 to 5.82. The ratios are listed below.

The Belle data has a mean ratio of 3.8 with a standard deviation of 0.42*; these values were used in estimating total transuranics and upper bounds.

Location	Depth, cm					
	0		10		20	
	"A"	"B"	"A"	"B"	"A"	"B"
2-BL-0	5.06	3.85	3.61	5.82	4.33	5.77
6-S-4	3.55	4.24	4.37	4.65	5.26	3.19
8-BL-0	3.70	4.42	3.52	3.71	3.68	3.76
12-S-10	3.75	3.09	3.56	3.58	3.98	3.34
14-S-4	3.80	3.27	3.67	3.54	3.51	3.18

DETERMINATION OF THE RATIO OF TOTAL TRANSURANICS TO AMERICIUM IN SOIL ON ISLAND CLARA

DOE/ERSP TECH NOTE NO. 2.9 DATED: April 1978

AUTHORS: J. Giacomini, DRI
B. Friesen, DRI

Determination of one mean ratio for Clara was made using laboratory results from soil samples taken at four locations including two composites and three depths. Reference Tech Note 2.2-A for assumptions made in computing the mean ratio and associated error. The range of values is from 2.94 to 7.92. The ratios are listed below.

The Clara data has a mean ratio of 4.23 with a standard deviation of 0.98*; these values were used in estimating total transuranics and upper bounds.

Location	Depth, cm					
	0		10		20	
	"A"	"B"	"A"	"B"	"A"	"B"
1-S-1	4.98	5.32	5.04	6.39	6.03	7.92
4-S-3	3.03	5.60	5.03	3.57	3.63	3.14
7-S-5	5.19	5.17	2.94	3.54	3.94	2.95
10-S-6	4.43	4.04	6.63	5.37	3.13	3.51

*Due to a programming error, the standard deviation reported here is overestimated.

DETERMINATION OF THE RATIO OF TOTAL TRANSURANICS TO AMERICIUM IN SOIL ON ISLAND KATE

DOE/ERSP TECH NOTE NO. 2.10 DATED: March 1978

AUTHOR: J. Giacomini, DRI

Determination of one mean ratio for Kate was made using laboratory results from soil samples taken at five locations including two composites and three depths. Reference Tech Note 2.2-A for assumptions made in computing the mean ratio and associated error. The range of values is from 2.34 to 3.37. The ratios are as listed below.

The Kate data has a mean ratio of 2.7 with a standard deviation of 0.13*; these values were used in estimating total transuranics and upper bounds.

Location	Depth, cm					
	0		10		20	
	"A"	"B"	"A"	"B"	"A"	"B"
0-BL-0	2.50	2.61	2.82	2.48	2.86	2.91
4-N-2	2.79	2.59	2.74	2.34	2.77	2.91
4-S-2	2.50	2.58	2.56	2.54	2.36	2.77
8-S-2	2.79	2.59	2.77	2.64	2.86	3.23
8-S-8	2.59	2.77	3.16	2.57	2.79	3.37

DETERMINATION OF THE RATIO OF TOTAL TRANSURANICS TO AMERICIUM IN SOIL ON ISLAND NANCY

DOE/ERSP TECH NOTE NO. 2.11 DATED: March 1978

AUTHOR: J. Giacomini, DRI

Determination of one mean ratio for Nancy was made using laboratory results from soil samples taken at five locations including two composites and three depths. Reference Tech Note 2.2-A for assumptions made in computing the mean ratio and associated error. The range of values is from 2.32 to 3.94. The ratios are as listed below.

The Nancy data has a mean ratio of 2.7 with a standard deviation of 0.18*; these values were used in estimating total transuranics and upper bounds.

Location	Depth, cm					
	0		10		20	
	"A"	"B"	"A"	"B"	"A"	"B"
5-S-1	2.54	2.69	2.56	2.71	2.59	2.32
8-S-3	3.41	2.41	2.39	2.49	2.67	2.47
12-S-2	2.62	2.55	2.64	2.70	2.50	3.14
13-S-5	2.60	2.55	3.04	2.44	3.94	2.51
16-S-6	3.54	2.73	2.78	3.22	3.51	2.76

*Due to a programming error, the standard deviation reported here is overestimated.

DETERMINATION OF THE RATIO OF TOTAL TRANSURANICS TO AMERICIUM IN SOIL ON ISLAND DAISY

DOE/ERSP TECH NOTE NO. 2.12 DATED: April 1978

AUTHOR: B. Friesen, DRI

Determination of one mean ratio for Daisy was made using laboratory results from soil samples taken at four locations including two composites and three depths. Reference Tech Note 2.2-A for assumptions made in computing the mean ratio and associated error. The range of values is from 2.66 to 9.22. The ratios are as listed below.

The Daisy data has a mean ratio of 3.72 with a standard deviation of 0.56*; these values were used in estimating total transuranics and upper bounds.

Location	Depth, cm					
	0		10		20	
	"A"	"B"	"A"	"B"	"A"	"B"
2-BL-0	4.58	4.73	5.45	**	9.22***	4.55
6-E-2	5.16	4.23	3.44	3.32	3.50	3.11
8-E-8	3.20	3.10	3.48	5.41	3.89	3.67
10-BL-0	3.68	4.44	4.18	3.18	4.40	2.66

DETERMINATION OF THE RATIO OF TOTAL TRANSURANICS TO AMERICIUM IN SOIL ON ISLAND TILDA

DOE/ERSP TECH NOTE NO. 2.13 DATED: April 1978

AUTHOR: B. Friesen, DRI

Determination of one mean ratio for Tilda was made using laboratory results from soil samples taken at six locations including two composites and three depths. Reference Tech Note 2.2-A for assumptions made in computing the mean ratio and associated error. The range of values is from 2.00 to 8.00. The ratios are as listed below.

The Tilda data has a mean ratio of 2.76 with a standard deviation of 0.3*; these values were used in estimating total transuranics and upper bounds.

Location	Depth, cm					
	0		10		20	
	"A"	"B"	"A"	"B"	"A"	"B"
2-BL-0	2.85	5.00	**	2.74	**	3.78
6-N-4	2.54	2.43	2.73	2.26	2.82	2.44
8-S-4	2.48	2.91	6.12	3.41	2.00	3.12
12-S-12	2.71	2.57	**	2.72	3.73	2.52
14-N-4	2.08	3.39	2.51	2.95	8.00	2.58
14.25-S-2	2.66	2.80	2.64	3.51	3.16	3.07

*Due to a programming error, the standard deviation reported here is overestimated.
**One or more of the computational components was less than the minimum detectable activity.
***This one higher ratio had no measurable influence on the mean ratio because the relevant values were very low.

DETERMINATION OF THE RATIO OF TOTAL TRANSURANICS TO AMERICIUM IN SOIL ON ISLAND WILMA

DOE/ERSP TECH NOTE NO. 2.14 DATED: April 1978

AUTHOR: B. Friesen, DRI

Determination of one mean ratio for Wilma was made using laboratory results from soil samples taken at four locations including two composites and two depths. Reference Tech Note 2.2-A for assumptions made in computing the mean ratio and associated error. The range of values is from 2.43 to 4.50. The ratios are as listed below.

The Wilma data has a mean ratio of 2.73 with a standard deviation of 0.19*; these values were used in computing total transuranics.

Estimates and upper bounds were not computed because of insufficient data; indicated ^{241}Am concentrations do not warrant collection of more data.

Location	Depth, cm					
	0		10		20	
	"A"	"B"	"A"	"B"	"A"	"B"
0-S-4	3.76	3.48	5.58	2.63	**	3.35
2-N-2	3.17	2.57	2.70	2.54	2.60	2.84
4-N-6	2.43	2.71	2.75	3.49	2.53	3.29
8-N-8	2.70	2.60	2.65	2.65	4.50	2.83

DETERMINATION OF THE RATIO OF TOTAL TRANSURANICS TO AMERICIUM IN SOIL ON ISLAND MARY

DOE/ERSP TECH NOTE NO. 2.15 DATED: May 1978

AUTHOR: B. Friesen, DRI

Determination of one mean ratio for Mary was made using laboratory results from soil samples taken at five locations including two composites and three depths. Reference Tech Note 2.2-A for assumptions made in computing the mean ratio and associated error. The range of values is from 2.33 to 6.09. The ratios are as listed below.

The Mary data has a mean ratio of 2.94 with a standard deviation of 0.42*; these values were used in computing total transuranics.

Estimates and upper bounds were not computed because of insufficient data; indicated ^{241}Am concentrations do not warrant collection of more data.

Location	Depth, cm					
	0		10		20	
	"A"	"B"	"A"	"B"	"A"	"B"
0-BL-0	2.85	2.33	2.78	6.09	2.63	2.78
2-N-2	2.90	2.39	2.72	2.77	3.07	2.63
6-BL-0	3.00	2.51	3.47	5.74	2.86	4.20
10-BL-0	2.64	3.31	3.52	2.83	3.70	4.64
12-S-2	3.44	2.70	2.54	2.83	2.78	4.46

*Due to a programming error, the standard deviation reported here is overestimated.
**One or more of the computational components was less than the minimum detectable activity.

DETERMINATION OF THE RATIO OF TOTAL TRANSURANICS TO AMERICIUM IN SOIL ON ISLAND RUBY

DOE/ERSP TECH NOTE NO. 2.16 DATED: May 1978

AUTHOR: B. Friesen, DRI

Determination of one mean ratio for Ruby was made using laboratory results from soil samples taken at four locations including two composites and three depths. Reference Tech Note 2.2-A for assumptions made in computing the mean ratio and associated error. The range of values is from 4.42 to 12.35. The ratios are as listed below.

The Ruby data has a mean ratio of 6.42 with a standard deviation of 0.88*; these values were used in computing total transuranics.

Estimates and upper bounds were not computed because of insufficient data; indicated ^{241}Am concentrations do not warrant collection of more data.

Location	Depth, cm					
	0		10		20	
	"A"	"B"	"A"	"B"	"A"	"B"
1-BL-0	5.56	9.48	12.35	4.80	4.95	5.40
3-BL-0	4.97	6.57	9.03	5.42	6.52	4.42
4-BL-0	6.10	7.63	7.84	5.58	8.39	6.05
5-BL-0	4.44	7.37	8.63	4.82	5.54	5.36

TOTAL TRANSURANICS ON ISLET PEARL'S DAUGHTER

DOE/ERSP TECH NOTE NO. 2.17 DATED: May 1978

AUTHOR: B. Friesen, DRI

Soil samples were taken from the surface only at three locations with four composites at each location. Minimum, maximum and mean total transuranics from the four composites are as listed.

A ratio of total transuranics to americium was not computed for Pearl's Daughter since the islet is too small to do the in situ ^{241}Am gamma survey.

Location	TRU		
	Minimum	Maximum	Mean
0-BL-0	72.5	165.24	117.12
1-BL-0	69.1	125.6	107.9
2-BL-0	105.6	164.6	142.1

*Due to a programming error, the standard deviation reported here is overestimated.

TOTAL TRANSURANICS ON ISLET PERCY

DOE/ERSP TECH NOTE NO. 2.18 DATED: May 1978

AUTHOR: B. Friesen, DRI

Soil samples were taken from the surface only at six locations with four composites at each location. Minimum, maximum and mean total transuranics from the four composites are as listed below.

A ratio of total transuranics to americium was not computed for Percy since the islet is too small to do the in situ ^{241}Am gamma survey.

	TRU		
Location	Minimum	Maximum	Mean
2-BL-0	3.39	5.45	4.44
4-BL-0	1.94	5.14	3.28
6-BL-0	2.53	3.95	3.36
8-S-1	10.76	17.05	12.44
10-S-2	5.08	5.62	5.43
12-S-3	4.97	6.77	5.79

TOTAL TRANSURANICS ON ISLET EDNA

DOE/ERSP TECH NOTE NO. 2.19 DATED: 20 May 1978

AUTHOR: B. Friesen, DRI

Soil samples were taken from the surface only at seven locations with four composites at each location. Minimum, maximum and mean total transuranics from the four composites are as listed.

A ratio of total transuranics to americium was not computed for Edna since the islet is too small to do the in situ ^{241}Am gamma survey.

	TRU		
Location	Minimum	Maximum	Mean
1-BL-0	27.97	30.20	29.06
2-BL-0	23.77	29.61	26.59
3-BL-0	27.06	29.40	28.23
4-BL-0	29.50	34.42	32.29
4-N-1	33.50	37.09	34.46
5-BL-0	31.82	37.66	33.89
6-BL-0	30.30	34.83	33.34

ADDENDUM TO TECH NOTE 2.19: TOTAL TRANSURANICS ON ISLET EDNA

DOE/ERSP TECH NOTE NO. 2.19-A DATED: June 1978

AUTHOR: M. Barnes, DRI

Data from surface soil samples have become available for eight additional locations, with four composites for all but three locations, which had two composites each. Minimum, maximum and mean total transuranics from the composites are listed below for the additional locations.

The islet is too small to do the in situ ^{241}Am gamma survey, so a ratio of total transuranics to americium was not computed. These data do not affect the conclusions contained in the transmittal letter dated 20 May 1978.

	TRU		
Location	Minimum	Maximum	Mean
6-N-1	36.27	39.14	38.60
6-S-1	34.55	35.38	34.96 (two composites only)
7-BL-0	29.77	33.69	32.33
8-BL-0	34.52	39.74	37.46
8-N-1	27.96	32.43	30.82
B	33.20	36.45	34.82 (two composites only)
C	31.53	35.93	33.73 (two composites only)
K	31.00	33.62	32.19

TOTAL TRANSURANICS ON ISLET SALLY'S CHILD

DOE/ERSP TECH NOTE NO. 2.20 DATED: May 1978

AUTHOR: B. Friesen, DRI

Soil samples were taken from the surface only at six locations with two composites at each location. Minimum, maximum and mean total transuranics from the two composites are listed.

A ratio of total transuranics to americium was not computed for Sally's Child since the islet is too small to do the in situ ^{241}Am gamma survey.

	TRU		
Location	Minimum	Maximum	Mean
1-BL-0	19.10	26.48	22.79
3-BL-0	18.78	20.96	19.87
5-BL-0	26.98	33.38	30.18
7-BL-0	12.49	13.65	13.07
7-N-1	16.90	18.83	17.86
7-S-1	14.35	26.59	20.47

DETERMINATION OF THE RATIO OF TOTAL TRANSURANICS TO AMERICIUM IN THE CAPE MIXAN AREA, ISLAND SALLY

DOE/ERSP TECH NOTE NO. 2.21 DATED: June 1978

AUTHOR: M. Barnes, DRI

There were two distinct ratios of total transuranics (TRU) to americium in the Cape Mixan area on the western tip of Sally. Most of the area had a ratio from the same population as in the Yuma ground zero region. However, one small area had americium concentrations much higher than the remainder of Cape Mixan, and this small area was therefore soil-sampled intensively. The TRU to americium ratio in these soil samples was also much higher than for the rest of Cape Mixan. Figure B-2-5 is a map of Cape Mixan which shows the location of the anomalous area.

Some of the soil samples in the anomalous area were composites of six subsamples each, taken at three depths, 0, 10, and 20 cm. The locations and ratios for these samples are in Table B-2-5. The rest of the soil samples were single samples, not composites, and were surface only. These ratios and locations are in Table B-2-6. All of these ratios were included in computing a mean ratio and associated error for the small anomalous area, using the methods and assumptions referenced in Tech Note 2.2-A.

The remainder of Cape Mixan had uniformly lower americium concentrations and soil samples taken at location 17-N-7 showed a TRU to americium ratio very similar to the Yuma ground zero area. Therefore, the ratio and error computed for Yuma was used to calculate TRU in the remainder of Cape Mixan. Table B-2-7 contains the locations and ratios from which the Yuma area value was computed.

The ratio computed for the small anomalous area was 9.58, with error 0.66*. The ratio for Yuma ground zero area, and for the remainder of Cape Mixan, was 5.31 with error 0.90*. These ratios were used in estimating average concentrations of total transuranics and upper bounds on the estimates.

*Due to programming error, the standard deviation reported here is overestimated.

TABLE B-2-5. RATIO OF TRU/AM IN SOIL COMPOSITES FROM THE CAPE MIXAN AREA ON ISLAND SALLY

Location and Composite	TRU/Am 0 cm	10 cm	20 cm
-11-N-5 A	9.82	10.26	7.88
-11-N-5 B	11.35	9.6	9.83
-13-N-5 A	10.13	8.55	9.26
-13-N-5 B	10.67	10.59	10.5

TABLE B-2-6. RATIO OF TRU/AM IN SINGLE SOIL SAMPLES FROM THE CAPE MIXAN AREA ON ISLAND SALLY

Location	TRU/Am
-13-N-5.5	9.39
-11-N-5	8.87
-12-N-4	10.79
-12-N-5	8.46
-12.5-N-5	8.85
-12.5-N-5.5	8.31

TABLE B-2-7. RATIO OF TRU/AM IN SOIL FROM THE YUMA AREA ON ISLAND SALLY

Location and Composite	TRU/Am 0 cm	10 cm	20 cm
10-S-7 A	3.65	*	6.33
10-S-7 B	4.66	*	*
10-S-8 A	5.43	7.23	5.11
10-S-8 B	4.85	**	4.73
12-S-9 A	11.46	4.67	4.76
12-S-9 B	5.55	3.96	3.61
12-S-10 A	6.35	4.01	5.38
12-S-10 B	4.68	5.27	2.96

* ^{241}Am less than minimum detectable activity
** Gross alpha >400; laboratory did not analyze

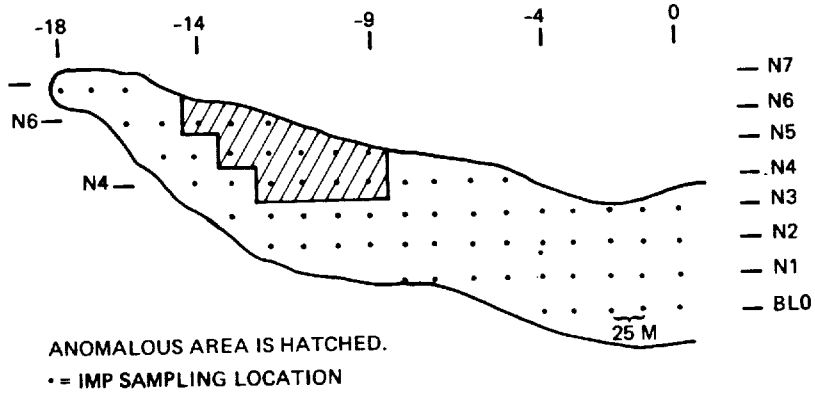


FIGURE B-2-5. SALLY CAPE MIXAN AREA

TOTAL TRANSURANICS ON ISLET MARY'S DAUGHTER

DOE/ERSP TECH NOTE NO. 2.22 DATED: 14 August 1978

AUTHOR: J. Giacomini, DRI

Soil samples were taken from the surface only at four locations with two composites at each location. Minimum, maximum and mean total transuranics from the two composites are listed below. Since the island was not surveyed or staked, the locations were chosen by quartering the island along the north, south, east and west compass directions from the approximate center of the island. Samples were taken half way between the high tide line and the center of the island along each major axis.

A ratio of total transuranics to americium was not computed for Mary's Daughter since the islet is too small to do the in situ ^{241}Am gamma survey.

	TRU		
Location	Minimum	Maximum	Mean
North	93.00	138.83	115.92
East	46.50	55.59	51.05
South	31.72	47.70	39.71
West	8.82	10.38	10.60

DETERMINATION OF THE RATIO OF TOTAL TRANSURANICS TO AMERICIUM IN SOIL FROM THE AOMON CRYPT

DOE/ERSP TECH NOTE NO. 2.23 DATED: 6 February 1979

AUTHOR: B. Friesen, DRI

Determination of one mean ratio for the Aomon Crypt was made using laboratory results from soil core samples taken at 34 locations within the Crypt area. Samples were taken from 7 depth intervals from 22 different holes, with emphasis on the area in the vicinity of the center monument. Reference Tech Note 2.2-A for assumptions made in computing the mean ratio and associated error. The range of values is from 4.64 to 7.98. The ratios are listed in Table B-2-8.

Three of the computed ratios were observed to be less than 5.0; when these three values are deleted from the computations the mean ratio is 6.17 with standard deviation 0.64. The soil used to fill the Crypt may have come from the Kickapoo area where the ratio was determined to be 6.16. Some soil may also have been taken from the Yuma area where the ratio at the surface was 3.86 and for subsurface was 5.3. The data suggest that the mixing of soils may have occurred, leading to the 3 values indicated by the asterisks in Table B-2-8. There have not been enough samples processed through the laboratory to substantiate the mixing hypothesis nor to suggest where the boundaries, if any, would be. The difference in ratio between Kickapoo and Yuma soils is such that, with respect to the 400 pCi/g criteria, ^{241}Am values in the range from 64.9 to 75.5 would be of interest. All samples indicated by IMP screening to be greater than 25 pCi/g were gamma scanned in the laboratory; only 3 of 71 such samples had ^{241}Am in the 65-76 pCi/g range.

The total transuranics to americium ratios were examined to see if there was a significant difference either by depth or by lateral extent. No significant differences were found. Values for total transuranics were found to increase with depth to the 16-18 ft. interval. Screening of 217 samples from below 18 ft., taken from 60 different drill holes, showed no sample with ^{241}Am activity greater than 8 pCi/g.

On the basis of the foregoing, a mean ratio of 6.17 with standard deviation 0.64 was used uniformly throughout the Aomon Crypt to estimate TRU concentrations from the ^{241}Am gamma activities.

TABLE B-2-8. TRU/AM RATIOS IN THE AOMON CRYPT ON ISLAND SALLY

Stake Location	Depth Interval, Ft.	Ratio	Stake Location	Depth Interval, Ft.	Ratio
24-37	0-2	5.61	24 - 45	8-10	5.82
25-39	0-2	5.51	25 - 46	8-10	6.24
24-45	0-2	6.12	27 - 44	8-10	7.39
25-44	2-4	5.66	24.5 - 44	10-12	6.56
24-46	2-4	5.94	25 - 48	10-12	5.66
25-49	2-4	6.65	26.5 - 43.5	11-13	6.88
24-51	2-4	6.18	26 - 44	10-12	7.09
			26 - 46	10-12	5.79
24-44	4-6	5.53			
24-46	4-6	6.52	25 - 47	12-14	6.50
25-49	4-6	7.98	26 - 46	12-14	5.88
25-50	4-6	6.02			
27-45	4-6	6.08	25 - 47	14-16	5.88
			26 - 45	14-16	5.42
24-44	6-8	5.86			
24-46	6-8	6.01	25 - 47	16-18	6.13
24-47	6-8	6.19			
25-38	6-8	7.41	24 - 53	0-2	4.73*
25-49	6-8	6.77	25 - 52	8-10	4.90*
26-44	6-8	7.32	26 - 45	16-18	4.64*

DETERMINATION OF THE RATIO OF TOTAL TRANSURANICS TO AMERICIUM IN SOIL ON SOUTHERN YVONNE

DOE/ERSP TECH NOTE NO. 2.24 DATED: 19 April 1979

AUTHOR: J. Giacomini, DRI

Determination of one mean ratio for Southern Yvonne was made using laboratory results from surface soil samples taken at six locations. Four locations had four composites while the other two locations had two composites for a total of twenty samples. Reference Tech Note 2.2-A for assumptions made in computing the mean ratio and associated error. The range of values is from 6.40 to 10.14. The ratios are listed below.

The Southern Yvonne data have a mean ratio of 8.2 with a standard deviation of 0.74**; these values were used in computing total transuranics.

	TRU/Am			
	Composite			
Location	A	B	C	D
SE 112 - 80	8.85	8.01	9.00	6.40
SE 116 - 80	7.18	8.73	-	-
SE 86 - 70	7.08	10.14	-	-
SE 76 - 76	8.58	7.79	10.07	7.90
SE 72 - 72	8.36	9.76	9.13	9.21
SE 64 - 64	9.14	7.71	6.85	9.31

*Excluded from computation as explained in text.
**Due to a programming error,the standard deviation reported here is overestimated.

CORRECTION OF ^{241}Am FOR CONTRIBUTION OF ^{155}Eu

DOE/ERSP TECH NOTE NO. 3.0 DATED: November 1977

AUTHOR: F. Tomnovec, EG&G

The EG&G IMP detects the presence of ^{241}Am by measuring the 59.553 keV gamma-ray emitted by this isotope. Quite often in the gamma-ray spectrum measured by the IMP there is a quantity of ^{155}Eu. This isotope of europium has three gamma-rays. The energies and branching ratios for the two gamma rays of interest are 60.01 keV, 1.32%; 86.55 keV, 32.2%. From the branching ratios we compute that for every 100 of the 86.55 keV gamma-rays there are 4.1 of the 60.010 keV gamma-rays. The resolution of the IMP detector system is approximately 1 keV; therefore, we are unable to resolve the 60.010 keV gamma-ray of ^{155}Eu from the 59.553 keV gamma-ray line of ^{241}Am.

Whenever the ^{155}Eu 86.550 keV gamma-ray exceeds 10 pCi/gm we make a correction to the ^{241}Am by subtracting 4.1% of the ^{155}Eu 86.550 keV gamma-ray from the ^{241}Am. Table B-3-1 shows the correction for Pearl, the only island to need any corrections at this time.

TABLE B-3-1. ^{155}Eu CORRECTION TO ^{241}Am DATA ON PEARL

Run	Stake No.	^{155}Eu(86.550 keV) (pCi/g)	^{155}Eu(60.010 keV) (pCi/g)	^{241}Am (pCi/g)	^{241}Am Corrected (pCi/g)
118	1-N-1	21.7	0.89	35.2	34.3
120	0-N-1	13.8	0.57	23.2	22.6
122	0-BL-0	13.3	0.55	24.0	23.4
123	0-S-1	12.9	0.53	22.5	22.0
125	-1-BL-0	12.2	0.50	19.7	19.2
101	3-S-2	14.1	0.58	22.2	21.6
102	3-N-1	11.9	0.49	20.6	20.1
103	2-N-1	14.3	0.65	21.0	20.4
105	2-BL-0	13.0	0.53	19.5	19.0
109	2-S-1	14.2	0.58	23.8	23.2
96	3-N-2	11.3	0.46	23.8	23.3
68	4-N-2	10.5	0.43	22.9	22.5
76	6-N-2	10.6	0.43	21.1	20.7
20	4-S-3	12.3	0.50	21.0	20.5
22	5-S-3	22.9	0.94	35.9	35.0
34	5-S-4	12.6	0.52	22.3	21.8

REVISION OF ^{155}Eu CORRECTION FACTOR FOR ^{241}Am

DOE/ERSP TECH NOTE NO. 3.1 DATED: 22 March 1979

AUTHOR: R. Jaffe, EG&G

A slight correction is recommended to the original Technical Note 3 subtraction factor that accounts for the 60.0 keV gamma from the ^{155}Eu which appears in the 59.5 keV gamma peak used to detect ^{241}Am. The factor of 4.53% of the ^{155}Eu should be used, rather than the 4.1% originally calculated. The 4.53% factor accounts for the greater penetration of the predominant 86.5 keV gamma used to calculate ^{155}Eu, as discussed in EG&G Report RSSD-78-177, "In Situ Determination of ^{241}Am at Enewetak Atoll," by Tipton, Fritzsche, and Villaire (Aug. 1978).

The formula to correct ^{241}Am concentration is: ^{241}Am (corrected) = $^{241}Am - 0.0453\ ^{155}Eu$

Only where ^{155}Eu is greater than half of the ^{241}Am concentration is a correction factor above about 2% required. This condition was encountered at a few locations on Pearl and corrected values furnished with Tech Note 3. No changes to those values are necessary.

SOIL DISTURBANCE EXPERIMENT

DOE/ERSP TECH NOTE NO. 4.0 DATED: 8 December 1977

AUTHOR: F. Tomnovec, EG&G

During the Enewetak cleanup program various people have been concerned with the measurements taken with the EG&G IMP. Their concern was with the effect of the road (which is bulldozed and cleared of heavy brush) on the IMP's measurements. The road is necessary for the surveyors to stake out and establish a grid system. The IMP travels this road, pausing at each stake to make a measurement. The resultant radiation grid is used by DRI to establish certain radiation patterns, which will be used in determining the land areas that need soil removal to lower the level of radioactivity to a recommended level.

During IMP measurements at Pearl it was evident that high radiation fields of ^{60}Co could be from neutron induced activation in steel, which was used extensively for building, and also in the tower housing the nuclear event. Any steel debris that could be neutron activated could have been originally close enough to be contaminated by the fireball, and then ejected outward by the blast or later human efforts.

It was decided to send in the 1st RADCON Team and the 84th Engineers to remove all visible metal debris. In some cases large steel I beams were bulldozed out of the ground. When the operation was complete the radiation levels had been reduced. The ^{60}Co had been removed by the removal of the steel, but the decrease in the ^{241}Am was questionable. Table B-4-1 shows the results of the debris removal at three stake positions. In an effort to explain that the decrease was solely from the removal of the metal debris, Table B-4-2 was constructed. This table compares the measurement station with several stations that are adjacent. Station 1-N-1 looks quite similar to its adjacent neighbors. Pictures taken at the site show extensive brush removal, but only track marks seem to be the major evidence of soil disturbance. One can postulate that the removal of the metal debris was also the principal reason for the removal of the ^{241}Am. Station 2-S-1 indicates only an 11% reduction of the ^{241}Am , yet the soil appears to be disturbed as much as 1-N-1. The removal of the metal debris sharply reduced the contribution from the ^{60}Co. Station 5-S-3 was the least disturbed of the three stations, yet somehow the ^{241}Am was dramatically reduced. Some debris was also removed as evidenced by the reduction in ^{60}Co.

The lack of a simple way to remove the metal debris by the use of a dozer, without removing the thick heavy brush which conceals the debris, brings up the inevitable question: Did the disturbance of the soil by the dozer reduce the ^{241}Am? To help answer this question an experiment was performed to progressively disturb the soil, and measure the effect by taking an IMP measurement after each disturbance.

The area chosen was island Pearl, station 5-N-1. This station is one of the areas that had been used in the previous brush attenuation experiment. A 70 ft. diameter circle had been carefully cut by hand out of the dense underbrush. A soil sampling program had also been conducted at this station, both on the surface and at 10 and 20 cm in depth. The results of the measurements are presented in Table B-4-3. The most startling fact is the small effect of removing the top four inches of soil in the road. The reason can be found if one examines Table B-1-4 of Tech Note 1.0. The effect of the road on the radiation field seen by the detector is 17.4%. Table B-4-4 is the soil sampling data on Pearl as a function of depth. Table B-4-5 is the same data, but the data has been averaged for the two samples A & B.

Table B-4-6 presents the data as a ratio of the subsurfaces to the surface activity. From this table we can expect on the average that after removal of the top 4 inches there will still be 66% of the activity of the top soil exposed.

The original activity measured by the IMP over this undisturbed soil was 20.6 pCi/g. The road is responsible for 17.4% of the radiation field from this cleared area. The contribution of the road to the radiation field was 20.6 pCi/g X 0.174 equals 3.58 pCi/g. The remainder of the cleared area accounts for 17.02 pCi/g of the radiation field. The effect of the removal of the top 4 inches of the

road leaves 66% of the activity which would be a contribution of 0.66 X 3.58 pCi/g and equal to a radiation field of 2.37 pCi/g. When combined with the 17.02 pCi/g the IMP should measure 19.39 pCi/g. It actually saw 18.9 pCi/g or within 2.6% of the 19.39 pCi/g value.

The effect of the IMP moving back and forth over the road 10 times was small; therefore, the movement of the IMP along the road to make a measurement is very small. The use of a bulldozer to clear a road of brush by scraping a blade along the surface of the soil does not effect the IMP measurements appreciably. Only when the road has been bladed deeply would there be a significant change in the radiation field. Finally, in some of the debris removal stations, such as 1-N-1 and 2-S-1 where the brush was cleared away by the dozer, one can expect a decrease in the radiation from the movement back and forth of the dozer tracks. In the experiment, dozer tracks were made in the north and south direction and then in the east and west direction. The result was a decrease in the radiation field of 16.4%, but at station 1-N-1 and 2-S-1 the brush was removed, thereby increasing the radiation field because of the previous brush attenuation of 14.7%. This result offset the decrease and leaves us with the knowledge that the metal debris removal was responsible for the reduction in the ^{241}Am. The final item one can see in this soil disturbance experiment was the very large effect when the dozer made circles. Keeping one track slow and the other rapid causes a vigorous deep churning motion of the soil.

TABLE B-4-1. RESULTS OF DEBRIS CLEARING ON PEARL

1-N-1	With Debris (pCi/g)	Without Debris (pCi/g)	Change (%)
^{241}Am	32.2	22.7	-30
^{155}Eu	21.5	11.6	-46
^{137}Cs	17.8	14.8	-17
^{60}Co	62.3	19.1	-69
2-S-1			
^{241}Am	23.8	21.2	-11
^{155}Eu	14.2	11.1	-22
^{137}Cs	19.3	17.7	- 8
^{60}Co	91.7	34.9	-62
5-S-3			
^{241}Am	41.3	25.9	-37
^{155}Eu	23.7	15.1	-36
^{137}Cs	36.3	27.4	-25
^{60}Co	37.3	28.8	-23

TABLE B-4-2. COMPARISON WITH ADJACENT STATIONS AFTER DEBRIS CLEARING

Isotope	After Debris was removed 0-N-1 (pCi/g)	1-N-1 (pCi/g)	Before Debris was removed 2-N-1 (pCi/g)	1-N-1 (pCi/g)
^{241}Am	23.2	22.7	21.0	32.2
^{155}Eu	13.8	11.6	14.3	21.5
^{137}Cs	18.0	14.8	15.8	17.8
^{60}Co	14.0	19.1	31.4	62.3

Isotope	4-S-3 (pCi/g)	5-S-3 (pCi/g)	5-S-4 (pCi/g)	5-S-3 (pCi/g)
^{241}Am	21.0	25.9	22.3	41.3
^{155}Eu	12.3	15.1	12.6	23.7
^{137}Cs	27.9	27.4	19.4	36.3
^{60}Co	24.5	28.8	21.4	37.3

Isotope	1-S-1 (pCi/g)	2-S-1 (pCi/g)	3-S-1 (pCi/g)	2-S-1 (pCi/g)
^{241}Am	13.3	21.2	13.5	23.8
^{155}Eu	8.2	11.1	9.3	14.2
^{137}Cs	10.3	17.7	11.4	19.3
^{60}Co	23.0	34.9	16.9	91.7

TABLE B-4-3. SOIL DISTURBANCE RESULTS

Pearl 5-N-1 ^{241}Am 5 Dec 77

Conditions	Measurements (pCi/g)	Change (%)	Differential Change (%)
Average of 3 measurements	20.6	0.0	
IMP disturbs road 10 times	19.5	-5.3	5.3
Dozer removes 4" of road	18.9	-8.2	2.9
*Dozer tracks parallel and all North-South Direction	18.3	-11.1	2.9
*Dozer tracks parallel and all East-West Direction	15.8	-23.3	12.2
Dozer tracks disturb soil in a circular motion	10.5	-49.0	25.7

*These dozer tracks are side by side in one direction over the entire surface of the cleared area.

TABLE B-4-4. BASIC DATA OF ^{241}Am FROM SOIL SAMPLING ON PEARL, SAMPLES A & B

Stake No.	0 cm (pCi/g)	10 cm (pCi/g)	20 cm (pCi/g)
	18.3	27.4	6.86
8-B-0	21.8	54.9	7.56
	23.0	11.9	7.54
1-N-1	33.5	37.1	26.3
	28.2	15.4	13.2
3-S-1	6.34	3.10	2.46
	84.0	27.3	24.7
5.5-S-3	68.0	10.4	12.5
	87.0	5.45	1.80
6-S-1	73.5	4.44	1.55
	3.99	5.13	3.29
8-S-4	3.85	3.50	2.80
	10.9	2.30	2.48
9-S-2	11.7	7.52	3.70
	3.29	2.37	2.19
11-S-5	1.66	1.58	0.66
	9.98	0.72	0.39
5-N-1	20.4	4.71	3.13
	47.4	18.2	5.55
5-S-3	65.4	23.8	22.8
	21.5	2.67	0.47
1-S-1	10.2	15.0	9.32

TABLE B-4-5. ^{241}Am DATA AVERAGED FOR A AND B SOIL SAMPLES

Stake No.	0 cm (pCi/g)	10 cm (pCi/g)	20 cm (pCi/g)
8-B-0	20.05	41.15	7.21
1-N-1	28.25	24.50	16.92
3-S-1	17.27	9.25	7.83
5.5-S-3	76.00	18.85	18.60
6-S-1	80.25	4.95	1.68
8-S-4	3.92	4.32	3.05
9-S-2	11.30	4.91	3.0
11-S-5	2.48	1.98	1.43
5-N-1	15.19	2.72	1.76
5-S-3	56.4	21.0	14.18
1-S-1	15.8	8.84	4.90

TABLE B-4-6. RATIO OF THE ^{241}Am ACTIVITY AS A FUNCTION OF DEPTH

Stake No.	0 cm	10 cm	20 cm
8-B-0	1.0	2.05	0.36
1-N-1	1.0	0.87	0.60
3-S-1	1.0	0.54	0.45
5.5-S-3	1.0	0.25	0.24
6-S-1	1.0	0.06	0.02
8-S-4	1.0	1.10	0.78
9-S-2	1.0	0.43	0.27
11-S-5	1.0	0.80	0.58
5-N-1	1.0	0.18	0.12
5-S-3	1.0	0.37	0.25
1-S-1	1.0	0.56	0.31
Average = $\bar{x}$ - 1.0	$\bar{x}$ = 0.66		$\bar{x}$ = 0.36
	σ = 0.56		σ = 0.22
	$\frac{\sigma}{\bar{x}}$ = 85%		$\frac{\sigma}{\bar{x}}$ = 62%

CORRECTION FACTOR FOR DETECTOR (SN: 496)
OPERATING AT LOW VOLTAGE

DOE/ERSP TECH NOTE NO. 5.0 DATED: March 1978

AUTHOR: J. Giacomini, DRI

The PGT detector (SN: 496) installed on th EG&G IMP is supposed to be operated at -3000 volts. In the first weeks of operation the detector was operated at -2000 volts which introduced an inefficiency bias. To find a correction factor for the lower efficiency of the ^{241}Am data already recorded, an area on Sally was surveyed with the IMP using the detector at the -2000 voltage and then resurveyed using the correct voltage of -3000. The list below shows the ^{241}Am, in pCi/g, with both voltages. Figure B-5-1 is a plot of the data.

The locations marked with * were not used in the analysis because the results were below the minimum detector capability. A simple mean was used to determine a correction factor. The mean of the nine numbers was 1.6 with a standard deviation of 0.24. This factor was used to multiply the ^{241}Am data surveyed with the low voltage to obtain the adjusted values.

Location	^{241}Am at -2000 V.	^{241}Am at -3000 V.	Ratio $\frac{(-3000\ V.)}{(-2000\ V.)}$
26-N-9	1.0	1.2	1.2
26-N-11	13.2	19.5	1.48
26-N-13	16.0	26.5	1.66
26-N-14	25.8	38.4	1.49
*25-N-10	0.7	1.2	1.71
*25-N-9	0.3	0.6	2.0
*25-N-11	0.4	0.6	1.5
24-N-13	4.1	8.4	2.05
24-N-14	11.6	20.2	1.74
26.5-N-14	25.2	38.0	1.51
26.5-N-13	17.0	30.2	1.78
26.5-N-12	25.1	39.4	1.57

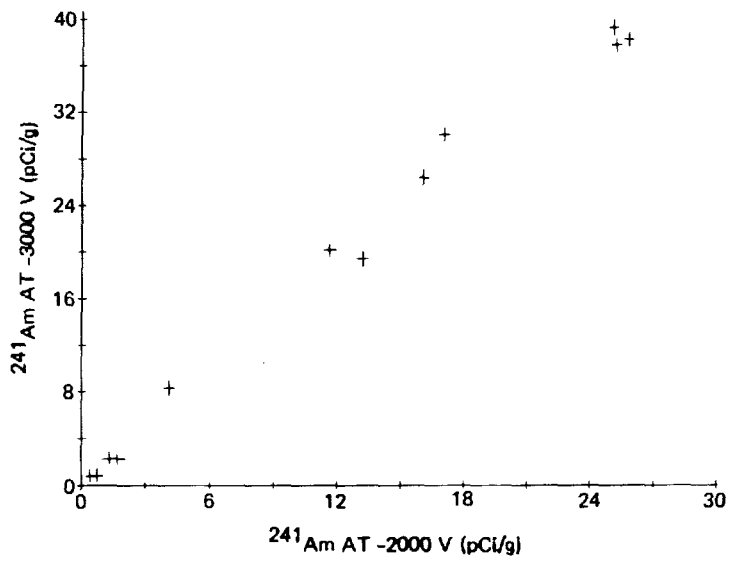


FIGURE B-5-1. PLOT OF ^{241}Am AT -3000V VS ^{241}Am AT -2000V

CORRECTION FACTOR FOR DETECTOR (SN: 496)
OPERATING AT LOW VOLTAGE ON ISLAND ALICE

DOE/ERSP TECH NOTE NO. 5.1 DATED: June 1978

AUTHOR: M. Barnes, DRI

The voltage correction factor computed using the method outlined in Tech Note 5 was not correct for the data taken in the initial survey of Alice. This is because the magnitude of the inefficiency bias is very unstable near -2000 volts, so that small fluctuations in voltage can produce large changes in the bias.

A comparison of the IMP data from Alice, corrected by the 1.6 factor from Tech Note 5, with the soil data showed that the IMP values were still much too low. Accordingly, the island was resurveyed with the IMP, and additional soil samples were also taken. The TRU to americium ratio was the same for the new soil samples as for the original.

The list below shows the ^{241}Am readings at -2000 volts, and at -3000 volts at the eight locations which were surveyed both times. Figure B-5-2 is a plot of the data. The locations marked with (*) were not used in the analysis because they were severely disturbed by blasting between the first and second surveys.

A simple mean was used to determine an additional correction factor. The mean of the six numbers was 1.72 with a standard deviation of 0.18. This factor was used to multiply the ^{241}Am data from the low-voltage survey, which had already been corrected by the 1.6 factor, to obtain final adjusted values.

Location	^{241}Am at -2000 V**	^{241}Am at -3000 V	Ratio $\frac{\text{-3000 V.}}{\text{-2000 V.**}}$
*0-BL-0	0.8	3.1	3.88
*2-BL-0	3.5	3.0	0.86
4-N-2	9.0	17.3	1.92
8-BL-0	10.1	18.0	1.78
12-S-2	16.3	23.8	1.46
12-S-4	7.8	14.4	1.85
14-S-2	13.6	24.4	1.79
16-S-2	19.8	30.4	1.54

**Corrected by factor of 1.6 computed in Tech Note 5.

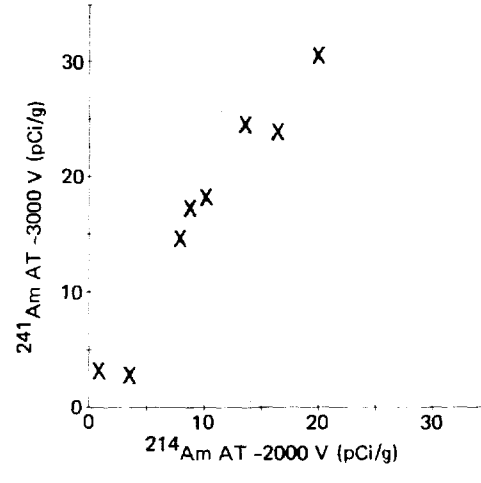


FIGURE B-5-2. PLOT OF ^{241}Am at -3000V vs - 2000 v (CORRECTED BY 1.6 FACTOR) DATA FROM ISLAND ALICE

CORRECTION FACTORS FOR DETECTOR SN 496

DOE/ERSP TECH NOTE NO. 5.2 DATED: 19 August 1978

AUTHOR: R. Jaffe, EG&G

The subject detector is an intrinsic germanium detector produced by Princeton Gamma Tech, Model IG 1916, with preamplifier Model RG-11, as are all the detectors used in the IMP radiation measurement vans.

Detector SN 496 was shipped to EG&G, Las Vegas, 17 July 1977. It arrived at Enewetak and was calibrated at the ERSP counting laboratory starting 31 January 1978. It was brought to Ursula 2 February and installed in IMP I. The IMP I - detector 496 combination was in use until 12 July 1978. This memo discusses ^{241}Am measurements using detector 496.

A correction factor is required for data obtained with detector 496 to correctly relate that data to the data from the other detectors in use. This is due to the smaller effective area of the detector, as noted by the manufacturer, and by previous use at the Nevada Test Site. The factor was stated as 1.06. Direct comparison of readings taken with detector 496 and detector 393 at eleven locations gave a ratio of 1.10 $\pm$ 0.07 as the factor by which detector 496 readings are multiplied to make them comparable to detector 393 readings. Table B-5-1 gives the comparison data.

This factor of 1.10 has been applied to all data taken with detector 496.*

Time Period - 3 February to 25 February

The detector was mistakenly operated at a bias voltage of -2000 rather than -3000 from 3 February to 25 February 1978. This was discovered on 25 February and steps were taken to determine the correction factor needed for the data accumulated during the period of misoperation. The islands which had been measured were: Lucy, 3 and 4 February; Alice, 7 to 9 February; Belle, 13 to 15 February and Sally, 21 to 25 February. (Table B-5-2 lists islands, dates and comments.) Remeasurements at nine grid locations and data analysis (Tech Note 5, Correction Factor for Detector (SN: 496) Operating at Low Voltage) gave a factor of 1.6 $\pm$ 0.24.

A similar comparison of 13 other grid locations plus two at the grid locations included in the nine just mentioned (a total of 15 grid locations) gave a correction factor of 1.6 + 0.11 (EG&G ERSP Office File, Sally IMP I - III Cross Check). Additional corroboration is provided by the experiments conducted at that time using a field calibration source. The ratio of response at -3000/-2000 volts bias was 1.69 for a single measurement pair. Since 25 February the islands of Sally, Lucy, and Alice have been remeasured.

For Lucy, the 1.6 factor was verified. For Alice, the remeasurements did not verify the 1.6 factor, and an additional factor of 1.72 was applied, as discussed in Tech Note 5.1 (Correction Factor for Detector (SN: 496) Operating at Low Voltage on Island Alice, by M. Barnes.)

Time Period 21 March to 12 July

Field calibration of detectors is performed three times daily when on-site. A source is installed in a sample pan at a reproduced distance below the detector entrance window. The source consists of ^{241}Am, ^{137}Cs, ^{60}Co (and a minor amount of ^{155}Eu), sealed in glass beads and plastic in a 3-1/2 inch plastic dish. The source is counted for five minutes and the detector preamplifier gain and zero settings are adjusted to locate the 59.5, 661.6, 1173.2, and 1332.5 keV peaks in the correct channels of the pulse height analyzer. Typically, about 20,000 counts are accumulated for ^{241}Am. Data scatter is attributed to the effect of environmental conditions on the detector and electronics. The detector "barrel" is exposed to temperatures ranging above 94°F, a mean relative humidity of 77%, and intense rain squalls. First stages of the preamp are built into the detector Dewar. The other electronics are located in the air conditioned pod. The standard

*See Appendix D for correction factors used later in the project.

deviation of calibration response values is about 7%. Figure B-5-3 and Table B-5-3 show the response data from 27 February onward. Evidently, a decrease in response of the detector occurred between 17 March and 21 March. Between these dates the detector was removed from its barrel, another tried and found unsuitable, and 496 reinstalled. The mean response from 25 February to 17 March was 579 ± 31; mean response from 21 March to 12 July was 524 ± 20. The ratio is 1.11.

Statistical analysis of the two sample populations (27 February to 17 March vs. 21 March to 12 July) was conducted using the Student's "t" technique (conducted by J. J. Giacomini of Desert Research Institute). Comparison of the difference between means of the two populations with the standard deviation of the differences gives a "t" value whose magnitude implies a difference in the two populations. The probability of observing this large a "t" value for the null hypothesis, i.e., that the two sample populations are not different, is less than 0.001. A similar examination for the ^{137}Cs and ^{60}Co peaks gives the same conclusion. Table B-5-4 gives a summary of the basic statistics.

There are three corroborating data points:

(1) Detector effective area measurements by EG&G at Las Vegas before island use show a ratio of 1.12 for detectors 393/496. Measurements on 15 and 22 July at Ursula give a ratio of 1.22.

(2) Calibrations performed in May 1978 for the soil sample screening method give a ratio of 1.19 for detector 393/496. (Recall that the March 1978 field experiment gave a ratio of 1.10 for these two detectors.)

(3) Efficiency measurements at the ERSP Enewetak counting laboratory for detector 496 show a ratio of 1.16 for ^{241}Am, comparing 2 February to 25 July data.

Recommendation

It is recommended that detector 496 be corrected by multiplying its readings by a factor of 1.16 for degradation during the period 21 March to 12 July. This is based on the field calibration data averages, the counting laboratory results, and a comparison of detector effective area as measured at Ursula on 15 July, with the effective area of 19 used in the IMP calculation program.

The factor of 1.10 to account for the smaller active area of 496 relative to the other detectors is still applicable for the period 25 February to 12 July. The correction factor recommended for 21 March to 12 July data is 1.10 X 1.16 = 1.276 = 1.28.

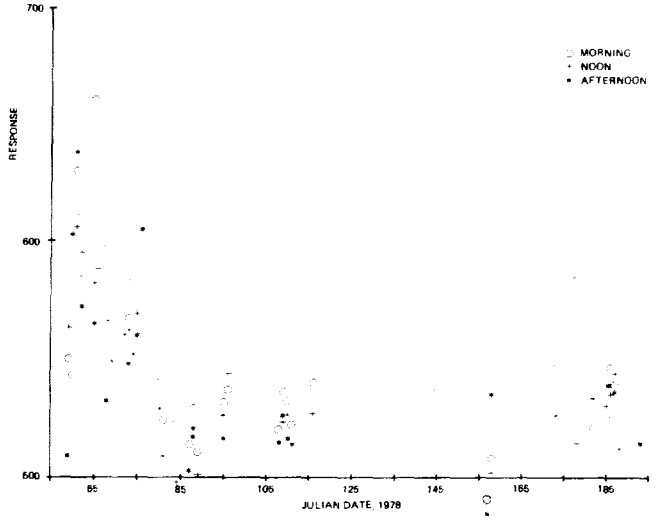


FIGURE B-5-3. AMERICIUM 241 CALIBRATION RESPONSE FOR DETECTOR 496 27 FEB TO 12 JULY 1978

TABLE B-5-1. DETECTOR COMPARISON DATA FROM THE SALLY KICKAPOO AREA 2 MARCH 1978

STAKE LOCATION	^{241}Am Value (pCi/gm) DETECTOR 496	DETECTOR 393	NOTES
26-N-10	8.5	8.3	
26-N-9	1.2	1.5	1
26-N-11	19.5	20.6	
26-N-12	31.3	35.1	
26-N-13	26.5	28.3	
26-N-14	38.4	44.2	
26-N-11	0.6	0.7	2
25-N-10	1.2	1.5	1
25-N-9	0.6	0.4	2
24-N-11	0.1	0.6	2
24-N-12	0.7	1.0	2
24-N-13	8.4	8.9	
24-N-14	20.2	21.4	
26.5-N-14	38.0	44.2	
26.5-N-13	30.2	32.3	
26.5-N-12	39.4	45.2	

Notes: 1. Both points close to lower limit of detectability; therefore only one used to avoid overweighting the mean.
2. Below lower limit of detectability; not included in the mean.

TABLE B-5-2. ISLANDS MEASURED USING DETECTOR 496

DATE (1978) Gregorian	Julian	ISLAND	COMMENT
February 3, 4	35, 36	Lucy	Low voltage
February 7, 9	39, 41	Alice	Low voltage
February 13, 16	45, 48	Belle	Low voltage
February 21, 25	53, 57	Sally	Low voltage
February 27	59	Sally	Correct voltage after this date
March 1	60	Tilda	
March 2	61	Sally	Intercomparison experiment with detector 393
March 3	62	Tilda	
March 6, 7	65, 66	Tilda	
March 9, 10	68, 69	Kate	
March 13, 15	72, 74	Nancy	
March 16, 17	75, 76	Lucy	Remeasurement
March 21, 22	80, 81	Wilma	Response degradation this date
March 25	84	Sally	
March 28	87	Ruby	
March 29, 30	88, 89	Mary	
April 5, 6	95, 96	Sally	
April 18, 21	108, 111	Alice	Remeasurement
April 26	116	Sally	
May 25	145	Sally	
June 7	158	Sally	
June 22	173	Sally	
June 27	178	Sally	
July 1	182	Sally	
July 4	185	Sally	
July 5, 6	186, 187	Pearl	
July 7	188	Sally	
July 12	193	Sally	

TABLE B-5-3. DETECTOR 496 FIELD CALIBRATION DATA - 1978

(IMP I SOURCE)

Julian Date	No. of Measurements	Normalized Response	Response	Standard Deviation	% Std. Dev.
^{241}Am					
59-76	34	1.00	579	31.0	5.35
80-193	60	.905	524	20.2	3.87
59-193	94	.940	544	36.1	6.65
59-193 Am	37		552	37.1	6.72
59-193 Noon	36		540	33.4	6.18
59-193 PM	21		534	37.4	6.99
^{137}Cs					
59-76	34	1.00	232	12.8	5.52
80-193	58	.931	216	22.8	10.6
59-193	92	.957	222	21.2	9.55
^{60}Co					
59-76	34	1.00	186	9.10	4.90
80-193	58	.892	186	9.27	5.59
59-193	92	.930	173	13.2	7.64

TABLE B-5-4. DETECTOR 496

SUMMARY OF BASIC STATISTICS

DAYS	^{241}Am		^{137}Cs	^{60}Co
59-76	n_1 = 34		34	34
	$\bar{x}_1$ = 578.62		231.74	185.71
	s_1 = 30.98		12.80	9.10
80-193	n_2 = 60		58	58
	$\bar{x}_2$ = 523.68		215.57	166.02
	s_2 = 20.25		22.84	9.27
$\bar{x}_1 - \bar{x}_2$		54.94	16.17	19.69
S	5.29	4.27	1.99	
$\bar{x}_1 - \bar{x}_2$				
t	10.39	3.79	9.89	
p	<.001	<.001	<.001	

Notes:

1. "t" is the ratio of $(\bar{x}_1 - \bar{x}_2)/\underline{\underline{S}}\ \bar{x}_1 - \bar{x}_1$
2. $\underline{\underline{S}}\bar{x}_1 - \bar{x}_2$ is the square root of the sample variance of the difference.
3. "p" is the probability that the null hypothesis is correct.

IMP SOIL SAMPLE COUNTING SYSTEM

DOE/ERSP TECH NOTE NO. 6.0 DATED: May 1978

AUTHOR: Z. Burson, EG&G

Introduction

There is a need to develop an in-field, soil sample assay screening method to allow operational decisions to be made in (or near) real time. Possible applications are as follows:

1. Subsurface Soil Sampling: When soil sampling is performed below the surface at a particular site, it is desired to define the extent of contamination at all levels (down to 100 cm). To do this in one visit an in-field screening method is necessary.

2. Sample Screening: It is desired to screen soil samples as to activity in order to decide on which samples to process in the lab. It appears that at least half of the samples taken have activity below 2 pCi/g ^{241}Am.

3. Truck Sampling: In the future there may be a need to estimate the soil activity in particular trucks in real time.

4. Soil Removal: In the future there may be a need to estimate the activity in soil in real time as an aid to soil removal.

   The intent here was to develop, test and calibrate a soil sample holder to be used with the IMPs and the associated counting system. It is not intended to ever be used in place of laboratory soil sample counting or for any permanent records or certification.

Soil Sample Holder

Standard soil samples are routinely counted in the laboratory in a plastic petri dish about 9 cm diameter and 2 cm deep. The petri dish is placed 3 cm from the face of the Ge (Li) detector in a counting shield.

It was intended that the counting geometry for the IMPs be as close as reasonably achieveable to the laboratory counting system.

The soil sample holders, as designed and built, are shown in Figure B-6-1. The lead surrounding the soil sample reduces the ^{241}Am background to negligible levels. The foam rubber allows pressure to be applied to the holder, thus assuring a reasonable consistency in positioning.

It is noted, however, that exact, known positioning cannot be achieved; thus inconsistencies of a few percent between soil sample results is to be expected.

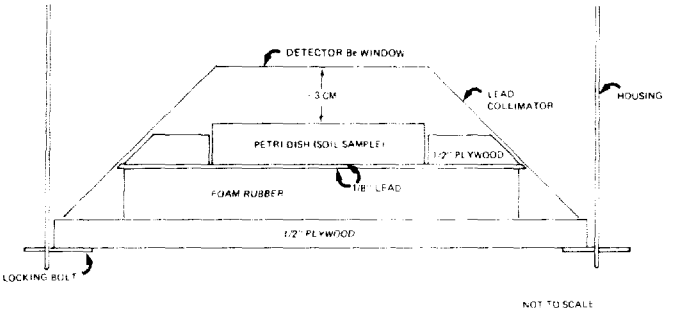


FIGURE B-6-1. SOIL SAMPLE HOLDER FOR IMP DETECTORS

Calibration

Two soil samples, in which ^{241}Am concentrations had been previously determined in the laboratory, were taken to Ursula and several measurements taken with the samples in place. The samples were removed and reinserted into the holder each time a count was taken.

The results are given in Table B-6-1. The soil samples used in the calibration were composed of dry soil, previously calibrated in the EIC laboratory.

For a simple estimate of the uncertainty of the results, we assume $\pm$ 1 pCi/g ^{241}Am or $\pm$ 15%, whichever is greater, assuming a 5 minute count and low background. If weight and moisture content are not known, the uncertainty increases.

After many samples have been counted by the IMP and processed by lab analysis, it is intended that an addendum in this Tech Note be prepared, summarizing the comparisons.*

Testing

Soil samples were counted at the Cape Mixan site and the IMP shed as well as truck samples at Kickapoo. The system seems to work adequately as designed. The following are observations, suggestions and recommendations in regard to applications of the technique:

1. Soil samples should be counted in an area where the ^{137}Cs and ^{60}Co levels are low. At the Cape Mixan area levels were high producing background counts under the ^{241}Am peak of 400 counts. Background at the IMP shed is about 20 counts in 5 minutes.

2. Dry soil in the petri dish must be estimated or measured. Currently, we are estimating 100 grams while we are waiting for a scale to be delivered.

3. To determine soil content above or below 400 pCi/g TRU for truck samples, a counting time of 150 seconds is adequate.

TABLE B-6-1. CALIBRATION RESULTS OF IMP SOIL SAMPLE COUNTING SYSTEM

IMP I, Detector 496

Soil Sample	Net Count in ^{241}AM	Ratio
pCi	Peak (5 min)	pCi/count
10,895	953	11.43
10,895	921	11.83
4,479	396	11.31
4,479	371	12.07
4,479	350	12.90
4,479	372	12.04
4,479	394	11.37
4,479	400	11.20
4,479	416	10.77

Average = 11.66 $\pm$ 0.63

IMP III, Detector 513

Soil Sample	Net Count in ^{241}Am	Ratio
pCi	Peak (5 min)	pCi count
4,479	426	10.51
4,479	446	10.04
4,479	512	8.75
4,479	486	9.22
4,479	456	9.82
4,479	436	10.27

Average = 9.77 $\pm$ 0.67

*See Tech Note 6.1.

COMPARISONS OF IMP SCREENING AND LAB RESULTS

DOE/ERSP TECH NOTE NO. 6.1 DATED: 9 September 1978

AUTHOR: J. Giacomini, DRI

An in-the-field soil screening procedure has been developed whereby soil samples are counted using the in situ van (IMP). A physical description is given by Burson in Tech Note 6.0, IMP Soil Sample Counting System. This tech note offers data comparing the field screening method to laboratory assay methods for identical samples.

Table B-6-2 shows results for IMP screening and by radiochemistry and alpha spectroscopy. The mean ratio for IMP to gamma results is 1.05 with a standard deviation of 0.35. The mean ratio for the IMP to chemistry results is 1.20 with a standard deviation of 0.32. Table B-6-3 shows ^{241}Am results for soil samples counted by the IMP and by laboratory gamma counting. The results shown are for soil samples collected from Sally. Figure B-6-2 is a plot of the data shown in Table B-6-3. The line shown is the simple linear regression line calculated from the data plotted. The regression line has a slope of 0.96 and an intercept of 0.53. The correlation coefficient is 0.94. The 95% confidence interval for both sets of data includes the ratio 1.0.

Using the IMP as described in Tech Note 6.0 is an acceptable method of in-the-field soil sample screening. It is not intended to be used as a replacement for laboratory soil sample counting or analysis by radiochemistry but does provide a method for rapid field screening of ^{241}Am in soil samples.

TABLE B-6-2. COMPARISON OF IMP SCREENING DATA WITH LAB CHEMISTRY RESULTS (pCi/g ^{241}Am, BALLMILLED SAMPLES)

STAKE LOCATION	DEPTH,cm	IMP	GAMMA	CHEM.	RATIO (IMP/CHEM)
-11.5-N-4.5	0	5	4.97	5.64	.89
	20	2	0.90	1.30	1.54
	40	<1	<MDA	0.25	-
	60	<1	0.10	0.25	-
	80	<1	<MDA	0.17	-
	100	<1	0.13	0.29	-
9.25-S-7.25	0	13	27.42	11.59	1.12
	60	3.5	2.56	2.67	1.31
9.25-S-7.5	0	3	3.84	3.32	.90
	20	118	121.75	122.04	.97
-14-N-6	0	2.5	0.6	2.70	.93
	20	2.8	2.47	2.65	1.06
	40	4.5	2.69	2.43	1.85
	80	4.0	3.15	2.86	1.40

TABLE B-6-3. COMPARISONS OF IMP SCREENING DATA (pCi/g ^{241}Am) WITH LAB GAMMA DATA (pCi/g ^{241}Am) (UNBALLMILLED SAMPLES, SAME PETRI DISH)

STAKE LOCATION	DEPTH	IMP SCREEN	LAB GAMMA	RATIO (IMP/LAB)
11.5-N-4.5	0	5	4.39	1.14
	20	2	3.44	0.58
	40	<2	0.20	-
11-N-5	0	5	3.51	1.42
12-N-4	0	<2	2.41	-
	20	7	6.88	1.02
12-N-5	0	5	3.62	1.38
	20	2.5	2.39	1.05
	40	2.5	1.41	1.77
	80	<2	<MDA	-
	100	4	3.97	1.01
12.5-N-5.5	0	5.5	4.24	1.30
13-N-5.5	0	6	6.64	0.90
	20	2.5	2.44	1.02
8-S-6.5	0	2	1.52	1.32
	80	<2	<MDA	-
8.5-S-6.5	60	<2	<MDA	-
9.25-S-7.25	0	13	27.42	0.47
	60	3.5	2.58	1.36
9.25-S-7.5	0	3	3.75	0.80
	20	118	119.23	0.99
9.25-S-7.75	0	61	51.80	1.18
	20	63	80.53	0.78
9.25-S-8	0	58	45.59	1.27
	20	67	71.71	0.93
	40	2	2.45	0.82
9.5-S-7.25	0	20	51.08	0.39
	20	5.5	6.80	0.81
9.5-S-7.75	0	22	19.44	1.13
	20	11	8.57	1.28
	60	<2	<MDA	-
	100	3	3.82	0.79
9.75-S-7.75	0	63	77.59	0.81
	20	25	22.80	1.10
	40	<2	<MDA	-
	80	<2	0.28	-
9.75-S-8	0	34	46.70	0.73
	20	13	10.05	1.29
	40	54	55.89	0.97
9.5-S-8.25	0	49	53.54	0.92
	20	70	72.11	0.97
10.25-S-8	0	<2	<MDA	-
10-S-8.25	0	98	61.24	1.60
	20	44	21.64	2.03
	40	15	39.78	0.38
10.25-S-8	0	87	76.69	1.13
10-S-9.5	0	2	2.09	0.96
	20	5	3.47	1.44
	80	2	1.66	1.20
10.5-S-9.5	40	<2	1.99	-
11-S-8.5	0	4	6.53	0.61
	20	<2	<MDA	-0

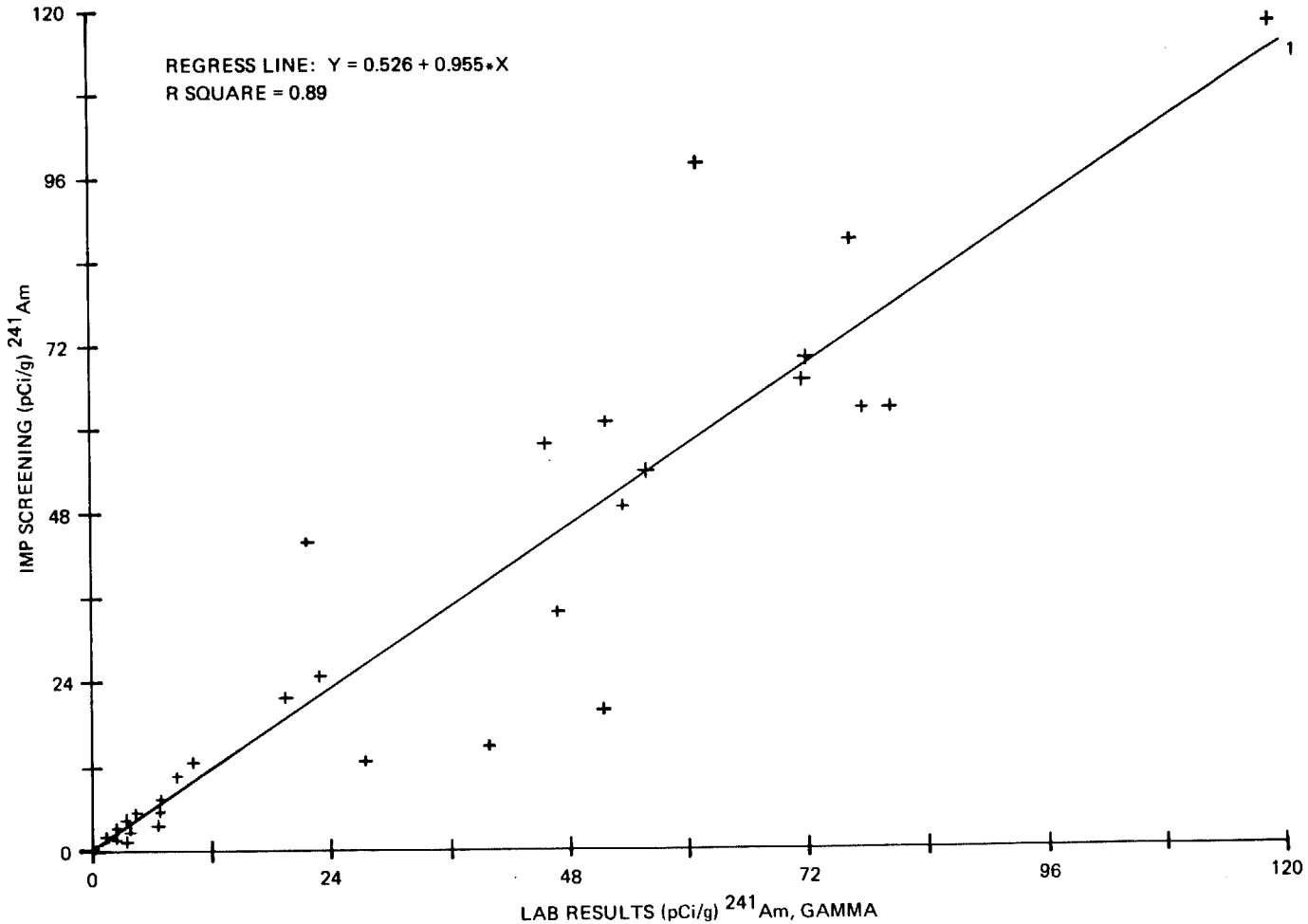


FIGURE B-6-2. PLOT OF IMP SCREENING VS. LABORATORY RESULTS FOR ^{241}Am GAMMA

ESTIMATION OF EXCISION VOLUMES FOR AREAS OF SUBSURFACE CONTAMINATION

DOE/ERSP TECH NOTE NO. 7.0 DATED: April 1978

AUTHOR: B. Friesen, DRI

Introduction

Subsurface contamination at activity levels above excision criteria is known to exist on several northern islands in the Enewetak Atoll. Long term planning of cleanup action requires knowledge of both surface and subsurface excision volumes. Surface volumes can be estimated, retaining full view of necessary assumptions, from the combined efforts of soil sampling and in situ ^{241}Am gamma surveys; however, estimation of subsurface volumes is more complex. This tech note is intended to describe the method used to derive a broad-brush first estimate of subsurface volumes to be excised.

This exercise was undertaken to produce preliminary results in time for a 3-4 May 78 meeting in Washington, D.C.

While the demand for data afforded us an opportunity to step through the procedures, the paucity of data in many areas made estimation of volumes very tenuous and highly unsatisfactory.

Data Selection

All surface and subsurface soil analysis results from an area on a given island were assembled into one list in order by location. Every type of available data was tabulated. In evaluating this data, preference was given first to chemically determined total transuranics, then to laboratory counted ^{241}Am gamma, then to gross alpha determinations, either laboratory or field counted. If gross alpha was available from both backhoe and auger profiles at the same location, preference was given to the backhoe profile data. In essence, the symbols placed on the estimation maps represent the most accurate data available for each point at each level.

Estimation Maps

Maps were drawn for each of eight areas: Irene 13-N-1 Area; Irene, Central Area; Janet, Easy/X-ray Area; Janet, Item GZ; Pearl, 5-S-3 Area; Pearl, 1-N-1 Area; Sally, Kickapoo GZ; Sally, Yuma GZ. Each map page contained representations of 3 subsurface depths or "plates." The first page for an area contained plates representing the plane at 0, 20 and 40 cm. The second page for an area showed the plane at 60, 80 and 100 cm. The intent of this graphic portrayal is to simulate a three-dimensional representation. Each page had grid tick marks on all boundaries to facilitate plotting data symbols, and beach lines were shown where applicable.

Date Symbols

Four symbols were selected to show different levels of activity with the size or intensity of the symbol increasing with level of activity as follows:

. = less than 40 pCi/g
+ = greater than 39.9 but less than 100
* = greater than 99.99 but less than 400
# = greater than 400

The appropriate symbol was then plotted at the appropriate location on the plate map. Only the highest quality value was plotted when more than one was available from the same location and depth. All of the plate maps are labelled to indicate that the plotted symbols represent gross alpha, pCi/g, when in fact approximately half of the values were of better quality than gross alpha. Alternative labelling would have implied better data quality than existed or would have required a more complex selection of symbols to portray both magnitude and quality of each datum entry.

Excision Envelopes

Once the datum symbols were all plotted, the next step was to draw boundary lines around each of the symbol types if a pattern existed, or around individual isolated symbols. After much discussion the decision was made that Bruce Church would draw ALL of the boundary lines due to the highly subjective nature of the task; no two people could draw the lines in exactly the same place. It is evident from a scan of the plate maps that the lines drawn are not strictly isopleths. It is also evident that additional profile data are required to adequately define the boundaries in many areas. When sufficient data have been collected, the boundary lines should be redrawn with due observance of the rules governing isopleths.

Translation to Volumes

The boundaries were traced onto square grid paper for each depth and each criterion line, then the curved boundaries were squared off as close as reasonably possible. Next, the enclosed squares were counted and adjustment made for the difference in scale between x and y directions. The adjusted area for each depth and activity line was then translated to volume by appropriate multiplication. The assumption was made that the activity shown on a plate extended downward through the 20 cm thickness of the plate. While this procedure may not accurately portray reality it produces a number that is probably close to the volume that would actually be excised.

Summation of Volumes

The final product of this exercise is a table of numbers showing the volume by depth for each criterion level for each area and summarized by island. These data were NOT accumulated into a neat form due to the highly preliminary nature of the results. The procedure has been outlined, however, and is subject to refinement as additional data are collected and the entire exercise is repeated for final estimates.

(Editor's Note: Sixteen pages of "maps" were drawn for this exercise, but were not distributed with the Tech Note. A specimen of the plate map for the 13-N-1 area of Irene is presented in Figure B-7-1.)

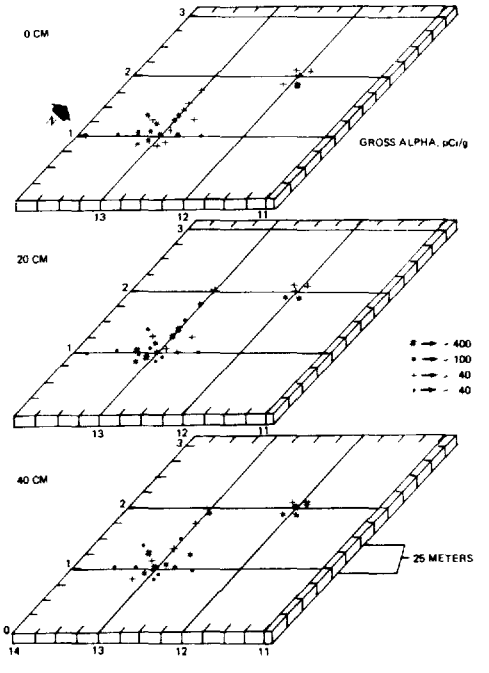


FIGURE B-7-1. PICTURE OF THE 13N1 AREA OF IRENE

FIELD INVESTIGATION OF SOIL SAMPLE TO IMP RESULTS

DOE/ERSP TECH NOTE NO. 8.0

DATED:
Draft - May 1978
Final - August 1978

AUTHOR: Z. Burson, EG&G
B. Friesen, DRI

I. Introduction

For the coarse grid survey of ^{241}Am on Enewetak Atoll, surface soil samples are taken in every four hectare parcel of each of the 17 larger northern islands. However, no island is sampled in less than four locations. The locations chosen always coincide with an IMP measurement.

Table B-8-1 lists the measured soil sample to IMP ratio results for the islands surveyed.

The weighted average ratio of soil to IMP is 1.23 $\pm$ 0.21 using the number of composites per island as the weighting factor. The range in values shown in Table B-8-1 is 0.18 to 3.21. In view of the fact that the measurement errors are a larger percentage of the measured value for low activity levels than for higher activity levels, a better indicator of agreement differences could be derived using the activity level as a weighting factor. This result is obtained by using the ratio of the means instead of the mean of the ratios as given above. The ratio of the means for all 17 islands is 1.25. (The computational procedure is to sum the soil sample results for all samples, sum the IMP value for all soil sample locations, divide each sum by the number of observations, then divide soil by IMP to obtain the ratio of the means.) The ratio of the means does not readily convert to graphic form so Figure B-8-1 is included to show the distribution of individual ratios using the same input as was used to compute the ratio of the means.

Rather than arbitrarily correct the IMP results to match the soil sample results or vice versa, it seemed appropriate to investigate some of the factors that contribute to the comparisons.

II. Factors Influencing Comparisons

There are a number of factors that influence the comparison of soil sample and IMP readings. Some of these are listed below and briefly discussed.

A. Background subtraction in ^{241}Am photopeak IMP readings. The background subtraction routine in the IMP data reduction program considers channels on both sides of the ^{241}Am photopeak. The influence of this routine in the calibration data as related to the actual field conditions should be investigated.

B. Soil Density. Does the fact of different soil densities affect the IMP and soil sample calibration?

C. ^{241}Am vertical distribution in the soil. What is the vertical distribution of ^{241}Am in the soil and how does this influence the soil sample-IMP comparisons?

D. Field-of-View. Does the soil sampling procedure adequately sample the IMP's field-of-view? Several items in this category are:

1. Effect of rocks in the field-of-view.
2. What is the variability from point to point? Are enough soil samples being taken?
3. What is the effect of changing the sampling board and rope knots?
4. What are the roadway effects?
5. What is the influence of the IMP and boom in the field-of-view of the detector?

TABLE B-8-1. RESULTS OF SOIL SAMPLE TO IMP RATIOS

Island	No. of Locations	No. of Composites	Ratio* Min.	Ratio* Max.	Ratio* Avg.	Standard Deviation
Alice	4	8	1.02	2.51	1.39	0.51
Belle	5	10	0.18	1.78	1.17	0.47
Clara	4	8	0.41	1.84	1.28	0.46
Daisy	4	8	0.33	1.34	0.93	0.40
Irene	10	20	0.61	2.78	1.45	0.63
Janet	29	58	0.27	1.91	1.09	0.40
Kate	5	10	0.59	1.58	0.98	0.32
Lucy	5	10	0.31	2.93	1.67	0.78
Mary	5	10	0.64	1.91	1.20	0.46
Nancy	5	10	0.65	2.75	1.43	0.71
Olive	4	8	0.60	1.97	1.24	0.39
Pearl	10	20	0.40	1.84	1.10	0.39
Ruby**	3	6	0.57	1.63	0.94	0.36
Sally**	3	6	0.50	3.08	1.41	0.95
Tilda	6	12	0.55	2.14	1.21	0.46
Vera	4	8	1.05	2.39	1.48	0.42
Wilma**	3	6	0.84	3.21	1.88	0.79

* Includes detector and brush corrections.
**Used only data points greater than 1 pCi/g.

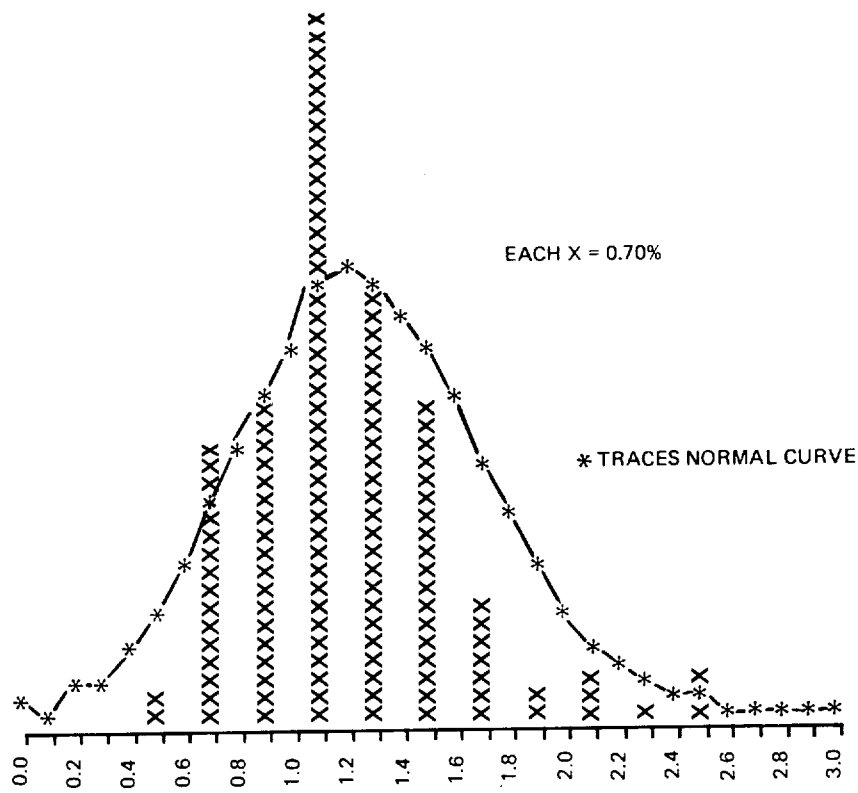


FIGURE B-8-1. HISTOGRAM OF INDIVIDUAL VALUES USED TO COMPUTE RATIO OF THE MEANS

E. Brush Attenuation. Is there a bias in the brush attenuation factor used?

F. Soil Moisture. The soil sample results are given in activity in dry soil. What is the influence of soil moisture on the IMP readings?

III. Experiment Objective

The above list is not intended to be complete or comprehensive. It is apparent, however, that there are many factors that influence the comparison of IMP readings to soil sample results. When this list was prepared (3 May 1978), it was the intention of the ERSP to investigate these items, as time permitted. Some could be investigated by experiment and some by computations.

The intention of this experiment was to investigate items C and D.2 in Section II.

A relatively undisturbed area on the island of Tilda was chosen for the experiment (Figure B-8-2). The ^{241}Am concentrations were about 5 pCi/g. The location had little or no brush. The area was roped off and designated a DOE test area to be undisturbed until the end of the cleanup project.

IV. Description of Field Experiment

The location was divided into two areas, one for detailed measurements and one for a control area. A sketch of these two areas is shown in Figure B-8-3. Access lanes were chosen for minimum disturbance of the soil.

IMPs I and III were used for measurement at both areas with the detector at 740 cm and 460 cm heights. Two 15-minute measurements were made at each point at each height.

For the control area, normal soil samples were taken for the A and B composites. The "cookie cutter" was used for these samples. From the weight of the soil collected and the depth of the instrument, it is estimated that the depth of sampling was from the surface to about 2.5 cm.

For the experimental area, 12 different spots were chosen for soil samples, corresponding to the normal A and B locations. The soil from each location and depth was kept separate. For 6 of the locations, 2 samples were taken (0 to 2.5 cm and 2.5 to 5 cm). For the other six locations, 6 samples were taken (0 to 1.5, 1.5 to 3, 3 to 4.5, 4.5 to 6, 6 to 8, 8 to 10 cm). The locations circled in Figure B-8-4 correspond to the latter 6 locations.

For the 6 locations where only 2 samples were taken, the cookie cutter was used. For the other locations (circled in Figure B-8-4), a different method was used. Two pieces of tin, about 20 x 30 cm in size, were taped (yellow) with 1.5 cm strips for reference. The two pieces of tin were then "sawed" into the soil to a depth of 10 cm forming a 90° angle with each other. Soil was then removed from the perimeter of the sample area and placed into a plastic bag. With a third piece of tin a 1.5 cm layer was "cut" off the top and removed. Successive layers were then removed in like manner. After sampling was completed, the soil from the bag was placed back into the hole.

All sampling locations were in undisturbed soil. At only one location was it necessary to stop short of 10 cm depth due to a ledge of old beach rock.

V. Results

The IMP results are tabulated in Table B-8-2 and summarized in Table B-8-3. The control area appears to contain a little higher ^{241}Am activity than the experimental area. The decrease in values with increase in height is as expected (approximately 10%) for the control area, but is not consistent for the experimental area. Little significance should be placed on this, however, because activity within the area is not likely to be uniform and brush is not uniform within the area.

It is noted that IMP I, detector No. 496, requires a correction of 1.1 because of detector size. It is also noted, after applying the detector correction factor, that the results of IMP III appear to be slightly greater in value than those of IMP I. The averages are within counting statistics.

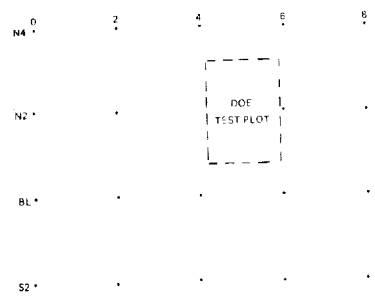


FIGURE B-8-2. DOE TEST PLOT LOCATION ON TILDA

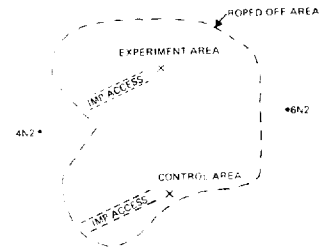


FIGURE B-8-3. DETAILS OF DOE TEST PLOT

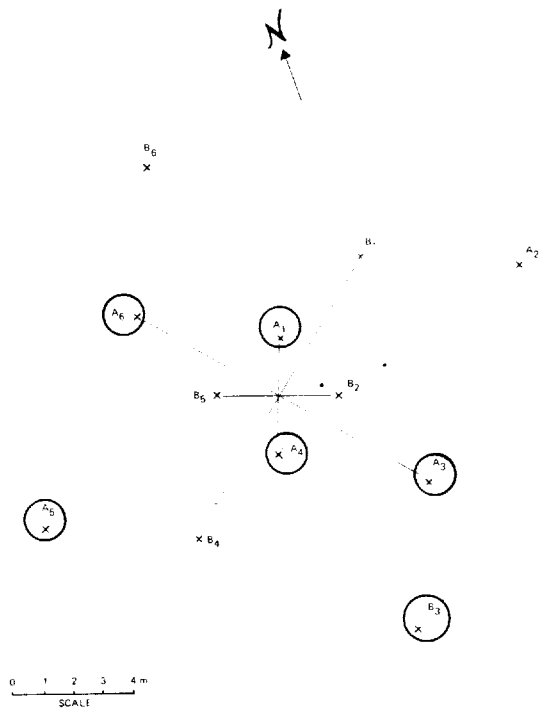


FIGURE B-8-4. SOIL SAMPLE LOCATIONS IN EXPERIMENT AREA

TABLE B-8-2. IMP DATA* FROM DOE TEST PLOT - 17 AND 18 MAY 1978

Area	Height (cm)	Run No.	Net Count** ^{241}Am	^{241}Am** pCi/g	^{137}Cs pCi/g
IMP I, Detector 496					
Exp.	740	11055	585	5.1	5.8
Exp.	740	11056	635	5.5	6.0
Exp.	460	11057	600	5.17	5.8
Exp.	460	11058	581	5.0	5.6
Control	460	11059	703	6.1	7.7
Control	460	11060	573	5.0	7.4
Control	740	11061	602	5.2	6.8
Control	740	11062	634	5.4	6.9
IMP III, Detector 513					
Exp.	740	32151	608	5.2	6.3
Exp.	740	32152	609	5.2	6.2
Exp.	460	32153	635	5.4	6.0
Exp.	460	32154	639	5.5	5.7
Control	460	32147	786	6.7	7.0
Control	460	32148	762	6.5	7.0
Control	740	32149	722	6.2	7.0
Control	740	32150	673	5.8	6.9

*900 seconds counting time.
**A detector sensitivity correction factor of 1.1 was applied to data from detector 496.

TABLE B-8-3. SUMMARY* OF IMP DATA FROM DOE TEST PILOT

	Avg pCi/g in Exp. Area		Avg. pCi/g in Control Area	
IMP	740 cm Height	460 cm Height	740 cm Height	460 cm Height
I	5.48	5.25	5.68	5.91
III	5.40	5.65	6.45	7.10
Both	5.44	5.45	6.07	6.51

*Includes brush corrections but not height corrections.

The soil sample results are given in Tables B-8-4 and B-8-5 and plotted in Figures B-8-5.a, B-8-5.b and B-8-6.

Several conclusions are noted:

A. The activity is highly variable from point to point and as a function of depth. The surface ^{241}Am activity varied from 2.25 to 14.14 pCi/g.

B. Six out of twelve sample locations showed the surface concentrations to be greater than subsurface. The other six showed subsurface activity to be greater.

C. The average surface activity (0 to 1.5 cm) was 6.98 pCi/g; the average for 0 to 2.5 cm was 7.99 pCi/g; the average for 0 to 3 cm was 9.55 pCi/g, and the average for the IMP reading was 5.44 pCi/g.

Additional analysis of the data presented in Table B-8-4 leads to several interesting observations. In terms of accuracy of measurement at different stages of soil sample analysis, one might expect an unballmilled sample to be least accurate, a ballmilled sample more accurate and counting after chemical separation and isolation to be most accurate of the three stages. In this context, the unballmilled and ballmilled samples would show high variability around the results by chemistry. Figure B-8-7 shows this to be the case, with 7 of the 12 samples having the results by chemistry at some point between the other two. The magnitude of the differences shown for the A_3 sample is unexpected, especially with the ballmilled value so far from the chemistry number. This is further illustrated in Figure B-8-8 where the M1 plot of ballmilled samples shows a definite high side bias due to the one large value from the A_3 sample. Deleting the A_3 sample produces the plot labelled M2 which reaches stability rather quickly and also indicates the true value of the A_3 sample is probably between 15 and 20 rather than 36.6 as reported.

Figure B-8-9 is included to show that, in general, with the degree of variability present in these data, six samples are not enough to develop a stabilized mean.

VI. Conclusions and Recommendations

There appears to be variability in ^{241}Am activity at any point of measurement (before mixing). Variability has been observed within a given soil sample, as well as within a given area. This means that if soil sample data are to be compared to the IMP data (for a given measurement), a multitude of samples are required. Data in Figure B-8-6 illustrate this problem.

Because of the high variability of activity from point to point, this experiment cannot be used to "verify" soil sample to IMP ratios.

The IMP "samples" 16 to 20 million grams of surface soil. During this experiment only a few thousand grams were sampled by the soil sample technique. The average surface soil samples read about 40% higher than the IMP readings. However, the average soil sample concentrations (0 to 3 cm and 0 to 2.5 cm) of 8.33 pCi/g contained a standard deviation of $\pm$ 3.64.

It should be pointed out that the soil samples determine activity in dry soil containing particle sizes less than about 0.5 cm in diameter averaged over about the top 2.5 to 3 cm. The IMP samples the soil-rock-humus-water matrix in situ to a depth that is variable according to vertical and horizontal distribution of the activity. The IMP conversion factor assumes uniform distribution.

Calculations have shown that if the distribution is exponentially decreasing with depth, a soil sampling depth of 0 to 3 cm should provide a good comparison with IMP readings (Figure B-8-10). Any other sampling depth would be more dependent on the vertical distribution.

It is evident that at half the locations in the experimental area, the activity increases with depth. The area was mostly clear of brush. The soil was coarse sand. It seems reasonable, then, that over a period of 20 years, much of the surface activity has moved down to below the surface.

TABLE B-8-4. LAB RESULTS OF SOIL SAMPLES FROM THE TILDA EXPERIMENTAL PLOT

Location	Depth (cm)	Gross Alpha (pCi/g)	^{241}Am Gamma N.B.M.[1] pCi/g	^{241}Am Gamma B.M.[2] pCi/g	Chemistry ^{239}Pu pCi/g	Chemistry ^{238}Pu pCi/g	Chemistry ^{241}Am pCi/g
A-1	0 - 1.5	36	7.52	7.21	15.08	0.04	9.80
	1.5 - 3.0	68	13.91	14.50	30.38	0.04	16.78
	3.0 - 4.5	185	25.31	31.18	51.07	0.08	32.02
	4.5 - 6	155	28.41	19.22	38.11	0.08	22.50
	6 - 8	3	2.18	2.18	3.53	0.03	2.06
	8 - 10	*	1.27	*	*	*	*
A-2	0 - 2.5	50	14.14	13.57	29.22	0.10	17.18
	2.5 - 5	*	1.60	*	*	*	*
A-3	0 - 1.5	53	8.87	36.60	19.96	0.03	13.04
	1.5 - 3	68	18.20	14.76	23.37	0.04	17.17
	3 - 4.5	107	10.82	12.26	16.83	0.08	10.79
	4.5 - 6	*	1.47	*	*	*	*
	6 - 7	*	0.76	*	*	*	*
A-4	0 - 1.5	22	5.51	5.78	9.64	0.05	5.85
	1.5 - 3	-	1.22	*	*	*	*
	3 - 4.5	*	0.90	*	*	*	*
	4.5 - 6	*	0.19	*	*	*	*
	6 - 8	*	MDA	*	*	*	*
	8 - 10	*	MDA	*	*	*	*
A-5	0 - 1.5	35	7.62	6.56	11.42	0.06	6.74
	1.5 - 3	*	0.70	*	*	*	*
	3 - 4.5	50	5.85	10.13	16.52	0.02	10.79
	4.5 - 6	59	10.28	9.99	17.06	0.02	10.79
	6 - 8	40	16.77	4.51	7.75	0.02	5.10
	6 - 10	8	4.17	1.70	3.16	0.01	2.05

[1]N.B.M. means Not Ballmilled
[2]B.M. means Ballmilled
* Less than 2 pCi/g, not laboratory processed.

TABLE B-8-4. LAB RESULTS OF SOIL SAMPLES FROM THE TILDA EXPERIMENTAL PLOT - Continued

Location	Depth (cm)	Gross Alpha (pCi/g)	^{241}Am Gamma N.B.M.[1] pCi/g	^{241}Am Gamma B.M.[2] pCi/g	Chemistry ^{239}Pu pCi/g	Chemistry ^{238}Pu pCi/g	Chemistry ^{241}Am pCi/g
A-6	0 - 1.5	29	3.27	2.90	6.91	0.05	3.94
	1.5 - 3	74	11.13	12.71	23.29	0.09	14.95
	3 - 4.5	-	0.86	*	*	*	*
	4.5 - 6	-	0.22	*	*	*	*
	6 - 8	-	MDA	*	*	*	*
	8 - 10	-	0.26	*	*	*	*
B-1	0 - 2.5	7	7.01	3.45	7.12	0.02	5.21
	2.5 - 5	7	4.16	3.32	6.43	0.04	4.30
B-2	0 - 2.5	22	3.79	3.16	5.70	0.03	3.59
	2.5 - 5	*	0.74	*	*	*	*
B-3	0 - 1.5	47	9.06	8.93	16.89	0.01	8.93
	1.5 - 3	54	14.92	13.86	24.15	0.06	14.89
	3 - 4.5	60	6.18	5.34	10.72	0.01	7.41
	4.5 - 6	*	1.64	*	*	*	*
	6 - 8	*	0.67	*	*	*	*
	8 - 10	*	0.22	*	*	*	*
B-4	0 - 2.5	40	13.34	7.32	14.59	0.04	8.77
	2.5 - 5	-	1.02	*	*	*	*
B-5	0 - 2.5	19	7.38	5.74	10.42	0.05	5.91
	2.5 - 5	9	2.81	2.62	5.50	0.03	3.24
B-6	0 - 2.5	6	2.25	1.83	2.96	0.02	2.09
	2.5 - 5	3	2.93	3.45	6.67	0.05	3.81
Control	(A)0 - 2.5	39	9.39	9.05	16.10	0.03	9.55
Control	(B)0 - 2.5	43	9.52	8.14	16.16	0.03	11.59

* Less than 2 pCi/g, not laboratory processed.

TABLE B-8-5. RATIOS OF LAB RESULTS OF SOIL SAMPLES FROM THE TILDA EXPERIEMENTAL PLOT

Location	Depth (cm)	TRU[1] Chem (pCi/g)	TRU Chem Am / (N.B.M.)		^{241}Am B.M. / N.B.M.	^{241}Am Chem / N.B.M.	Chem / B.M.
A-1	0 - 1.5	24.92	3.31	0.96	1.30	1.35	
	1.5 - 3.0	47.20	3.39	1.04	1.21	1.16	
	3.0 - 4.5	83.17	3.29	1.23	1.27	1.03	
	4.5 - 6	60.69	2.14	0.68	0.79	1.16	
	6 - 8	5.62	2.58	1.00	0.94	0.94	
A-2	0 - 2.5	46.50	3.29	0.96	1.21	1.26	
A-3	0 - 1.5	33.03	3.72	4.13	1.47	0.36	
	1.5 - 3	40.58	2.23	0.81	0.94	1.16	
	3 - 4.5	27.20	2.56	1.13	1.00	0.88	
A-4	0 - 1.5	15.54	2.82	1.05	1.06	1.01	
A-5	0 - 1.5	18.22	2.39	0.86	0.88	1.02	
	3 - 4.5	27.33	4.67	1.73	1.84	1.06	
	4.5 - 6	27.87	2.71	0.97	1.05	1.08	
	6 - 8	12.87	0.77	0.27	0.30	1.11	
	8 - 10	5.22	1.25	0.41	0.49	1.20	
A-6	0 - 1.5	10.80	3.30	0.89	2.20	1.35	
	1.5 - 3	38.33	3.44	1.14	1.34	1.18	
B-1	0 - 2.5	12.35	1.76	0.49	0.74	1.51	
	2.5 - 5	10.77	2.59	0.80	1.03	1.29	
B-2	0 - 2.5	9.32	2.46	0.83	0.95	1.14	
B-3	0 - 1.5	25.83	2.85	0.99	0.99	1.00	
	1.5 - 3	39.10	2.62	0.93	1.00	1.08	
	3 - 4.5	18.14	2.94	0.86	1.20	1.40	
B-4	0 - 2.5	23.40	1.75	0.55	0.66	1.20	
B-5	0 - 2.5	16.38	2.22	0.78	0.80	1.03	
	2.5 - 5	8.77	3.12	0.93	1.15	1.24	
	0 - 2.5	5.07	2.25	0.81	0.93	1.15	
	2.5 - 5	10.53	3.59	1.18	1.30	1.10	
Control							
(A)	0 - 2.5	25.68	2.73	0.96	1.02	1.06	
(B)	0 - 2.5	27.78	2.92	0.86	1.22	1.42	

[1]TRU means Total Transuranics.

It is recommended that the same experiment be repeated in two additional areas:

1. An undisturbed area containing heavy brush, and

2. An area heavily disturbed or deliberately disturbed where the top cm is expected to be uniform in activity.

More general recommendations are as follows:

1. As time permits, factors should be examined which contribute to biasing the IMP and/or soil sample results.

2. The surface soil activity relating to the cleanup criteria should be more clearly defined. Are we talking about activity per gram of dry soil less than a certain particle size, containing no rocks, averaged over the top 3 cm? Or are we talking about activity per gram of in situ material averaged over the area and depth of whatever the IMP sees?

3. If the definition relates more closely to the soil samples, then it is recommended that all the IMP measurements be multiplied by an empirically determined correction factor according to Table B-8-1, providing that factors leading to biasing in the soil sample results have been examined and resolved.

4. If the definition relates more closely to the IMP readings, then it is recommended that no corrections be made unless biasing of greater than 10 percent in one direction has been verified.

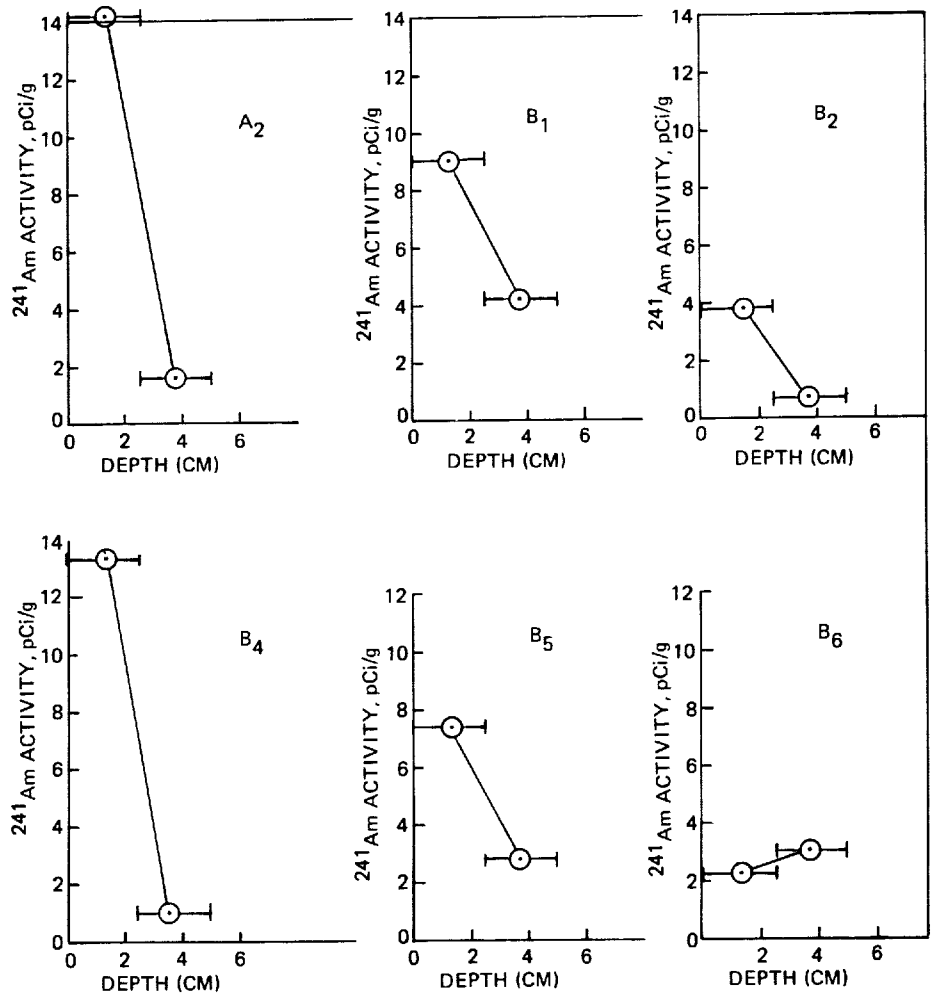


FIGURE B-8-5.a. ^{241}Am ACTIVITY VERSUS DEPTH IN THE EXPERIMENTAL PLOT FOR SAMPLES NOT BALLMILLED

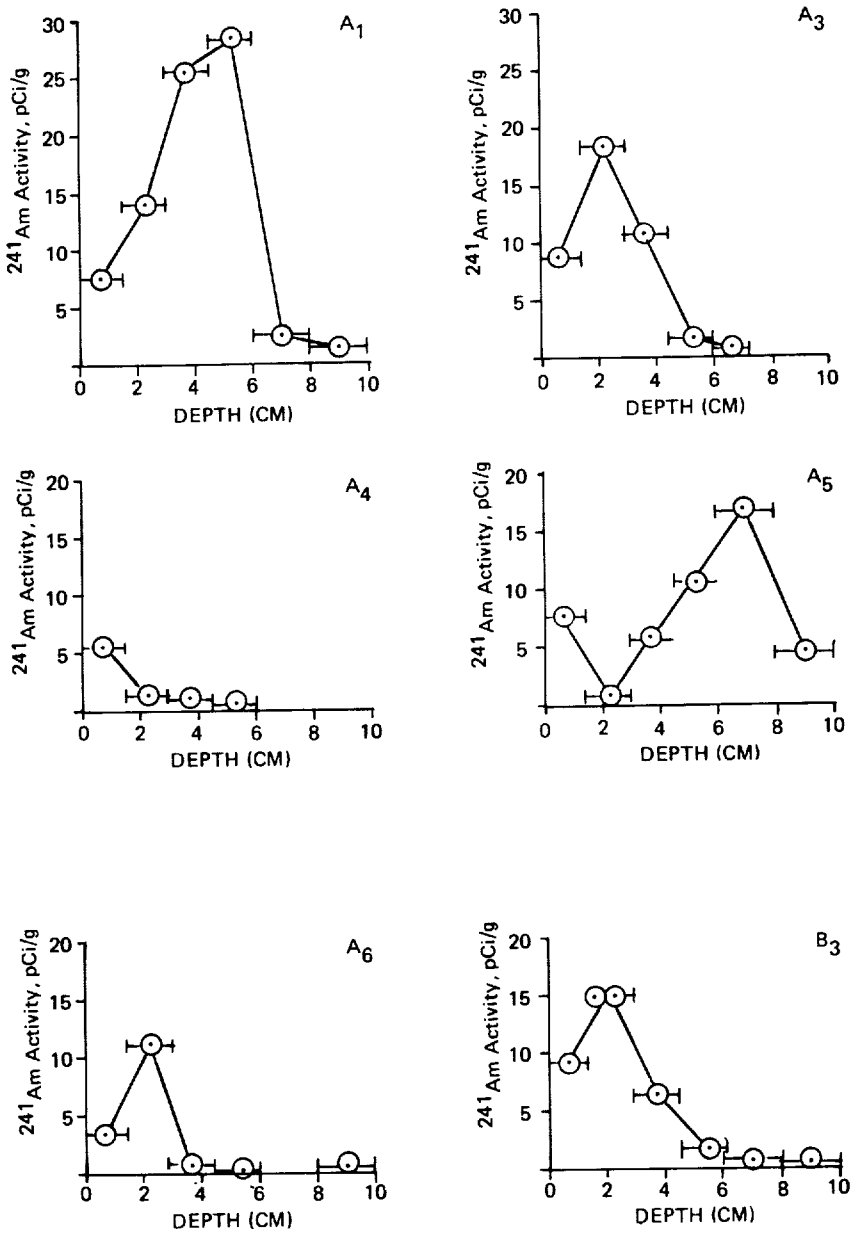


FIGURE B-8-5.b. ^{241}Am ACTIVITY VERSUS DEPTH IN THE EXPERIMENTAL PLOT FOR SAMPLES NOT BALLMILLED

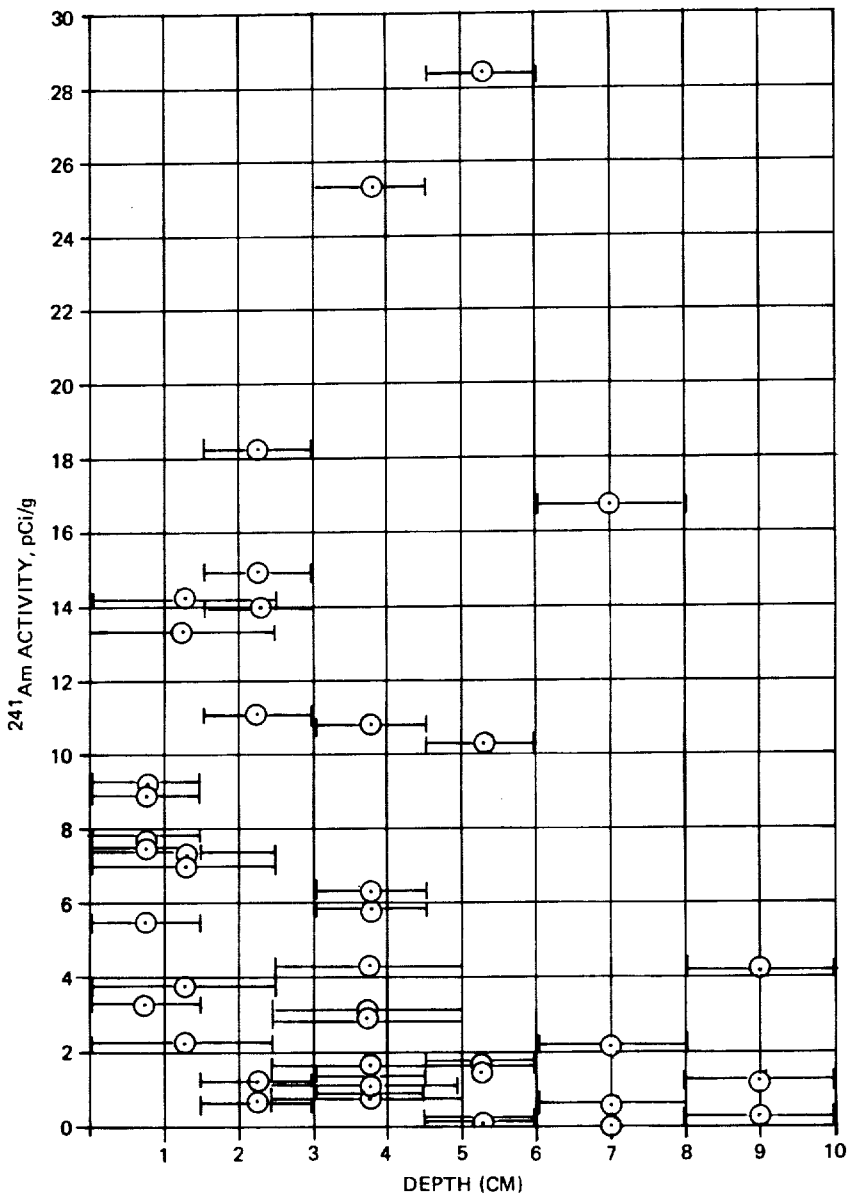


FIGURE B-8-6. ^{241}Am ACTIVITY VERSUS DEPTH AT 12 LOCATIONS ON EXPERIMENTAL PLOT

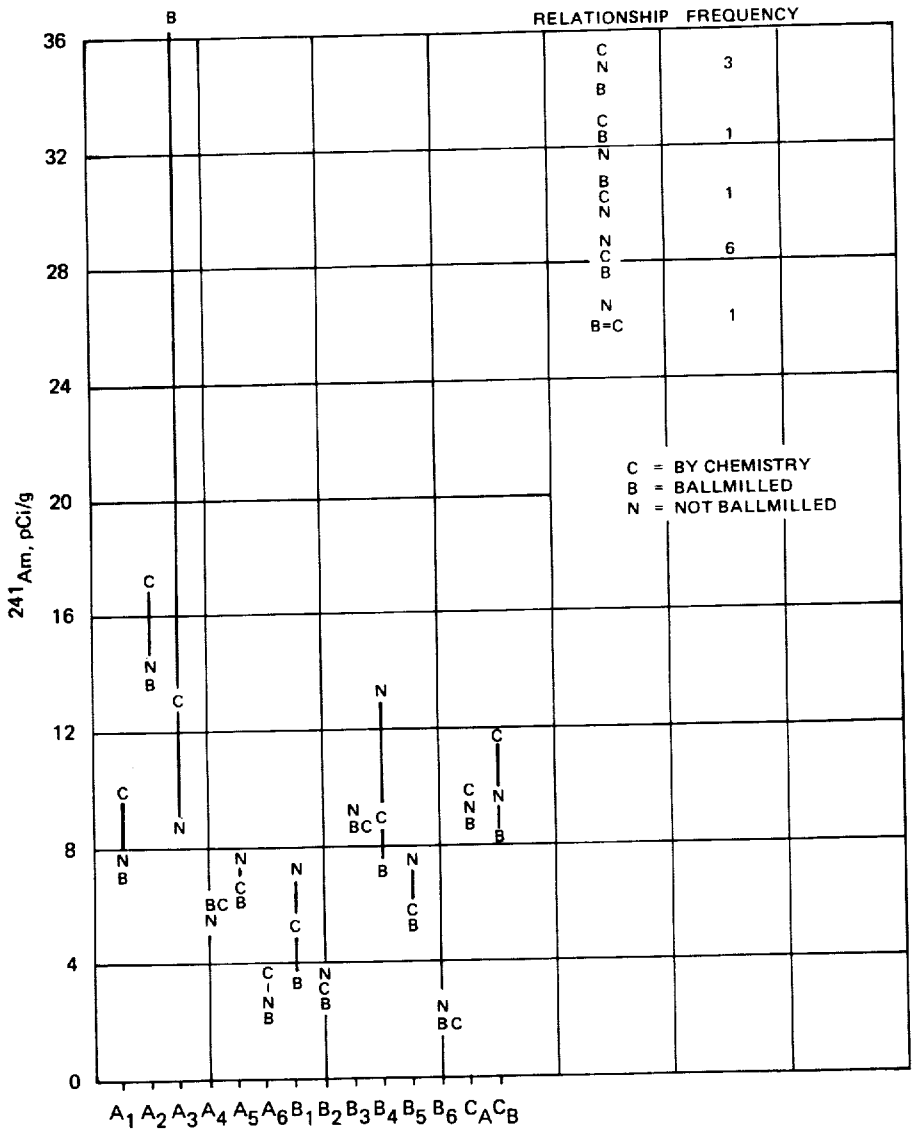


FIGURE B-8-7. COMPARISON OF SOIL SAMPLE RESULTS AT THREE STAGES OF ANALYSIS (ALIQUOTS OF THE SAME SAMPLE)

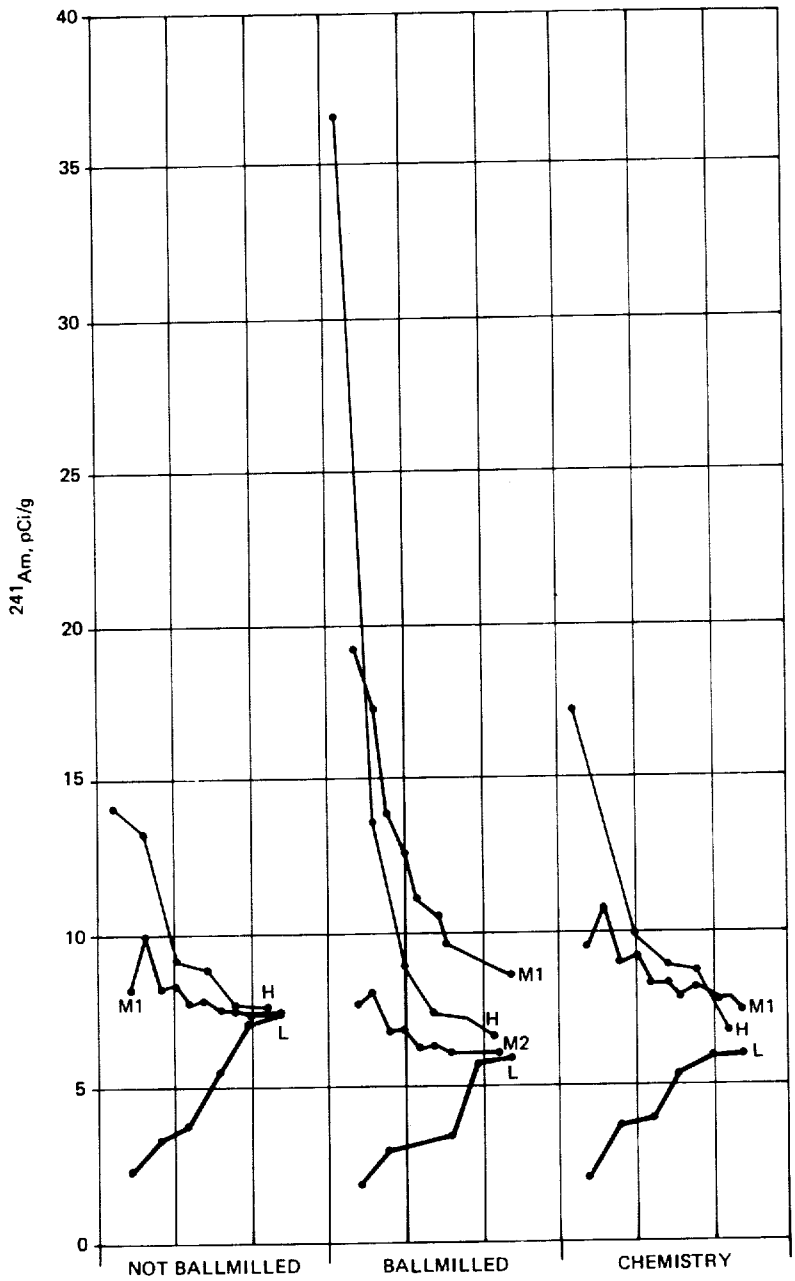


FIGURE B-8-8. PLOTS OF THE PROGRESSIVE ACCUMULATED MEANS OF ^{241}Am VALUES FROM 3 STAGES OF ANALYSIS

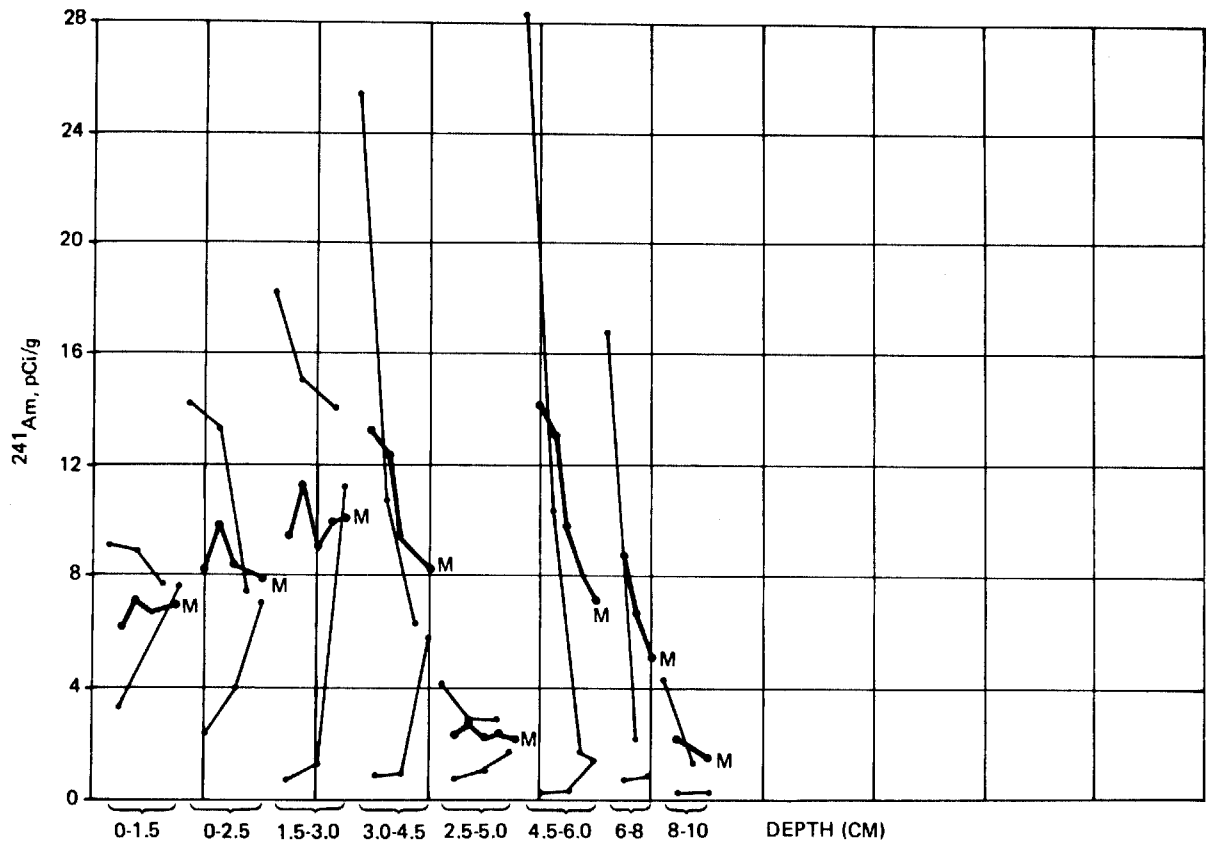


FIGURE B-8-9. PLOTS OF ^{241}Am, pCi/g FROM 8 DEPTHS IN EXPERIMENTAL AREA

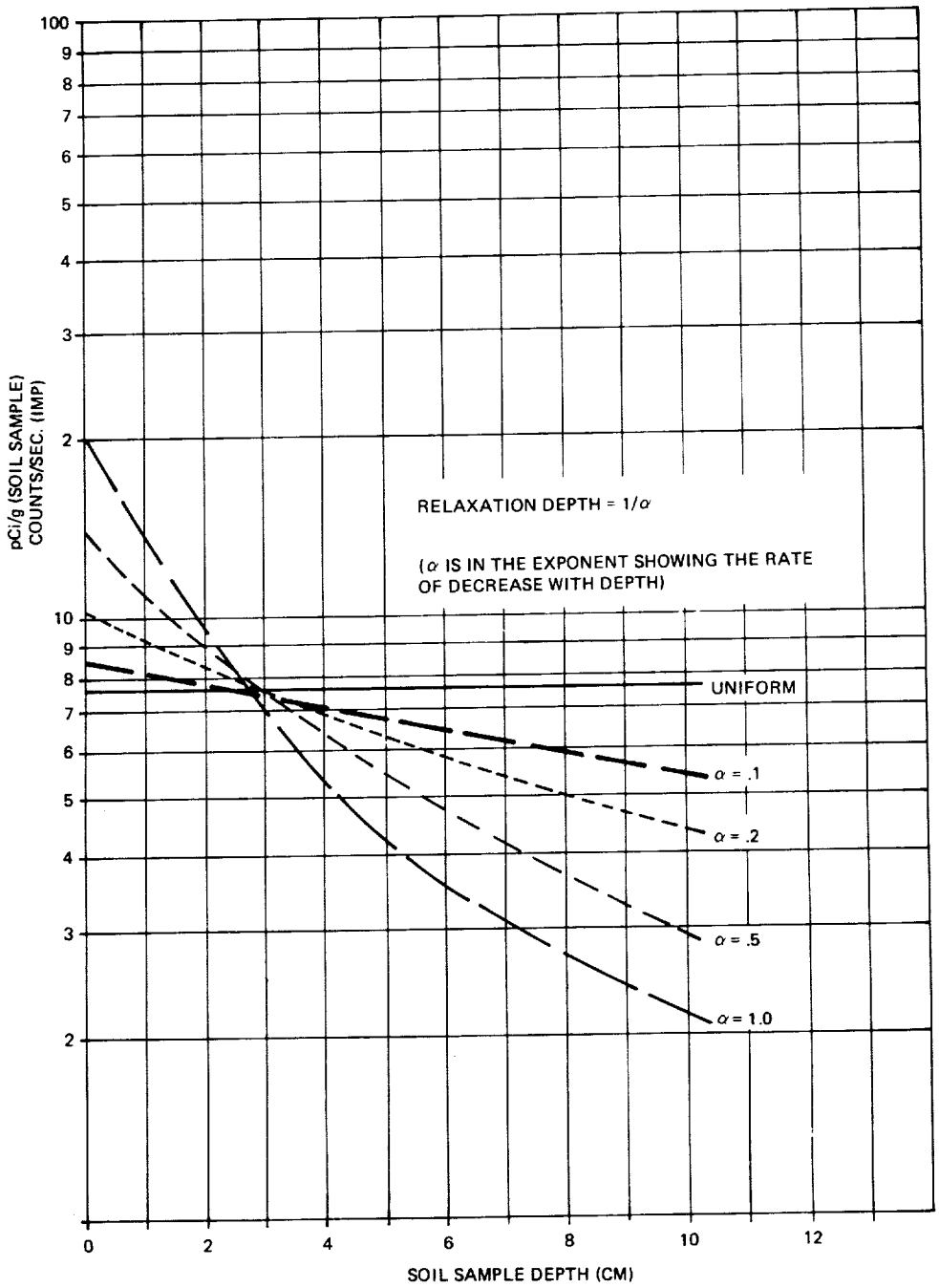


FIGURE B-8-10. IMP SENSITIVITY TO ^{241}Am SOIL CONCENTRATIONS AS A FUNCTON OF SOIL SAMPLE DEPTH.

SELECTION OF POTENTIAL SOIL PLOWING EXPERIMENTAL AREAS

ON THE ISLAND OF JANET

DOE/ERSP TECH NOTE NO. 9.0 DATED: 12 May 1978

AUTHOR: Dale H. Denham, LLL

Summary

Three 25m x 75m areas, including eight stake locations on a 25m grid, were selected on the island of Janet as potential sites to conduct one or more plowing experiments. The purpose of said plowing experiment(s) was stated in the 15 May TWX from FCDNA (Albuquerque) to USDOE (Las Vegas) as follows: "To evaluate the effectiveness of plowing in dose reduction for Food Gathering, Agricultural and Potential Residence islands". Implicit in that definition is that plowing may provide an alternative to or be used to supplement soil removal. Janet was chosen since it met all of the island "types" listed in the above definition and is one of the most important islands for cleanup.

The three areas so chosen include two in the NW sector and one in the SW sector (see Figure B-9-1). One location is about 350 m from the Item Ground Zero (GZ), a second is about 625 m from both the Item and Easy/X-ray GZ areas, and the third is about 850 m from the Easy/X-ray GZ. All three areas were selected because they exhibited relatively uniform and significant surface contamination levels (30-70 pCi/g TRU, based on previous IMP surveys and surface soil sampling), and they were relatively free of major debris or vegetation.

Soil samples were collected at the eight stake locations in each experimental plot (designated as Plow X-1, X-2 and X-3) for a total of 120 samples per plot (16 additional samples were collected in Plow X-1 because the profile samples were collected to a depth of 120 cm rather than 100 cm as for the other plots). Plastic petri dishes were filled with soil for approximately half of the samples. The soil in these petri dishes was then categorized into several soil types and then gamma-scanned with the IMP for both ^{241}Am and ^{137}Cs activity levels. Some samples from the Plow X-1 plot were processed through the laboratory.

Preliminary results from the visual soil characterization and IMP screening indicate that all three plots exhibit similar data. The following conclusions are based on these preliminary observations:

1. The soil is basically in 3 layers: the top 20 to 40 cm is mostly a brown sand and soil mixture with some vegetation (root matter) and small pebbles; the middle layer, ranging from about 30 to 60 cm below the surface, is composed of a richer mixture of dark brown, moist soil and sand; and the bottom layer (60 to 120 cm below grade) is mostly coral sand and pebbles interspersed with some brown and gray sand (Figure B-9-2).

2. Average surface concentrations of ^{241}Am were 30 pCi/g, 14 pCi/g, and 24 pCi/g in the X-1, X-2 and X-3 plots, respectively, corresponding to 100 pCi/g, 46 pCi/g and 80 pCi/g TRU (using the computed TRU/Am ratio of 3.3).

3. The ^{241}Am concentration decreased approximately exponentially with depth below the surface; an order of magnitude decrease was observed in the first 15 to 20 cm.

4. Average surface concentrations of ^{137}Cs were 340 pCi/g, 86 pCi/g and 270 pCi/g, in the X-1 to X-3 plots, respectively.

5. The ^{137}Cs concentrations also decreased with depth, but at a less pronounced rate than for ^{241}Am.

6. The highest ^{137}Cs concentrations were observed in the richest soil fractions. Apparently no ^{241}Am or ^{137}Cs (above their respective MDLs of 1 to 2 pCi/g and 8 to 10 pCi/g, respectively) have leached through to the coral sand layer about 60 cm below grade.

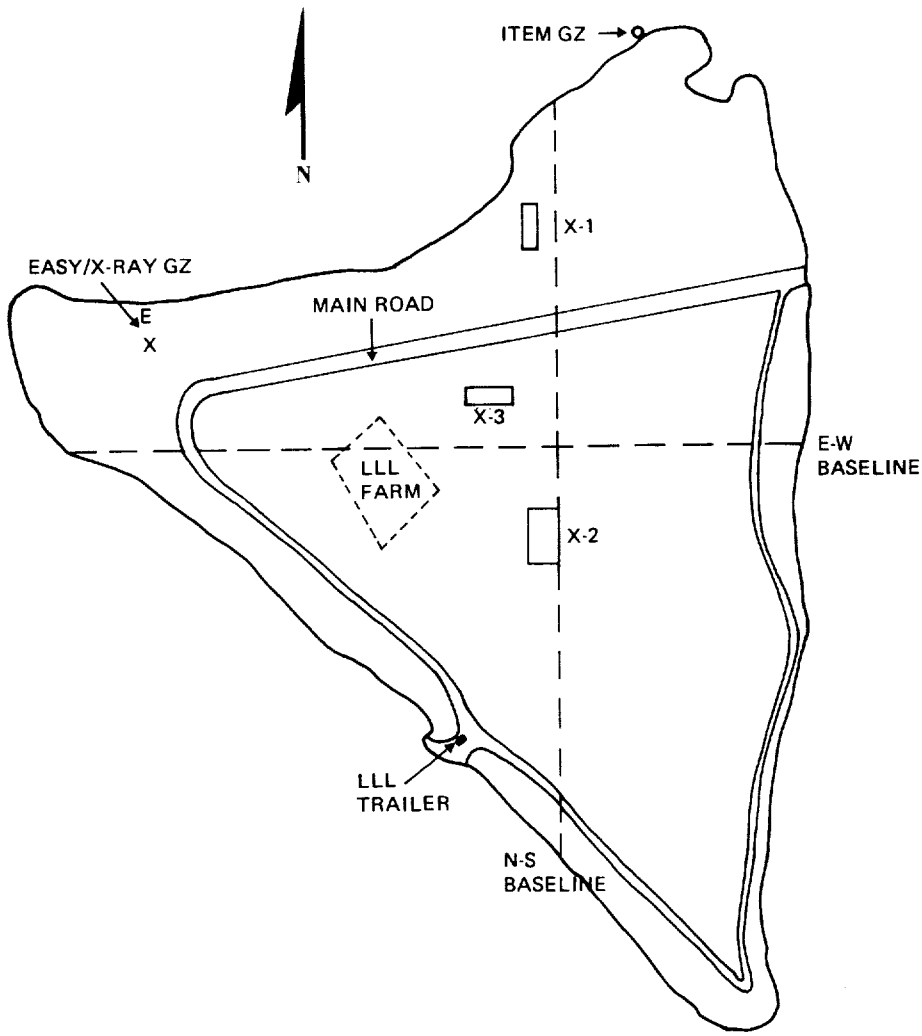


FIGURE B-9-1. MAP OF JANET SHOWING LOCATIONS OF PROPOSED PLOWING EXPERIMENT PLOTS, MAY 1978

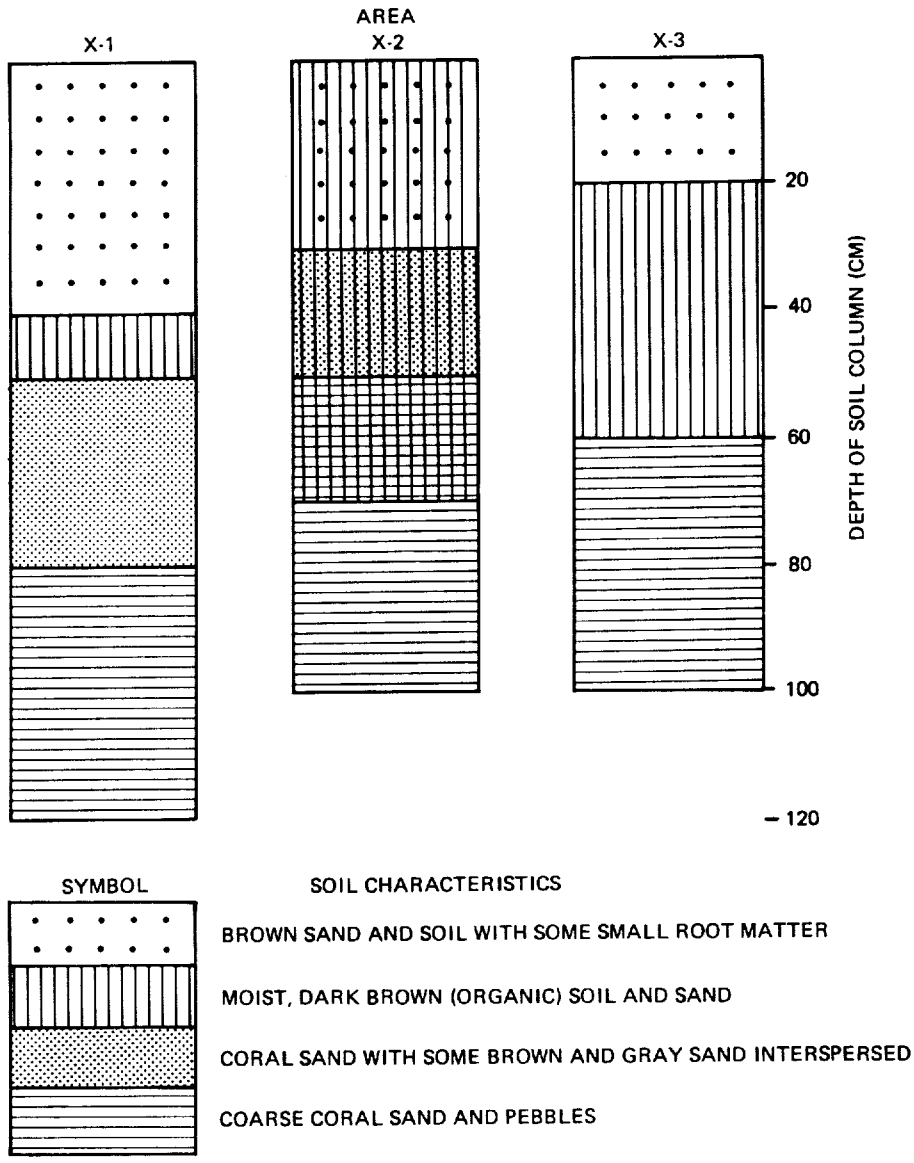


FIGURE B-9-2. SOIL PROFILE CHARACTERISTICS IN PROPOSED PLOWING EXPERIMENT AREAS

Introduction

This tech note has been prepared to describe the investigatory phase of choosing three possible sites in which to conduct a series of plowing experiments. The purpose of such plowing experiments is "to evaluate the effectiveness of plowing in dose reduction for food gathering, agricultural and potential residence islands", on Enewetak Atoll in the Marshall Islands.

From this preliminary investigation and the professional judgements of Drs. Chester Francis (ORNL) and Raleigh Jones (University of Hawaii), the plan is to define:

1. Test plot location(s).

2. Pre and post plowing data requirements.

3. Any other factors deemed necessary to fully evaluate resultant effect on dose pathways.

In this preliminary investigation the following assumptions were made to limit the scope of any plowing experiments to the equipment and resources available on Atoll:

1. It is desirable to ascertain the effects of plowing soil known to have surface contamination only.

2. It is desirable to ascertain the effects of plowing soil when contamination is known to exist below the surface.

3. Experiments should be performed in areas where concentration levels (TRU, ^{137}Cs, etc.) match those expected to be considered for plowing.

4. The island of Janet should be considered first, since it is the island most likely to be considered for plowing as a means of reducing the surface concentrations of radioactivity.

Three plots were chosen in case the desired characteristics (such as soil profile or radionuclide content) were not met in one of the plots. It is anticipated that only one or two plots will actually be plowed for evaluation.

A plowing planning meeting was held on 11 May 1978 in the DOE office trailer at Enewetak. Attendees (three military and four DOE) are listed in the minutes of that meeting, attached to this note as Annex A. During that meeting it was concluded the minimum area to be plowed should be 60 x 110 meters enclosing (in the center of the area to be plowed) a 2 x 4 set of stakes on a 25 meter grid.

Locations and Methods of Sampling/Analysis

The three 25m x 75m areas (including eight stake locations on a 25m grid) selected are shown on the Janet map in Figure B-9-1. The areas or plots are designated on the map as Plow X-1, X-2 and X-3. In addition to these three rectangular areas, other identifying features are shown: the north-south and east-west baselines (dashed lines) for the island grid system; the three ground zero locations; the LLL farm and housing trailer; and the runway and perimeter roads.

Specific grid designations for the three potential experimental areas are:

	PLOW X-1	PLOW X-2	PLOW X-3
	NW	SW	NW
	1-13 2-13	0-11 1-11 3-3	3-4
	1-14 2-14	0-12 1-12 4-3	4-4
	1-15 2-15	0-13 1-13 5-3	5-4
	1-16 2-16	0-14 1-14 6-3	6-4
Sampling Date	18 May 78	25 May 78	26 May 78

The Plow X-1 plot was chosen because it showed the highest surface concentrations of TRU on the island; was in an area relatively clear of vegetation and debris; had not been a heavily vegetated area when the cleanup project began (see EG&G aerial survey photos of 1972); was in the original IMP 25 meter "test grid" area and in one of the final 25 meter grid areas for which lots of data have been recorded; and lastly, soil samples were collected and analyzed previously in the surface to 20 cm depth at stake location NW 2-14 (allowing comparison of the data over time and by two different sampling techniques).

Following collection of the soil samples in the Plow X-1 area, the ERSP Manager suggested samples be collected in areas where the surface concentration of TRU was less than 50 pCi/g. He and the DRI Statistician reviewed the IMP data and recommended three additional areas based solely on the IMP data, namely: (1) in the SE quadrant 100 meters or so south of the three story structure (already a pile of rubble by this time) and to the east of the road leading to that structure; (2) in the NW quadrant between the beach and the runway north of the LLL farm; and (3) in the SW quadrant directly east of the LLL farm.

The ERSP Tech Advisor and the EIC Soil Sampling Supervisor visually checked the areas suggested above for appropriateness to sample (i.e., level, clear of vegetation and debris, etc.). It was also considered desirable to select areas in which the IMP had made measurements on a 25 meter grid, although this latter consideration was not essential.

Based on the above criteria, we selected the other two plots, Plow X-2 and X-3. Both of these plots were chosen in areas which were windrowed as part of the brush removal program prior to surveying or IMP measurements. Now, only ground cover type vegetation (grasses and morning glory vines) is present in those two areas. The Plow X-2 plot is north of the old LLL trailer site and in an area about 100 to 150 meters south of the line of concrete pads and bunkers which extended west from the large 3-story structure. Consequently, there may be some shrapnel or other debris in the X-2 area from the blasting which has occurred to effect removal of those structures. No obvious debris was noted during the soil sampling effort.

The Plow X-3 plot is located in an area 200 to 300 meters north of the debris removal effort noted above. It is located within one of the areas where IMP measurements were made on a 25 meter grid, between two of the original windrows. The area between those two windrows contains some surface asphalt and concrete, especially just to the southwest of the 8-stake plot chosen.

All three potential plowing experiment plots are delineated in the field with 1.5- to 2-m long red posts of wood or aluminum pipe to stake out the corners of each area. Because there is a lot of debris removal activity on the island, including blasting, the military supervisors on island were instructed to request their personnel keep all vehicles out of those designated areas.

All soil sampling for the three experimental plots was done by the Navy soil samplers under EIC supervision and at the request of the DOE Tech Advisor. Soil samples were collected at each of the 24 grid locations (8 per plot) using the techniques given in DOE/ERSP Procedure No. 4, "Soil

Sampling Procedure." Four surface composite samples (A, B, C, and D) were collected at each stake location. At the conclusion of that operation in each plot area, a backhoe was used to provide holes for subsurface profile sampling. These holes were dug about 30 to 50 cm away from the actual grid locations to avoid moving the stakes and to a nominal depth of 120 to 140 cm. Sidewall soil samples were collected every 10 cm starting at a depth of 120 cm in the X-1 area and at a depth of 100 cm for the X-2 and X-3 areas. The 5 cm thick cut removed by the sampling tool was centered on the respective depths below the surface. The samples were collected from the lower elevations first to avoid contaminating those samples with soil from near the surface which is expected to have the highest concentrations of radioactivity. The nominal sample size was about 500 cm^3. If less material was removed from a cut because of rocks or other debris, a second cut was made at the same depth to insure sufficient sample. Except for the X-1 location samples, each was placed in a separate plastic bag and then in an appropriate size (1/2 or 1 gallon) steel paint can and labelled according to DOE/ERSP Procedure No. 4. The X-1 location samples were placed directly in steel cans.

A petri dish with nominal capacity of 100 to 150 grams of soil was prepared in the field from the sample cans for approximately half of the samples and sealed with black electrical tape. The date, stake location, and depth of sample were recorded on the top of the petri dish.

Petri dish samples were prepared for the A and B surface composites at all locations and for each of the subsurface samples from 0 to 100/120 cm depth in two diagonally opposed locations (i.e., at stakes NW 2-14 and NW 1-15; SB 0-14 and SW 1-11; NW 3-3 and NW 6-4) for each plot. Other subsurface petri dish samples were prepared alternately for the odd (10, 30, 50, etc.) or even (20, 40, 60, etc.) depths. Petri dishes for these latter samples generally were not made for more than one "coral sand" depth per stake location. Hence, at some locations petri dish samples do not exist below the 50 to 60 cm depth. All petri dishes were filled by the use of a plastic teaspoon, stirring up the soil in the bag or can with each scoop. Rocks, large pebbles and large pieces of vegetation were deliberately excluded from the petri dish, even though many of the cans included such material.

Petri dish samples were visually scanned for soil characterization and the information was recorded in the Tech Advisor's daily log. These same petri dish samples were also wet-weighed to the nearest gram on a triple beam balance and given a 5-minute gamma scan according to DOE/ERSP Procedure No. 21, "Soil Sample Screening by IMP." The approximate calibration factors for this IMP screening technique were 0.1 pCi/g and 1 pCi/g for the net counts observed in 5 minutes for ^{241}Am and ^{137}Cs, respectively.

Although it is anticipated that a number of additional analyses may be required, it was felt these preliminary estimates of ^{241}Am and ^{137}Cs concentrations in conjunction with soil characteristics would be adequate for experts to judge the merits of these three plots as potential plowing experiment areas. Projected data requirements included ^{90}Sr, ^{239}Pu, soil pH, and percent humus. Because of these projections and the "Laboratory Soil Sample Procedures," DOE/ERSP Procedure No. 8, all of the surface samples (A, B, C, D) and about one-third of the subsurface samples from Plow X-1 were analyzed in the EIC lab. The surface samples received gross alpha, ^{241}Am (gamma), and $^{238, 239, 240}Pu$ analyses while the subsurface samples received gross alpha and ^{241}Am (gamma) analyses. All of these samples were dried, so percent moisture was determined and density was measured for the surface samples.

Preliminary Results

Soil characteristics are based on visual observations by the DOE Tech Advisor and the EIC Soil Sampling Supervisor. The soil categorization was based on these parameters:

Material	Color	Texture/Wetness
Soil	Dark Brown	Fine
Sand	Brown	Coarse
Vegetation	Light Brown	Moist (condensation on petri)
Pebbles	Gray	Wet (excess water in petri)
	Coral	

These soil characteristics are recorded in the Tech Advisor's log for each of the 189 petri dishes prepared (49, 69, 71 for X-1, X-2 and X-3, respectively). The soil characteristics were grouped by depth for each plot area. Only those characteristics which predominated are shown in Figure B-9-2, because of the subjective nature of the data.

All three plots exhibit a surface layer of brown sand and soil containing some root matter; however, the depth of that layer was greatest (40 cm) for the X-1 plot and least (20 cm) for the X-3 plot. Plot X-2 showed the shallowest layer of soil, only about 30 cm thick, prior to hitting the gray and coral sand layer which continued to the 100 cm depth. Plot X-3 showed the thickest layer (about 40 cm) of dark brown soil, also assumed to be the richest soil. Coral sand regions were noted from 50 to 60 cm below the surface in Plot X-1 and X-3, while the same layer in Plot X-2 was observed only 30 cm below grade.

The average and range of ^{137}Cs, ^{241}Am and TRU concentrations, in pCi/g dry weight, observed from the IMP screening data and lab analyses are presented below for the surface sample A and B composites and 5 cm deep profiles.

	^{137}Cs*		^{241}Am*		TRU+	
Location	Average	Range	Average	Range	Average	Range
X-1	340	150-640	30	9-72	97	42-210
X-2	86	57-120	14	4-24	No Analysis	
X-3	270	160-430	24	11-48	No Analysis	

* Approximate values based on IMP screening at Ursula.
\+ Sum of 238, 239, 240Pu and ^{241}Am (gamma) from lab analyses.

These values are based on an assumed moisture content of 10% for the IMP screened samples and actual dry weights for those samples counted in the lab.

The subsurface concentrations for ^{137}Cs and ^{241}Am are presented in Figures B-9-3, B-9-4 and B-9-5 for each of the plots. As expected, the data suggest that essentially all of the ^{137}Cs and ^{241}Am are contained within the upper soil-sand layers and not in the coral sand below about 50 to 60 cm. Both the ^{137}Cs and ^{241}Am concentrations decrease with depth below the surface. An order of magnitude decrease in concentration was observed in the first 15 to 20 cm for ^{241}Am and in the first 20 to 30 cm for ^{137}Cs.

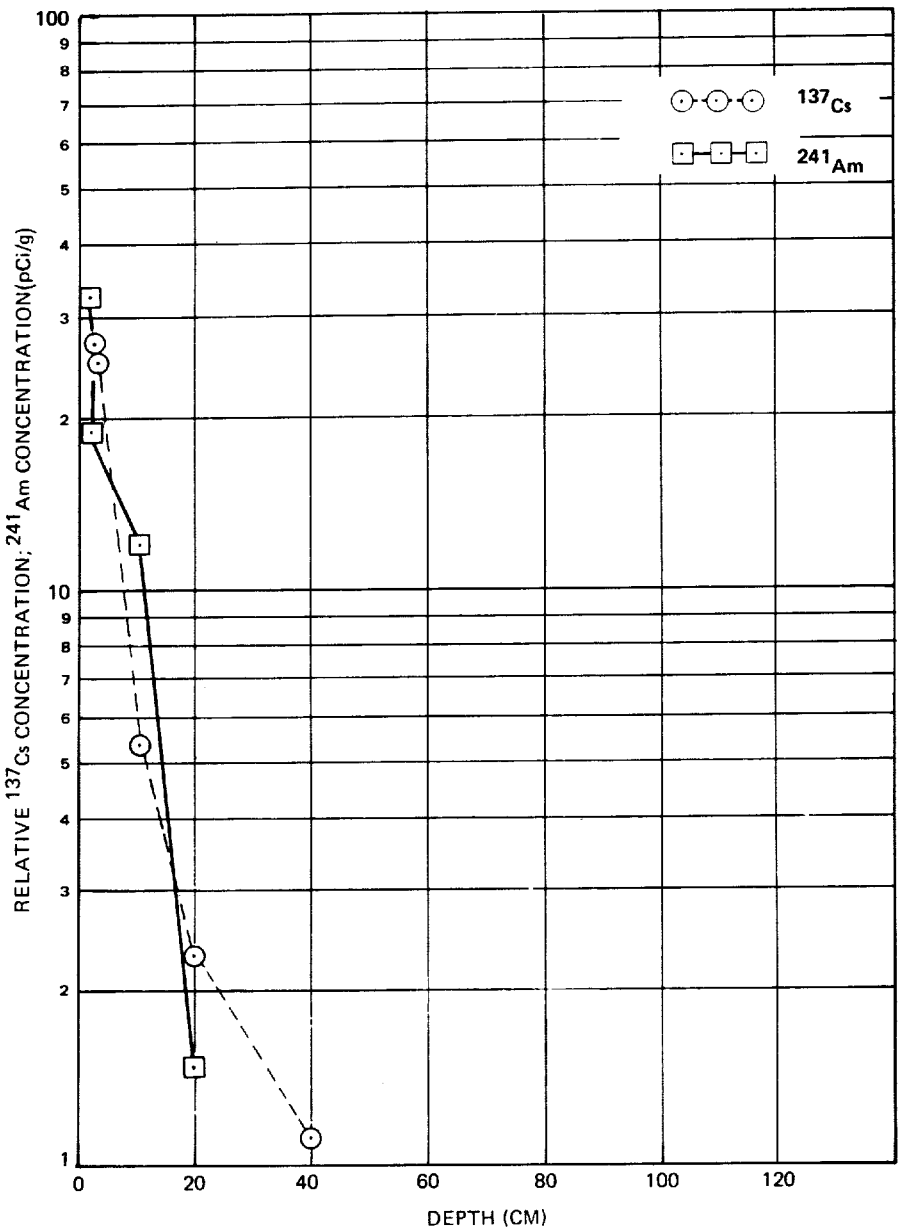


FIGURE B-9-3. CONCENTRATIONS OF ^{137}Cs AND ^{241}Am VERSUS DEPTH IN THE PLOW X-1 AREA OF ISLAND JANET.

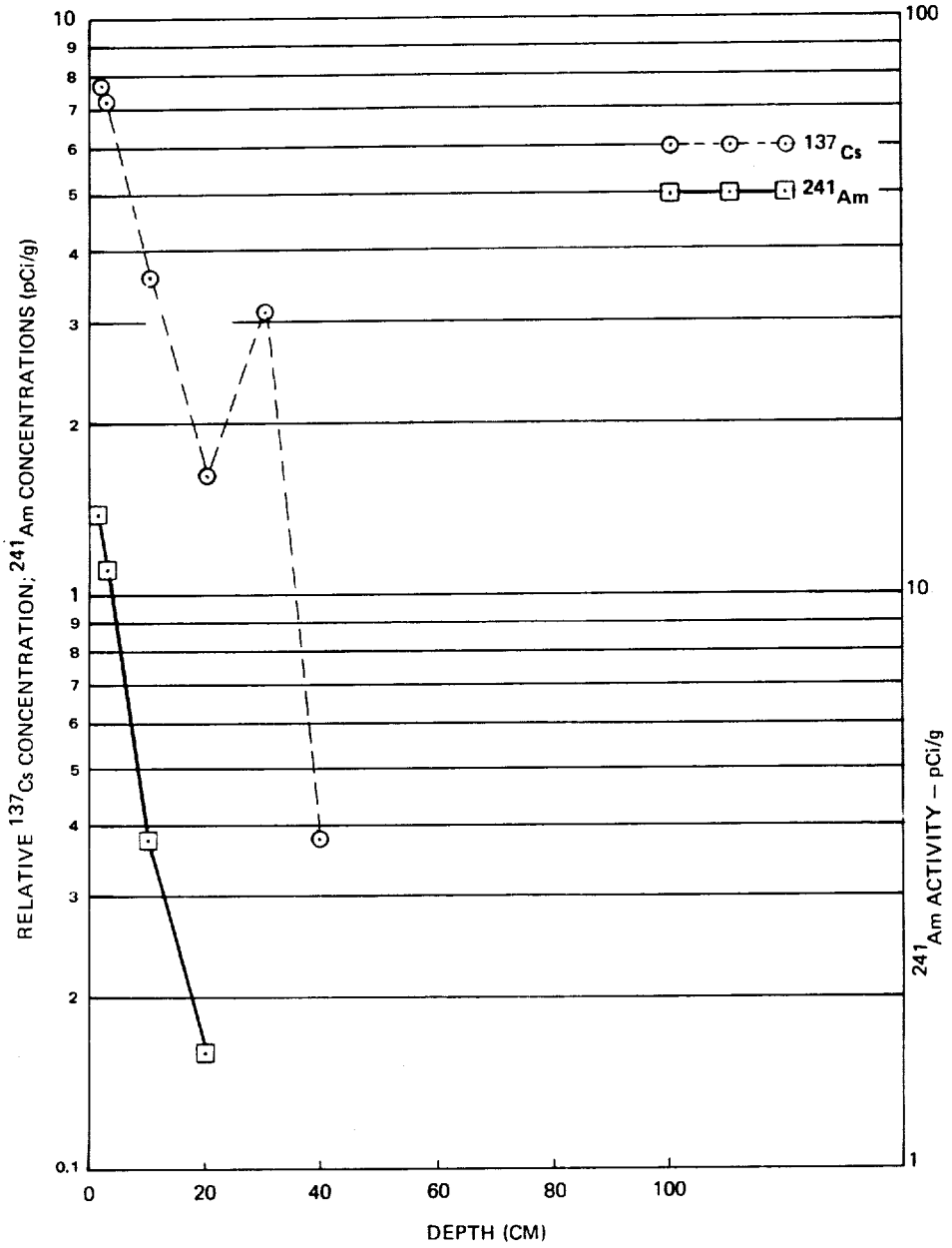


FIGURE B-9-4. CONCENTRATION OF ^{137}Cs AND ^{241}Am VERSUS DEPTH IN THE PLOW X-2 AREA OF ISLAND JANET

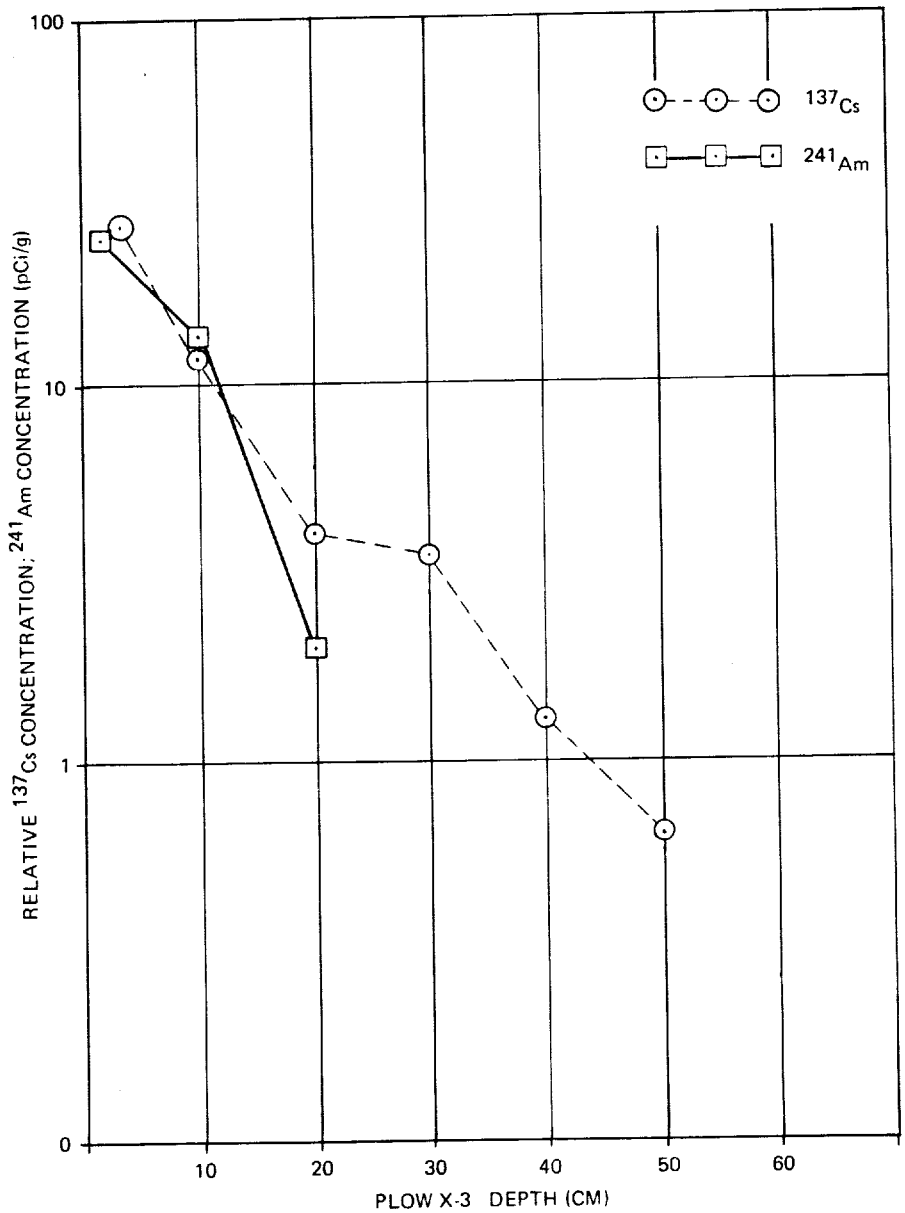


FIGURE B-9-5. CONCENTRATIONS OF ^{137}Cs AND ^{241}Am VERSUS DEPTH IN THE PLOW X–3 AREA OF ISLAND JANET

ANNEX A

PLOWING PLANNING MEETING

11 May 1978

Attendees: LTC Joseph Briggs - J3, JTG
LTC Edwin Dodd - J2, Rad Con., JTG
Major Maximilian Toch - J3, JTG
Paul Mudra - DOE/ERSP Manager
Bert Friesen - DOE/DRI Statistician
Robert Boland - DOE/ERSP Tech Advisor
Dale Denham - DOE/ERSP Tech Advisor

Purpose: To develop preliminary plans for testing the effectiveness of soil plowing on surface and subsurface contamination.

Assume: It is desirable to ascertain the effects of plowing soil known to have surface contamination only.

It is desirable to ascertain what the effects are of plowing when quantities of contamination are known to exist in the subsurface.

Tests should by performed in areas whose concentration levels most closely simulate areas expected to be considered for plowing.

It is desirable to perform tests on islands which are potentials for plowing so that test efforts can result in the most beneficial use of resources in bottom line considerations.

Consider islands of Sally and Janet first.

Proposed Test Area(s) Characteristics:

Minimum areal extent:

60 meters wide
110 meters long

IMP Stations:

8 ea. on 25 meter grid (full boom height).
21 ea. on 12.5 meter grid (1/2 boom height).

Surface Soil Sample Stations:

8 surface soil samples (composites A, B, C and D) to be taken at 25 meter IMP Stations.

Subsurface Soil Sample Stations:

8 subsurface backhoe sidewall sample stations with samples taken at 10 cm (3 cm samples) increments down to 100 cm.

Special Data Collection:

Other data such as soil pH, percent humus, etc., may need to be collected based on recommendations made by experts.

Side by side (or similar) plots need be established for each type of plow to be used for comparing results.

Other Considerations:

All test areas should be surveyed with mine (metal) detectors to assure removal of dangerous ordnance can be effected prior to plowing.

Scientific wells installed and operated by LLL on Janet should be surveyed in, marked and protected.

The LLL Janet farm is off-limits for plowing.

Janet trees and other plants identified by LLL should be protected.

PLOWING EXPERIMENT: ON-SITE REPORT*

DOE/ERSP TECH NOTE NO. 9.1 DATED: August 1978

AUTHORS: D. Denham, LLL
M. Barnes, DRI
T. Crites, LLL

Introduction

The purpose of the plowing experiment was stated in the 15 May TWX from FCDNA (Albuquerque) to U.S. DOE (Las Vegas) as follows: "To evaluate the effectiveness of plowing in dose reduction for food gathering, agricultural, and potential residence islands." A planning meeting was held at Enewetak (11 May 1978) to more fully define the JTG requirements of such an experiment. Three 50-m x 100-m areas were selected on the island of Janet as potential sites for the experiment (Figure B-9-1). These were chosen because they exhibited relatively uniform and significant surface contamination levels (30-70 pCi/g TRU) and were relatively free of major debris or vegetation. A detailed report on these areas was prepared as Tech Note 9.0, part of which is included in the following section.

Preliminary Work

1. Site Selection

a. Surface Measurements

Standard IMP survey measurements were made on a 25-m grid in each of the three plots considered. Results of this surface measurement of ^{241}Am are:

Plow X Plot	Average	Minimum	Maximum
1	20.8	14.7	30.6
2	8.8	6.5	11.2
3	14.6	11.7	18.2

Surface (2.5 cm) soil samples were collected on the A, B, C, and D composite plan (See Figure A-4-1) at each of the IMPed points (24 grid locations). Petri dish samples were made of these composites and screened with the IMP detector on Ursula. Average values of the IMP screening of those samples are:

Plow X Plot	241Am (pCi/g)
1	32.2
2	14.0
3	24.1

b. Profile Samples

To aid in site selection, soil profile samples were taken at each of the three plot locations. Holes were dug to a nominal depth of 120 to 140 cm at several points in each plot. Sidewall samples were taken with a standard tool (5 cm deep by 10 cm square) and IMP screened for ^{241}Am and ^{137}Cs content. The ^{241}Am results are plotted in Figure B-9-6. Soil profile observations are characterized in Figure B-9-2.

*A modified version of this note by the same authors was published in the April 1980 issue of Health Physics; "The Effect of Plowing on ^{241}Am Contamination in Sandy Soil," Health Physics 38, 699-703.

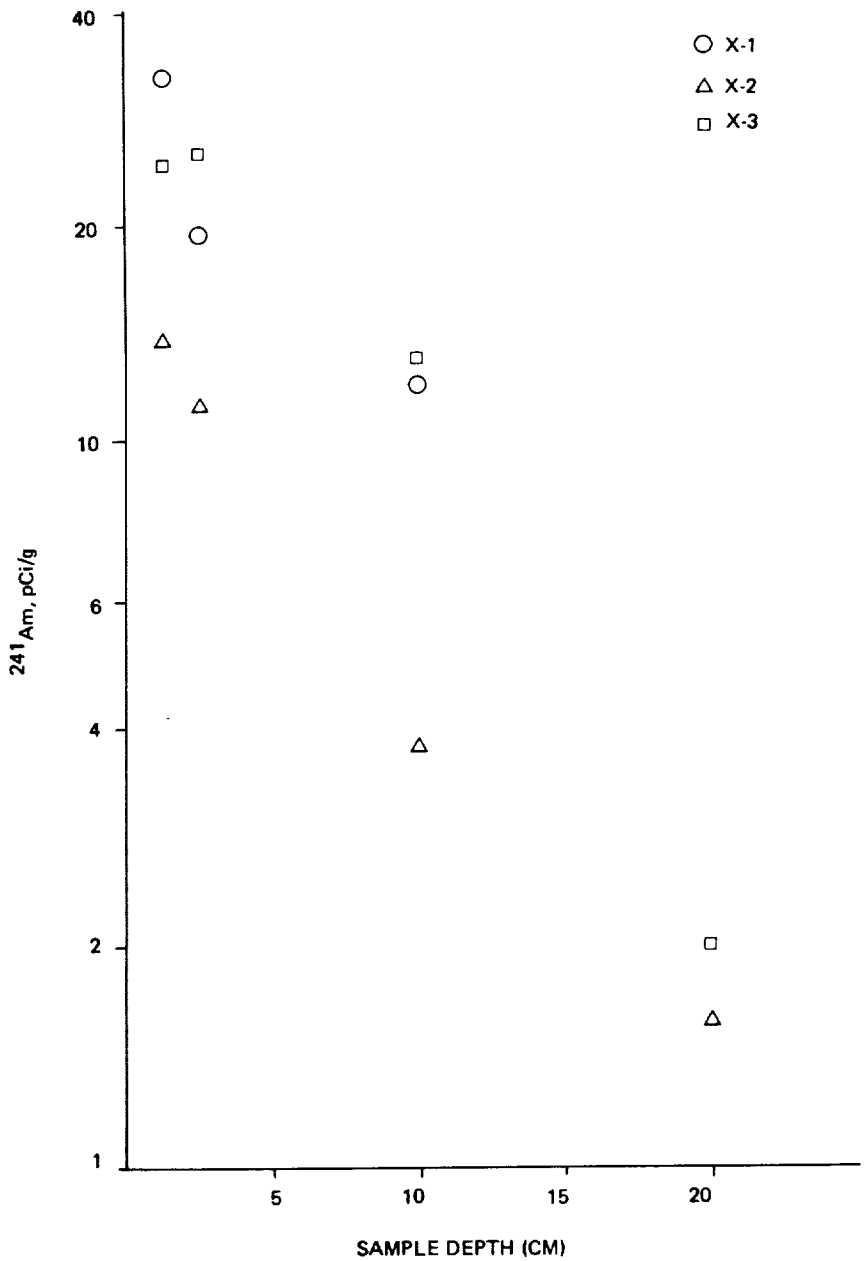


FIGURE B-9-6. AVERAGE SOIL CONCENTRATIONS OF ^{241}Am VS. DEPTH IN PROPOSED PLOWING EXPERIMENT AREAS

c. Ground Condition

The Plow X-1 plot is an area relatively clear of vegetation and debris and has not been heavily vegetated since the cleanup project began. Plots X-2 and X-3 were in areas which were windrowed in the fall of 1977 as part of the brush removal program prior to surveying or IMP measurements. Now, only ground cover type vegetation (grasses and morning glory vines) is present in those two areas. The Plow X-2 plot is near areas in which extensive blasting has taken place and may have been subjected to some shrapnel. The Plow X-3 area contains some surface asphalt and concrete.

2. Primary Site

a. Plot Plan

Consideration of the three sites led to the choice of Plow X-1 as the actual experiment area. The area contained eight IMP locations and was sectioned off in blocks as shown in Figure B-9-7. Results of two surface contamination measurement techniques are also given in this figure. The data values above each center point (grid location) were determined by IMPing; those below the point are the average of four surface soil sample composites.

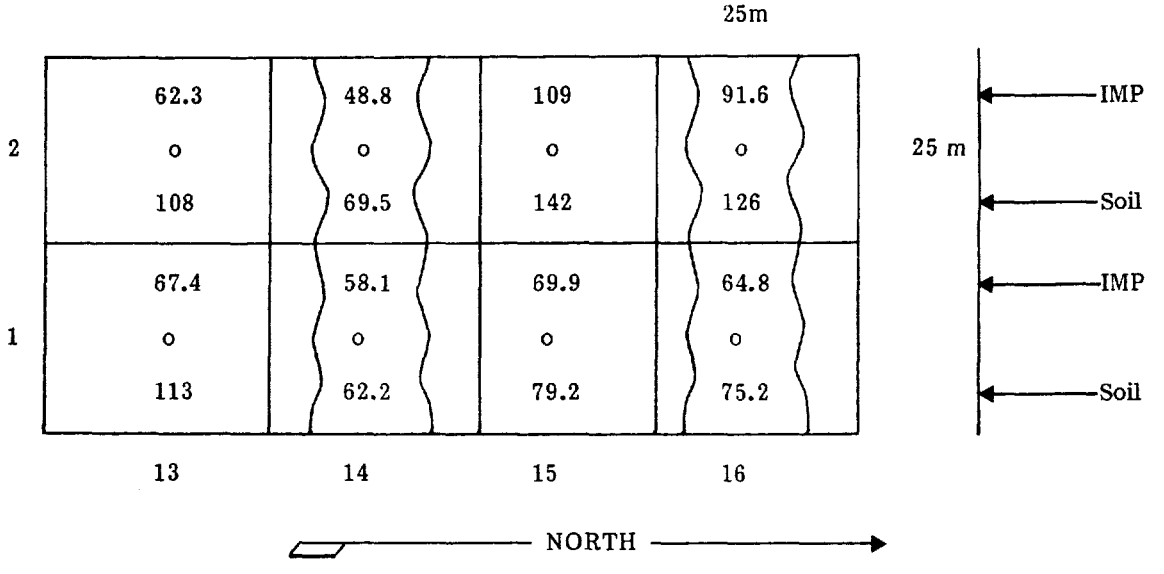


FIGURE B-9-7. Plow X-1 Plot Plan Showing Average TRU Concentrations From IMP and Surface Soil, pCi/g

Grid point designations are also shown at the edge of the plot, giving the 25 m survey locations. The two regions which were later plowed are indicated by wavy lines in rows 14 and 16.

b. Radioactivity Profile Characterization

An extensive sampling program was employed to define the radioactivity profile in the Plow X-1 plot. Figure B-9-8 shows the sampling array with the different sample types coded on the plot. Again, the wavy lines indicate those blocks which were plowed.

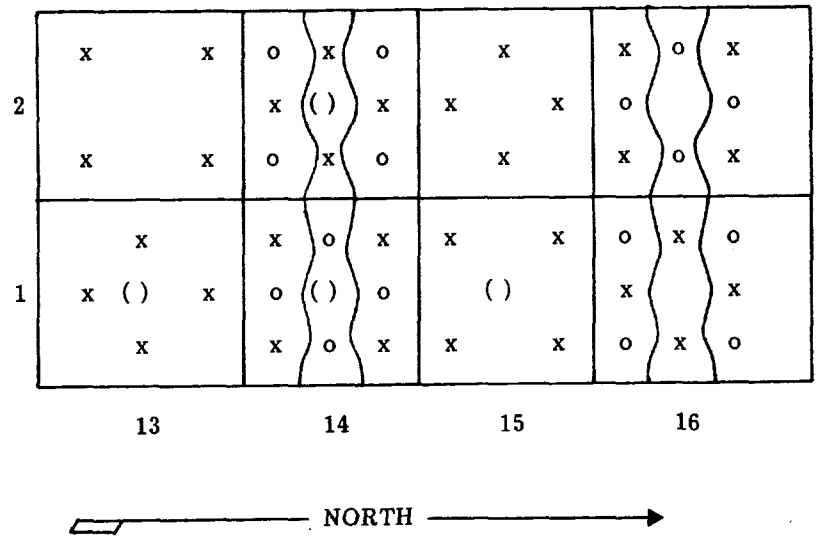


FIGURE B-9-8. Plow X-1 Soil Sampling Locations

Locations denoted "( )" were deep (about 120 cm) sample holes made prior to site selection to characterize the soil down to coral bedrock or water. The "x" locations were profile sampled to 50 cm before plowing to better define the radioactivity profile over the plow experiment area in the region in which mixing was expected to occur due to plowing. Those positions designated "o" were sampled to 50 cm depth after plowing for evaluation of the plowing effects. Tables B-9-1 and -2 summarize the results of IMP screening the pre-plow profile samples.

Only the ^{241}Am (pCi/g) results are given in each case. Samples were taken with the standard 5 cm thick sidewall sampling tool. Sample depth designates the centerline of the sample point unless a spread is denoted (i.e., 5 to 10) in which case these are the sample boundaries. Sample locations are keyed to the grid coordinates shown in Figure B-9-8. For example: 1-13 is the center "( )" of the lower lefthand corner block of Figure B-9-8 and 2.25-16.25 is the "x" in the upper righthand corner block of Figure B-9-8.

A plot of the average ^{241}Am activity versus sample depth, for the four blocks plowed, is given in Figure B-9-9.

Plowing Experience

1. Site Preparation

One of the first tasks involved was to fill in those holes dug for soil profile sampling by the backhoe. Once these were smoothed, the area was carefully staked and the control plots were roped off. Miscellaneous debris were dragged from the site and brush was generally cleared out. Though vegetation cover in this area was relatively light, a front-end loader was used to remove most of it. A concrete block about 0.5 m cube was found buried just below the surface in the corner of block 2-14. This was removed with a front-end loader prior to starting plowing. "Control" areas were cleared to a lesser extent than planned plow areas.

2. Problems Encountered/Challenges Met

The inability of the hydraulic ram to raise and lower the plow required that a front-end loader stand by to put the point in the ground and lift it out. This inconvenience resulted in plowing around the plot, through each section, without taking the plow out of the ground. Much brush

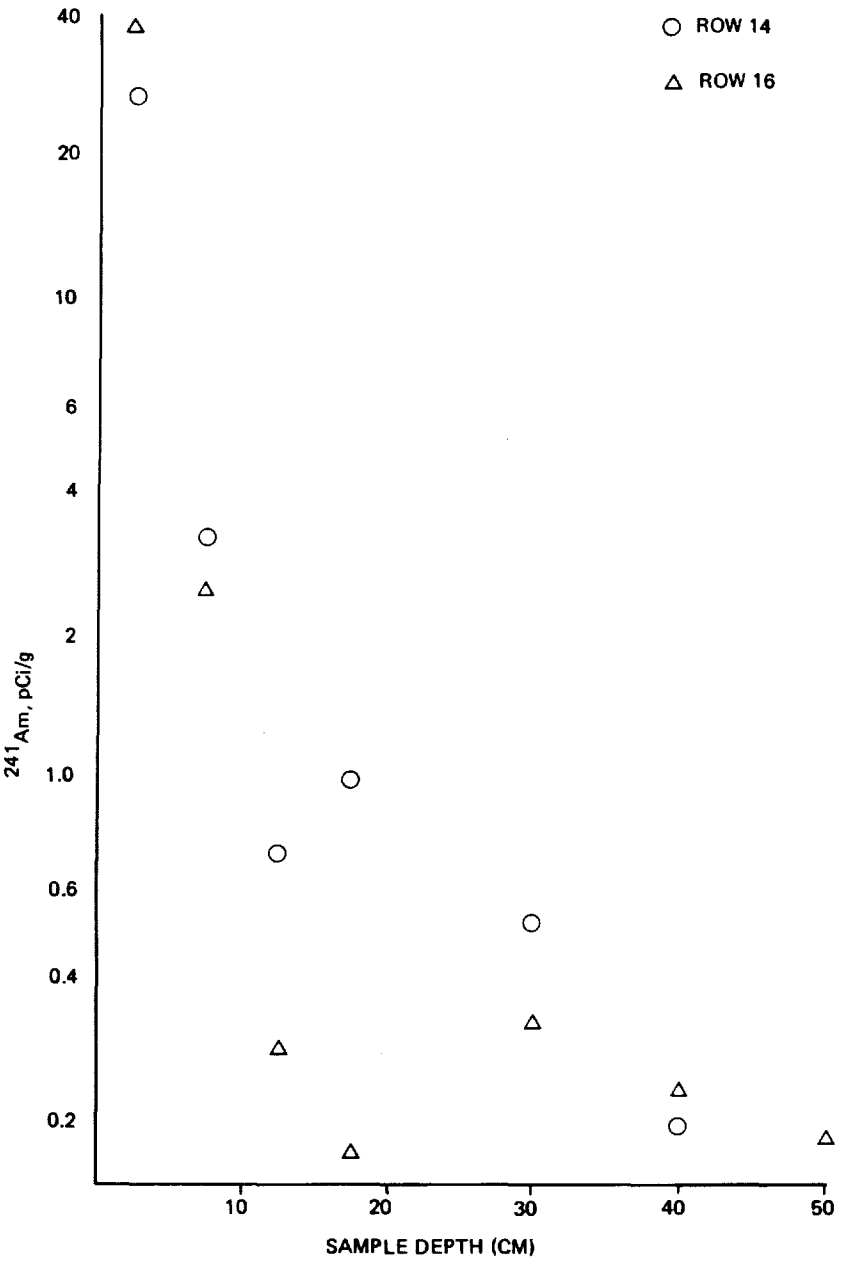


FIGURE B-9-9. AVERAGE SOIL CONCENTRATIONS OF ^{241}Am VS. DEPTH IN X-1 AREA BEFORE PLOWING

and dead branches were encountered in these turning areas. This material so fouled the plow and interfered with its ability to turn the soil that it was necessary to stop frequently and clear the plow by hand. A bulldozer was used to blade off this area and work then proceeded much more smoothly.

The bulldozer operator experienced some initial difficulty in properly overlapping the furrows and in aligning the cuts to the track. By the second day, however, this was well worked out and plowing progressed much better. Occasionally old cable was turned up. This would hang in the plow and eventually required clearing. Clearing the plow of debris required lifting it out of the ground with a front-end loader and was done outside of the measurement plots in each case.

Actual plowing time for the two sections (1/4 hectare) was 1-1/2 hours. The plow was pulled to its full depth (about 50 cm) at a rate of approximately 67 m/min. This was accomplished without difficulty despite occasional uprooting of large pieces of coral. Turning at each end slowed progress somewhat.

3. Ground Preparation Post-Plowing

Plowing left the ground very rough. The hills and valleys of the furrows were such as to preclude moving the IMP in for measurements and would have made profile soil sampling questionable (the surface varied by up to 20 cm). To facilitate measurements, the plowed areas were backbladed with a bulldozer and then tracked over several times to smooth and compact the surface. A couple of rains followed before measurements could be initiated, leaving a firm soil which was easily sampled. As drying occurred, the surface became quite dusty.

Results

1. IMP Survey

An IMP survey of the plowed blocks showed considerable reduction in surface contamination. Re-survey of the "control" (unplowed) blocks on the same date showed no significant change from earlier measurements. Figure B-9-10 shows the numerical results of the IMP estimate of total transuranics (TRU), based on ^{241}Am measurements, both before and after plowing. Further discussion of these results is given in the "Statistical Analysis" below.

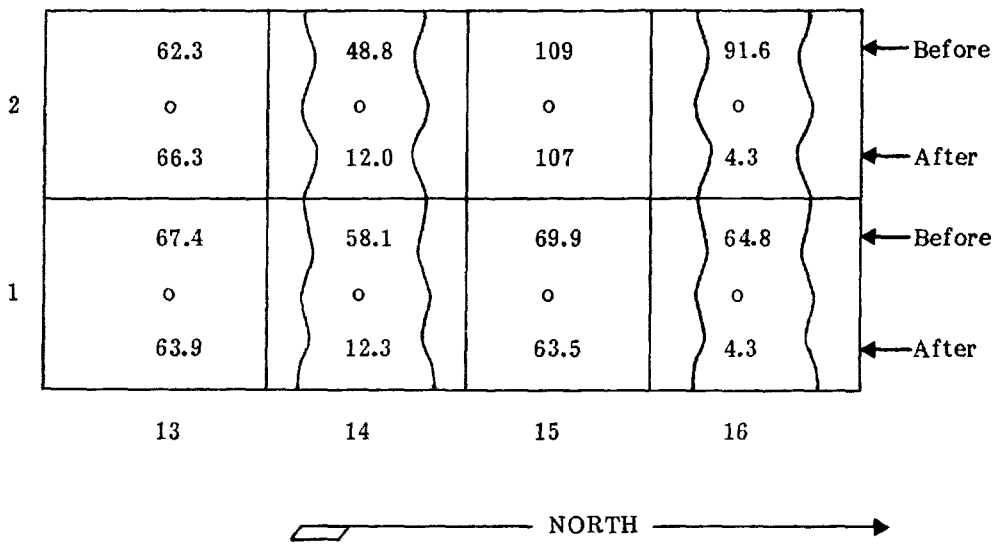


Figure B-9-10. Comparison of IMP TRU Surface Concentrations Before and After Plowing, pCi/g

2. Soil Profile

a. Physical Appearance

The surface of the plowed blocks appeared of uniform texture and color following the smoothing operation and rain which occurred between plowing and sampling. The backhoe had no difficulty in making holes which retained vertical structure in this region. The soil appeared to be reasonably well-mixed, though occasional darker (organic) patches or layers could be seen running through lighter coral regions. Such layers occurred from 5 to 40 cm in the "16" blocks, but were less noticeable in the "14" blocks, which appeared well-mixed down to the coral area at 40 cm.

b. Radionuclide Distribution

Results of profile sampling are presented in Table B-9-3 and average values are graphed in Figure B-9-11.

3. Statistical Analysis

The plow experiment area consisted of eight stake locations laid out in a 2 x 4 rectangle at 25 m spacing. Before plowing the surface TRU values (from IMP readings) at these locations ranged from 48.8 to 109 pCi/g, with a mean of 71.5 pCi/g. After plowing the TRU surface values ranged from 12.3 to 4.3 pCi/g, with a mean of 8.2 pCi/g. It was decided that half the area would remain unplowed so that the necessary "control" areas could be available for possible future plant uptake studies. These control plots were irrelevant in analyzing the effect of plowing on redistributing radionuclides in the soil. Each plowed location served as both untreated (before plowing) and treated (after plowing) observations for statistical purposes.

Practical limitations on the plowing technique coupled with mechanical difficulties in the plow precluded application of standard randomization methods. As a compromise, the plot was divided into four sets of 2 x 1 rectangles, each containing either two unplowed blocks or two plowed blocks. It was also known from previous experience that adjacent strips should not be treated the same, so that only two possible configurations (first plot plow or first plot control) were available. One of these was chosen at random, resulting in the experimental configuration shown in Figures B-9-7, -8 and -10.

There were two primary aspects of interest in the experiment: the effect of plowing on surface TRU contamination, and the possibility that plowing alters the distribution of TRU contamination in the soil profile. IMP surveys at the eight stake locations before and after plowing measured the first effect, and a series of backhoe profile soil samples taken before and after measured the second.

Pre-plowing samples were taken in all eight blocks, but post-plowing samples only in the plowed blocks. The post-samples were taken in different locations from the original samples to avoid confounding plow effects with backhoe effects. Profile samples were taken at seven depths (0 to 5 cm, 5 to 10 cm, 15 to 20 cm, 30 cm, 40 cm, 50 cm) in each of four backhoe holes in each treatment block. This resulted in a total of 32 profile sets pre-plowing and 16 sets post-plowing.

During site preparation operations, the surface soil was disturbed in some areas. Some similar operations would be necessary in any field plowing application, so this disturbance was considered an integral part of the plowing treatment for statistical purposes.

4. Results of Statistical Analysis

The surface changes, as measured by the IMP, were analyzed with a two-way analysis of variance (ANOVA). The experiment was handled as a randomized block design with two treatments (before and after plowing) on each of four blocks. The ANOVA results are shown in Table B-9-4.

The F value of 27.22 is significant at the 97.5% confidence level. The mean TRU concentration in the plowed blocks was 62.8 pCi/g before plowing and 8.2 pCi/g after plowing, an 87% reduction.

A comparison of the original with the repeat IMP readings on the unplowed blocks shows that the treated blocks may legitimately be used as self-controls. The original TRU concentrations averaged 77.2 pCi/g, and the repeat values averaged 75.2 pCi/g. This is well within the measurement error of the IMP detector, and shows that the untreated concentrations did not change between the measurements.

To test whether the pattern of contamination in the soil was altered by plowing, a multivariate analysis of variance was performed on the soil profile data. The null hypothesis was that the vector of mean concentrations by depth was not changed by plowing, and the alternative was that the vector of means was significantly altered. The maximum likelihood estimator was used, yielding a chi-square (seven degrees of freedom) statistic of 16.7. The null hypothesis can be rejected at the 97.5% confidence level; i.e., plowing did significantly alter the vector of mean concentrations.

The last part of the statistical analysis was an attempt to describe the after-plowing distribution mathematically. If the plow mixed the soil, and hence the contamination, the concentrations would be fairly uniform with depth. To check this, a linear regression of mean ^{241}Am concentration as a function of depth was performed for each of the four plowed blocks. The slopes of the lines were then tested for significant deviations from zero. The null hypothesis was that the slope was zero; i.e., there was no gradient with depth. The results are:

Plot No.	Equation of Line	Test of $H_0:B_1 = 0$ vs. $H_1:B_1 \neq 0$
1	$Y = 3.6 - 0.06X$	Accept H_0 at 90%
2	$Y = 0.7 + 0.007X$	Accept H_0 at 80%
3	$Y = 0.89 + 0.03X$	Accept H_0 at 80%
4	$Y = 0.47 + 0.02X$	Accept H_0 at 80%

In all four cases, the slope did not significantly differ from zero, so that some mixing apparently did take place.

However, in each block there were at least two subsurface observations of concentrations much higher than the bulk of the depth samples. This indicates that some of the surface contamination is deposited by the plow at depth without being mixed. Of the ten such "hot" spots, two were near the surface (0 to 10 cm), two were at 10 to 15 cm, and the remainder were 30 cm or deeper. The TRU concentrations in the 10 spots ranged from 25% to 100% of the original (before-plowing) TRU from IMP value, with a median of 35%. There was a weak trend of less contamination (as percent of original) being deposited with increasing depth for the "hot" spots. Other than these "hot" spots, observed TRU values rarely exceeded 6.6 pCi/g, regardless of the original surface concentration.

Conclusions

The plowing experiment has clearly demonstrated that surface contamination can be reduced substantially by plowing in Enewetak-type conditions. The multivariate analysis confirmed that the distribution of contamination across the entire profile is altered significantly. Contamination is mixed throughout the plowed profile; however, some proportion is deposited at depth with little mixing. In mixed areas, the contamination is highly diluted, regardless of the original concentration. "Hot" spots are inevitable and can be expected to result in concentrations of 25-50% of the original surface levels. These "hot" spots were observed to occur at all depths sampled, but most were observed at 30 cm or deeper.

This portion of the plowing experiment has addressed only the location of radioactive contamination as measured by ^{241}Am. Inferences may be drawn as to the reduction in surface dose rate and resuspension potential from this work. Changes in plant uptake of radioactive material due to changes in radioactivity profile, risk due to future possible earthmoving operations in the area, and the political question of dilution vs. removal of radioactive contamination have not been addressed.

TABLE B-9-1. SOIL CONCENTRATION OF ^{241}Am (pCi/g) BASED ON IMP SCREENING — DEEP SAMPLE PROFILES

Sample Depth (cm)	Sample Location (NW) 1-13	1-14	2-14	1-15
Surface	-	44.9	9.1	8.9
10	-	-	0.4	0.6
20	0	-	-	0.1
30	-	-	0.2	0
40	0.4	1.1	0	0
50	-	0	0.9	0.4
60	0	0.5	0	0
70	-	0.6	0.3	0
80	0	0.4	0.2	0.3
90	-	0	0	0
100	0	0.5	0.5	0.3
110	-	0	0.1	0.6
120	-	0.4	0	0

Dashes in the table indicate no sample at that location and depth.

TABLE B-9-2. SOIL CONCENTRATION OF ^{241}Am (pCi/g) BASED ON IMP SCREENING — CHARACTERIZATION PROFILES

	Sample Depth (cm)						
Sample Location (NW)	0-5	5-10	10-15	15-20	30	40	50
0.75-13	22.3	5.6	1.0	2.8	0.7	0.4	0.1
1-12.75	16.6	2.0	1.1	1.8	1.2	0	0
1-13.25	55.7	1.7	1.4	0.6	0	0.5	0
1.25-13	3.6	0.2	0.2	0	0.1	0	0
1.75-12.75	141.3	3.3	0	1.0	0.5	0.5	0.1
1.75-13.25	17.9	6.0	0.3	0	0.5	0.7	0
2.25-12.75	28.0	42.2	33.7	80.4	1.0	0.3	0.1
2.25-13.25	28.7	4.4	1.9	0.7	1.0	0	0.4
0.75-13.75	15.2	2.1	2.2	0.7	0.8	0	0
0.75-14.25	1.4	0.7	0.1	0.7	0.9	0	0
1.25-13.75	6.4	0.7	0	1.1	0.9	0.3	0
1.25-14.25	4.8	1.9	2.6	0	0.2	0.4	0
1.75-14	76.0	0.5	0	0.4	0	0.5	0
2-13.75	7.7	0.8	0	0	0.3	0.3	0
2-14.25	88.3	17.1	0.5	5.4	0.4	0	0
2.25-14	14.1	2.4	0.4	0	0.7	0.1	0
0.75-14.75	0.9	0.1	0.5	0.3	0.3	0.3	0.3
0.75-15.25	28.9	1.3	0.1	0.6	0	0	1.0
1.25-14.75	21.0	0.9	0	0.8	0.2	0.7	1.0
1.25-15.25	0	0	0	0	0.1	0	0.4
1.75-15	71.0	6.5	0.9	1.0	0.8	0	0.3
2-14.75	7.6	0.3	0.3	0.6	1.0	0.2	0
2-15.25	250.5	0.7	0	0	0	0.4	0.6
2.75-15	37.6	0.4	0.2	0.2	0.1	0.1	0
0.75-16	0	0.9	0	0	1.0	0	0
1-15.75	235.2	3.0	0	0.2	0	1.0	0.5
1-16.25	0.7	0.3	0.4	0	0.3	0	0
1.25-16	22.1	2.1	0	0	0.2	0	0.1
1.75-15.75	27.0	0.8	0.3	0.3	0.4	0	0
1.75-16.25	0.3	0.3	0.3	0	0.4	0.4	0.5
2.25-15.75	15.2	0	0.6	0.5	0.1	0	0.4
2.25-16.25	25.7	12.9	0.7	0.4	0.2	0.5	0

TABLE B-9-3. SOIL CONCENTRATION OF 241Am (pCi/g) BASED ON IMP SCREENING -- POST-PLOW SOIL PROFILES

	Sample Depth (cm)						
Sample Location (NW)	0-5	5-10	10-15	15-20	30	40	50
0.75-14	1.1	0.5	5.4	0	0.7	0.3	1.0
1-13.75	0.6	0.9	0.7	0.5	0.2	4.8	3.2
1-14.25	0	0	0.9	0	0	0.3	0.8
1.25-14	2.5	0	0.4	0	0	0.2	0
1.75-13.75	9.0	13.1	14.7	1.9	1.2	0	0.2
1.75-14.25	0.6	1.2	0	0.8	12.0	1.4	0.1
2.25-13.75	0.1	0.1	2.7	0	0	0	0.5
2.25-14.25	0	0.5	0	0	1.7	1.3	0.3
0.75-15.75	0.9	0.6	0.2	0	7.2	0.9	1.1
0.75-16.25	1.8	0.6	0	0	0.1	0	0
1.25-15.75	0.1	0	0.4	0	0.3	1.5	4.8
1.25-16.25	1.7	0	0.2	2.6	0.3	0.5	0.8
1.75-16	2.6	3.8	0	1.7	1.1	1.4	9.0
2-15.75	0.7	0.5	0	1.9	15.0	0	0.3
2-16.25	0.4	0	0	0.8	0.1	0.3	0
2.25-16	0.7	0.8	0.5	0.3	0.6	0.2	0

Comparison of these profile values with those in Table B-9-2 reveals an obvious change in radionuclide distribution. This change is examined in greater detail by statistical analysis.

TABLE B-9-4. ANALYSIS OF VARIANCE, TRU (FROM IMP) BEFORE AND AFTER PLOWING

Source	Degrees of Freedom	Sum of Squares	Mean Square	F
Total	7	7712.115		
Blocks	3	345.405	115.135	
Treatments	1	6635.52	6635.52	27.22
Residual	3	731.19	243.73	

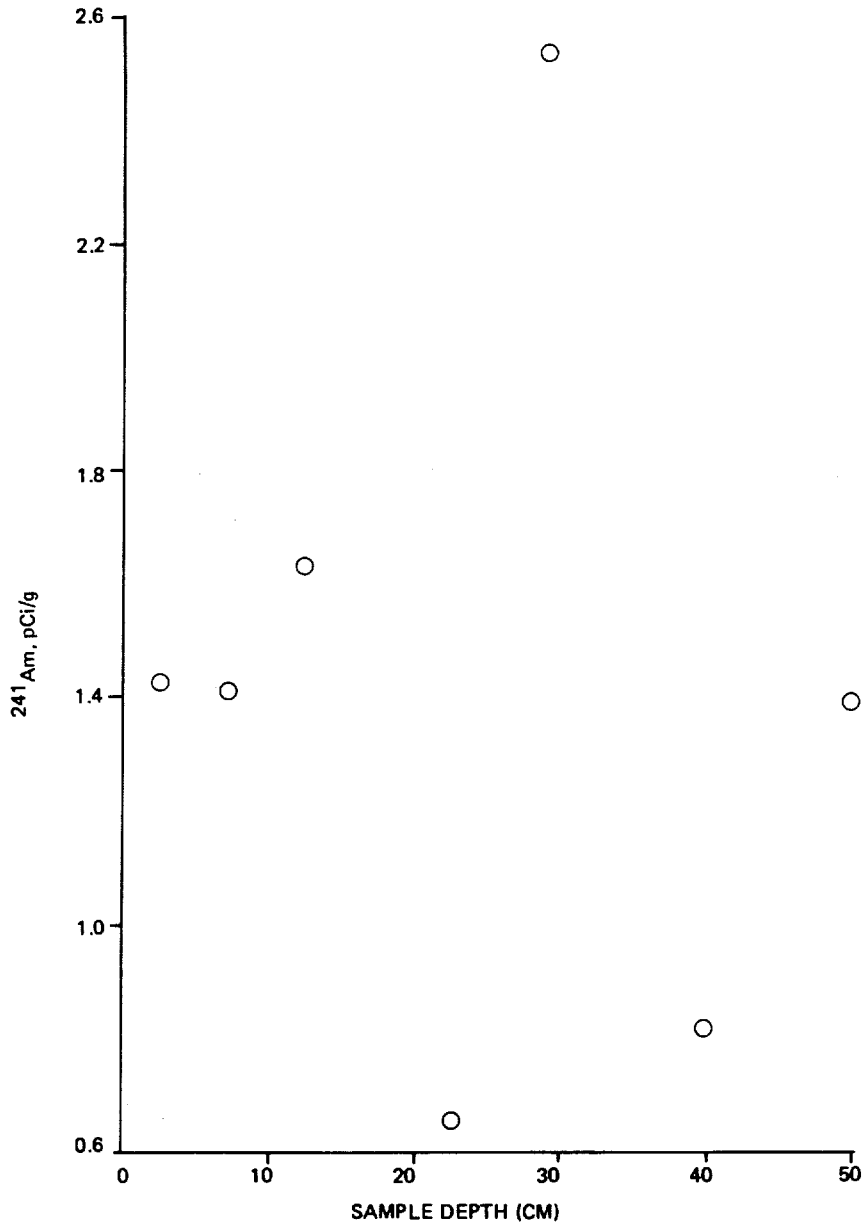


FIGURE B-9-11. AVERAGE SOIL CONCENTRATIONS OF ^{241}Am VS. DEPTH IN ROWS 14 AND 16 OF X-1 AREA AFTER PLOWING

COMPUTATION OF TOTAL TRU ACTIVITY EXCISED IN THE

KICKAPOO AREA OF SALLY

DOE/ERSP TECH NOTE NO. 10.0 DATED: 28 July 1978

AUTHOR: M. Barnes, DRI

Two different computations of total TRU activity (in curies) removed from Kickapoo were made. One was based on soil samples taken from each individual truckload of soil which were gamma-scanned for ^{241}Am activity. The other was based on IMP readings on the surface, taken before, during, and after the excision process. Both estimates required knowledge of certain information from outside sources; unfortunately, the information was not always consistent or accurate. Therefore, this note will explain in detail only the methods and mathematics used in deriving the estimates.

The actual estimates will be shown for each of the various sets of information from outside sources, since ERSP is not in a position to judge the validity of such information.

Estimates Using Truck Soil Samples

Each truck was soil sampled using one or both of two different methods. Originally, three samples were taken from the top of each truck after loading and composited to form "top" samples. This method has obvious statistical drawbacks, including being biased high as an estimate of the truck average. Later, a sample was taken from each scoop going into the trucks, and the samples from all scoops for each truckload were composited to form "mixed" samples. This method, while not as biased as the original one, still is biased high. Bias is present in both methods due to the fact that the dispersion variance* of soil samples within a truck increases with average concentration. Thus high values should be, but are not, given less weight in estimating the average concentration in a truck. (No data are available to compute the proper weights.)

The two methods were compared for the thirty truckloads for which both types of samples were taken. The mean of the top samples was 31.7 pCi/g TRU, with a sample standard deviation of 29.8. The mixed samples had similar results, with a mean of 25.8 pCi/g TRU and sample standard deviation of 32.3. However, 20 of the 30 pairs had a higher top sample value than mixed sample value. A sign test was performed to test the hypothesis that the two types of samples came from distributions having the same median. This hypothesis can be rejected at the 95% confidence level, i.e., the median of the top sample distribution is significantly higher than the mixed sample median.

Therefore, following this comparison experiment, all samples taken were of the mixed type.

Estimates of total activity were made by multiplying the cubic yards held by a truck by the concentration in each sample from that truck and summing the cubic yards for total volume and the products for total activity. Mixed sample results were used whenever available. Truck sizes (by truck number, which was the soil sample identifier) were obtained from S-3, 84th Engineer Battalion. The nominal cubic yardages for each truck size were also provided by S-3, 84th Engineers, but two different values were given at different times, as follows:

Date of Yardage Information	Nominal Cubic Yards Per Truck			Total Volume	Total Curies
	5 Ton	10 Ton	20 Ton		
17 July 1978	3	5	12	5500 cu. yds.	0.95
22 July 1978	3	5	10	4500 cu. yds.	0.77

The truck sample data were ^{241}Am by gamma scan, and a fixed ratio of 6.16 was used to convert to TRU concentrations.

*Dispersion variance of soil samples within a truck defined as the variance of the distribution of concentration values from every possible soil sample within each truck.

Estimates Using IMP Survey Results

The IMP survey results were used to make computations of total activity removed by fitting a function to the gradient of concentration with depth. The function was integrated to find the average concentration in the soil removed, and that value was multiplied by the total volume excised and a constant which converted pCi/g to Ci/yd^3 to compute the total activity removed.

Two types of functions were considered, linear and exponential. Combinations of these were also considered. It was necessary only to know the form of the function, since that determines the form of the integral. The form of the function was determined from the gradient in backhoe profile soil samples, then the integration computations were performed on the IMP values.

The soil gradient in areas without substantial subsurface contamination is clearly of a different form than the gradient in areas with such contamination. Therefore, the functions were fit separately to the soil data from the two pockets of subsurface contamination, and to data from the remainder of Kickapoo. Figures B-10-1 and B-10-2 are graphs of the soil data from the east side pocket of subsurface contamination and from the vicinity of the pandanus tree, respectively. Figure B-10-3 shows the soil data from the remainder of the Kickapoo area. Figure B-10-4 is a map showing the relative locations of these three areas.

The gradient in Figure B-10-3 is clearly exponential in form. Figure B-10-1 shows a rise in concentration from the surface to 20 cm, then an exponential falloff below 20 cm. There was insufficient data to model the rise with anything other than a linear function, so the chosen function was linear to 20 cm (assumed equivalent to after 1 lift), then exponential below 20 cm. There was also not sufficient data to adequately fit the Figure B-10-2 gradient, so the same assumptions, i.e., linear from surface to 20 cm, exponential below 20 cm, were made for the subsurface pocket near the pandanus tree.

Mathematical Computations

Under the assumption of an exponential gradient, the function is of the form ke^{-cx}, where k is the average concentration before excision, x is depth in cm, and c is a constant. Then the average after excision is ke^{-cd}, where d is the total depth of the excision. Then the average concentration is

$$k \cdot \frac{1}{d} \int_0^d e^{-cx}\, dx = k \cdot \frac{1}{cd}\left(1 - e^{-cd}\right).$$

k is averaged from the IMP readings before excision. Let k_1 be the average from the IMP readings after excision. Then,

$$\frac{k_1}{k} = e^{-cd}$$

so $$cd = -\ln\left(\frac{k_1}{k}\right).$$

Then the average concentration is

$$k \cdot \frac{1}{-\ln\left(\frac{k_1}{k}\right)}\left(1 - \frac{k_1}{k}\right).$$

For the linear case the average concentration is simply $(1/2)(k + k_1)$. Note that it is not necessary to compute either c or d. However, the assumption is made in both models that d is constant for the area the IMP readings are averaged over.

Results

Outside the subsurface deposits, the average TRU concentration before any excision was 131 pCi/g, and after all lifts the average was 31.8 pCi/g. Therefore,

$$k = 131$$
$$k_1 = 31.8$$
$$e^{-cd} = \frac{31.8}{131} = 0.2427$$
$$cd = \ln(0.2427) = 1.4158$$
$$\frac{1}{cd} = 0.7063$$

and the average concentration in soil removed was

$$131 \times 0.7063(1 - 0.2427) = 70.1 \text{ pCi/g}.$$

Then the total activity removed is

$$70.1 \text{ pCi/g} \times \text{cubic yards excised} \times 1.185\ 10^{-6}(\text{Ci/yd}^3)(\text{pCi/g}).$$

In the areas with subsurface contamination, the assumption was made that the total soil depth lifted was approximately 50 cm. The top 20 cm, or 0.4 of the total volume for these areas, was soil having a linear gradient, and the remaining 30 cm (0.6 of the total) was soil with an exponential gradient.

Thus, for the top 20 cm, the before-excision average was 203 pCi/g TRU, and the after-excision (one lift only) value was 194 pCi/g TRU. So the average for the top 20 cm was

$$0.5(203 + 194) = 198.5 \text{ pCi/g}.$$

For the remaining soil the "before" excision value is the value after one lift, 194 pCi/g, and the average after all excision was 85.4 pCi/g. Then, for the remaining 30 cm,

$$k = 194$$
$$k_1 = 85.4$$
$$\frac{k_1}{k} = 0.4402$$
$$\frac{1}{cd} = 1.2187$$

and the average was

$$194 \times 1.2187(1 - 0.4402) = 132.4 \text{ pCi/g}.$$

The average concentration for the entire profile was therefore

$$0.4(198.5) + 0.6(132.4) = 158.8 \text{ pCi/g TRU}.$$

Then the total activity removed from these areas was

$$158.8 \times \text{total volume removed from these areas} \times 1.185 \times 10^{-6}.$$

The total activity removed from Kickapoo is the sum of the activity removed from the "without subsurface contamination" and "with subsurface contamination" areas.

DOE received several different estimates of the total volume of soil removed from Kickapoo. The results for each of these estimates using mixed linear and exponential assumptions are:

Date & Source of Total Volume Estimate	Estimate of Total Volume	Volume Distribution: Areas with Subsurface Contamination	Volume Distribution: Areas without Subsurface Contamination	Total Activity Removed
		cu. yd.	cu. yd.	Ci
7 July 78, J3	4000	1175	2825	0.45
22 July 78, B Co 84th Engr	4400	1290	3110	0.50
22 July 78, FRST-truck sample sheets	4500	1320	3180	0.51

In order to check how much effect the models chosen have on the estimates of total activity removed, the estimates were repeated assuming only linear gradients. That is, the average for areas without subsurface contamination was computed as

$$0.5(131 + 31.8) = 81.4 \text{ pCi/g TRU.}$$

In areas with subsurface contamination, the assumption was that the gradient was linear with a positive slope of 20 cm and linear with a negative slope below 20 cm. The average concentration would then be

$$0.4\ [0.5(203 + 194)] + 0.6\ [0.5(194 + 85.4)]$$
$$= 0.4\ (198.5) + 0.6\ (139.7) = 163.2 \text{ pCi/g TRU.}$$

The computed activity removed for the various volume estimates under the all-linear assumption is:

Estimated Total Volume	Total Activity Removed
4000 cu. yds.	0.50 Ci
4400 cu. yds.	0.55 Ci
4500 cu. yds.	0.56 Ci

The differences between the models are far less than the difference between the two methods (IMP versus truck samples). The IMP method is preferable for a number of reasons:

1. The truck samples are biased high.
2. Truck volumes are difficult to estimate accurately, and are not likely to be consistent.
3. IMP readings average over a large area, thus taking a larger sample of the population.
4. IMP readings are unbiased and have much lower variance than soil samples.
5. Total activity computations are fairly insensitive to errors in fitting a function to the soil gradient.

Therefore, the values derived by the mixed linear and exponential models are to be considered the most reliable, and the IMP sampling data is preferable for future computations of total activity removed.

(Editor's Note: Following thorough reappraisal of various measurement parameters (cf. Tech Note 23) the final estimates of TRU activity in soil removed from Island Sally are: Kickapoo, 0.85 Ci; Yuma 0.28 Ci; Hustead, 0.16 Ci; Aomon Crypt, 0.93 Ci; Island Total, 2.22 Ci).

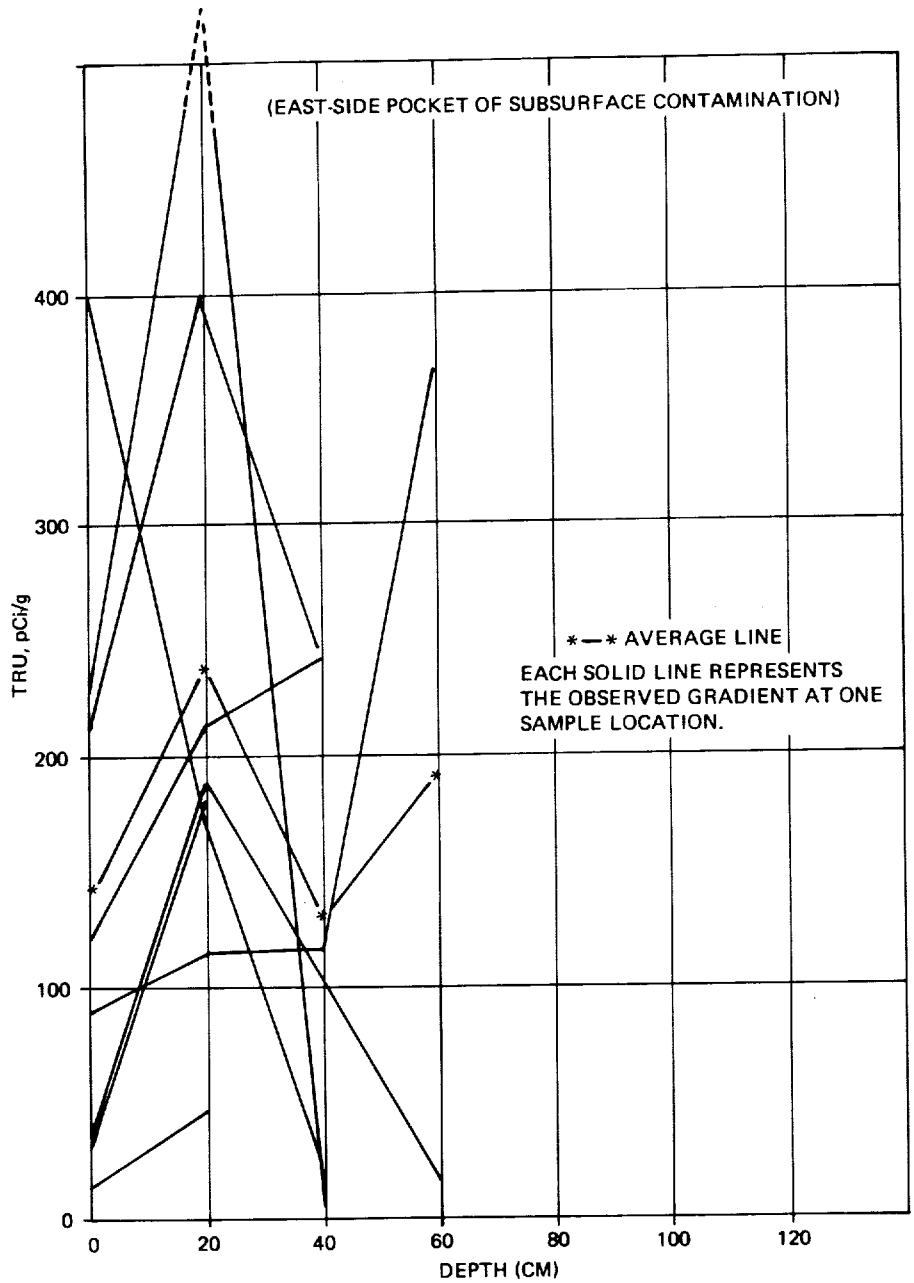


FIGURE B-10-1. SOIL GRADIENT—KICKAPOO AREA (EAST-SIDE POCKET OF SUBSURFACE CONTAMINATION)

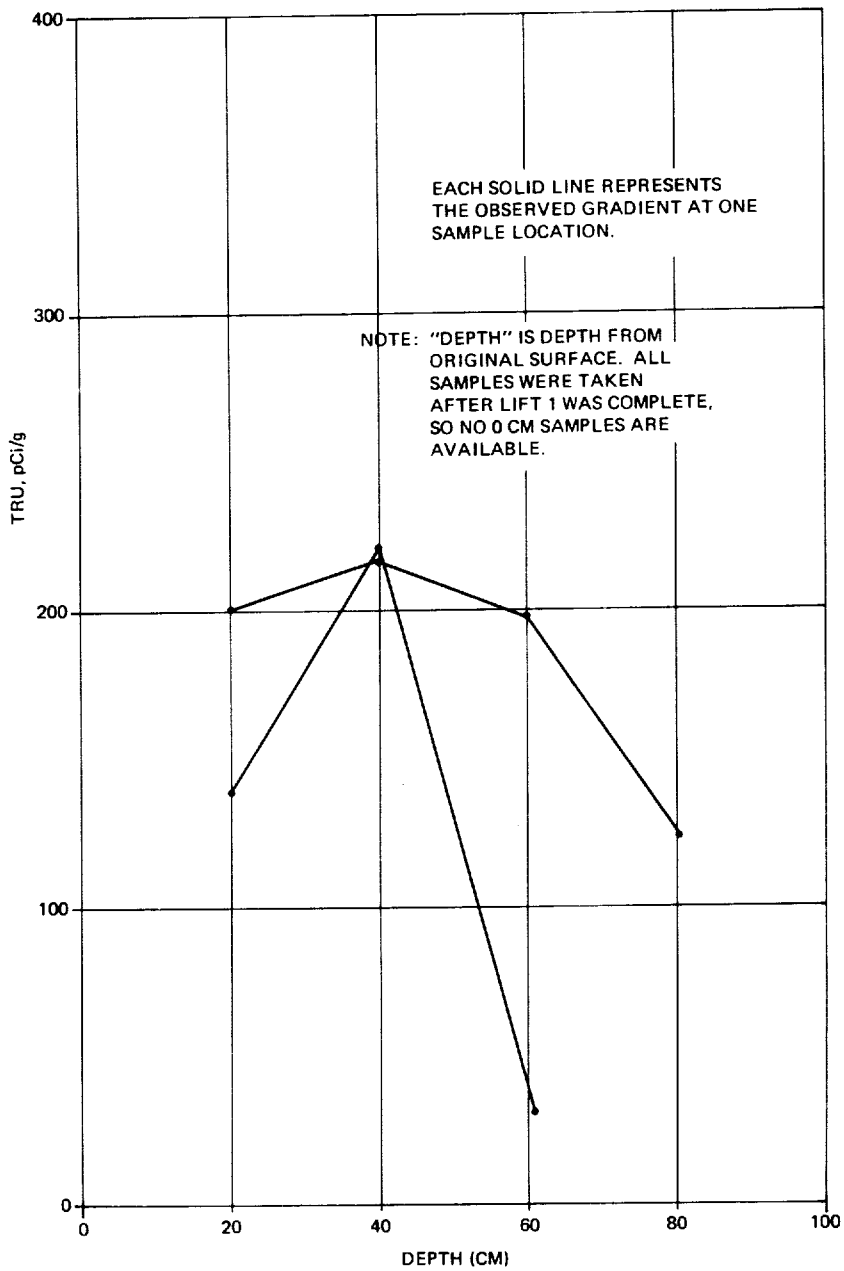


FIGURE B-10-2. SOIL GRADIENT–KICKAPOO AREA (POCKET OF SURFACE CONTAMINATION NEAR PANDANUS)

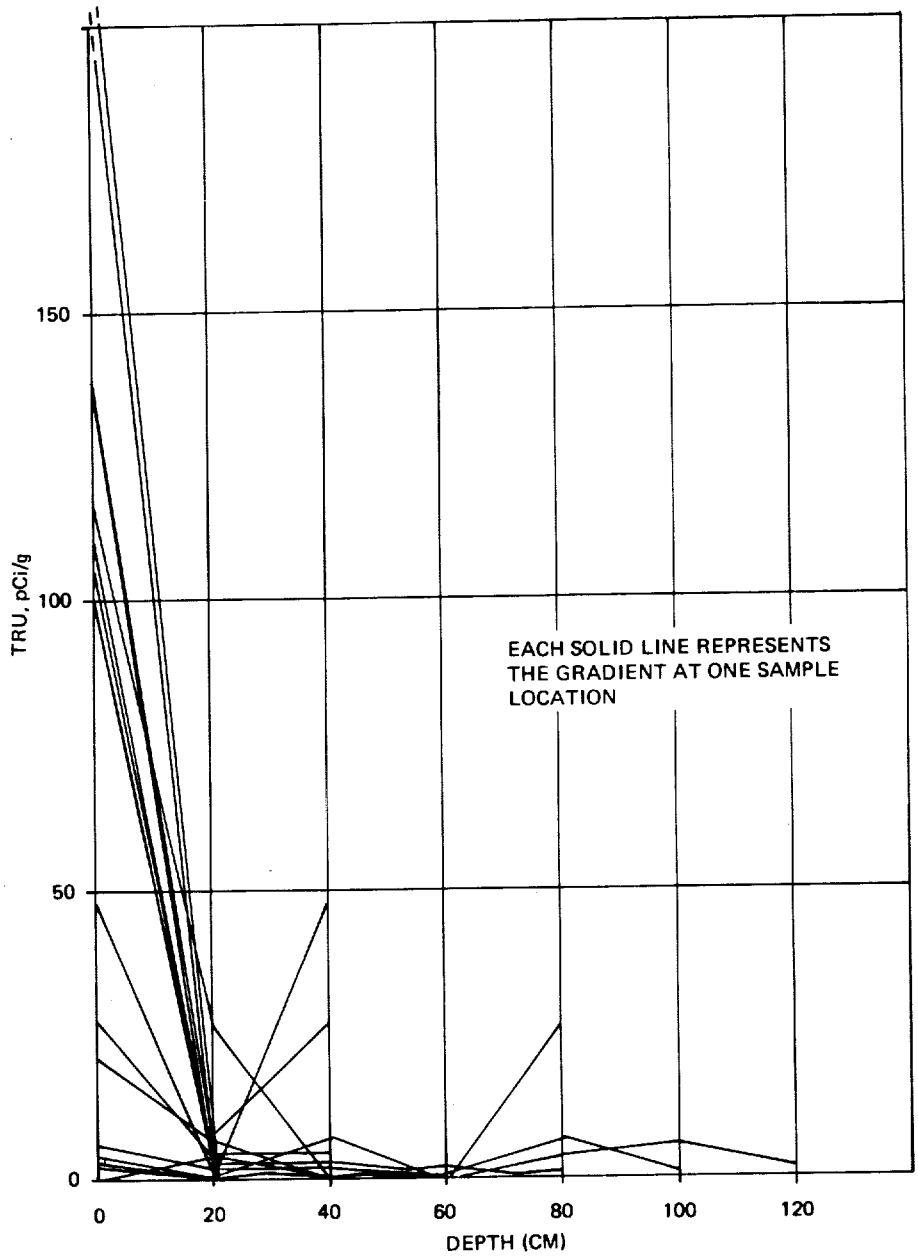


FIGURE B-10-3. SOIL GRADIENT—KICKAPOO AREA (LOCATIONS HAVING NO SUBSURFACE CONTAMINATION)

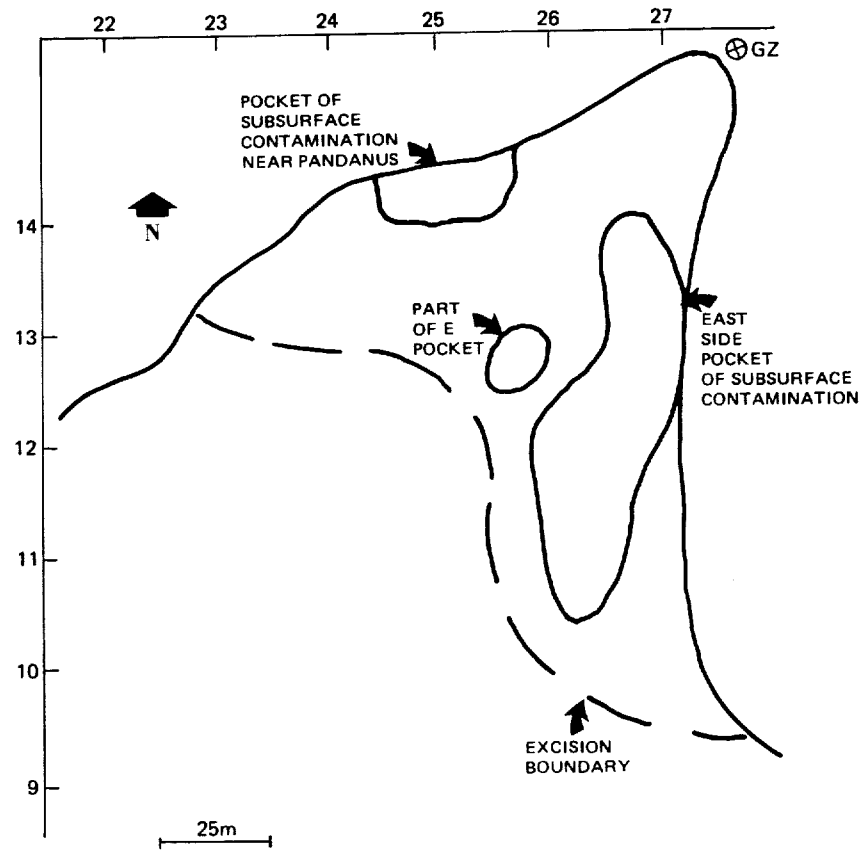


FIGURE B-10-4. MAP OF KICKAPOO AREA

COMPUTATION OF TOTAL TRU ACTIVITY REMOVED FROM THE HUSTEAD AREA OF ISLAND SALLY

DOE/ERSP TECH NOTE NO. 10.1 DATED: 28 July 1978

AUTHOR: M. G. Barnes, DRI

The total activity removed from the Hustead area was computed using TRU values computed from IMP survey readings taken before and after soil excision. Soil gradient models were fitted separately to the portion having subsurface contamination exceeding 80 pCi/g TRU, and to the remainder of the area.

Soil profile data for the area without subsurface contamination are shown in Figure B-10-5. The gradient is exponential, with before excision average of 64.7 pCi/g TRU, and after excision average 21.5 pCi/g TRU. Then, using the notation of Tech Note 10.0,

$$k = 64.7$$

$$k_1 = 21.5$$

$$\frac{k_1}{k} = 0.332$$

$$\frac{1}{cd} = 0.907$$

The average TRU concentration in the soil removed was therefore

$$64.7 \times 0.907(1-0.332) = 39.2 \text{ pCi/g TRU.}$$

The total volume of soil excised from this section was 460 cubic yards, so the total activity removed was

$$39.2 \times 460 \times 1.185 \times 10^{-6} = 0.02 \text{ Ci.}$$

Soil profile data for the area with subsurface contamination are shown in Figure B-10-6. The gradient rises to a peak at 20 cm and drops off exponentially below 20 cm. The rise was modelled as linear, since not enough data are available to fit any other model. It was assumed that the IMP readings after the first lift represent the peak concentration, and the total excision depth was 40 cm (2 lifts). Then the average concentration in soil removed was

$$0.5(56.8 + 86.5) + 0.5(86.5 \times 1.1371(1-0.4150)) = 64.6 \text{ pCi/g TRU.}$$

The volume of soil removed from this section was 740 cubic yards, so the total activity removed was

$$64.6 \times 740 \times 1.185 \times 10^{-6} = 0.06 \text{ Ci.}$$

The total activity removed from the Hustead area,* as calculated by these methods, would be:

$$0.02 \text{ Ci} + 0.06 \text{ Ci} = 0.08 \text{ Ci.}$$

*See Editor's Note on page B-10-4.

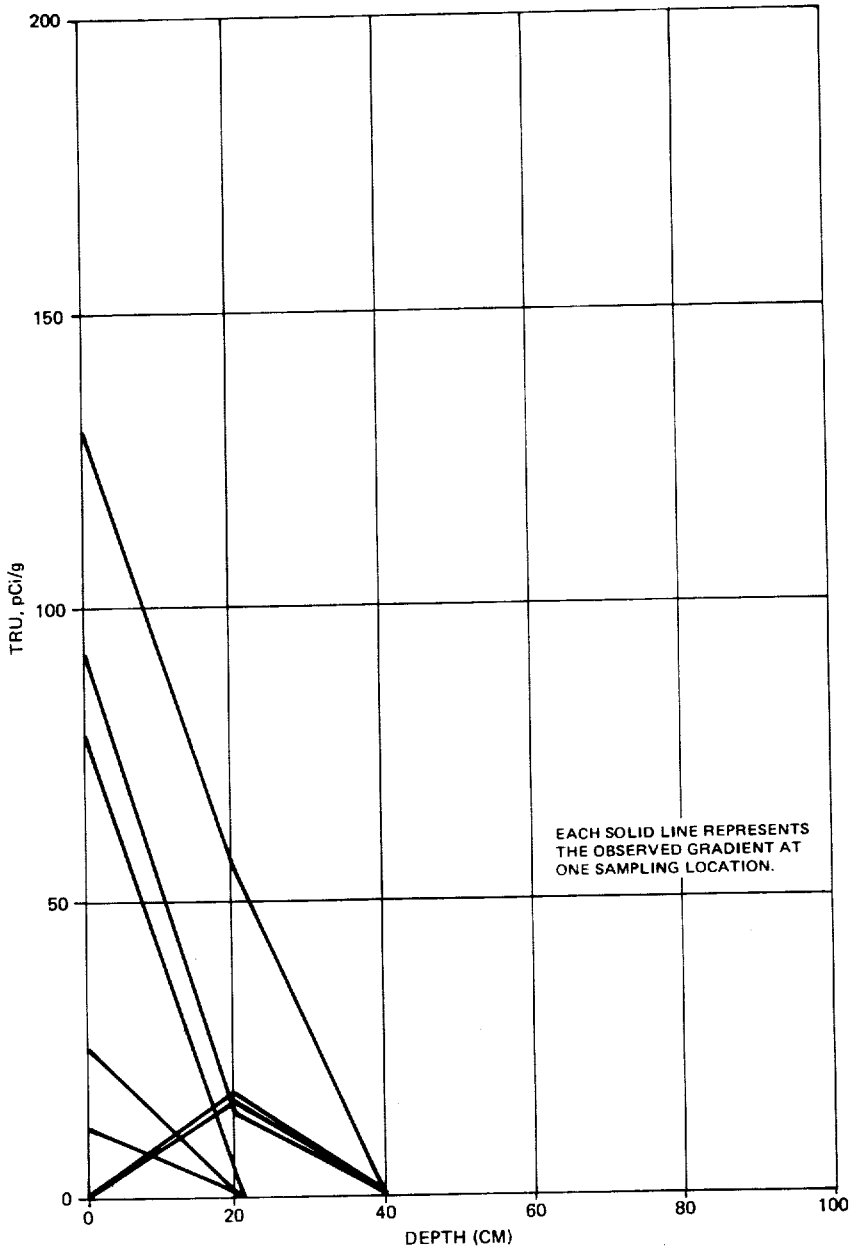


FIGURE B-10-5. HUSTEAD AREA SOIL GRADIENT (SECTION WITHOUT SUBSURFACE CONTAMINATION)

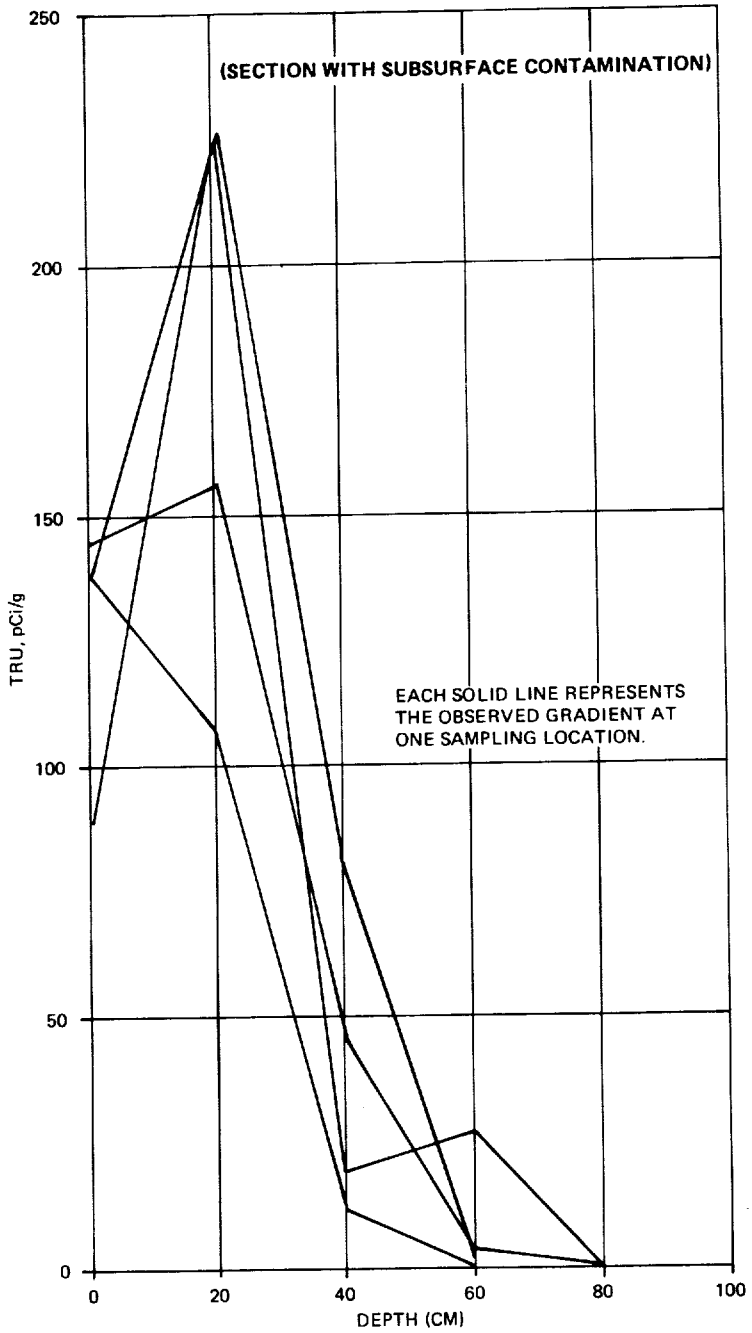


FIGURE B-10-6. HUSTEAD AREA SOIL GRADIENT (SECTION WITH SUBSURFACE CONTAMINATION)

EFFECTIVE AREA FACTOR FOR DETECTOR SN 483

DOE/ERSP TECH NOTE NO. 11.0 DATED: August 18, 1978

AUTHOR: R. J. Jaffe, EG&G

Detector No. 483 is an intrinsic germanium planar detector, model IG 1916, produced by Princeton Gamma Tech (PGT). It has been in use by Desert Research Institute at the Nevada Test Site doing in situ monitoring, and was repaired and calibrated by PGT 1 August 1978. It arrived at Enewetak on 11 August 1978, was calibrated and used by the Enewetak counting laboratory and then installed in IMP I on 16 August 1978.

A standard effective area determination was conducted. This consists of duplicate determinations of count rate at four distances between 100 and 250 cm from a certified ^{241}Am source (119.4 μCi $\pm$ 2%). The source remains in its plastic container and is fastened to a sample holder tray using one thickness of cloth fiber tape. The attenuation factor ($\mu\tau$) for the plastic container top and tape is estimated at 0.027. Experimental measurements (5 pairs of runs over two days) give 1.037 as the ratio for uncovered/covered source gamma flux. The equation used to calculate A_o with this factor included is:

$$A_o = 2.738 \times d^2 \times \text{Counts} \times 10^{-8} \text{ Counts-sec}^{-1}/\gamma\text{-sec}^{-1}\text{-cm}^{-2}$$

where Counts = Net Counts in ^{241}Am peak for a counting time of 5 minutes.

The effective area of detector 483 is 16.6 cm^2. The previous measurement of detector 483 at Las Vegas was 17.2 cm^2. A similar difference averaging about 3.5% has been observed in A_o measurements at Las Vegas compared to measurements at Ursula for other detectors as well, and is currently under study. The effective area based on comparison of Enewetak counting laboratory data (normalized to detector 393) is 17.2 cm^2.

The IMP calibration equation is based on a detector effective area of 19 cm^2. The effective area correction factor for detector 483 is 1.15.

SURFACE SAMPLING OF CONCRETE BUNKERS

DOE/ERSP TECH NOTE NO. 13.0 DATED: September 1978

AUTHOR: T. Crites, RI

Introduction

The Field Radiation Support Team (FRST) has made extensive surveys of bunker surfaces. This information has been summarized and diagrammed by J2. The DOE has only limited information about the radionuclide make-up of this contamination. During the 1972 survey, beta ratios reportedly were found to be higher on concrete surfaces than elsewhere. This led to a general assumption that the contamination is largely ^{90}Sr. Recent discussions and various bunker disposal experiments have led to the decision to leave the majority of these bunkers as they are. In an effort to establish a method for future definition of the hazard involved, samples were taken of two concrete surfaces for radiochemical analysis.

Sample Collection

Surface samples were taken from two bunkers on Irene; a horizontal surface at Ivy Station 200, corresponding to FRST location 7 or 8, and a vertical surface on Ivy Station 600 FRST location 24. In each location a 10 cm x 10 cm area was marked off and a reading taken with the EIC pancake probe model HP-210. Readings were made on the "C" scale with the detector probe in contact with the concrete surface. A 30 cm by 56 cm (12 x 22 in.) plastic bag was taped on three sides of the designated area as shown in Figure B-13-1.

A hammer and chisel were used to remove the concrete surface. Care was taken to make a smooth cut of uniform depth across the designated area. By controlling the direction of cut and holding the bag top open, but close to the top of the sample area, one can get nearly all of the chips and fines into the bag. Sample was chipped away and measurements made with the HP-210 until approximately half the apparent activity had been removed. At that time the bag was replaced with a new bag and a second sample taken until another half of the activity had been removed. The change in surface activity is given with sample number and location in Table B-13-1.

The depth of each cut appeared to be about 1 mm, generating approximately 10 cc of sample at each point.

Sample Results

The concrete samples were submitted to the EIC radiochemistry laboratory for analysis. Results of their work are presented in Table B-13-2.

Cobalt, cesium, and that ^{241}Am column so noted were analyzed by gamma counting. The other nuclides were analyzed using chemistry techniques described in the EIC laboratory manuals.

Conclusions

Bunker concrete contamination is largely due to ^{90}Sr and ^{137}Cs. These two isotopes appear in similar orders of magnitude on the surface, but ^{90}Sr activity falls off much more rapidly as surface material is removed. Analysis for one of them does not give direct data for the other. HP-210 readings appear to track with the ^{90}Sr activity (beta contamination), decreasing in a similar fashion. Correlation between the two sample locations is not good (factor of nearly two in cpm/pCi/g). This may indicate a sampling technique problem, but will require more than two trials to determine. The HP-210 does not track with the total pCi/g present.

If it becomes necessary to provide more complete documentation of bunker contamination in the certification phase, the hammer and chisel method appears to be a good starting point.

TABLE B-13-1. CONCRETE SAMPLES FROM BUNKERS ON ISLAND IRENE

Sample	Sample Location	Avg. HP-210 Reading (cpm/probe area) Before Sampling	After Sampling
1	Ivy Station 200 Surface	13700	6894
2	Ivy Station 200 Second Cut	6894	3876
3	Ivy Station 600 Surface	10745	4854
4	Ivy Station 600 Second Cut	4854	2484

TABLE B-13-2. SAMPLE ANALYSIS RESULTS (pCi/g±2σ)

Sample	Lab. Number	^{90}Sr	^{137}Cs	^{60}Co
1	00-08447	493.9+2.6%	315+3.1%	11.48+37%
2	00-08448	247.6±3.4%	470±2.2%	6.41±49%
3	00-08449	215.6±4.9%	565±1.8%	10.06±34%
4	00-08450	109.4±6.9%	557±0.95%	5.69±51%

Sample	Lab. Number	^{239}Pu	^{238}Pu	^{241}Am, Chem	^{241}Am, Gamma
1	00-08447	0.59+28%	0.15+56%	0.85+60%	MDA
2	00-08448	1.01±22%	0.36±37%	0.32±140%	MDA
3	00-08449	0.43±34%	0.11±67%	0.17±200%	3.89+240%
4	00-08450	0.59±28%	0.20±49%	0.38±120%	6.48±130%

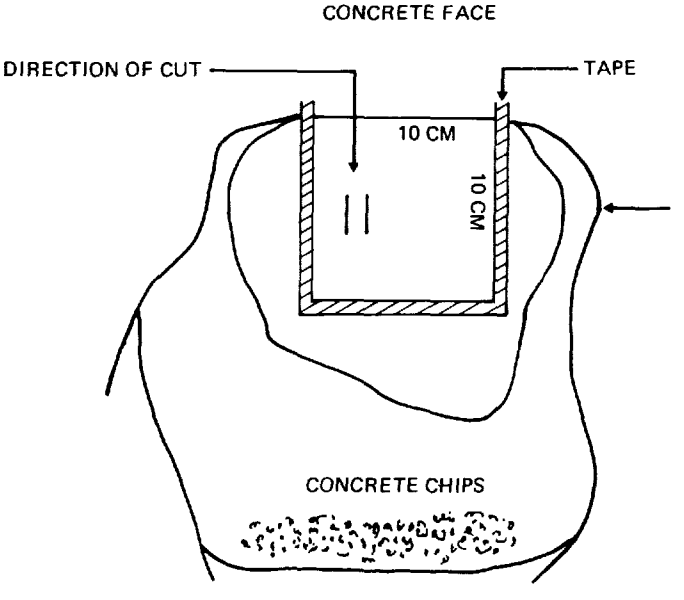


FIGURE B-13-1. CONCRETE SURFACE SAMPLING CONFIGURATION

ESTIMATED TRU CONTENT AND RECOMMENDED DISPOSITION OF YVONNE HIGH-GRADE SOIL/DEBRIS STORED IN HARDTACK STATION 1610 BUNKER

DOE/ERSP TECH NOTE NO. 14.0 DATED: 21 May 1979

AUTHORS: D. H. Denham, PNL
N. R. Johnson, EIC

Summary

Based on recent grab sampling and evaluation of previously collected data, such as Field Radiological Support Team (FRST) hot-spot survey data, JTG Rad Con Division files, and DOE Tech Advisor notes, it is concluded that the material currently stored in the referenced bunker on Yvonne contains about 60 mCi (TRU). Much of this activity appears to be uniformly spread throughout the 400-plus plastic bags of collected soil /debris. The remaining activity, about 10 mCi, is contained within a few bags of soil or in discrete chunks which have been isolated in separate containers. These discrete chunks appear to be weathered metal fragments (possibly molten in the past) with or without concrete/soil attached. Because of the relatively small TRU content of this debris (tens of millicuries) compared to the estimated quantities already disposed of in the Cactus Crater (tens of curies), all of the material in the bunker (including the leaking ^{137}Cs source) should be removed from the bunker and disposed of in the central portion of the Cactus Crater dome.

Introduction and Background

With the initiation of the Enewetak cleanup effort in the spring of 1977, a major concern was the possibility of finding particles of plutonium metal, especially on the island of Yvonne. All radiological survey efforts since 1971 have confirmed that the northern half of Yvonne is a heterogeneous conglomeration of radioactive debris, both on the surface and buried. The complexity of the radiological conditions on this section of the island was produced by several nuclear events, most notably Quince, which failed to produce a fission yield resulting in the dispersal of the plutonium within the device by the high explosives. The rather detailed FIDLER survey late in 1972 (NVO-140) led to the isolation of milligram-size fragments of plutonium. However, no mention is made of whether these "hot particles" were gathered into a common area or whether they were disposed of in the lagoon or other "suitable" location.

Soil Collection and Storage

For a period of approximately one month (28 November through 23 December) in 1977 a group of the Air Force FRST were deployed with PG-2 survey meters to locate and bag up "hot spots" in the Fig/Quince area on Yvonne. Only those soil/debris areas yielding greater than 3000 cpm near the surface (on contact) were to be included. At each location thus defined, an initial reading (cpm) was taken followed by alternate soil removal (in about one-inch increments) and resurvey. In general, two soil layers were removed and put in a plastic bag at each location.

If the count rate was below 3000 cpm after the first scoop of soil was removed, no further soil was removed. About 450 such locations were found with the initial or succeeding count rates ranging from slightly above 3000 cpm to upwards of 500,000 cpm per location.

At some point, probably in the spring of 1978, all of these bags were numbered and transported to the Hardtack Station 1610 bunker. Each of the plastic bags were tied shut and sequentially numbered by marking pen on a piece of masking tape. A list of the bag numbers and the location from which the samples came (i.e., so many meters and direction from the applicable grid stakes) was made by the FRST. That list enumerated 437 bags, 35 of which were noted as torn when placed in the bunker. In addition to the above "record", Capt. Peter H. Meyers (Rad Con Division) prepared a memorandum for record entitled "Field Sample Survey" dated 29 May 1978. In that memorandum Capt. Meyers listed 9 samples which were radiologically evaluated by the Rad Con Division and also placed in the Hardtack bunker. Of these 9 samples, only the two "baby food jars" indicated beta-gamma radiation levels significantly above the ambient background. No external

alpha contamination was noted on any of the containers (glass jars and sealed metal cans). The other "sample" of interest was the one cubic foot wooden box suspected of containing the leaking 10 mCi ^{137}Cs calibration source in its lead pig. Its exterior reading was 30 $\mu R/hr$.

Estimates of Bunker Activity

Two independent estimates were made of the ^{241}Am content in the 400 plus bags. The FRST data compiled during soil collection was grouped according to activity level (i.e., sum of count rates for the soil removed and bagged per location). Those data are summarized below indicating that 90% of the bags contain less than 100,000 cpm, while only about 1% contain activity levels greater than 500,000 cpm. Based on these data, an assumed PG-2 calibration factor, and 2700 grams of soil per bag, the total ^{241}Am activity was estimated to be 2.5 mCi.

Gross Activity Level Thousands of cpm	Percent of Bags
less than 50	82.0
50 to 100	8.1
100 to 200	5.8
200 to 300	1.3
300 to 400	0.8
400 to 500	0.7
greater than 500	1.3

The second method involved the collection in petri dishes of seven soil samples taken at random from the pile of bags on 17 May 1979. These latter samples were taken from the available loose sand/soil from torn bags and that which had accumulated over the past year on the surface of other bags, probably as a result of personnel movements within the bunker either at the time of putting the bags in storage or during subsequent investigations. In addition to these seven samples, the entire area was surveyed with a PG-2 at which time three bags and a single concrete chunk were isolated from the rest of the pile. Based on field measurements, these three bags were assigned an activity level 100 times greater than the average found from the petri dish samples.

Specific gross gamma measurements (PG-2) were made on each of the petri samples, the concrete chunk (which was also photographed), and the two "baby food jars". These data are summarized in Table B-14-1 along with calibration data done back at the Eberline trailer on Enewetak.

These data (300 to 5000 pCi/g, ^{241}Am) compare favorably with the IMP pre and post lift values for the Fig/Quince area. The IMP TRU values ranged from 75 to 4100 pCi/g pre lift and 59 to 7000 pCi/g post lift.

To estimate the total TRU within the bunker, the following assumptions were made:

1. Soil volume in bunker is 4.5 ft. x 9.5 ft. x 1 ft.

   (43 ft^3 or 1.2×10^6 cm^3)

2. Bulk soil density is 1.5 g/cm^3

3. Three "hot" bags at 1000 g/bag

4. Average ^{241}Am concentration in bags (excluding 3 above) is average of 7 petri samples (2300 pCi/g)

5. Pu/Am ratio is 10

Hence, the calculation for ^{241}Am content and total TRU follow:

Bulk soil = $(1.2 \times 10^6\ cm^3)(1.5\ g/cm^3)(2300\ pCi/g)$		= 4.2 mCi
"Hot" bags = (1000 g/bag)(3 bags)$(2.3 \times 10^5\ pCi/g)$		= 0.7 mCi
Jars = 92μCi		0.1 mCi
Concrete chunk = 260μCi		0.3 mCi
	^{241}Am Sum	5.3 mCi
	$^{239,240}Pu$ (10 x ^{241}Am)	53 mCi
	Total TRU	60 mCi

Recommendations

Since the total contained radioactivity in the bunker is small relative to the TRU already deposited in the Cactus Crater and is a small volume (approximately 2 cubic yards total), it is recommended that the radioactive debris stored in the bunker be removed and disposed of in the Cactus Crater dome. This includes all of the remaining bags, loose sand and soil, and the metal cans, jars and wooden box. These items should all be treated as being alpha contaminated and disposed of in the most expeditious manner.

TABLE B-14-1. RESULTS OF FIELD GROSS GAMMA ANALYSIS OF SELECTED SAMPLES IN YVONNE STORAGE BUNKER

Sample No.	^{241}Am pCi/g or μCi*	Comments
1	1300	Composite of loose soil at rear of bunker
2	420	Composite of torn bags
3	340	Composite of torn bags
4	2200	Composite of loose soil near center of pile
5	5200	Soil from torn bag #181
6	1100	Soil from torn bag near entrance
7	580	Sand/soil from floor near entrance
Jar 1	14	Weathered metal part
Jar 2	78	Flaked gray metal with soil
Concrete	260	Concrete chunk with bluish gray metal in center

*Petri sample data (pCi/g) based on measurements at approximately 10 cm from detector. Discrete source data (μCi) based on measurements at 1m from detector. Calibration data follows: (1) Net cpm with PG-2 at 3, 4 and 5 inches from a 31,600 dpm ^{241}Am soil standard were 48, 23 and 14, respectively (approximate background of 30 cpm, 1.6×10^{-3} cpm/pCi at 4 inches); (2) Net cpm with PG-2 at 1 meter from 0.52μCi ^{241}Am plated source was 30(58 cpm/μCi).

ACTIVITY LEVELS IN SOIL STOCKPILE ON YVONNE NEAR SOUTHERN LIP OF CACTUS CRATER

DOE/ERSP TECH NOTE NO. 15.0 DATED: 25 May 1979

AUTHORS: D. H. Denham, PNL
N. R. Johnson, EIC

Introduction and Sampling

In preparation for the Tremie operation for crater disposal of contaminated soil and debris on the north end of Yvonne, part of the original Cactus Crater lip was dozed away from the crater. Although there was concern that the crater lip may have significant subsurface contamination, portable instrument surveys and soil sampling by the FRST (fall 1977) apparently did not confirm that suspicion.

Following completion of the Tremie operation, another section of the original crater lip was dozed away from the crater toward the south in early May 1979. That action left a readily accessible lip face (see Figure B-15-1) 3-4 m high and of similar width. Ten sidewall samples of this face were taken by Dick Powell (EIC) and John Gallimore (DOE Tech Advisor) on 11 May 1979. During the ensuing week further portions of the crater lip were dozed away from the old lip area to provide space for completing the circular concrete keywall. All of this lip material was pushed into a 2000 m^3* soil stockpile (see Figure B-15-1) bounded approximately by excess keywall sections, debris hauling roads, and the remaining crater lip. This action uncovered several line-of-sight (LOS) pipes.**

At the request of LTC Al Erickson, J-3, JTG, we launched a second soil sampling mission to Yvonne on 17 May 1979. The purpose of this latter mission was to characterize the radioactivity, primarily TRU, within this 2000 m^3 stockpile near the southern lip of Cactus Crater. A sketch of the stockpile showing the approximate locations of samples is shown in Figure B-15-2. Surface soil samples were collected in petri dishes from 10 locations (what would have been location No. 6 was missed) on top of the pile and 7 locations on the 7-meter high southern face. Subsurface samples were collected at surface locations 5 and 8 near the center of the pile. These samples (numbers 12 to 16 at 5 and 17 to 19 at 8) were taken at 20 cm intervals to a maximum depth of 1 m. Six subsurface samples (numbers 29 to 34) were taken at about 60 cm depth (perpendicular to the sloping face) along the western and eastern sides of the 7-meter high southern face.

Results and Conclusions

Based on our physical measurements of the stockpile, we estimated the volume to be a few percent above that estimated by JTG. A total of 41 soil samples were collected as part of these characterizations. The 10 initial samples taken on 11 May are assumed to represent the "bottom" of the stockpile since they were collected prior to the time that portion of the crater lip was dozed away. Results of the other 31 samples provide an indication of the surface and limited subsurface activity levels in the pile. All samples were collected in petri dishes and were gamma scanned by the EG&G IMP at Ursula. The results are presented below. Note: These values are based on a nominal weight of 130 g per sample since the individual samples were not weighed. This should not result in greater than a 30% error in the estimated values.

Estimated Radionuclide Concentrations (pCi/g)

	^{241}Am	^{137}Cs	^{60}Co
Average	1.3	25	7.3
Range	0 - 3.5	12 - 54	1.8 - 16

*Volume furnished by JTG
**The original Tech Note included a 5-frame photo composite that was not suitable for reproduction here. Figure references have been changed to reflect the deletion.

The ^{137}Cs data compare very well with the NVO-140 values (40-70 pCi/g), while the ^{60}Co levels are lower than expected. For comparison, the NVO-140 ^{60}Co values decay-corrected to May 1979 would range from 2-60 pCi/g. Since the ^{241}Am concentrations were all below 4 pCi/g, it is not likely that the average TRU concentrations would exceed 40 pCi/g (TRU/^{241}Am ratio in NVO-140 is 9).

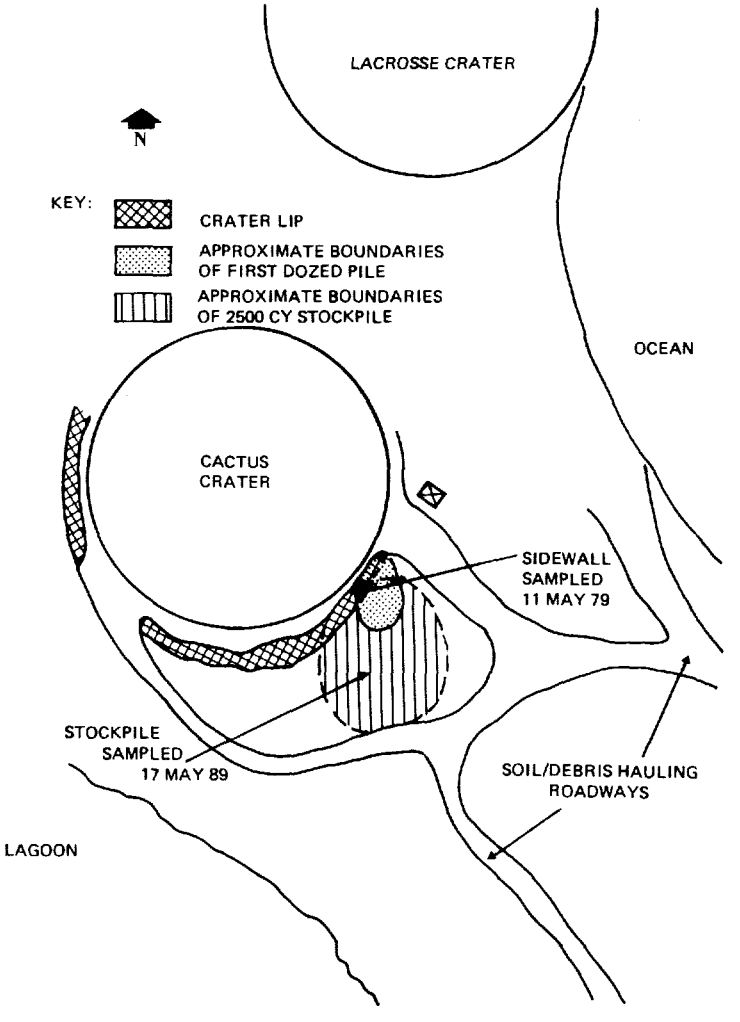


FIGURE B-15-1. NORTH END OF RUNIT SHOWING ROADWAYS, LACROSSE AND CACTUS CRATERS, AND APPROXIMATE BOUNDARIES OF CRATER LIP MATERIAL

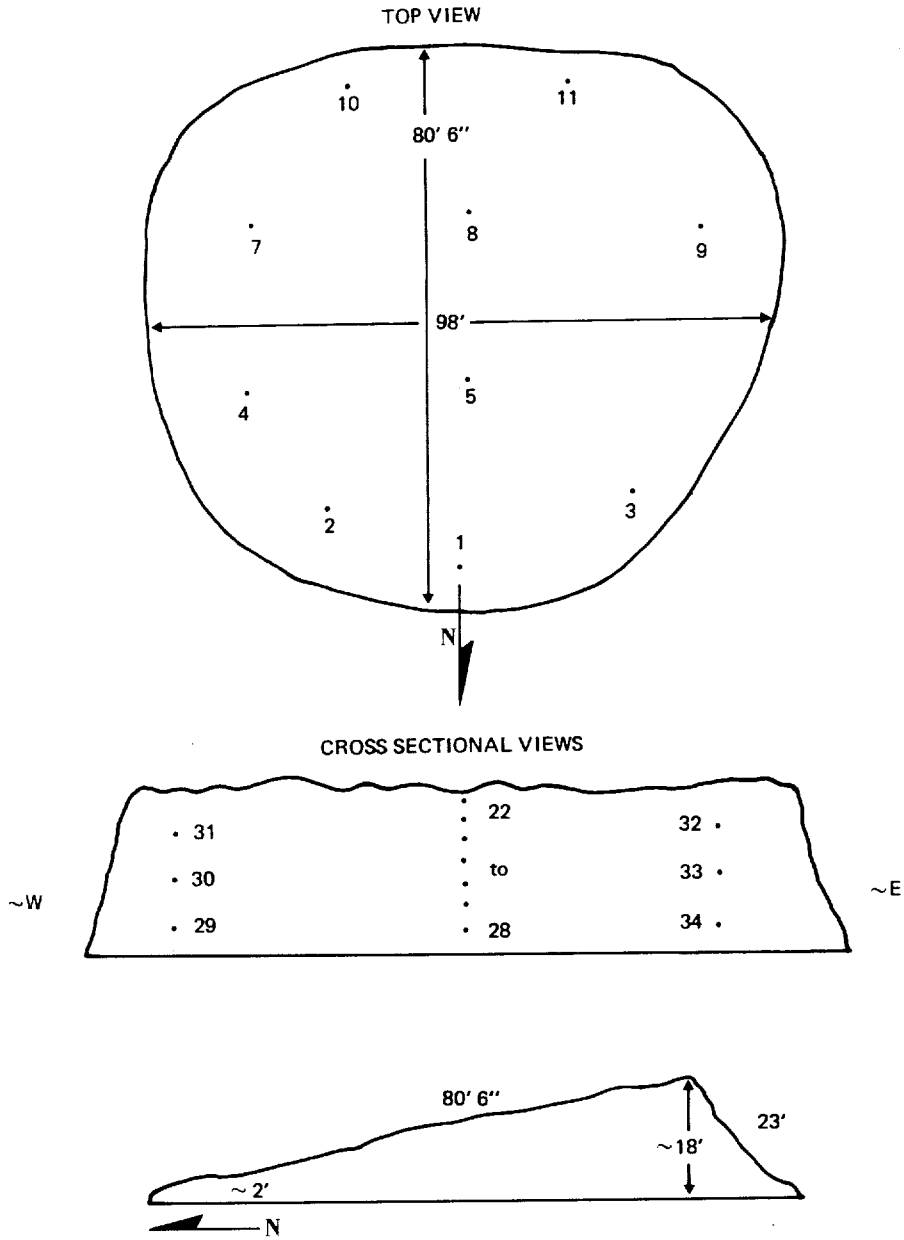


FIGURE B-15-2. SKETCHES OF 2500 CY STOCKPILE SHOWING APPROXIMATE LOCATIONS OF SAMPLING POINTS

FIELD INSPECTION OF GRID STAKES AND PORTABLE INSTRUMENT (PG-2) SURVEY OF FIG/QUINCE AREA ON YVONNE

DOE/ERSP TECH NOTE NO. 16.0 DATED: 8 June 1979

AUTHOR: D. H. Denham, PNL

In reviewing the Fig/Quince IMP data, both pre- and post-lift, it was apparent that a number of potentially key locations were missed. Hence, it was assumed these grid locations along both sides of the island were not measured because of missing stakes, terrain too difficult for the IMPs, or physical barriers like bunkers or roadways. Previously it had been decided no soil lifts or further meaurements would be made in roadways since they were laid out in the "cleanest" part of the area.

Methods

On 28 May 1979, the DOE Tech Advisor (Denham) and EG&G Scientist (Jobst) were deployed to Yvonne to determine why no post-lift IMP values exist for certain grid locations (see Figure B-16-1). This was an on-foot survey in which the location of missing stakes was estimated by stepping off the distance from existing stake locations. In addition, a PG-2 survey instrument (low-energy gamma detector and count rate meter) and petri dishes were taken along during the on-foot survey. PG-2 measurements were made with the detector positioned 1 meter above grade at a number of marked locations and at 25-meter unmarked locations missed during the post-lift IMP survey.

Another more extensive PG-2 survey was conducted by the DOE Tech Advisor (Denham) and EG&G Scientist (Tipton) on 1 and 2 June over much of the Fig/Quince area. This second mission was launched to better define potential excision areas on Yvonne, especially those with activity levels greater than 400 pCi/g TRU. This latter survey was made on a 12.5 m grid (6.25 m grid around the 12 NE 12 location).

Results and Discussion

The "no measurement" locations along both sides of the island from the 8 South line to the 28 North line were examined to determine suitability for staking and IMPing. Of the 19 locations so checked, 4 had stakes in place (of which 3 were in unlifted areas), 7 may be in the water or below the high-water mark, and 1 each may fall on a roadway or at a cliff-beach interface. There were no indications of stakes at the remaining questionable locations. Specific grid data and comments concerning the reasons for not IMPing these locations are presented in Table B-16-1.

Although these were not "hot-spot" surveys, the PG-2s were carried between locations with the detector about 40 cm above grade and the count rate speaker turned on. Hence, the surveyors were at least aware of those areas traversed in which significant contamination levels existed. Only one "hot-spot" was detected beyond those areas previously identified by the IMP surveys. This was observed on the 2 June survey at approximately grid location 4-SE-6. The estimated (PG-2) soil TRU concentration at that location and the two others identified by the IMP are listed below:

Location	4-SE-6	13-NE-12	0-0
Estimated Max. TRU, pCi/g	5,800	24,000	140,000

In addition to the PG-2 fine-grid survey in the 12-NE-12 area, we took three samples of the roadway lip material (ocean side) along the stretch from about the 10 N to 16 N lines. A concrete bunker is on the opposite side of the roadway on roughly the 16 N line. The results from those soil samples (petri dishes) ranged from 25 to 100 pCi/g* ^{241}Am. Using the previously established TRU/Am ratio of 14 (NVO-140), the approximate TRU concentrations along that roadway ranged from 300 to 1400 pCi/g, with the highest concentration about 15 m from stake number 12-NE-12.

* Calibration factor for ^{241}Am for PG-2 in contact with the petri dish is approximately 31 pCi/cpm.

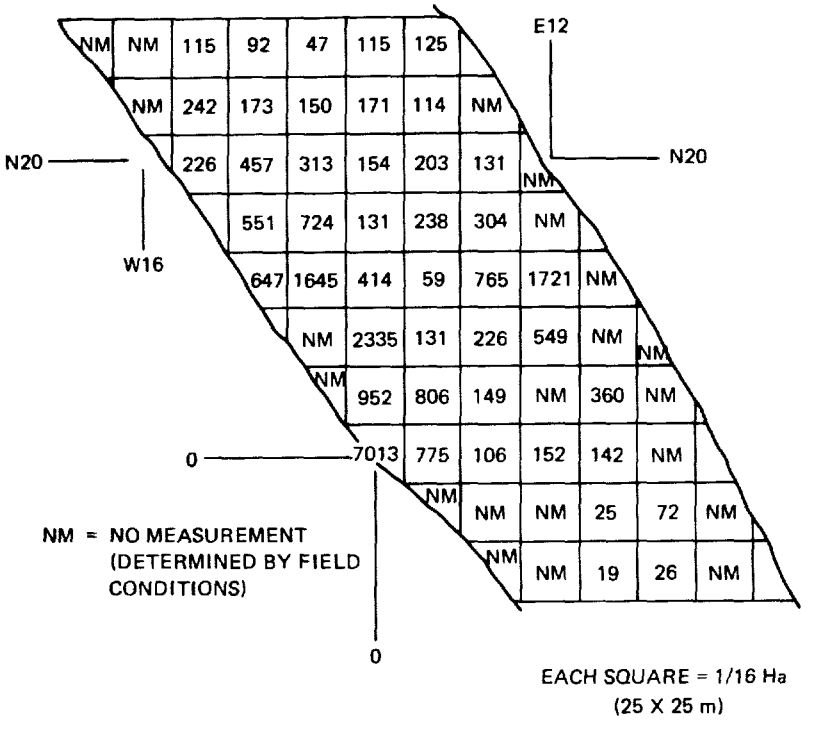


FIGURE B-16-1. MAP OF FIG/QUINCE AREA SHOWING POST–LIFT TRU CONCENTRATIONS (pCi/g) AND NO MEASUREMENT LOCATIONS

The PG-2 survey data are summarized in Tables B-16-2 and 3. To estimate the background count rate at each location we rotated the detector from the down-facing to up-facing position, maintaining it at 1 meter above grade. For those few locations at which we didn't make both up and down measurements, we took the average of the "up" values from locations where the "down" values were less than 400 cpm. The post-lift IMP data (pCi/g) are also included in Tables B-16-2 and 3. From these data it is possible to estimate a minimum sensitivity and calibration factor for the PG-2. The minimum sensitivity for the PG-2 was taken to be the average value of the IMP readings at grid locations at which the "up" exceeded or was nearly the same as the "down" count rate with the PG-2. This value was 110 $\pm$ 70 pCi/g TRU. Approximate field calibration factors for the PG-2 were calculated as follows:

(1) Ratio of the IMP pCi/g to PG-2 net cpm at specific 25 meter IMP stake locations (Table B-16-2); or

(2) Ratio of the IMP pCi/g to the average PG-2 net cpm from the five PG-2 12.5 meter measurements centered on each IMP stake location (Table B-16-3).

The average calibration factors so calculated are 2.6 ($\pm$ 80%) and 3.3 ($\pm$ 30%) pCi/g per cpm, respectively.

PG-2 measurements were made on both dates at some grid locations. These paired values are compared in Table B-16-4, showing reasonable agreement (within less than $\pm$ 40% of the respective averages) between the two data sets.

The PG-2 survey data, converted to pCi/g TRU, are presented in Figure B-16-2. This map is an expanded version of the one shown in Figure B-16-1 (IMP data only). From Figure B-16-2 it is evident that the highest surface contamination levels in the Fig/Quince area occur in areas along the two shorelines. Contours encompassing different degrees of surface contamination are shown on the map in Figure B-16-3. The contamination contours chosen (namely, 400, 1000, and 3000 pCi TRU/g) encompass areas of about 12,500 (1.25 ha), 3750 (0.38 ha), and 375 (0.04 ha) square meters, respectively. These surface areas agree with those determined from IMP data, but provide a more refined estimate of the boundaries between different contamination levels. In particular, the PG-2 data showed that there are inhomogeneities over the Fig/Quince area. Most notable of these are the "hot-spots" at 0 - 0 and 4-SE-6, and the larger "hot-zone" at 13-NE-12. This latter zone definitely is distributed, covering an area perhaps 5 to 10 meters on a side, while the two former areas are discrete spots, no more than a meter or two across.

Conclusions

The PG-2 surveys of 28 May and 2 June confirm that the surface TRU contamination in the Fig/Quince area on Yvonne is very inhomogenous, with zones of contamination ranging from "hot-spots" of the order of a meter across to zones of 50 to a few hundred square meters. Based on the data presented herein, it is recommended that JTG plan a several tier strategy for cleanup, taking into account the available space remaining in the Cactus Crater dome. A suggested plan and estimated volumes of soil to be excised (single lift only) are shown below in order of priority:

Priority	Area to Excise/Location	Estimated Volume (m^3)*
1	3 "hot-spots"; 0-0, 4-SE-6, 13-NE-12	8 - 15
2	>3000 pCi/g; 6-NE-2 to 10-NW-2	80
3	>1000 pCi/g; 3-NE-3 to 16-NW-6	500
	12-NE-6 to 14-NE-12	150
4	>400 pCi/g; lagoon side	1000 (balance after
	ocean side	700 removing items
		1 to 3 above)

* Does not include beach areas but assumes once an area is lifted, no further lift will be made in that region.

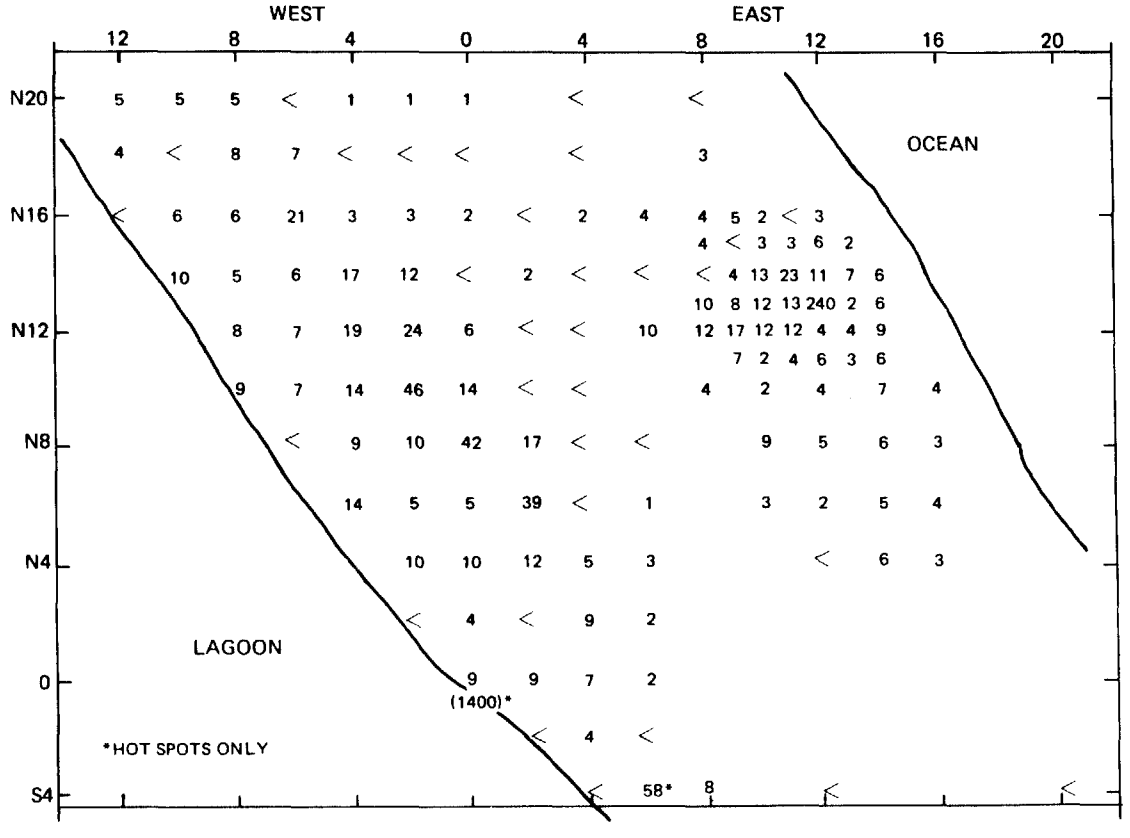


FIGURE B-16-2. ESTIMATED TRU IN HUNDREDS OF pCi/g BASED ON 28 MAY AND 2 JUNE 1979 PG-2 SURVEY

The "hot-spots" identified in priority 1 should be excised and disposed of in the crater. The DOE Tech Advisor or EG&G Scientist will provide PG-2 monitoring in support of that effort. Further, it is anticipated that those efforts will greatly reduce the average contamination levels in the 0 - 0 and 12-NE-12 1/16 ha areas. Following excision, those areas should be reIMPed along with the previously identified "no measurement" areas.

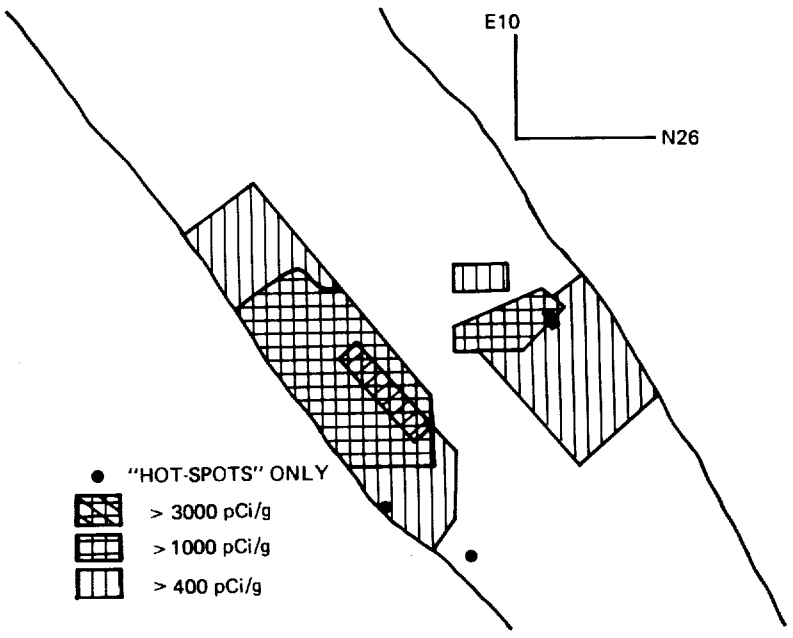


FIGURE B-16-3. SUGGESTED SOIL LIFT AREAS IN YVONNE FIG/QUINCE AREA

TABLE B-16-1. OBSERVED STATUS OF "NO MEASUREMENT" LOCATIONS ON YVONNE

Stake No.	Location*	Comments on Location and Reasons for not IMPing
8-SE-24	O	On beach, halfway between road and high-water mark; no stake.
8-SE-12	L	Between road and shore; no stake, may have been knocked down by traffic.
4-SE-24	O	May be in water***
4-SE-12	L	Stake in place near confluence of two roads; no apparent reason to have been missed.
4-SE-8**	L	Stake in place adjacent to profile sample hole in middle of scaevola; area not lifted.
4-SE-4**	L	On beach slope about 5 m from high-water mark; no stake
0-NE-20**	O	Near outer edge of road and large log; no stake, but may be on road and hence not IMPed.
4-NW-4**	L	May be in water***
4-NE-20**	O	May be in water***
8-NE-20**	O	May be in water***
8-NE-16**	O	Between road and high-water mark; no stake.
8-NW-4**	L	Cleared area about 10 m from high-water mark; no stake.
12-NE-16**	O	May be in water***
16-NE-12**	O	On beach below 1.5 m dropoff; 3 - 5 m from high-water mark, no stake.
20-NE-12	O	May be in water***
24-NE-8	O	On beach 2-3 m from high-water mark; stake repositioned by hand, probably missed during IMP survey.
24-NW-16	L	Stake already in place; readily accessible by IMP, not lifted.
28-NW-16	L	Easy IMP access in vegetated area; stake reset by hand, not lifted.
28-NW-20	L	May be in water***

* Side of island; O = ocean, L = Lagoon
** Most important stakes to IMP
*** No stakes will be set or IMP measurements made below high-water mark.

TABLE B-16-2. COMPARISON OF PG-2 SURVEY DATA AT 1 METER ABOVE GRADE AND IMP DATA IN FIG/QUINCE AREA, 28 MAY 1979

Stake No.	PG-2 (cpm)[a] Down	PG-2 (cpm)[a] Up(Background)	Net cpm	IMP TRU (pCi/g)	IMP/PG-2 pCi/g / Net cpm	Estimated pCi/g(± 80%)
12-SE-24	302	(184)[b]	118	-[c]	-	310
8-SE-24	148	(184)	-36	250	-	-
8-SE-20	150	(184)	-34	26	-	-
4-SE-20	198	(184)	14	72	5.1	-
0-SE-24	170	(184)	-14	-	-	-
4-NE-16	300	(184)	116	360	3.1	-
8-NE-16	276	(184)	92	-	-	240
12-NE-12	402	210	192	1,721	9.0	-
[d]	7,626	930	6,696	1,721	0.3	-
16-NE-12	323[e]	235[e]	88	-	-	230
20-NE-8	198	230	-32	131	-	-
24-NE-8	282	304	-22	-	-	-
32-NW-16	690	558	132	128	1.0	-
28-NW-16	386	408	-22	-	-	-
24-NW-16	478	380	98	-	-	260
20-NW-12	576	424	152	226	1.5	-
16-NW-12	304	318	-14	-	-	-
16-NW-8	648	390	258	551	2.1	-
16-NW-4	450	354	96	724	7.5	-
8-NW-4	722	310	412	-	-	1100
4-NW-0	594	236	358	952	2.7	-
0-NE-4	456	170	286	775	2.7	-
0 - 0	12,464	866	11,598	7,013	0.6	("hot" spot only)
4-SE-4	76	106	-30	-	-	-
4-SE-8	492	196	296	-	-	780
4-SE-12	174	148	26	64	2.5	-
8-SE-8	98	106	-8	-	-	-
8-SE-12	300	152	148	51	0.3	-
12-SE-16	82	106	-24	22	-	-
20-NE-4	256	286	-30	203	-	-

[a] Based on 0.5 min. counting time at each location.
[b] Parenthetical values estimated from average of other locations in which "down" reading was less than 400 cpm.
[c] Dash indicates no IMP measurement at that location.
[d] 9m from stake toward ocean.
[e] Average of two readings; one at higher elevation than other.

TABLE B-16-3. COMPARISON OF PG-2 SURVEY DATA AT 1 METER ABOVE GRADE AND IMP DATA IN FIG/QUINCE AREA

(2 June 1979)

Stake No.	PG-2 (cpm) Down	PG-2 (cpm) Up	Net	IMP TRU (pCi/g)	IMP/PG-2 pCi/g / Net cpm	Estimated pCi/g(± 30%)
20-NW-12	538	360	178	226	1.3	-
20-NW-10	472	332	140	-**	-	460
20-NW-8	504	360	144	457	3.2	-
20-NW-6	268	260	8	-	-	<100
20-NW-4	220	180	40	373	-	-
20-NW-2	310	280	30	-	-	100
20-NW-0	368	340	28	154	-	-
20-NE-4	272	254	18	203	-	-
18-NW-12	362	242	120	-	-	400
18-NW-10	218	198	10	-	-	<100
18-NW-8	674	422	252	-	-	830
18-NW-6	450	242	208	-	-	690
18-NW-4	116	160	-44	-	-	0
18-NW-2	150	160	-10	-	-	0
18-NW-0	198	188	10	-	-	<100
18-NE-4	100	158	-58	-	-	0
18-NE-8	250	144	106	-	-	350
16-NW-12	238	232	6	-	-	<100
16-NW-10	368	186	182	-	-	600
16-NW-8	408	270	138	551	2.0	-
16-NW-6	1,024	386	638	-	-	2,100
16-NW-4	460	342	118	724	2.6	-
16-NW-2	260	168	92	-	-	300
16-NW-0	192	148	44	131	-	-
16-NE-2	132	136	-4	-	-	0
16-NE-4	186	126	60	238	-	-
16-NE-6	256	140	116	-	-	380
16-NE-8	302	166	136	304	3.7	-
16-NE-9	284	144	140	-	-	460
16-NE-10	226	182	44	-	-	150
16-NE-11	82	154	-72	-	-	0
16-NE-12	242	148	94	-	-	310
15-NE-8	268	146	122	-	-	400
15-NE-9	150	130	20	-	-	<100
15-NE-10	242	164	78	-	-	260
15-NE-11	226	134	92	-	-	300
15-NE-12	384	208	176	-	-	580
15-NE-13	236	174	62	-	-	200
14-NW-10	630	318	312	-	-	1,000
14-NW-8	384	232	152	-	-	500

* Based on 0.5 min counting time at each location.
** Dash indicates no IMP measurement at that location.

TABLE B-16-3. Continued

Stake No.	PG-2 (cpm) Down	PG-2 (cpm) Up	Net	IMP TRU (pCi/g)	IMP/PG-2 pCi/g / Net cpm	Estimated pCi/g(± 30%)
14-NW-6	428	236	192	-**	-	640
14-NW-4	802	276	526	-	-	1,700
14-NW-2	658	284	374	-	-	1,200
14-NW-0	228	210	18	-	-	<100
14-NE-2	266	218	48	-	-	160
14-NE-4	80	140	-60	-	-	0
14-NE-6	104	124	-20	-	-	0
14-NE-8	214	202	12	-	-	<100
14-NE-9	288	156	132	-	-	440
14-NE-10	596	194	402	-	-	1,300
14-NE-11	886	200	686	-	-	2,300
14-NE-12	622	276	346	-	-	1,100
14-NE-13	420	196	224	-	-	740
14-NE-14	338	162	176	-	-	580
13-NE-8	430	128	302	-	-	1,000
13-NE-9	402	164	238	-	-	790
13-NE-10	558	192	366	-	-	1,200
13-NE-11	636	230	406	-	-	1,300
13-NE-12	7,638	480	7,158	-	-	24,000
13-NE-13	268	224	44	-	-	150
13-NE-14	384	192	192	-	-	630
12-NW-8	424	176	248	647	2.9	-
12-NW-6	554	342	212	-	-	700
12-NW-4	834	266	568	1,645	3.3	-
12-NW-2	1,016	280	736	-	-	2,400
12-NW-0	508	314	194	414	1.5	-
12-NE-2	126	206	-80	-	-	0
12-NE-4	148	196	-48	59	-	-
12-NE-6	446	154	292	-	-	970
12-NE-8	498	148	350	765	3.3	-
12-NE-9	700	182	518	-	-	1,700
12-NE-10	550	194	356	-	-	1,200
12-NE-11	612	254	358	-	-	1,200
12-NE-12	258	166	92	1,721	7.3	-
12-NE-13	294	182	112	-	-	370
12-NE-14	400	140	260	-	-	860
11-NE-9	338	128	210	-	-	690
11-NE-10	252	178	74	-	-	240
11-NE-11	262	150	112	-	-	370
11-NE-12	326	144	182	-	-	600
11-NE-13	254	154	100	-	-	330
11-NE-14	328	152	176	-	-	580
10-NW-8	410	130	280	-	-	930

* Based on 0.5 min counting time at each location.
** Dash indicates no IMP measurement at that location.

TABLE B-16-3. Continued

Stake No.	PG-2 (cpm) Down	PG-2 (cpm) Up	Net	IMP TRU (pCi/g)	IMP/PG-2 pCi/g / Net cpm	Estimated pCi/g(± 30%)
10-NW-6	420	196	224	-**	-	740
10-NW-4	692	260	432	-	-	1,400
10-NW-2	1,824	430	1,394	-	-	4,600
10-NW-0	716	288	428	-	-	1,400
10-NE-2	114	172	-58	-	-	0
10-NE-4	112	90	22	-	-	<100
10-NE-6	ROAD		-	-	-	-
10-NE-8	290	158	132	-	-	440
10-NE-10	270	204	66	-	-	220
10-NE-12	288	160	128	-	-	420
10-NE-14	362	138	224	-	-	740
10-NE-16	280	170	110	-	-	360
8-NW-6	98	124	-26	-	-	0
8-NW-4	404	180	224	-	-	740
8-NW-2	568	254	314	-	-	1,000
8-NW-0	1,530	270	1,260	2,335	4.4	-
8-NE-2	726	208	518	-	-	1,700
8-NE-4	134	190	-46	131	0.5	-
8-NE-6	186	206	-20	-	-	0
8-NE-8	ROAD		-	226	-	-
8-NE-10	416	158	258	-	-	850
8-NE-12	316	156	160	549	3.4	-
8-NE-14	344	146	198	-	-	650
8-NE-16	220	92	128	-	-	420
6-NW-4	570	138	432	-	-	1,400
6-NW-2	250	108	142	-	-	470
6-NW-0	384	228	156	-	-	520
6-NE-2	1,504	322	1,182	-	-	3,900
6-NE-4	148	178	-30	-	-	0
6-NE-6	150	114	36	-	-	120
6-NE-10	248	160	88	-	-	290
6-NE-12	180	112	68	-	-	220
6-NE-14	284	140	144	-	-	480
6-NE-16	272	148	124	-	-	410
4-NW-2	488	180	308	-	-	1,000
4-NW-0	490	170	320	952	3.8	-
4-NE-2	596	242	354	-	-	1,200
4-NE-4	318	172	146	806	4.6	-
4-NE-6	238	154	84	-	-	280
4-NE-10	ROAD		-	-	-	-
4-NE-12	120	112	8	-	-	<100
4-NE-14	294	114	180	-	-	600

* Based on 0.5 min counting time at each location.
** Dash indicates no IMP measurement at that location.

TABLE B-16-3. Continued

Stake No.	PG-2 (cpm) Down	PG-2 (cpm) Up	Net	IMP TRU (pCi/g)	IMP/PG-2 pCi/g / Net cpm	Estimated pCi/g(± 30%)
4-NE-16	220	106	114	360	3.2	-
2-NW-2	82	90	-8	-**	-	0
2-NW-0	220	90	130	-	-	430
2-NE-2	140	150	-10	-	-	0
2-NE-4	454	184	270	-	-	890
2-NE-6	194	130	64	-	-	210
0-NE-0	564	282	282	7,013	31.0	930
0-NE-2	456	194	262	-	-	870
0-NE-4	344	130	214	775	4.1	-
0-NE-6	176	114	62	-	-	200
2-SE-2	104	118	-14	-	-	0
2-SE-4	244	114	130	-	-	430
2-SE-6	106	96	10	-	-	<100
4-SE-4	56	66	-10	-	-	0
4-SE-6	1,872	118	1,754***	-	-	5,800***

* Based on 0.5 min counting time at each location.
** Dash indicates no IMP measurement at that location.
***"Hot-spot" only, not average for that location.

TABLE B-16-4. COMPARISON OF 28 MAY AND 2 JUNE PG-2 TRU CONCENTRATION ESTIMATES ON YVONNE

Grid Location	Estimated TRU (pCi/g) 28 May	Estimated TRU (pCi/g) 2 June
4-SE-4	<110	<110
0-NE-4	750	710
4-N-0	940	1,100
4-NE-16	300	380
8-NW-4	1,100	740
8-NE-16	240	420
12-NE-12	500	300
16-NW-8	680	460
16-NW-4	250	390
16-NE-12	230	310
20-NE-4	<110	60
20-NW-12	400	590

AOMON CRYPT IMP MEASUREMENTS

DOE/ERSP TECH NOTE NO. 17.0 DATED: 30 May 1979

AUTHOR: J. Jobst, EG&G

On 24 May 1979 DOE was requested by JTG to obtain IMP measurements on 9 stake locations just south of the Aomon Crypt sheet pile enclosure. Previous measurements east of the enclosure indicated that the east approach was clean; hence, trucks were permitted to approach the enclosure from the east and dump Tilda sand into the evacuated enclosure. If similar results were obtained on the south side, JTG planned to open this as an additional truck route. The following data were obtained on 25 May 1979 by IMP I (detector 483).

Stakes	^{241}Am (pCi/g)	TRU (pCi/g)
15.25-N-40	0.6	1.9
15-N-40.25	0.3	1.0
10-N-45.25	0.3	1.0
15.25-N-45	0.8	2.5
15-N-45.25	1.0	2.8
20-N-50	1.7	5.0
20-N-45.25	3.2	9.5
20.25-N-45	4.5	13.6
25-N-40.25	2.9	8.8

These data were accumulated at half-mast height (470 cm) so a correction factor of 1.05 was included in the americium results noted above. Soil sample data close to the source of the fill material (Tilda lagoon beach) showed a TRU/Am ratio of 3, which has been used to compute the last column. Since the TRU results are so low DOE indicated to J-3 (LTC Adcock) by radio, on 25 May, that DOE had no objections to using a south approach to the Crypt which pass over the above stake locations.

SOIL SAMPLING TO DEFINE THE BOUNDARIES OF SUBSURFACE ACTIVITY

DOE/ERSP TECH NOTE NO. 18.0 DATED: 25 June 1979

AUTHORS: B. Friesen, DRI
M. G. Barnes, DRI

The usual TRU subsurface sampling method has been to profile portions of the vertical interval from 0 to 120 cm. Discrete 5 cm samples have been taken at 0 to 5 cm and then centered on every 20 cm to maximum depth.

In contrast, the fission products sampling program required information on the entire 0 to 60 cm profile. Samples were taken in the intervals 0 to 5 cm, 5 to 10 cm, 10 to 15 cm, 15 to 25 cm, 25 to 40 cm, and 40 to 60 cm. As a result, a number of potential subsurface excision areas were identified on Irene and Pearl.

Severe time constraints on soil removal dictated that the boundaries of any potential excision area be determined as quickly and accurately as possible. The method described herein was specifically designed to achieve that goal. There are two aspects of the method: first, the use of IMP screening to speed resampling decisions; and second, the sampling method itself.

IMP Screening

A set of samples taken on day 1 would be prepared for counting in the usual manner the same day. The IMP detector would be used to count the samples on day 2, and the ^{241}Am results transmitted to the EG&G scientist by telephone as soon as the results were completed. Hard copy results would also be sent as soon as transportation became available. The data were converted to TRU and collated by the DRI statistician and the ERSP Tech Advisor. The next sampling iteration could then be planned in time for a mission on day 3. This method minimized time lags, and optimized use of sampling crews.

All samples with computed TRU activity exceeding 80 pCi/g were brought to the Enewetak lab for confirmation counting. Ten percent of the remaining samples were also counted in the lab for quality control purposes. The samples were counted "as is" in the lab, so all results were reported as pCi/g TRU, wet. Table B-18-1 gives the comparison of IMP with lab results for samples near 9-S-3 on Irene, counted both ways. Agreement was generally excellent; some of the few exceptions proved to be samples containing a very high-activity particle.

Sampling Method

The first step in the sampling process was to take soil samples for chemistry to confirm the TRU/Am ratio, which was known to change with depth on both Irene and Pearl. If the new ratio data indicated the TRU activity was actually less than 160 pCi/g for a location, it was dropped from further investigation.

Since the fission products sampling identified the depth that appeared to be above criterion, subsequent sampling checked the same interval. The intervals at 5 cm above and 5 cm below these "key" intervals were also sampled, to detect changes in the depth of the contamination "pocket". Once the horizontal boundary of the "pocket" had been determined, additional profiles were sampled within the boundaries with the usual TRU method, to determine the number of lifts required.

The sampling design is more efficient than a complete grid, in the sense of requiring fewer samples to define a boundary. It also reflects the requirement that subsurface activity be expressed as 1/16 hectare averages. Figure B-18-1 is the complete design for the first three sampling iterations. However, after the first iteration, only those samples were taken which were required to bound a location showing TRU activity exceeding 160 pCi/g. For example: if, in the first iteration,

only locations 1A and 1D exceeded 160 pCi/g TRU, and the others were lower, only locations 2A, 2B, 2F, 2G and 2H were sampled in the second iteration. If, of these, only 2H showed activity greater than 160 pCi/g, then only 3K and 3L would need to be sampled in the next iteration.

This was modified in practice to speed the process. If the general direction of the contamination pattern was evident, but not the extent, two iterations of samples would be taken at the same time in an attempt to "second-guess" the boundary's location. This modification was fairly successful in reducing the number of sampling missions.

The sampling distances were designed such that any four adjacent points in the same iteration together represent 1/16 hectare. Adjacent points in different iterations are also easily combined to form sample sets representing 1/16 hectare. From these combinations, it can be determined whether any 1/16 hectare has average TRU exceeding 160 pCi/g. This design also helps to determine the smallest area which, when excised, would reduce all 1/16 hectare average TRU activities below 160 pCi/g. This smaller area would be recommended to JTG for excision.

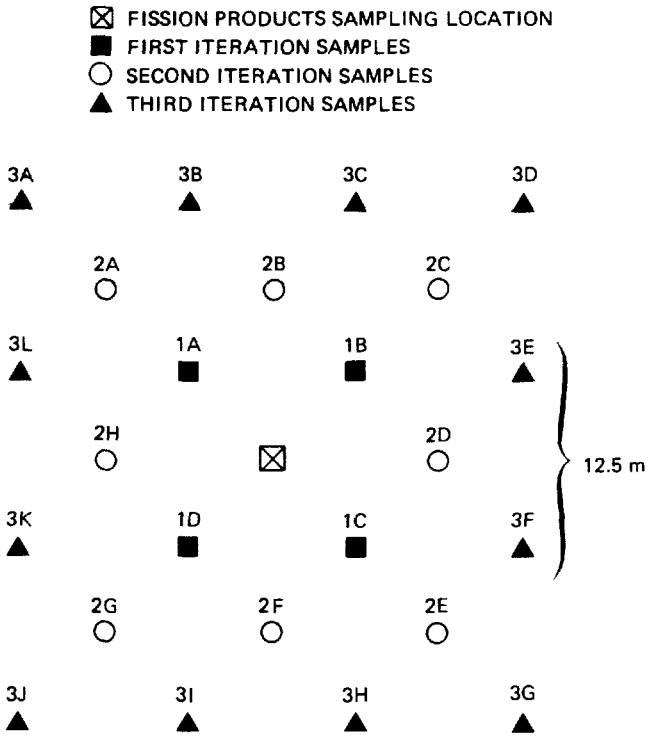


FIGURE B-18-1. SUBSURFACE ITERATIVE SAMPLING DESIGN

TABLE B-18-1. COMPARISON OF LAB WITH IMP ^{241}Am VALUES IN SOIL SAMPLES FROM IRENE

Location	Depth, cm	^{241}Am, pCi/g, Wet Wt. Imp	Lab
9.125-S-2.875	5 - 10	125	120
9.125-S-3.125	15 - 20	165	145
9.25-S-3.25	10 - 15	100	55
	15 - 20	75	44
9-S-3.25	5 - 10	65	66
	10 - 15	120	100
	15 - 20	190	125
8.875-S-3.125	5 - 10	165	145
	10 - 15	105	60
8.875-S-3.375	5 - 10	100	116
	10 - 15	100	89
8.75-S-3.25	5 - 10	140	134
	10 - 15	315	246
	15 - 20	260	244
8.625-S-3.125	10 - 15	155	119
	15 - 20	1,015	1,017
8.5-S-3.25	5 - 10	215	205
	10 - 15	155	186
	15 - 20	85	61
8.5-S-3.5	5 - 10	250	281
	10 - 15	220	226
	15 - 20	185	158

ESTIMATION OF AVERAGE TRU ACTIVITY IN SOIL SUBSURFACE INTERVALS DIFFERENT FROM THOSE SAMPLED

DOE/ERSP TECH NOTE NO. 19.0 DATED: 4 August 1979

AUTHOR: M. G. Barnes, DRI

In order to determine whether an island meets Condition D*, information is needed about the TRU activity in any 5 cm subsurface soil depth increment. However, subsurface sampling normally includes the intervals 0 to 5 cm, 5 to 10 cm, etc., to some predetermined maximum depth. Thus, if it is not immediately clear from the sampling data whether or not condition D is satisfied, estimates must be made of activity in other intervals. This note describes a method of making such estimates, and gives an example of its use for data from islands Belle and Daisy. The method can be applied to any set of data for which the assumptions mentioned below hold.

On an island where fallout is the main source of contamination, with natural weathering the primary process affecting redistribution of contamination in the soil, it is reasonable to accept an exponential decline in contamination with depth. That is, the TRU activity at depth x, denoted TRU (x), is described by the equation:

$$TRU(x) = ke^{-cx}$$

where k is the surface activity and c is a constant. This assumption is common in the radiological literature, including, for example, NVO-140.

Given k and c, the average activity over any 5 cm depth interval, say x_1 to $x_1 + 5$, is:

$$\frac{1}{5}\int_{x_1}^{x_1+5} ke^{-cx}\,dx = \frac{k}{5\,c}\left(e^{-cx_1} - e^{-c\,(x_1+5.)}\right)$$

Ordinarily, however, all that is available is the sampling data, which is already in the form of averages over 5 cm intervals. In this case, if the assumption of exponential decline in activity with depth is correct, k and c can be estimated from the data. For example, if the 0 to 5 and 5 to 10 cm intervals were sampled, with activity measured as a_1 and a_2 respectively, then we have:

$$a_1 = \frac{1}{5}\int_0^5 ke^{-cx}\,dx = \frac{k}{5\cdot c}\left(1 - e^{-5c}\right).$$

$$a_2 = \frac{1}{5}\int_5^{10} ke^{-cx}\,dx = \frac{k}{5\cdot c}\left(e^{-5c} - e^{-10c}\right).$$

Then

$$\frac{a_2}{a_1} = \frac{e^{-5c} - e^{-10c}}{1 - e^{-5c}} = \frac{e^{-5c}(1 - e^{-5c})}{1 - e^{-5c}} = e^{-5c}$$

and $c = -\frac{1}{5}\ln\left(\frac{a_2}{a_1}\right)$;

hence $k = \frac{a_1\cdot 5\cdot c}{\left(1 - e^{-5c}\right)}$.

*Condition D requires that the TRU activity in any 5 cm depth interval below the surface not exceed 160 pCi/g when averaged over 1/16 ha.

The estimation procedure for other sampling intervals is quite similar.

Even if the distribution of activity in undisturbed soil were exponential, it is unlikely to remain exponential if the soil is disturbed to any appreciable extent. As an example, bulldozer disturbance during lane clearing often causes mixing in the top 10 cm or so of the soil in the lane. In these locations, the distribution of activity is likely to be linear to the depth of the disturbance, as indicated by Tech Notes 4, 9.0 and 9.1.

For the case of a linear distribution of activity, the average of any intervals contained within the disturbed profile can be calculated easily. For instance, assume again that the 0 to 5 and 5 to 10 cm intervals were sampled, with measured activities a_1 and a_2 respectively, and that the distribution of activity is linear from the surface to 10 cm. Then the activity at a depth x ($x \leq 10$ cm) is represented by the equation:

$$TRU(x) = m \cdot x + b$$

where m and b are constants. These can be estimated from the data, since the average of a linear function over an interval is the value of the function at the midpoint of the interval. That is, a_1 is the activity at 2.5 cm and a_2 is the activity at 7.5 cm. Therefore:

$$m = \frac{a_2 - a_1}{7.5 - 2.5} = \frac{1}{5}\left(a_2 - a_1.\right)$$

Also,

$$a_1 = 2.5\ m + b = 0.5\ (a_2 - a_1) + b,$$

so,

$$b = 1.5a_1 \quad - 0.5a_2.$$

Then the average over an interval from x_1 to $x_1 + 5$ would be:

$$\frac{TRU(x_1) + TRU(x_1 + 5)}{2} = \frac{mx_1 + b + m(x_1 + 5) + b}{2},$$

which simplifies to:

$$m(x_1 + 2.5) + b.$$

If an interval contains some activity with linear distribution and some with exponential, the average can still be estimated. The two sub-intervals can be estimated separately with appropriate modifications to the equations above. The average for the whole interval is then the weighted sum of the sub-interval averages, the weighting factor being the proportion of the whole contained in the respective parts.

Example Estimates from Islands Belle and Daisy

On the islands Belle and Daisy, there were a number of locations sampled in the 0 to 5, 5 to 10 and, in some cases, the 10 to 15 cm intervals. The subsurface interval with highest activity was 2.5 to 7.5 cm, so it was necessary to estimate the TRU activity in this interval.

The assumption that activity dropped exponentially with depth appeared to be generally reasonable. Figure B-19-1 shows the 5 cm average TRU activity as a function of depth at 15 sample sites in the vicinity of one stake location on Belle; the pattern of activity is typical of both Belle and Daisy. However, at disturbed locations with all very low activities, the distribution appeared to be linear, at least to 10 cm. See Table B-19-1 for example. Of the two obvious exceptions to the pattern in Figure B-19-1, one is a disturbed area, the other had measured TRU activities that were barely detectable.

Since the 5 cm averages are exponential, the underlying distribution must also be exponential. If so, the computed values of c should be similar from one location to another (though k would certainly not be constant). It is easier to actually work with 1/c for comparison rather than c, since 1/c, commonly called the "relaxation length," has units of distance, in this case centimeters.

Figures B-19-2 and 3 are histograms of the values of 1/c computed from the 0 to 5 and 5 to 10 cm samples and the 5 to 10 and 10 to 15 cm samples, respectively. While each set has some outliers, the bulk of the values lie between 1.5 and 3.5 cm, and the two medians, at 2.51 and 3.09 cm, are quite close together. Since the only data not included in these figures are from disturbed locations or locations where all activity was low, the conclusion of an exponential activity distribution with depth seems well justified.

In view of the foregoing, the activity in the 2.5 to 7.5 cm interval was computed using the methods described here for each location on Belle and Daisy where this information was required. At disturbed locations and those with very low activity, a linear distribution was assumed; at all other locations, an exponential form was used. Average TRU activities over 1/16 areas were then computed by using the simple means of the 2.5 to 7.5 cm estimates.

TABLE B-19-1. TRU ACTIVITY IN TYPICAL SUBSURFACE SAMPLES FROM ISLAND BELLE

(MDA = Less than minimum detectable activity)

Location	Average TRU Activity in Interval, pCi/g		
	0 - 5 cm	5 - 10 cm	10 - 15 cm
16-S-8*	96	178	10
16.125-S-7.875	433	52	16
15.875-S-7.875	60	10	5
16.125-S-8.125	167	6	<MDA
15.875-S-8.125	279	5	7
16.25-S-7.75	178	26	7
15.75-S-7.75	95	40	17
16.25-S-8.25	75	5	3
15.75-S-8.25	6	8	<MDA
16.5-S-8	41	5	5
16.5-S-7.5	671	31	5
16-S-7.5	303	34	6
15.5-S-7.5	268	24	14
16.25-S-7.25	42	5	<MDA
15.75-S-7.25	106	32	6
14-S-2*	289	181	32
6-N-2*	130	224	26
5.25-N-1.75	<MDA	<MDA	<MDA
6-N-1.5	6	5	<MDA
5.25-N-1.25	6	11	<MDA

* Disturbed locations

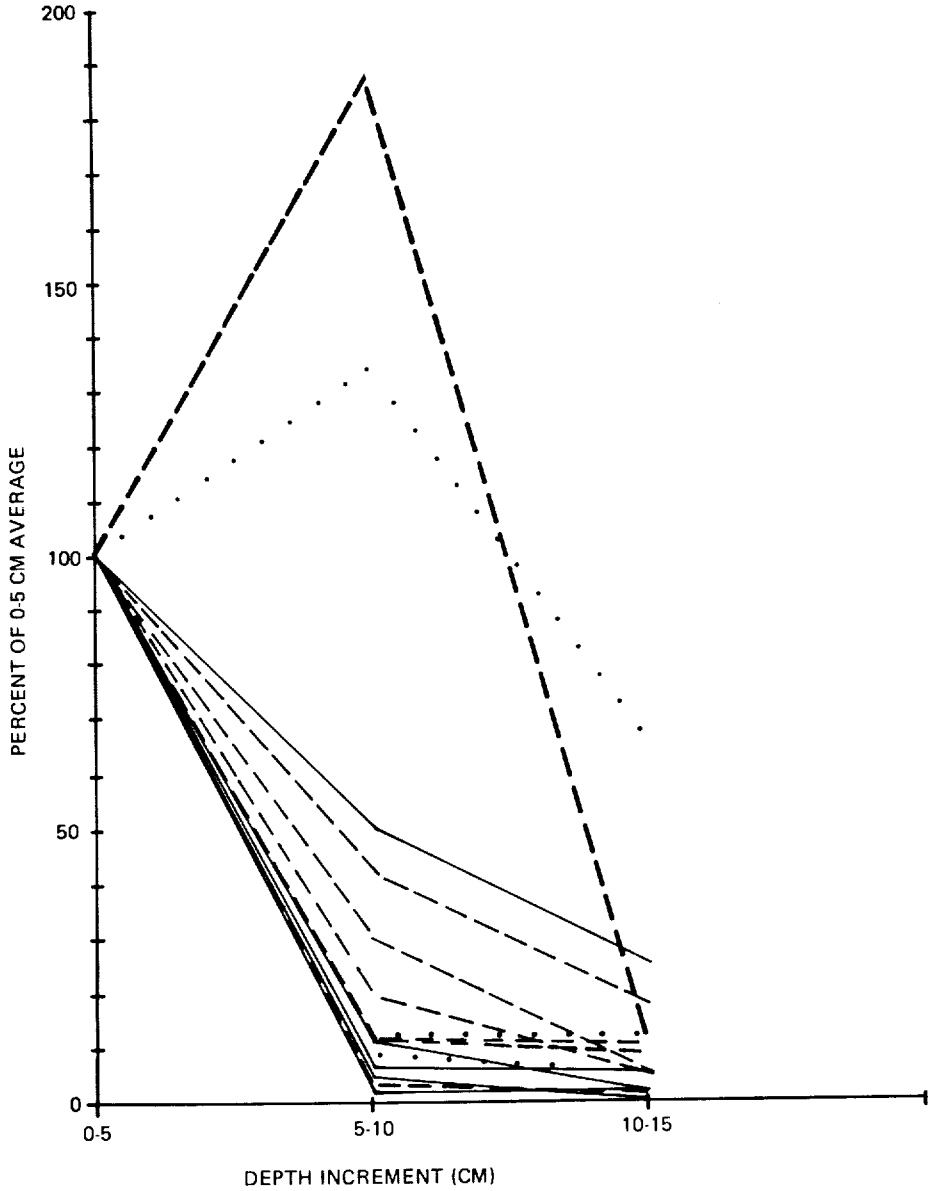


FIGURE B-19-1. TRU ACTIVITY AS A FUNCTION OF DEPTH, LOCATION 16S8, ISLAND BELLE

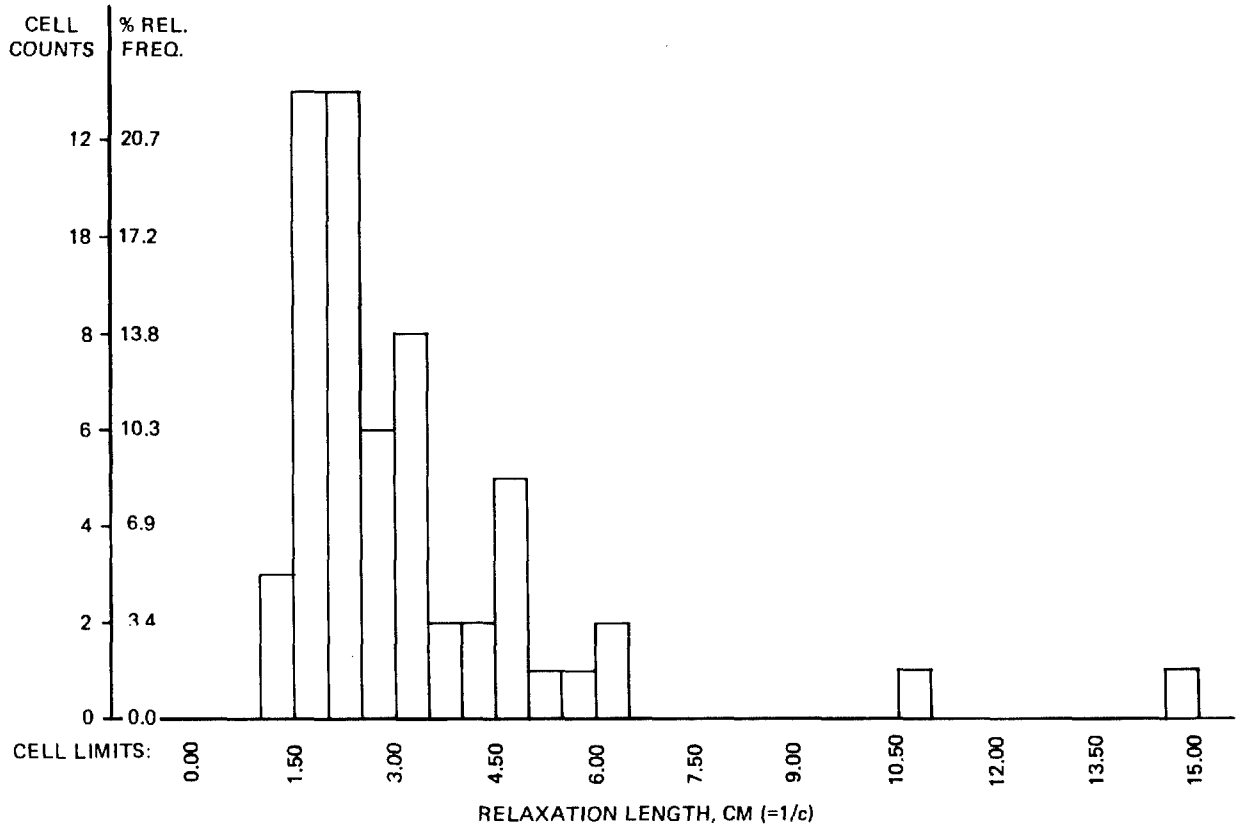


FIGURE B-19-2. HISTOGRAM OF "RELAXATION LENGTHS," COMPUTED FROM 0-5 AND 5-10 CM SAMPLES DATA FROM ISLANDS BELLE AND DAISY

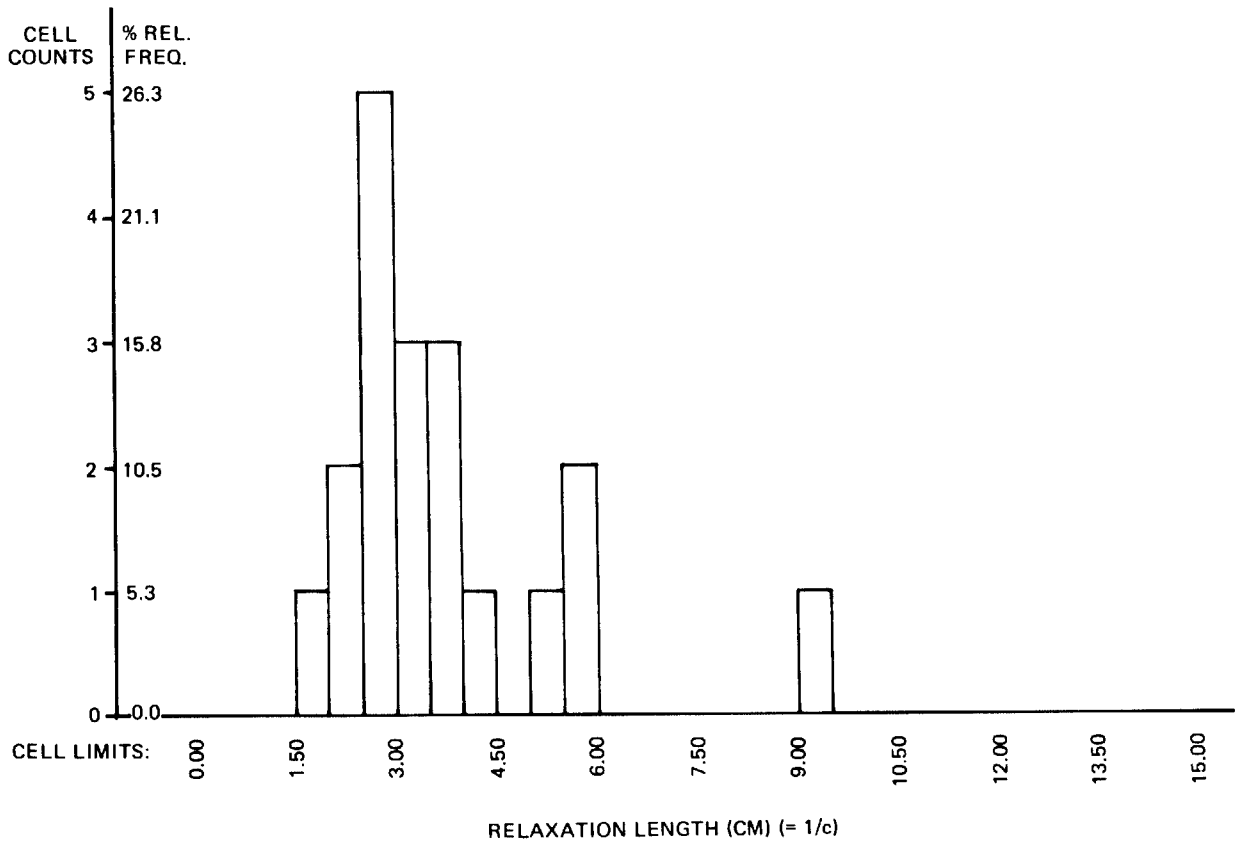


FIGURE B-19-3. HISTOGRAM OF "RELAXATION LENGTHS," COMPUTED FROM 5-10 AND 10-15 CM SAMPLES DATA FROM ISLAND BELLE

ERRORS AND ERROR PROPAGATION IN COMPUTED TRU ACTIVITY

DOE/ERSP TECH NOTE NO. 20.0 DATED: 5 March 1980

AUTHOR: Madaline Barnes, DRI

The data used in computing TRU activity were of several different types, and each type came from a different source. The bulk of the data was measured values of ^{241}Am provided by EG&G and extracted from spectra generated by the IMP detector. The peak areas were computed from net photopeak count rates, and the conversion to pCi/g was made using a factor determined by EG&G. In some cases correction factors related to the detector were also applied. The determination of when to apply such corrections and the amount of the correction were made by the EG&G scientist. The statistician received the uncorrected ^{241}Am values, and the list of corrections, if necessary. The actual corrections were always made by the statistician to reduce confusion and error.

Data used for computing TRU to ^{241}Am ratios were provided by EIC. These consisted of data from a chemical and alpha spectroscopic analysis of soil for ^{238}Pu, $^{239,240}Pu$ and a gamma analysis for ^{241}Am. Some samples also were analyzed chemically for ^{241}Am to provide a check on the gamma results. The gamma spectra were analyzed using methods very similar to those used by EG&G. The ratio was computed by the statistician, usually with ^{241}Am by gamma; sometimes ^{241}Am by chemistry was used due to detector problems or when samples had low activity. The decision about which type of ^{241}Am data to use was made by the statistician.

The third type of data used in TRU computations was a correction for signal attenuation to the IMP detector due to heavy brush. The correction factor, called the Brush Correction Factor (BCF), was determined empirically to be about 1.15 in an experiment done early in the cleanup on Island Pearl, which was supervised by the EG&G scientist. Details of the experiment and computation of the BCF are in Tech Notes 1.0 and 1.1. The proportion of the detector view that was covered by brush at each location was determined subjectively by the IMP technician in the field. The information was added to the stored spectrum at the time of sampling.

The general formula used for computing TRU is:

$$TRU = Am \times R \times (1-Br) + Am \times R \times Br \times 1.15 = (Am+0.15 \times Am \times Br) \times R$$

where

TRU = computed activity of $^{238}Pu + ^{239,240}Pu + ^{241}Am$

Am = measured ^{241}Am activity

R = computed ratio of $^{238}Pu + ^{239,240}Pu + ^{241}Am$ to ^{241}Am

1.15 = factor to correct for attenuation from 100% brush error

and

Br = proportion of detector view covered by brush

Possible detector-related corrections were adjustments for crystal effective area or changes in detector efficiency. During one time period in early 1978, one detector was operated at an incorrect voltage, and corrections had to be made to this data. For details on the voltage corrections, see Tech Notes 5, 5.1, and 5.2. Whenever any such corrections were required, they were made on the ^{241}Am value, which was then used in the general formula.

Sources of Error

Each type of data was subject to various kinds of error, only some of which were included on the error propagation computation.

The error term that was used for ^{241}Am from the IMP included a counting error based on assuming a Poisson distribution for photons falling in a certain channel of the spectrum. A blanket 10 percent of the actual value was added to this error to cover errors due to differences in soil density, depth distribution of activity in the soil, soil composition, etc.

Other errors not included in the propagation were uncertainty on the additional correction factors and inaccuracy of the net photopeak count computation due to gain shifts or resolution changes.

The error term on the ratio was based on the assumption that the variance of the TRU value increased linearly with ^{241}Am activity. The counting error on the ^{241}Am by gamma or chemistry was not included, nor were possible errors in the peak computation. Therefore, the equation used to compute the error on the ratio is only approximate, and not exact.

The error used with the BCF was the computed sample standard deviation on the experimental results. The experiment was performed on only one island, which had denser brush than many islands, and a mix of vegetation species different from some islands. It is therefore possible that there is a bias in the factor, or that the computed error might be incorrect for other islands.

Error Propagation

As indicated above, the three types of error included in the error propagation were the counting error on the IMP ^{241}Am value plus 10 percent of the actual value, the sample variance of the TRU/Am ratio data, and the sample variance of the experimental BCF data. The three variables involved were assumed to be independent, and the error was therefore computed in two steps:

1. The error on Am corrected for brush attenuation is:

$$S_C^2 = (Am^2 \times S_B^2 + 0.15^2 \times S_{Am}^2 + S_B^2 \times S_{Am}^2) \times Br^2 + S_{Am}^2$$

where

Am = measured ^{241}Am value

0.15 = brush attenuation correction factor minus one

S_{Am}^2 = counting error on ^{241}Am plus 10 percent of actual value

S_B^2 = sample variance of the BCF

S_C^2 = estimated variance of corrected Am

and

Br = proportion of brush in dectector view

The last term in parentheses was inadvertently left out of the program which did these computations, but the effect is in general relatively minor.

2. The error on the final TRU number corrected for brush is then:

$$S_F^2 = S_R^2 \times C^2 + S_C^2 \times R^2 + S_C^2 \times S_R^2$$

where

R = estimated ratio of TRU to ^{241}Am

C = estimated Am, corrected for brush attenuation

S_C^2 = the variance estimated in step 1

S_R^2 = sample variance of the estimated ratio

and

S_F^2 = estimated variance of final TRU value

The last term in this equation was also inadvertently left out of the program, but the effect is again relatively minor.

The estimated S_F was stored along with the final estimated TRU activity. In those cases where the data were used in kriging, the S_F values were incorporated in the equations used to find the optimum set of weights for the weighted moving average estimate. The effect of this was to make values having larger errors have less influence on the computed $_i$ than values with smaller errors. Also the variance of the kriging error was larger because these measurement variances were taken into consideration. Hence, the end effect of taking the propagated error into account was to make the 0.5 sigma upper bound on the final estimates larger.

Ranges and Distributions of Actual Errors

As shown in Figure B-20-1, the actual standard deviation estimate from the error propagation described above ranged from near 0 to over 50 pCi/g. Most of the standard deviation values were 30-40 percent of the TRU values as illustrated in Figure B-20-2. The two propagated errors which exceed 100 percent of the TRU value are associated with ^{241}Am values that were near or below the minimum detectable activity.

The propagated errors include the counting error plus 10 percent of the ^{241}Am value from the IMP, which typically ranged from 0.5 to 2.5 pCi/g, as shown in Figure B-20-3, with a few values outside this range. Also included were an estimated error on the TRU/Am ratio and on the factor used to correct for brush cover. Figure B-20-4 is a histogram of the estimated errors for all the ratios used on the northern islands, and Figure B-20-5 shows the experimentally-determined brush correction factors. Only a counting error plus 10 percent for the IMP ^{241}Am value was included because the reproducibility of the IMP value, as shown by Figure B-20-6, indicated that no other contribution to the sample variance needed to be added. In fact, the sample standard deviation for this set is 0.41 pCi/g, yet estimating the standard deviation from the counting errors gives 1.35 pCi/g. The counting errors overestimate the standard deviation because of the addition to the error of an arbitrary 10 percent of the actual value to allow for differences in the parameters which affect the factor which converts counts to pCi/g.

The computed TRU values include a correction for detector effective area changes, but no error term for the correction factor. As shown by Figure B-20-7, these errors were almost always less than 0.5 square centimeter (for a theoretical area of 19 square centimeters). This gives an error of less than 3 percent in the correction factor; in most cases the error was less than 1 percent.

The propagated error values were taken into consideration in making the kriging estimates of 0.25 and 0.5 hectare averages. The standard deviation of the kriging error is affected by the propagated errors, the variogram model used, and the geometry of the sampling points used for each estimate. Figure B-20-8 shows the distribution of standard deviations of the kriging error for northern islands for a standard neighborhood of sampling points, which is either a 3x3 or 4x4 array of points. The standard deviation is typically less than 6 pCi/g.

Other Errors not in Propagation Computation

There are some other errors which were not included in the propagation, but which can be estimated. The counting errors on the laboratory gamma scans of soil, seen in Figure B-20-9, and alpha spectroscopy of soil chemistry results, seen in Figure B-20-10, were not included. They were left out because they affect the TRU value only indirectly, through the TRU/Am ratio, for which a standard deviation was included in the propagation. Another error not included was that due to soil

disturbance in the access lanes. No precise estimate of this is available, but the experiment described in Tech Note 4.0 indicated that it is on the order of 2 percent.

A possible source of error that was not included is a bias in the estimates of brush cover, which were subjective. There appeared to be good agreement between the two regular IMP operators, but there may have been differences in judgment for substitute operators. For example, the two brush distributions for Belle shown in Figure B-20-11 and B-20-12 are quite different. Figure B-20-11 comes from the initial survey by an experienced operator, and Figure B-20-12 from a later survey by a substitute operator. As shown by Figure B-20-13, the later brush estimates are consistently lower. No brush removal occurred between the surveys, and seasonal variations would result in more cover during the later survey, not less, so the difference is not due to a real change in brush cover. However, at a maximum, the computed TRU value is only 6 percent higher for the original brush estimate than for the later estimate. No other information on the presence or extent of this possible bias is available.

Table B-20-1 shows the range of values for the sources mentioned above for which a standard deviation can be estimated. There are also other possible errors which cannot be estimated. For example, during the fall of 1977, the soil sampling procedure was being done incorrectly for some unknown length of time. Because the TRU/Am ratio remains fairly constant on an island, the mistake was assumed not to have affected the data adversely, but there is no way to check this assumption. There were also a number of equipment problems such as changes in detector efficiency or resolution and analyzer malfunction. Many of these were detected and corrected, but others may have been overlooked. Similarly, human errors crept in, for instance on sample labels, sample weights and results transcriptions. All of these that were found have been corrected, but some may have been missed. The data were checked several times to minimize these "man and machine" errors, but it is unlikely that they were eliminated totally. Overall, however, the propagated error value represents a reasonably good assessment of the TRU measurement variance, since all of the significant contributors to that variance are included.

TABLE B-20-1: RANGES OF STANDARD DEVIATION ESTIMATES

Source	Location	Ranges of Values
Propagated error on TRU, pCi/g	Janet	0.6 - 51.6
Propagated error on TRU, percent	Janet	27 - 398
Counting error-IMP ^{241}Am, pCi/g	Janet	0.1 - 4.6
Standard deviation of TRU/Am ratio*	Northern Islands	0.12 - 2.72
Computed brush correction factor	Pearl	1.05 - 1.42
IMP ^{241}Am-reproducibility study, pCi/g	Pearl	7.6 - 9.0
Standard deviation of detector effective area measurements, cm^2	Lojwa	0.07 - 0.58
Standard deviations of kriging error, pCi/g	Northern Islands	0.6 - 16.2
Counting error-lab gamma data, pCi/g	Janet	0.17 - 1.66
Counting error-lab alpha Spectroscopy data, pCi/g	Janet	0.19 - 6.39

*Due to a programming error the standard deviations reported here are overestimated.

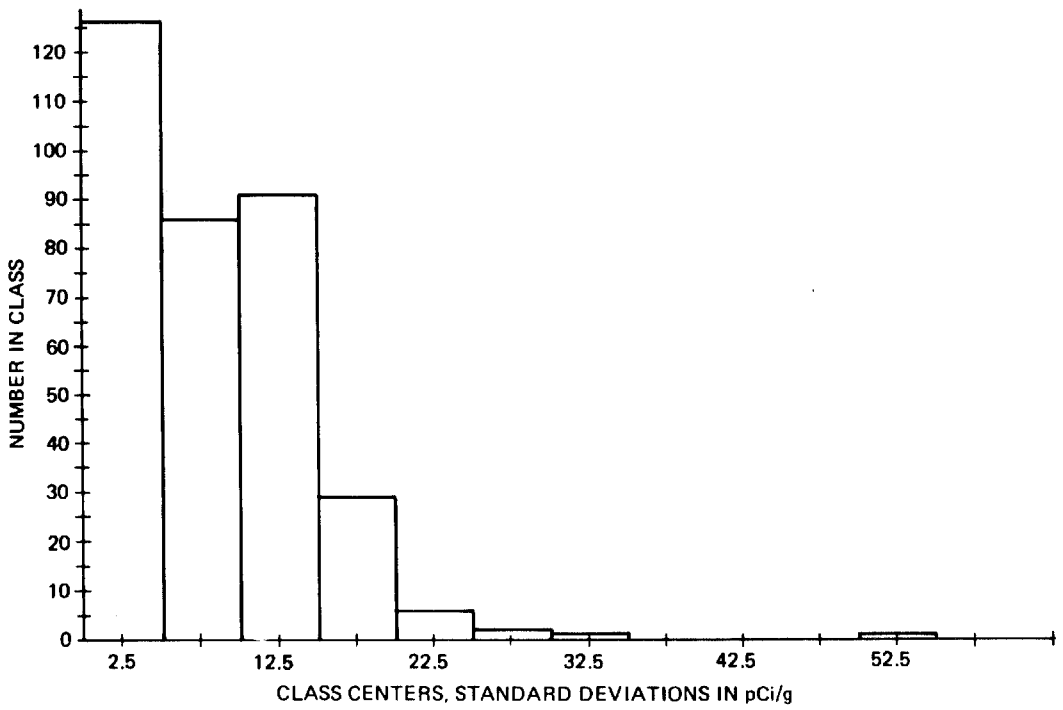


FIGURE B-20-1
PROPAGATED ERRORS ON TRU VALUES ON JANET

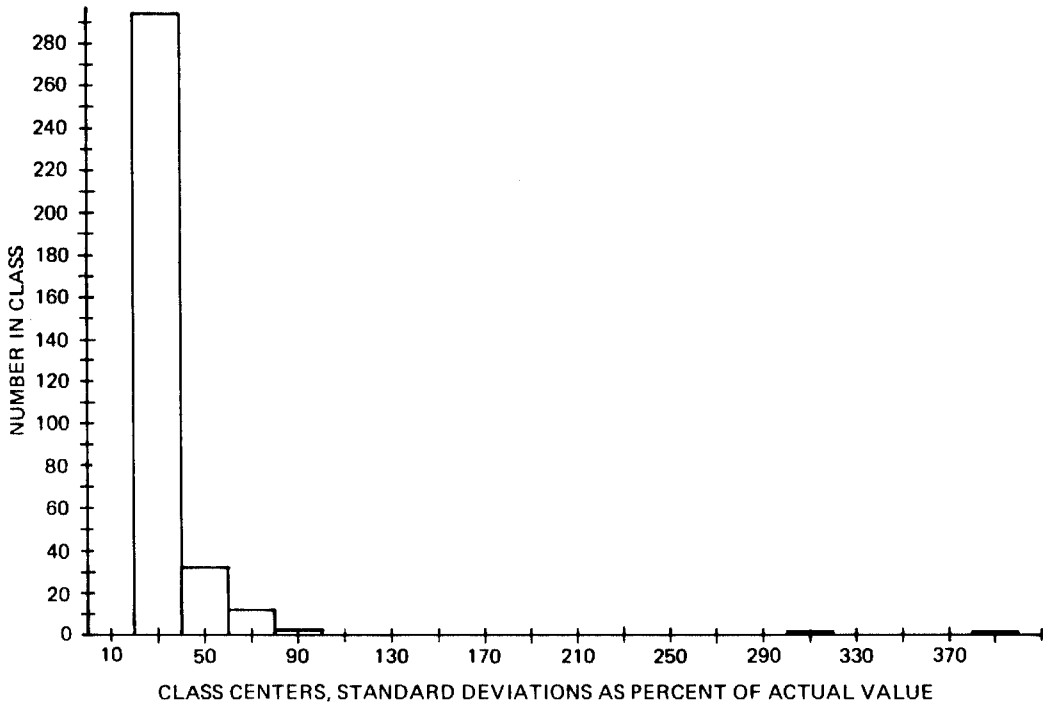


FIGURE B-20-2

PROPAGATED TRU ERRORS FROM JANET

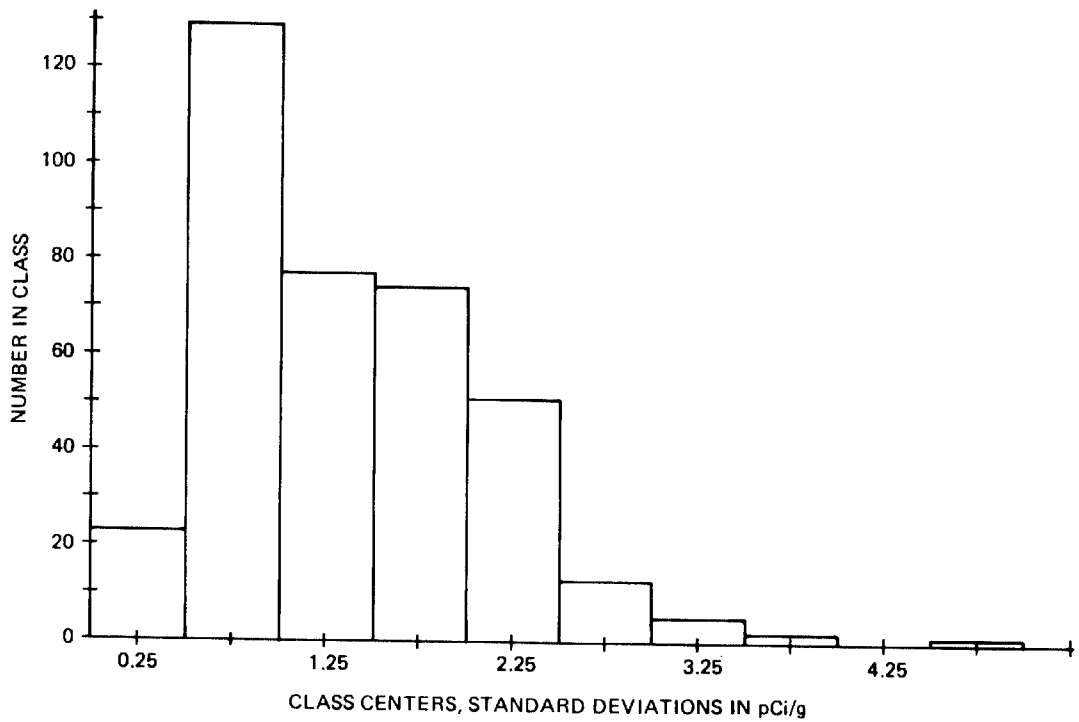


FIGURE B-20-3
ERRORS ON Am-241 VALUE FROM JANET IMP DATA

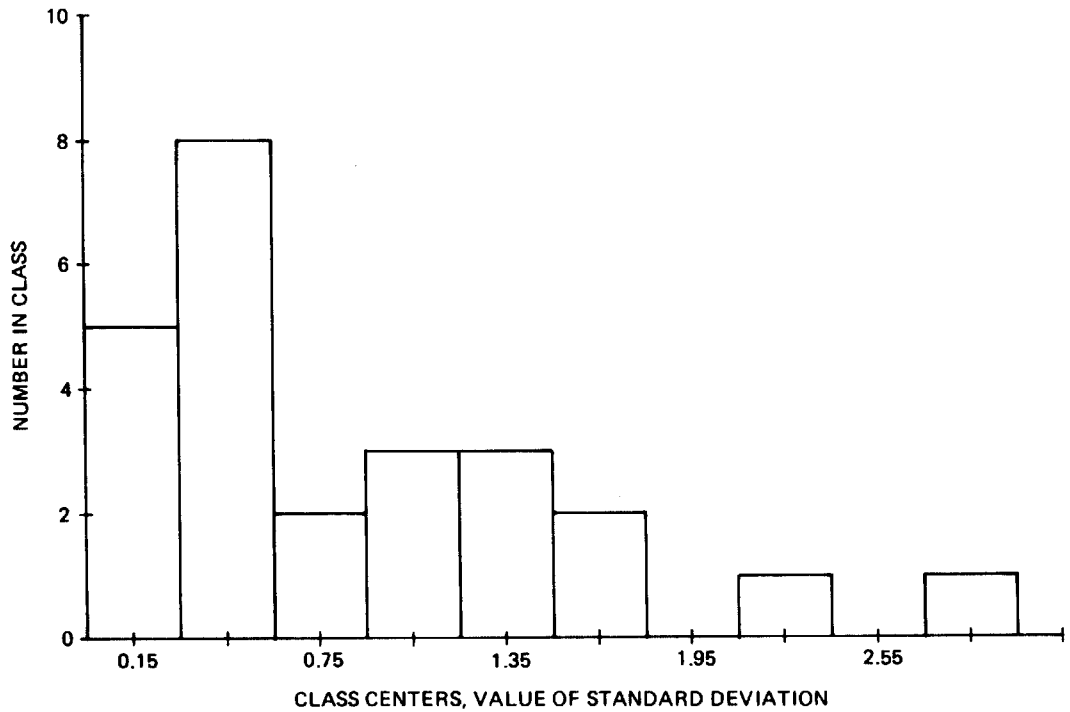


FIGURE B-20-4

ESTIMATED ERRORS ON TRU/Am RATIO FOR NORTHERN ISLANDS

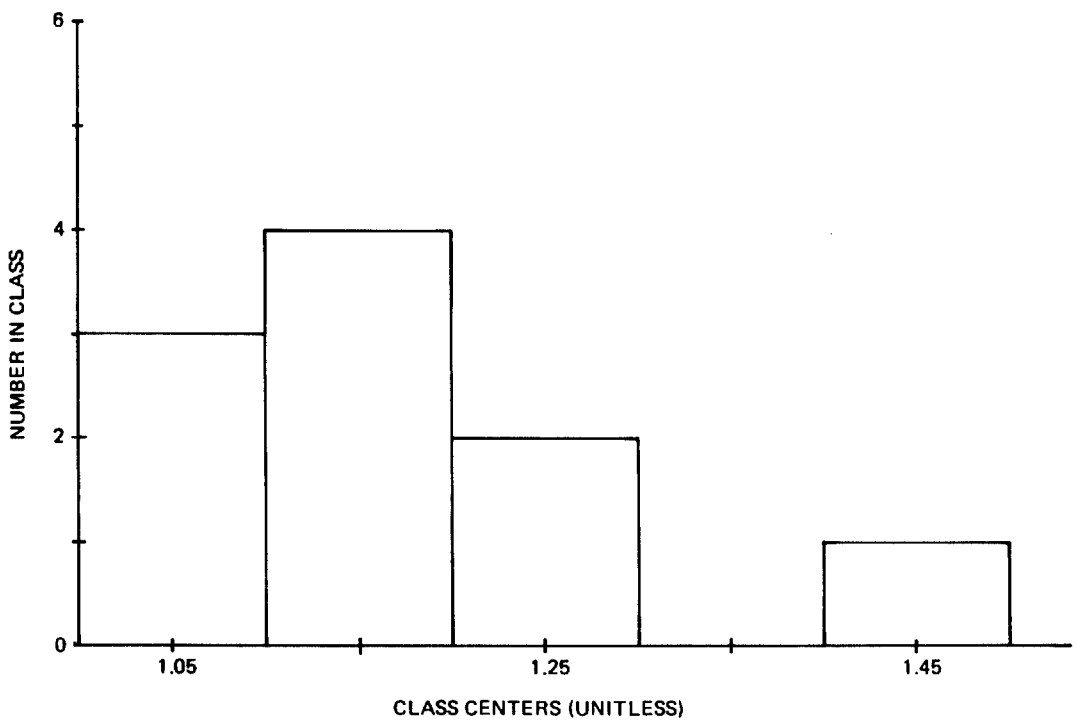


FIGURE B-20-5

COMPUTED VALUES OF BRUSH CORRECTION FACTOR FROM PEARL EXPERIMENT

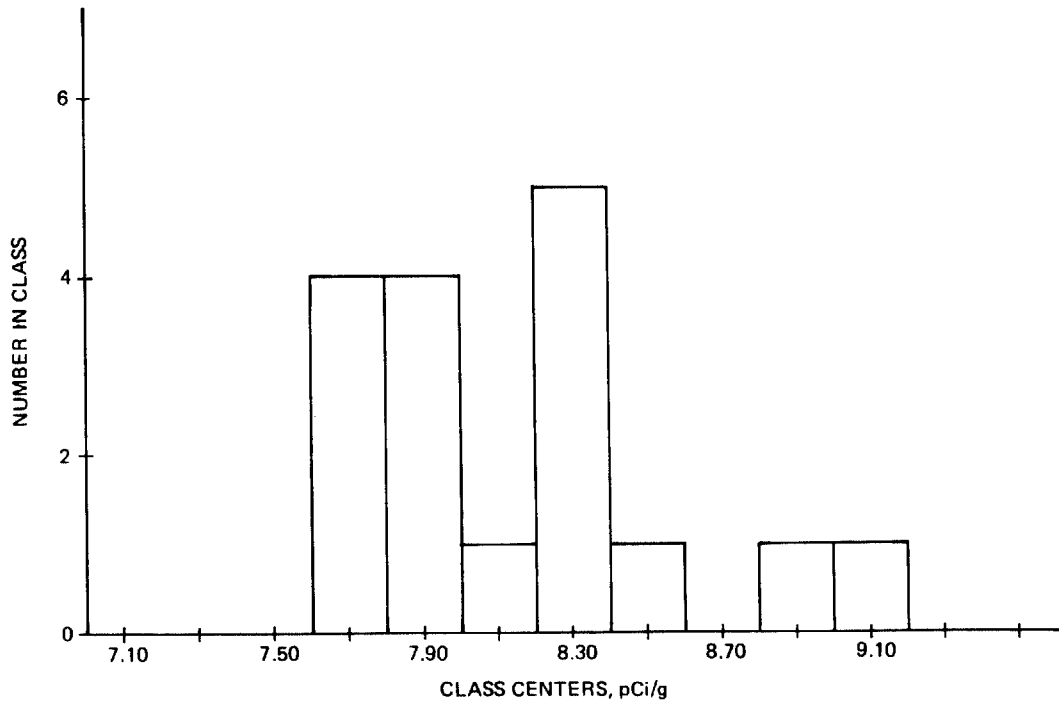


FIGURE B-20-6

RANGE OF Am-241 VALUES IN REPRODUCIBILITY STUDY ON PEARL

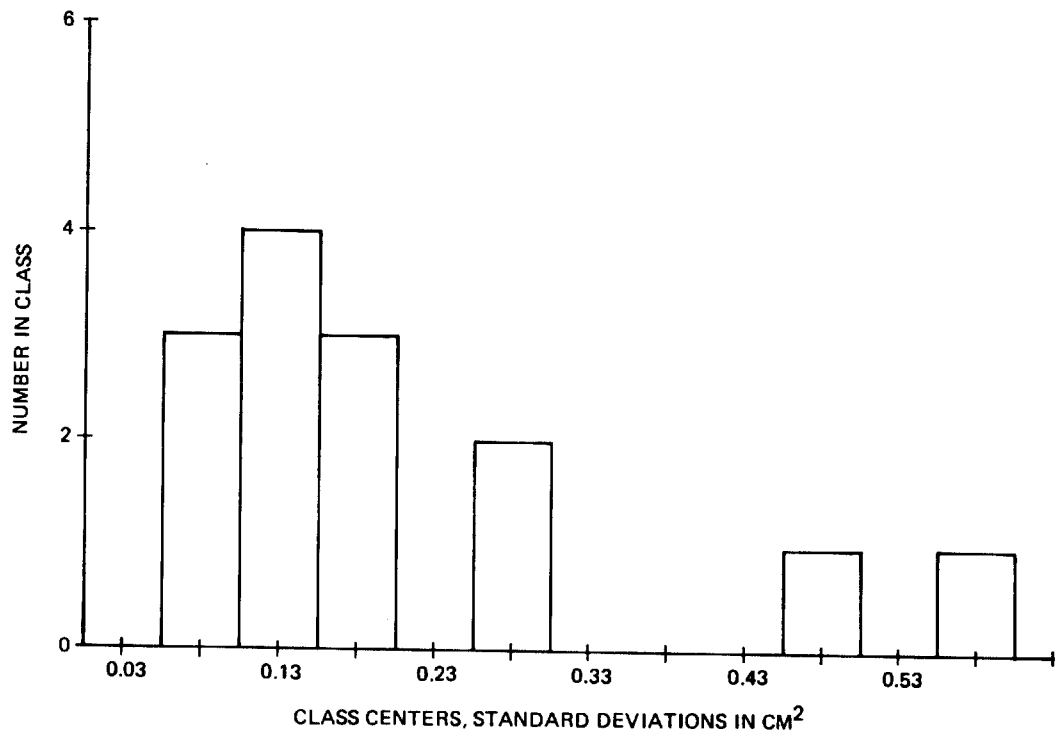


FIGURE B-20-7
ERRORS ON CRYSTAL EFFECTIVE AREA MEASUREMENTS
(THEORETICAL AREA = 19 cm^2)

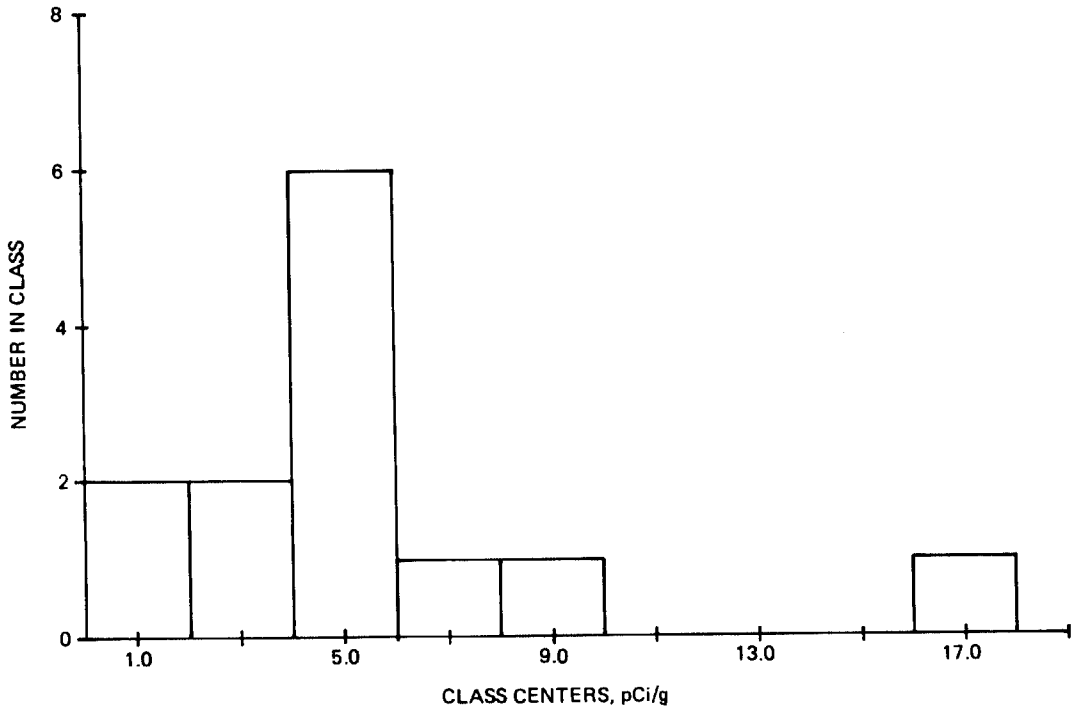


FIGURE B-20-8

STANDARD DEVIATION OF KRIGING ERROR FOR STANDARD NEIGHBORHOOD NORTHERN ISLANDS

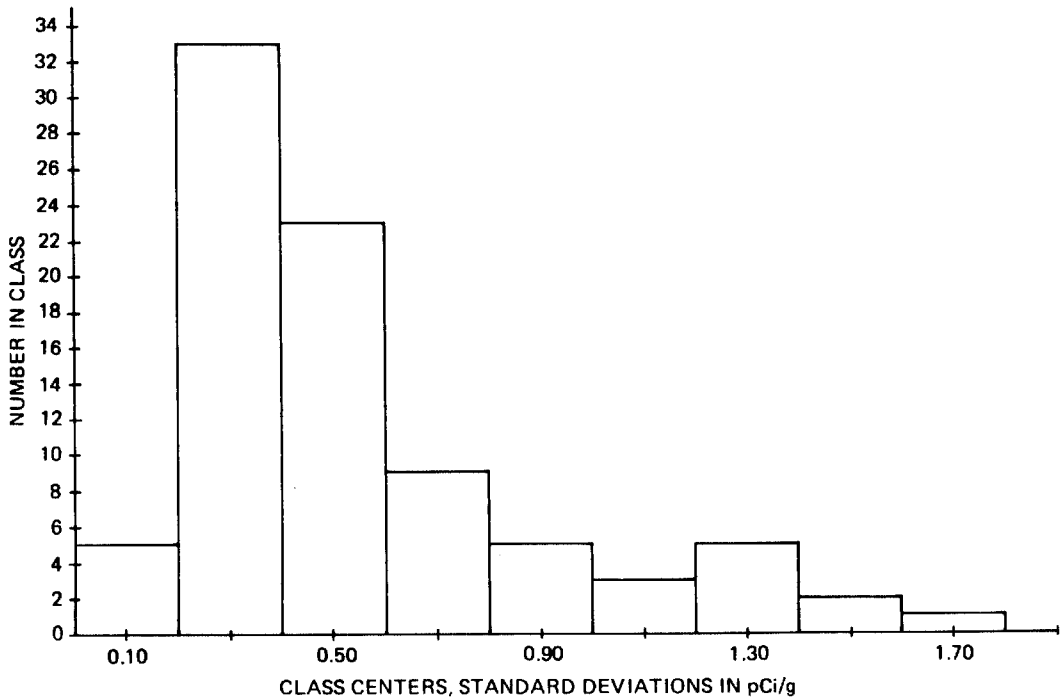


FIGURE B-20-9

ERRORS FROM LAB GAMMA ANALYSIS OF SOIL FROM JANET

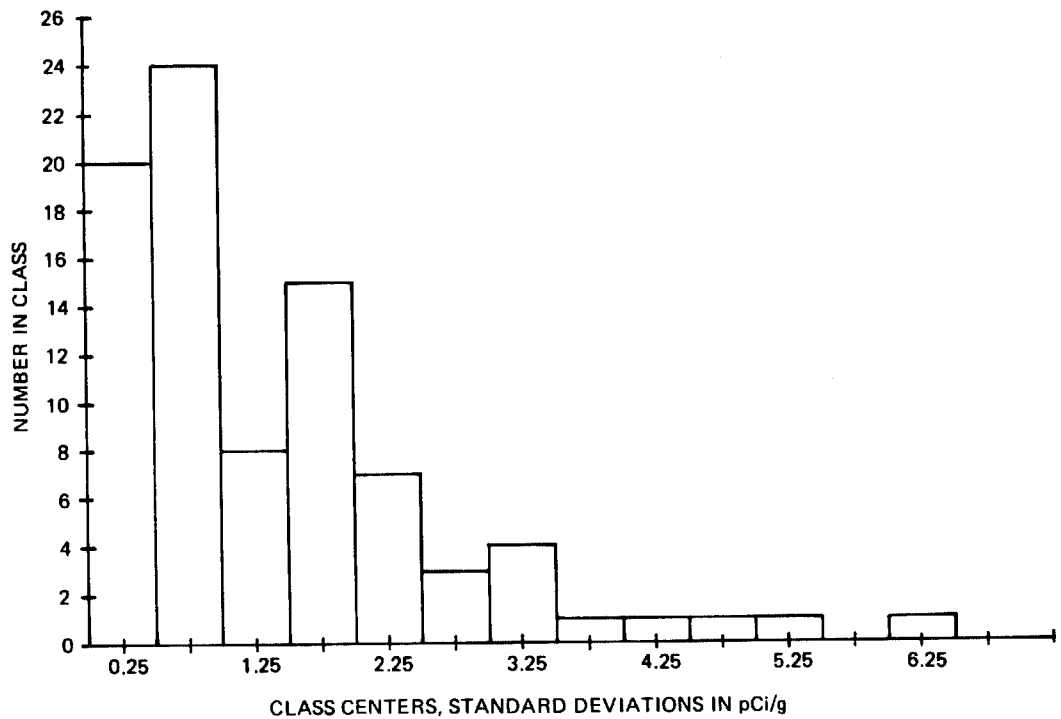


FIGURE B-20-10

ERRORS FROM ALPHA SPECTROSCOPY OF CHEMICALLY-EXTRACTED SOIL FROM JANET

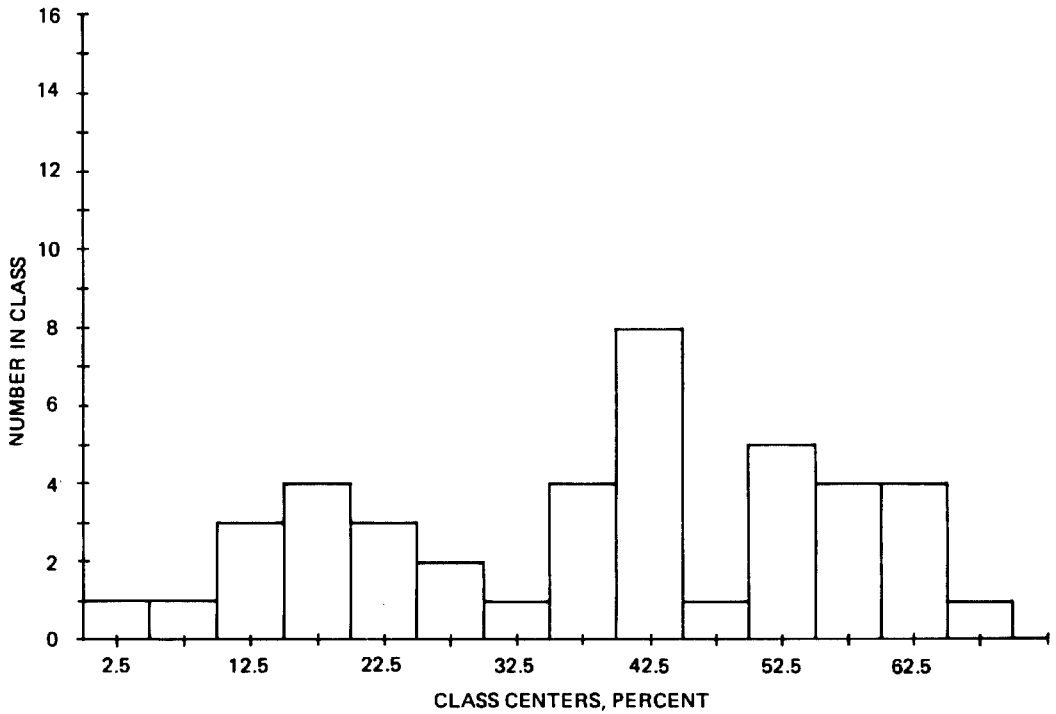


FIGURE B-20-11

BRUSH ESTIMATES BY IMP OPERATOR ON FIRST SURVEY OF BELLE

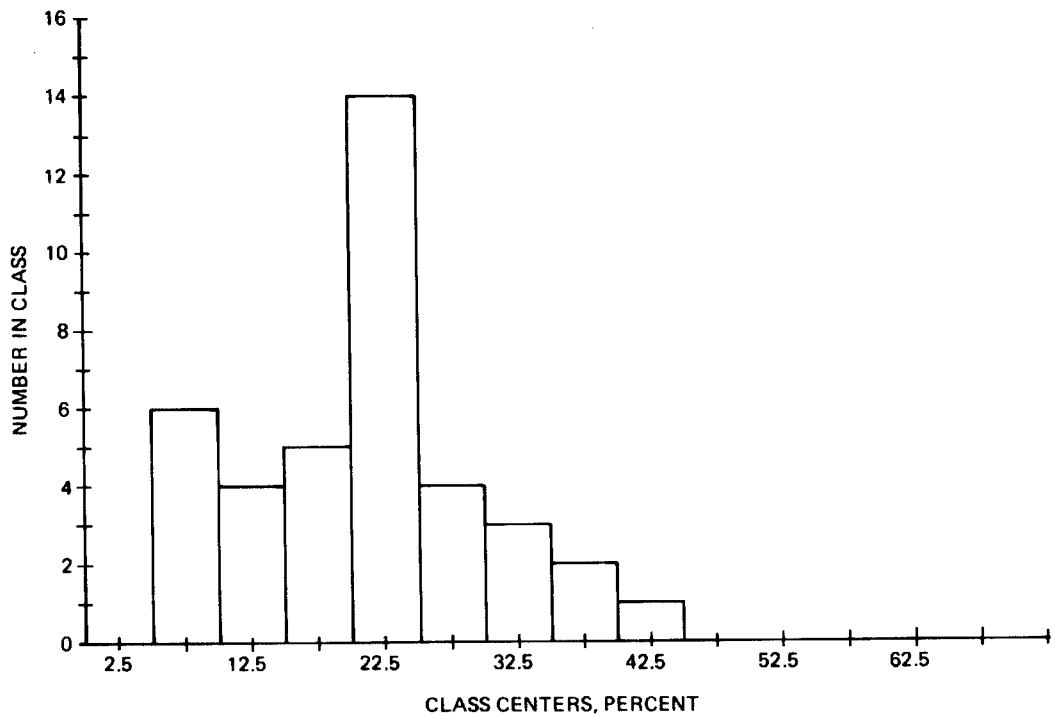


FIGURE B-20-12

BRUSH ESTIMATES BY IMP OPERATOR ON RESURVEY OF BELLE

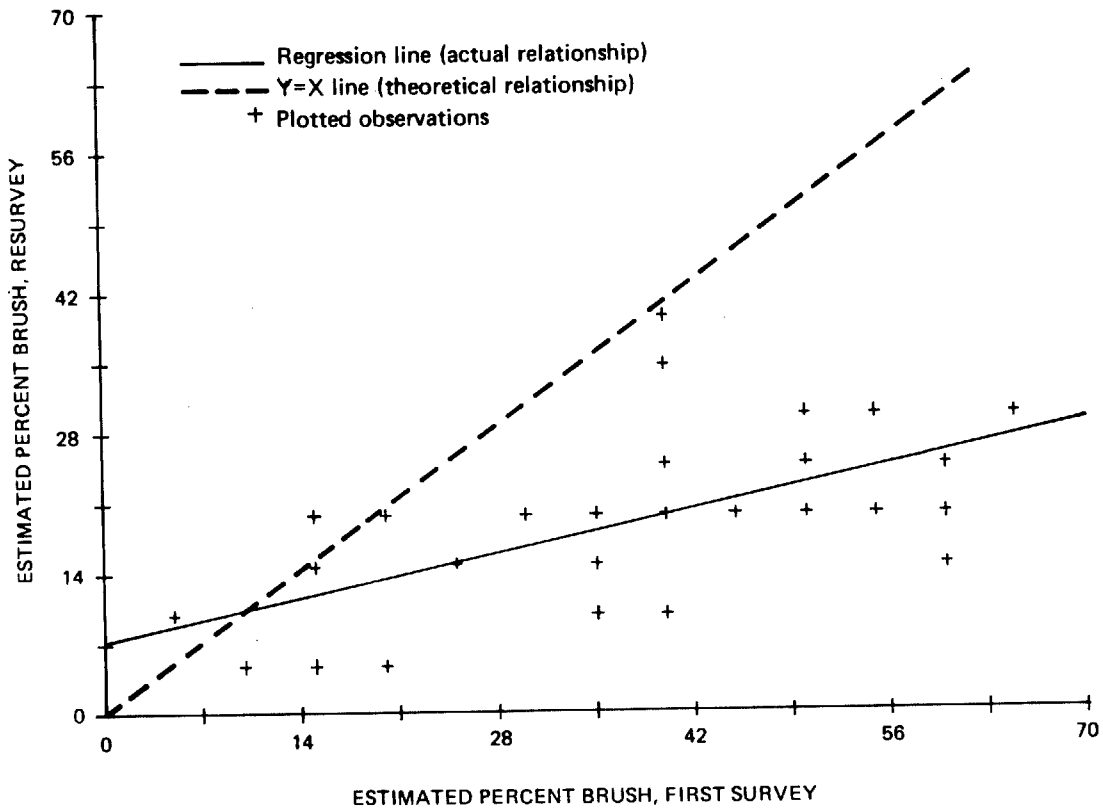


FIGURE B-20-13

COMPARISON OF PERCENT BRUSH ESTIMATES BY DIFFERENT IMP OPERATORS ON ISLAND BELLE

TABLE B-20-1: RANGES OF STANDARD DEVIATION ESTIMATES

Source	Location	Ranges of Values
Propagated error on TRU, pCi/g	Janet	0.6 - 51.6
Propagated error on TRU, percent	Janet	27 - 398
Counting error-IMP ^{241}Am, pCi/g	Janet	0.1 - 4.6
Standard deviation of TRU/Am ratio*	Northern Islands	0.12 - 2.72
Computed brush correction factor	Pearl	1.05 - 1.42
IMP ^{241}Am-reproducibility study, pCi/g	Pearl	7.6 - 9.0
Standard deviation of detector effective area measurements, cm^2	Lojwa	0.07 - 0.58
Standard deviations of kriging error, pCi/g	Northern Islands	0.6 - 16.2
Counting error-lab gamma data, pCi/g	Janet	0.17 - 1.66
Counting error-lab alpha Spectroscopy data, pCi/g	Janet	0.19 - 6.39

*Due to a programming error the standard deviations reported here are overestimated.

REPRODUCIBILITY OF IMP MEASUREMENTS

DOE/ERSP TECH NOTE NO. 21.0 DATED: 19 February 1980

AUTHOR: Joel Jobst, EG&G, Inc.
Raphael J. Jaffe, EG&G, Inc.

The determination of specific concentrations of transuranic elements in large quantities of soil is subject to errors and uncertainties. One such uncertainty is attributed to IMP measurements of the specific concentration of ^{241}Am, which are subject to both systematic variations and counting statistics.

A simple experiment has been conducted in order to estimate the IMP error. IMP I, equipped with detector 483, was driven to stake 3-N-0.5 on Pearl. This was a "total lift" area; that is, all brush and surface soil had been removed to a depth of several inches. The terrain was relatively flat, the soil rather moist because a rain had soaked the area in early morning hours. A 300-second calibration was done with the standard EG&G calibration source. Then eight consecutive 900-second measurements were made of 3-N-0.5. A noon calibration was made and nine more measurements were obtained at 3-N-0.5; finally an evening calibration was made at the close of the day's work.

The 17 measurements of ^{241}Am and ^{137}Cs obtained are plotted in Figure B-21-1 in the order in which they were obtained. These data, and the three calibration measurements, suggest that no systematic drift occurred during the day. For the calibrations, the ^{241}Am photopeak concentrations were 620.5 ± 66.4, 604.1 ± 64.7 and 609.6 ± 65.3 pCi/g. The measured ^{241}Am and ^{137}Cs concentrations obtained for location 3-N-0.5 are shown in Table B-21-1.

TABLE B-21-1. AMERICIUM AND CESIUM REPEAT MEASUREMENTS

Run	241Am (pCi/g)	137Cs (pCi/g)
632	8.1 ± 1.4	9.6 ± 1.3
633	7.7 ± 1.3	9.6 ± 1.3
634	8.4 ± 1.4	9.5 ± 1.3
635	7.6 ± 1.3	9.9 ± 1.3
636	7.7 ± 1.3	10.3 ± 1.4
637	8.2 ± 1.4	10.1 ± 1.3
638	8.3 ± 1.4	10.0 ± 1.3
639	7.9 ± 1.3	9.7 ± 1.3
641	7.9 ± 1.3	10.2 ± 1.4
642	8.3 ± 1.4	9.5 ± 1.3
643	9.0 ± 1.4	9.5 ± 1.3
644	7.8 ± 1.3	10.1 ± 1.3
645	7.8 ± 1.3	10.2 ± 1.4
646	7.7 ± 1.3	9.8 ± 1.3
647	8.2 ± 1.4	10.5 ± 1.4
648	8.2 ± 1.4	10.0 ± 1.3
649	8.9 ± 1.4	10.2 ± 1.4

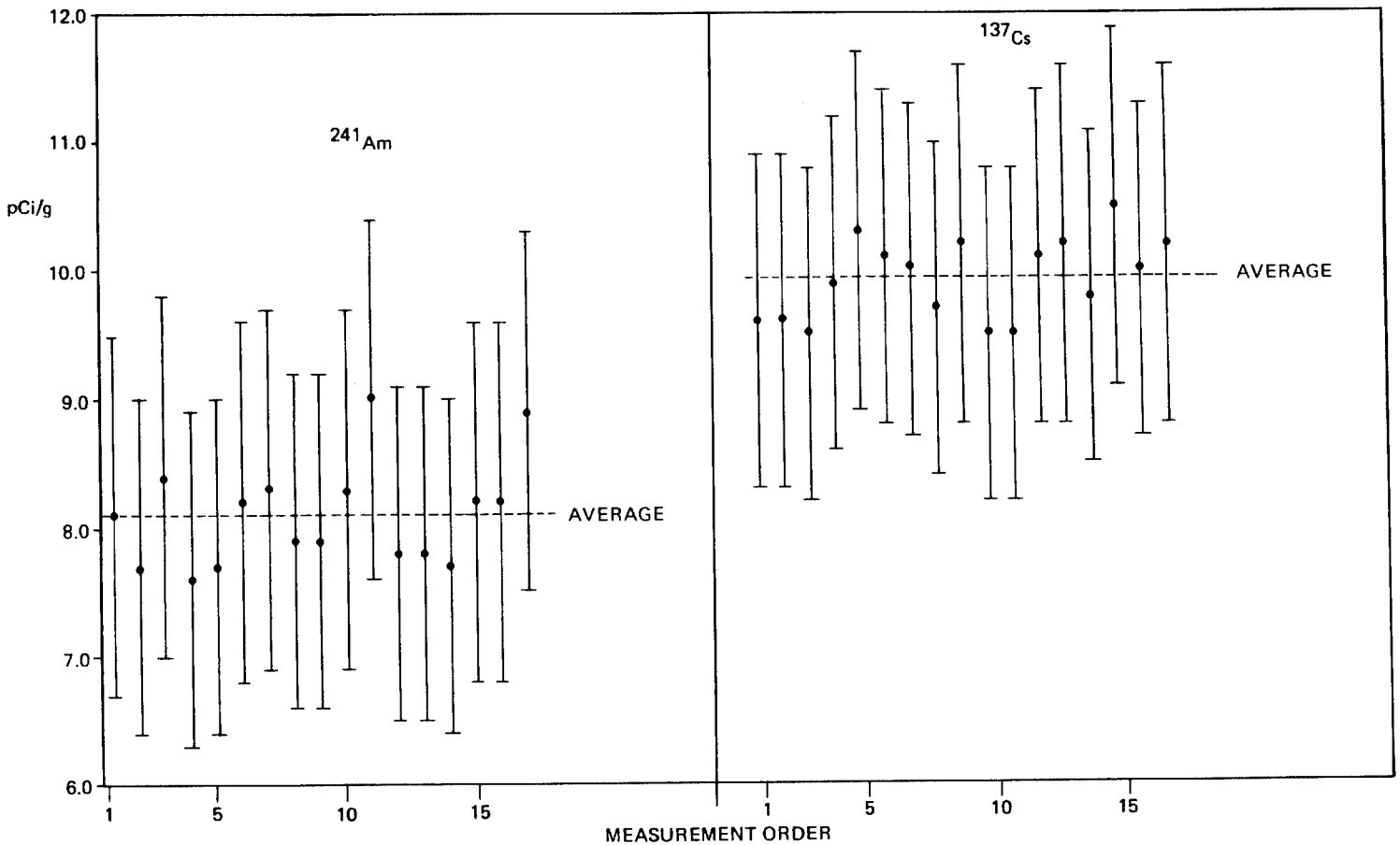


FIGURE B-21-1. PEARL AMERICIUM AND CESIUM MEASUREMENTS—3-N-0.5—29 MAY 1979

The average americium measurement is 8.1 pCi/g. The sample standard deviation is 0.41 pCi/g (5.0 percent). The average for cesium is 9.92 pCi/g, with a sample standard deviation of 0.32 pCi/g (3.2 percent).

Figure B-21-2 shows that, as one might anticipate, there is no apparent correlation between the individual americium and cesium concentration measurements. Linear regression analysis indicates that $R^2 = 0.03$, which supports this assumption.

It should be noted that the IMP was not moved during the course of the day. Hence, the above values do not include any error associated with repositioning the detector. It is likely that there was some drying of the soil during the progress of the experiment since it did not rain during the day. The results show no obvious change which might be associated with time of day.

Some informal reproducibility studies have been conducted of IMP remeasurements at the same location which involved repositioning the IMP on different days. Data from three comparisons are shown in Table B-21-2:

TABLE B-21-2. ^{241}Am MEASUREMENTS REPEATED ON DIFFERENT DAYS

Janet 6-NW-4		Pearl 4-N-1		Pearl 1-N-1	
Date	241Am (pCi/g)	Date	241Am (pCi/g)	Date	241Am(pCi/g)
09/22/77	21.3 ± 3.0	10/20/77	19.5 ± 2.7	10/28/77	35.2 ± 4.7
10/03/77	19.5 ± 2.8	10/27/77	18.0 ± 2.5	10/28/77	36.7 ± 5.8
10/05/77	20.3 ± 2.9	11/18/77	18.2 ± 2.5	11/18/77	32.2 ± 4.4
10/10/77	18.5 ± 2.7				
11/15/77	17.4 + 2.6				
Mean	19.4 ± 1.52		18.6 ± 0.81		34.7 ± 2.29
Std. Deviation	7.8%		4.4%		6.6%

For several islands, reproducibility has been studied by comparison of IMP readings taken several months apart. Different detectors were used for these comparison pairs. Usually, the IMP vehicle and electronics and the operating technician were different. Sometimes the measurement points had been restaked. Comparisons for two islands are given in Table B-21-3. The ratio of old/new americium values is 1.11 ± 0.10 for Pearl and 0.97 ± 0.12 for Lucy, and for both sets of data combined the ratio is 1.03 ± 0.13. Originally, a complete remeasurement of Lucy was planned but the plan was changed due to equipment failure after five locations had been remeasured. A comparison of these five new measurements with five previous measurements was close enough that ERSP management cancelled the balance of the remeasurements.

A set of IMP vs IMP measurements was obtained at the Tilda test plot, and was presented in Table B-8-2 of Tech Note 8. The ratio of IMP I/IMP III measurements is 1.03 ± 0.13 for four pairs of comparisons. Each point compared was itself the average of two measurements. The counting error for each single measurement was 5 to 6 percent. Tech Note 8 calls "effective area factor" the "detector sensitivity correction factor," and assigns the then used value of 1.1 to it for detector 496. Later investigation showed the proper effective area factor for detector 496 at that time was 1.28 instead of 1.1, as discussed in Tech Note 5.2. Data given below uses 1.28 for detector 496, and 1.00 for detector 513.

Area	Detector Height (cm)	Ratio
Exp.	740	1.17
	460	1.08
Control	740	1.03
	460	0.86
	Mean	1.03 ± 0.13

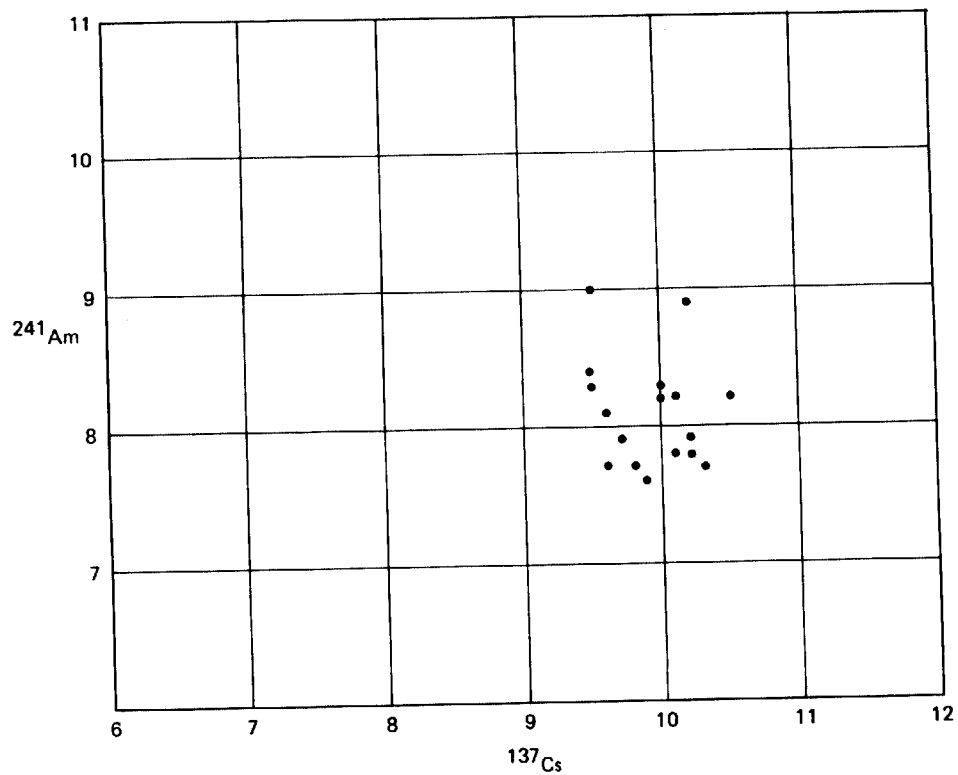


FIGURE B-21-2. ^{241}Am VS. ^{137}Cs MEASUREMENTS PEARL DATA, 29 MAY 1979

For the stake locations previously discussed, there were no changes in the radiological conditions at these sites between the two sets of measurements, so far as is known. Individual stake locations have been remeasured on 20 or more occasions because (1) fine grid data were required where previously a coarse grid had been measured, or (2) the validity of a measurement was doubted. These "reproducibility tests" were not formally analyzed; however, in many cases repeat measurements were within 10 percent of the first measurement and in most cases within 15 percent. Should a more exact value be desired for the overall reproducibility of IMP measurements, a formal study of these repeats is recommended.

TABLE B-21-3. IMP REPRODUCIBILITY STUDY

Island: PEARL

Stake	July 1978 Detector 496	March 1979 Detector 396	Ratio
3-N-2	17.3	16.2	1.07
1-BL-0	14.6	12.2	1.20
5-S-3	21.9	18.4	1.19
3-BL-0	6.9	7.0	0.99
		Mean	1.11 ± 0.10

Island: LUCY

Stake	March 1978 Detector 496	March 1979 Detector 396	Ratio
10-W-8	2.3	2.9	0.8
10-W-6	12.9	12.1	1.06
10-W-4	21.1	19.8	1.07
10-W-2	21.5	21.0	1.02
10-BL-0	19.7	22.5	0.88
		Mean	0.97 ± 0.12
		Both Combined Mean	1.03 ± 0.13

ERRORS AND ERROR PROPAGATION IN COMPUTED TRU ACTIVITY

DOE/ERSP TECH NOTE NO. 22.0 DATED: April, 1980

AUTHOR: W. John Tipton, EG&G, Inc.

Introduction

Conversion factors relating measured photopeak count rate data (as obtained with the IMP system) to source activity in the ground depend on certain properties of the soil in which the radioactivity is distributed. In particular, it is necessary to know the in situ soil density and soil moisture as well as the elemental composition of the soil. These parameters are required to obtain the linear attenuation coefficient (the inverse of the gamma ray mean free path) in soil for a given energy gamma ray. The soil density is also required to convert activity per unit volume to activity per unit mass.

A series of measurements were made between November 28 and December 11, 1979 over 9 islands to expand the rather limited data base which previously existed for these parameters. Using a nuclear density/moisture gauge, in situ measurements were taken at 182 locations in 73 areas over the 9 islands. A total of 124 soil samples were also obtained and sent to LLL for elemental composition analysis. An additional 11 samples were returned to EG&G in Las Vegas, NV for direct measurements of the linear attenuation coefficient.

Procedures

Direct in situ soil density and soil moisture measurements were made using a Troxler Model 3411 nuclear density/moisture gauge. The instrumentation and procedures employed were those specified by the American Society for Testing and Materials (ASTM). Standard procedures for measuring soil density by nuclear methods are given in ASTM D 2922-71 and for soil moisture in ASTM D 3017-72. Briefly, the in situ or wet density of soil is determined by measuring the attenuation of 662 keV gamma rays from a ^{137}Cs source through a given depth of soil. The moisture content, by weight, of soil is determined by measuring the moderation or slowing of fast neutrons from an Am-Be neutron source. Dry density is obtained by subtracting the moisture content from the wet density. The percent moisture is obtained by dividing the moisture content by the dry density.

In the Troxler Model 3411 gauge both the ^{137}Cs and the Am-Be sources are located in a probe which can be inserted to a given depth in the soil. The gamma ray and neutron detectors are placed on the surface at a fixed lateral displacement of 25 cm from the sources. After placing the sources at a given depth, gamma ray and neutron counts are accumulated for a period of one minute. The resulting counts are converted to wet density and moisture content using calibration curves supplied by the manufacturer.

Four independent measurements were made at each of the 182 locations sampled. Measurements were made with the sources located at a depth of 15 cm, 10 cm and 5 cm. The 5 cm measurement was repeated after rotating the detectors through an angle of 90°. Each measurement gives the average wet density and moisture content for that volume of soil lying between the sources and the detectors.

The standard procedure was to measure three locations within a given area to obtain an area average. Measurements were made 5 meters N, 5 meters SE and 5 meters SW of a given reference point, generally chosen to be one of the IMP measurement locations. This procedure was followed for 54 of the 73 different areas which were measured. Only a single location was measured in the other 18 areas.

Of the 18 areas where only a single location was measured, 13 were areas where a cross-calibration was performed between the nuclear density/moisture gauge and another technique for measuring soil density--the sand-cone method. In the sand-cone method soil is carefully removed down to a given depth. The resulting hole is then filled with fine sand having a known density. Measuring the weight of sand required to fill the hole gives the total volume of soil removed. The apparatus used

to determine the hole volume and the procedures followed were those specified in ASTM D 1556-64. A portion of soil removed was used to determine the moisture content by weighing the sample before and after drying, according to procedures given in ASTM D 2216-71.

Soil samples were taken at two of the three locations within each area where soil density measurements were made. Soil samples were also taken at each location where a sand-cone comparison was made. The samples were taken to a depth of 5 cm and included all organic material, roots and any aggregate which might have been present at the location. Each sample was sealed in a plastic bag and then inserted into a 1-gallon paint can. A total of 124 samples, taken from 9 islands, were obtained and shipped to LLL for composition analysis. Eleven of these samples were split, with half going to LLL and the other half going to EG&G, Las Vegas for direct soil attenuation measurements. At LLL the samples were dried at 75° C for 48 hours in commercial ovens. The samples were then ballmilled for 48 hours. After this preparation, the samples were sent to a commercial laboratory for composition analysis, including a determination of the percent organic material within each sample.

Results

1. Soil Density and Soil Moisture

Average soil density and soil moisture results were obtained over the top 5 cm, the top 10 cm and the top 15 cm of soil. A summary of the results for the 5 cm average is given in Table B-22-1. The 10 cm average gave a value of 1.56 g/cm^3 and the average for the 15 cm measurements was 1.59 g/cm^3, compared to a value of 1.53 g/cm^3 for the 5 cm measurements. Thus, there appears to be a slight increase in the density with depth. Figures B-22-1 and 2 show the distribution obtained for the area-averaged wet soil density and percent soil moisture, respectively, over the 73 areas which were measured. A standard deviation of 0.14 g/cm^3 was obtained for the soil density and 5% for the percent moisture.

As shown in Table B-22-1, almost half of the measurements were made on Janet. A grid pattern was established to provide uniform coverage over the island (see Figure B-22-3). Similar coverage was also obtained over Irene, Pearl and Sally. Only a few representative areas, however, were measured on the other islands.

Two types of calibration experiments were also conducted on Janet. The first was a check on repeatability for the nuclear density/moisture gauge. A series of 12 repeat measurements were made at the same location for each of the three source depths of interest. The results showed that the error associated with counting statistics was approximately 0.5% and, hence, negligible for all practical purposes. The second experiment was performed to cross-check the data obtained from the nuclear density/moisture gauge with another independent technique used for obtaining in situ density measurements. A total of 12 comparison measurements were made on Janet and one on Enewetak. The locations on Janet were spread around to provide a reasonable cross section for the island (see Figure B-22-3). The sand-cone measurements were taken to a depth of 10 cm or 15 cm depending on soil compaction. In all cases, the comparison was made with results from the nuclear gauge taken at the same depth as the sand-cone. Table B-22-2 shows the results of the comparison. It can be seen that both the density and soil moisture data compare quite well. The only exception is the percent moisture comparison at location 6. The soil sample sent to LLL from this location had a soil moisture content of 13%, which compares well with the nuclear moisture gauge results. It is not known why the field measurement for soil moisture was so much different for this particular location. There was no correlation observed between the comparison data and the radiation levels which were also measured at each location using a Ludlum Model 19 MicroR Meter, calibrated for ^{137}Cs. This indicates that the rather low ^{137}Cs levels in the soil at Enewetak did not significantly contribute to the nuclear density gauge detector compared to the counts from the built-in 8 millicurie source.

2. Mass Attenuation Coefficient

Two methods were used to determine the mass attenuation coefficient for 60 keV gamma rays in Enewetak soil. The first, and primary method, was to determine the elemental composition of the soil through chemical analysis. The soil mass attenuation coefficient can then be obtained from a

weighted average of the appropriate elemental mass attenuation coefficients. The second method used was to directly measure the attenuation of 60 keV gamma rays from a ^{241}Am source through a known thickness of soil.

The chemical analysis showed that the primary component of Enewetak soil is calcium carbonate with calcium contributing approximately 30-40% by weight, oxygen approximately 40-50% by weight, and carbon 10-12% by weight. There were a number of trace elements also identified; the most significant was magnesium which contributed approximately 1-2% by weight. Several trace elements such as sodium, strontium, chlorine and sulfur contributed a few tenths of a percent. The other trace elements generally contributed less than a tenth of a percent, with only a few exceptions. In one area on Mary both samples contained approximatey 4.5% iron. Iron also contributed approximately 1% by weight in one area on Enewetak. For more than half the samples, however, iron only contributed a few hundredths of a percent. Silicon and aluminum, which are two primary components of continental soil, were present in only trace amounts in the Enewetak soil. To help insure that no significant elements were missed in the chemical analysis, 20 samples were analyzed through emission spectroscopy. This analysis showed that nothing of significance was missed in the chemical analysis. The soil samples were also analyzed for organic content. Although the organic content varied from 0.5% to 25% by weight, most samples were in the range from 1% to 8% with an average of approximately 4% for all samples.

The in situ or wet soil mass attenuation coefficient for each of the 124 samples were obtained using the elemental plus organic analysis combined with the in situ soil moisture measured at each location with the nuclear moisture gauge. Elemental mass attenuation coefficients were based on National Bureau of Standards (NBS) cross section data.* The mass attenuation coefficient for organic material was estimated by using the value derived for cellulose. The results are summarized in Figure B-22-4. The average value obtained was 0.333 ± 0.12 cm^2/g. The average value for the dry, organic free component was 0.365 cm^2/g compared to 0.37 cm^2/g for pure calcium carbonate.

Eleven of the samples sent for chemical analysis were split with half of the sample going to Las Vegas for direct attenuation measurements. These samples were from 11 of the 12 locations on Janet where sand-cone comparisons were performed. For each sample, two petri dishes approximately 12 cm in diameter by 2.5 cm thick were filled with soil. Rocks greater than approximately 1 cm were not included. Otherwise, the samples were representative of the in situ soil including organic material, roots and small aggregate. Soil was packed into the petri dish to provide a density typical of the in situ densities which were measured at Enewetak--typically 1.4-1.6 g/cm^3. The volume of each petri dish was obtained by weighing the amount of water required to fill the dish.

The attenuation of gamma rays of a given energy through a given medium is given by

$$N = N_0 e^{-(\mu/\rho)\rho x}$$

By measuring the net photopeak counts through an empty petri dish (N_0), the net photopeak counts through the dish full of soil (N), the soil density within a given petri dish (ρ) and the soil thickness (x), the soil mass attenuation coefficient (μ/ρ) can be determined. Three independent measurements were made for each of the 11 soil samples -- one with each of the petri dish samples separately and one for both petri dishes stacked together. A 115 μCi ^{241}Am source was placed approximately 50 cm in front of a side-looking coaxial high purity germanium detector. Table B-22-3 gives the average of the three measurements for each of the 11 samples. Also shown are the results obtained from the soil sample analysis for each of the samples. As can be seen, the two approaches yield results which agree quite well with each other.

In addition to the 11 Enewetak samples, three soil samples obtained near Las Vegas were also analyzed in the same manner. The results for these samples are also shown in Table B-22-3. It can be seen that the mass attenuation coefficient for Las Vegas soil is significantly different from that for Enewetak soil.

*Photon Cross Sections, Attenuation Coefficients, and Energy Absorption Coefficients from 10 keV to 100 GeV (NSRDS-NBS 29), 1969.

TABLE B-22-1. RESULTS OF DECEMBER 1979 SURVEY TO OBTAIN IN SITU SOIL DENSITY, SOIL MOISTURE AND SOIL MASS ATTENUATION COEFFICIENTS AT ENEWETAK ATOLL

Island	Areas Measured	Locations Measured	Average (5cm) Wet Density (g/cm^3)	Average (5cm) Soil Moisture (%)	Average Mass Attenuation Coefficient (cm^2/g)
Belle	3	8	1.28	15	0.340
Irene	6	18	1.43	15	0.328
Janet	37	87	1.57	16	0.334
Mary	3	9	1.43	16	0.339
Pearl	6	18	1.52	15	0.338
Sally	6	18	1.51	19	0.332
Tilda	2	6	1.60	26	0.313
David	6	10	1.45	17	0.327
Enewetak	4	8	1.66	13	0.340
Total:	73	182	1.53 ± 0.14	16 ± 5	0.333 ± 0.012

TABLE B-22-2. COMPARISON BETWEEN THE TROXLER NUCLEAR DENSITY/MOISTURE GAUGE AND THE SAND-CONE TECHNIQUE

		WET DENSITY		DRY DENSITY		% MOISTURE	
		Sand Cone	Troxler	Sand Cone	Troxler	Sand Cone	Troxler
Janet	1.	1.69	1.66	1.46	1.43	15.8	16.1
	2.	1.64	1.71	1.43	1.46	14.7	17.1
	3.	1.81	1.72	1.46	1.42	24.0	20.7
	4.	1.60	1.63	1.37	1.35	16.8	20.7
	5.	1.83	1.77	1.67	1.60	9.6	10.6
	6.	1.57	1.46	1.22	1.30	28.7	12.3
	7.	1.64	1.50	1.43	1.31	14.4	14.4
	8.	1.68	1.61	1.41	1.41	19.1	14.2
	9.	1.71	1.71	1.49	1.48	14.8	15.5
	10.	1.68	1.59	1.43	1.36	17.0	16.9
	11.	1.57	1.52	1.34	1.32	16.9	15.2
	12.	1.66	1.77	1.47	1.55	12.8	13.8
Enewetak	1.	1.86	1.73	1.68	1.56	10.7	10.9

SAND CONE/TROXLER

	With #6	Without #6
Wet Density	1.03 ± 0.05	1.02 ± 0.05
Dry Density	1.02 ± 0.04	1.02 ± 0.04
% Moisture	1.11 ± .39	1.00 ± 0.14

TABLE B-22-3. COMPARISON BETWEEN THE CALCULATED MASS ATTENUATION COEFFICIENT BASED ON COMPOSITION ANALYSIS AND THAT OBTAINED BY DIRECT MEASUREMENT

	MASS ATTENUATION COEFFICIENT, μ/ρ (cm^2/g)	
SAMPLE	SOIL SAMPLE RESULTS	DIRECT MEASUREMENT
1	0.330	0.337
2	0.324	0.320
3	0.331	0.339
4	0.322	0.328
5	0.342	0.342
6	0.340	0.338
7	0.332	0.335
8	0.336	0.337
9	0.327	0.322
10	0.333	0.333
11	0.335	0.329
Average	0.332 ± 0.006	0.333 ± 0.007
Las Vegas		
Commercial Dirt		0.273
Garden Dirt		0.279
Desert Soil		0.246

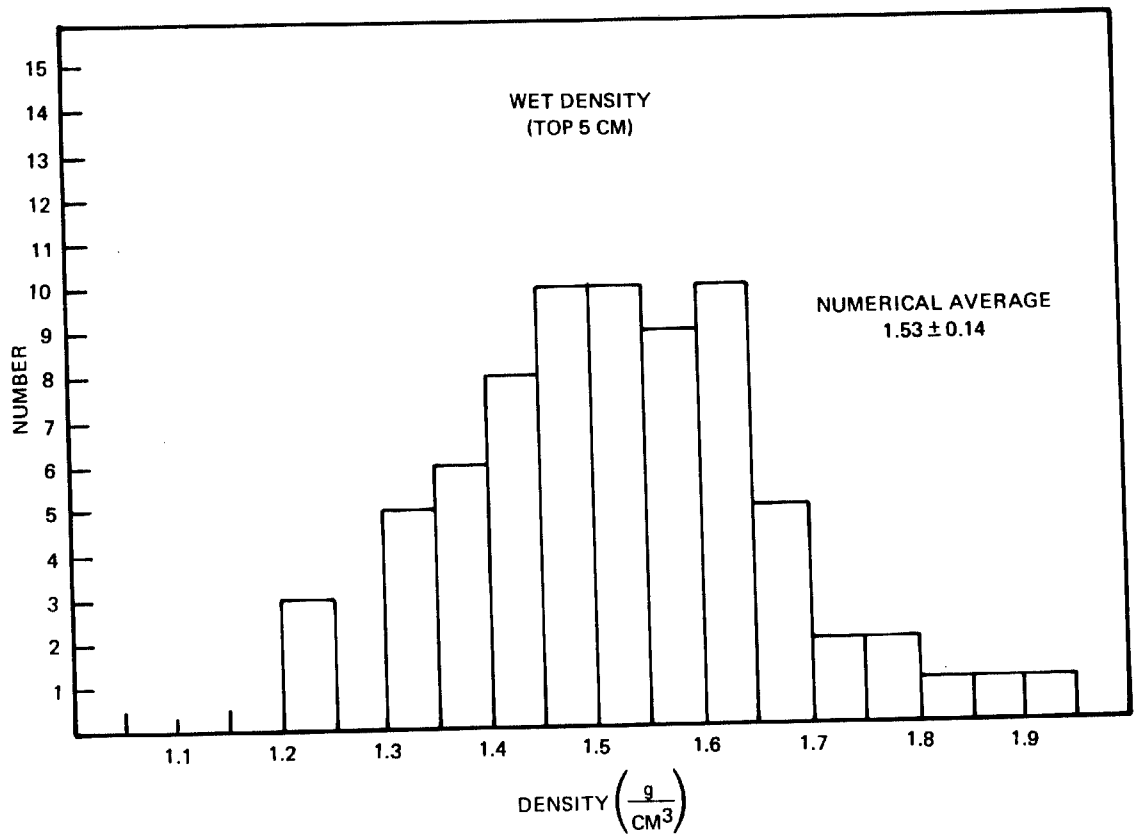


FIGURE B-22-1. DISTRIBUTION OF THE AVERAGE WET DENSITY (OVER THE TOP 5 CM) FOR THE 73 AREAS MEASURED WITH THE NUCLEAR DENSITY GAUGE

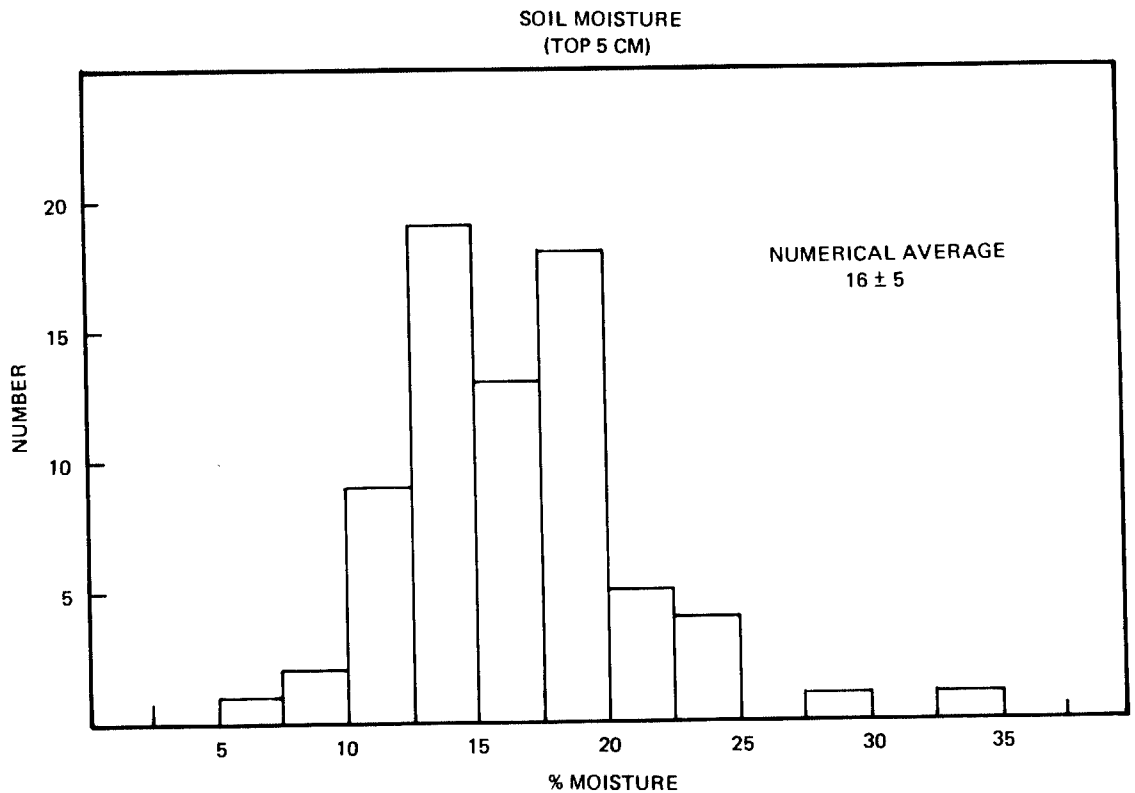


FIGURE B-22-2. DISTRIBUTION OF THE AVERAGE PERCENT MOISTURE (OVER THE TOP 5 CM) FOR THE 73 AREAS MEASURED WITH THE NUCLEAR MOISTURE GAUGE

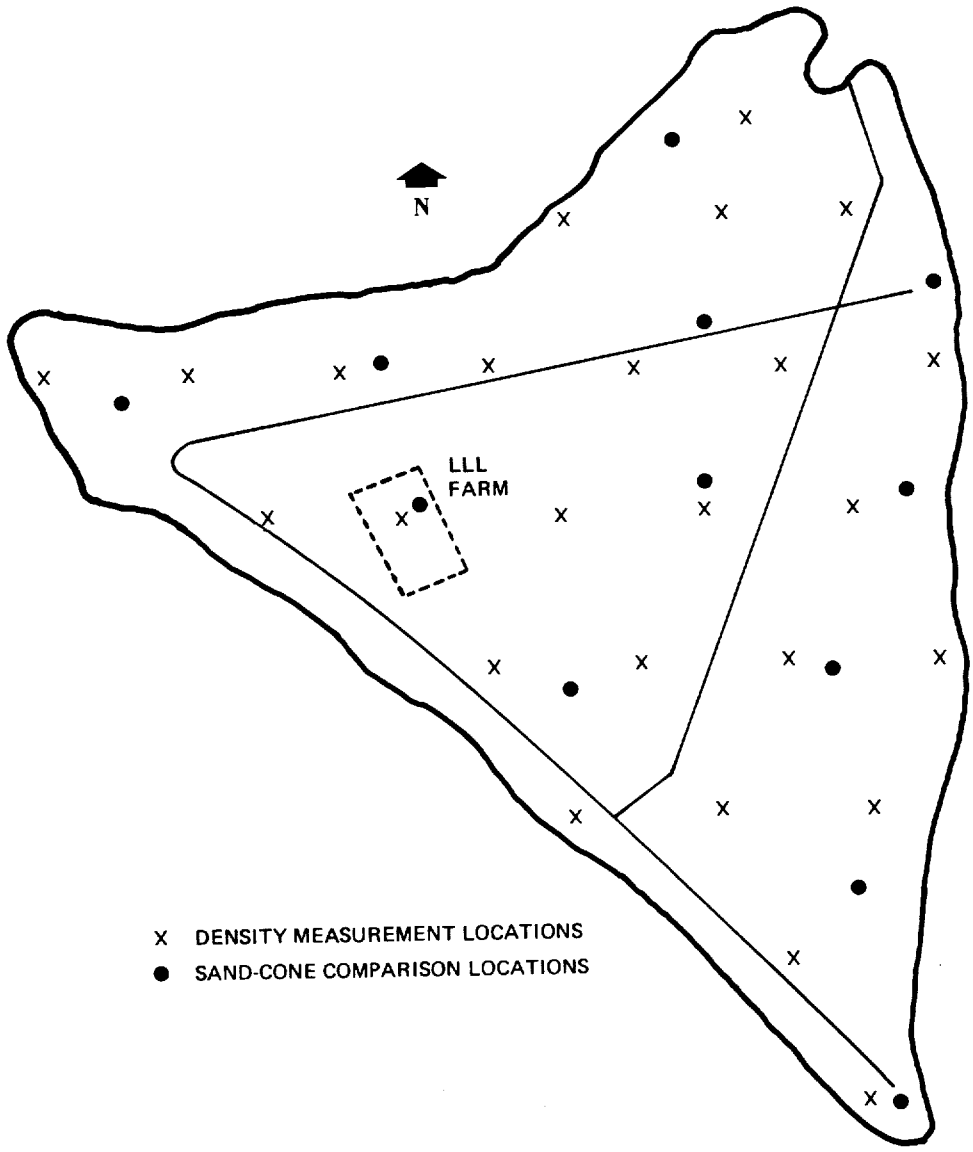


FIGURE B-22-3. A MAP OF JANET SHOWING THE 25 AREAS WHERE SOIL DENSITY MEASUREMENTS WERE MADE. ALSO SHOWN ARE THE 12 LOCATIONS WHERE CROSS-CALIBRATION MEASUREMENTS WERE MADE BETWEEN THE NUCLEAR DENSITY GAUGE AND THE SAND-CONE TECHNIQUE

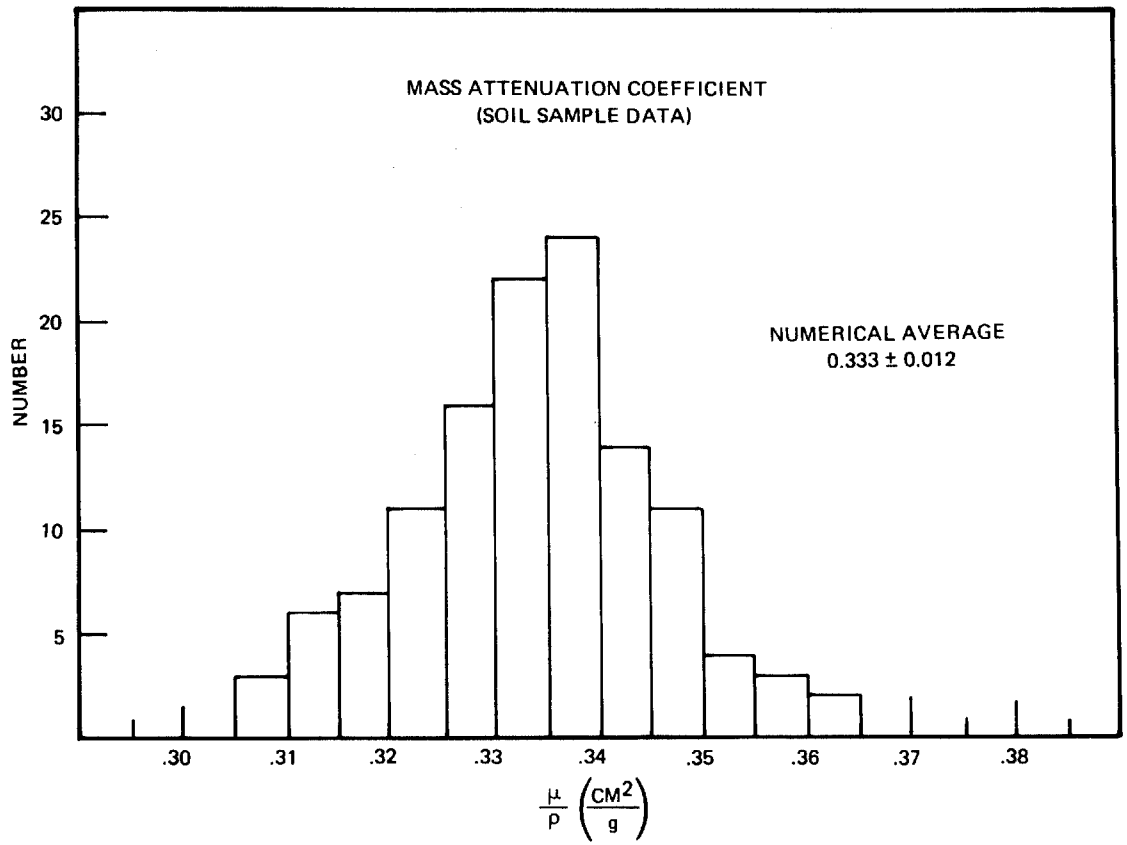


FIGURE B-22-4. DISTRIBUTION OF THE IN SITU MASS ATTENUATION COEFFICIENTS OBTAINED FROM ELEMENTAL PLUS ORGANIC ANALYSIS OF 124 SOIL SAMPLES

CORRECTION FACTOR FOR THE IMP ^{241}AM DATA

DOE/ERSP TECH NOTE NO. 23.0 DATED: APRIL 1980

AUTHOR: W. John Tipton, EG&G

Conversion factors for the IMP system, which relate measured photopeak count rate data to source activity in the ground, depend on certain properties of the soil in which the radioactivity is distributed. Specifically, a knowledge of the elemental composition of the soil, including soil moisture and organic content, and the in situ soil density is required to determine the gama ray attenuation properties of the soil matrix. In addition, the soil density is required to convert activity per unit volume to activity per unit mass.

The conversion factors used in the IMP field program were based on soil mass attenuation coefficients given by Beck, et al (Beck, 1972). (This report provides a detailed summary of in situ measurement techniques and contains numerous reference tables which are used quite extensively by various groups conducting these types of measurements.) The value used for the soil density, 1.2 g/cm^3, was based on measurements made by EIC during the initial soil sampling effort.

It was pointed out in the fall of 1979 that the soil mass attenuation coefficients given in Beck were based on a silicate soil instead of a calcium carbonate soil as exists at Enewetak. The difference in mass attenuation coefficients between Si and Ca is insignificant for gamma ray energies greater than a few hundred keV. As an example, for ^{137}Cs, with a gamma ray energy of 662 keV, the difference is 0.7%. This is the reason why soil composition is not a critical factor or a factor of concern for most types of in situ measurements. However, at low gamma ray energies there is a significant difference. In particular, for the 60 keV gamma ray from ^{241}Am there is a factor of two difference in mass attenuation coefficients between Si and Ca.

The actual attenuation coefficients required for deriving in situ conversion factors are those based on the complete soil matrix, including moisture content and organic materials. The detailed in situ soil composition data required did not exist for Enewetak soils. In order to obtain this type of data, a total of 124 soil samples were collected from nine islands in December 1979. These samples were analyzed for base elemental composition, moisture content, and organic content. The results led to an average value of 0.333 ± 0.012 cm^2/g for the soil mass attenuation coefficient at 60 keV, compared to the value of 0.248 cm^2/g which was used for deriving the original ^{241}Am conversion factor. Tech Note 22 discusses these measurements and the results in detail. As expected, results for ^{137}Cs and ^{60}Co energies were essentially the same as those used originally.

In addition to the lack of detailed data on soil composition, it was felt that the data available for in situ density were also rather limited and should be expanded. During December, 1979, in situ soil density and soil moisture measurements were taken at 182 locations on nine islands using a nuclear density/moisture gauge. The results indicated an average value of 1.53 ± 0.14 g/cm^3 for the in situ soil density and 16 ± 5%, by weight, for the soil moisture. Details of these measurements are also contained in Tech Note 22.

The revised values for the soil mass attenuation coefficient and the soil density lead to a new conversion factor for ^{241}Am of 8.95 pCi/g per cps. This necessitates a 16% increase in all ^{241}Am IMP data obtained during the cleanup project, which were based on the original conversion factor of 7.7 pCi/g per cps. (Note that 8.95/7.7 = 1.16.) In addition to this 16% correction, another 4% increase should be applied to account for a small shielding effect caused by the IMP being within the detector's field-of-view. This rather small systematic error had been neglected in the original conversion factor.

All ^{241}Am data obtained with the IMP system during the actual cleanup were low by 20%. However, all final data in the final report and on the island-by-island certification documents reflect the 1.20 correction factor. It should be pointed out that all IMP data contained in previous tech notes are also in error by 20%.

APPENDIX C: EQUIPMENT LISTS

This Appendix provides a listing of major components of equipment required by ERSP contractors for execution of the Enewetak Cleanup Project. List C-1 includes equipment under control of EG&G. List C-2 includes items assigned to the Desert Research Institute. List C-3 itemizes equipment required by Eberline Instrument Corp. for operation of the laboratory complex.

C-1 MAJOR EQUIPMENT FOR THE IMP SYSTEM

A. IMP Vehicle

Tracked vehicle manufactured by the Thiokol Corporation (now part of the DeLorean Manufacturing Company). Model No. 1404.
Dimensions: Length 116", Width 84", Height 75"
Engine: 104 CI, V4 Ford, 80 hp
Dual transmission with 12 forward gears
Loaded weight: 4800 lbs.
Ground pressure: 1 psi
Vehicle specially modified for Enewetak use by EG&G, Las Vegas.

B. Electric Generator

Onan Model 4.0 BF-3CR, R-V Series
Air cooled, 2 cylinder, gas driven engine
Power output: 4kW, 33 amps, 120V, 60 cy

C. Pneumatic Mast

Manufactured by the Telescoping Mast Division of the Will-Burt Company. Model TMD-7-30-PAGX.

D. Linear Actuator

Saginaw Part No. 5703835-5703725 : 1500 lb capacity, 18 in. stroke, 12 VDC power.

E. Air Conditioner

Duo-Therm Model 54608-235 : 7000 BTU capacity, 115 V AC, 10 amp. Roof mounted R-V type air conditioner.

F. Air Compressor

Teledyne Model 115-12, 12V DC power

G. Electric Winch

Sears Model 28.49401, 12V DC power

H. High Purity Germanium Detector

Princeton Gamma-Tech (PGT) Model No. IG1916. Planar type HPGe detector about 19 cm^2 by 1.6 cm thick. Mounted in 15 liter down-looking liquid nitrogen cryostat.

I. Pulse Height Analyzer

EG&G Nuclear Acquisition and Processing System (NAPS-20) Model CE-1460, microprocessor-based, 4096-channel, pulse height analyzer. Specially designed analyzer for field applications. Not commercially available.

J. Oscilloscope

Hewlett-Packard Model 1222A

K. Linear Amplifier

Tennelec Model TC 205A

L. HV Power Supply

Bertan Model 345 : 5kV output

M. Nimbin

Canberra Model 2000

N. Computer

Hewlett-Packard Model 9831A

O. Printer

Hewlett-Packard Model 9866B

C-2 DATA PROCESSING EQUIPMENT

A. Computer

Hewlett-Packard Model 9831A (Las Vegas and Enewetak)

B. Printer

Hewlett-Packard Model 9866B (Las Vegas and Enewetak)

C. Plotter

Hewlett-Packard Model 9872A (Las Vegas and Enewetak)

D. Disk Drive

Hewlett-Packard Model 9885M (Las Vegas and Enewetak)
Hewlett-Packard Model 9885S (Enewetak only)

E. Magnetic Type Transport

Ideas 4600 Series (Las Vegas only)

C-3 LABORATORY EQUIPMENT LIST

I. Sample Prep Trailer Equipment

A. Weighing Equipment

1. Pan balance, 0-240 g, 0.1 mg resolution, Mettler P11N/SW.
2. Toploader balance, 0-10 kg, 0.1 g resolution, Mettler P11N/SW.

B. Ovens and Furnaces

1. Drying oven, gravity convection, 50-200°C, 0.16 m^3 capacity Fisher Model 55G.
2. Muffle furnaces, Thermolyne Model FA-1730, 500-2000° F, with pyrometric regulators.
3. Planchet dryer, stainless steel box with 10 infrared heat lamps, Eberline 590085-1.

C. Hoods

1. Fume hood, Labconco 59-inch Model 5900 add air with base cabinet.
2. Dust hoods for drying ovens, muffle furnace bench, and grinder bench with 0.005-inch stainless steel assembled by Eberline, drawings 590085 - 040, 041, 043.

D. Air Handling Units and Filters

1. Fan units, 12-1/4-inch wheel, 1900 cfm, 1/2 hp, W. W. Grainger 7C635.
2. High efficiency particulate absolute filters, 24 x 24-inch rated 1000 scpm, MSA 73041.

E. Ballmill, Grinder

1. Ballmill, multitier units, roller type for cans, Fisher 784AV.
2. Grinder, general purpose mill, Fisher 8-415.
3. Stainless steel balls, 1-inch.

F. Counting Equipment

1. Sample screening unit, low energy gamma detector, 5-inch diameter NaI(Tl) x 0.063-inch thick crystal, Eberline RD-21 with 2-inch lead shield.
2. Readout was scaler/ratemeter Eberline PRS-1 or MS-2.
3. Gross alpha in soil, alpha scintillation probe 0.5 mg/cm^2 aluminized mylar window, Eberline AC-3/7 and 3/32-inch separator, active area 59 cm^2.
4. Readout was scaler/ratemeter Eberline PRS-1, MS-2 or Ludlum scaler Model 2200.
5. Gross beta in soil, thin window G. M. tube detector, 7 mg/cm^2 window thickness, 15.5 cm^2 area, Eberline HP-210.
6. Readout was scaler ratemeter Eberline PRS-1, MS-2 or Ludlum scaler Model 2200.
7. Calculator, Hewlett Packard Model 97, programmable printing.

II. Chemistry Laboratory Equipment

A. Weighing

1. Pan balance, 0-240 g, 0.1 mg resolution, Mettler Model H311.
2. Platform scale, 0-610 g, 0.1 g resolution, Ohaus Model 710.

B. Hoods

1. Fume hood, 2 each 59-inch add air type Labconco 59006.
2. Fume hood, 1 each 79-inch add air type Labconco 70706.
3. Plating hood, plastic sheet unit with external exhaust Eberline design.

C. Installed Equipment

1. Centrifuge, portable, with 6000 ml max. load, Damon/IEC Size 2, Model K-7165.
2. Glassware washer, Fisher Model 97-980D.
3. Vacuum pump, Fisher Model 75.
4. De-ionization system, 10-18 megohm/cm watfer cartridge housing Vaportronics VLT-1, organic filter .02, cat. #E-7-3032, and de-ionization cartridge #MRN-1 1200 grain.
5. Water softener, salt type, 48,000 grain W. W. Grainger #3E278.
6. Shaker, wrist-action Burrell Model 75, 12-flask capacity with timer.
7. Propane burner gas system.

D. Heating Equipment

1. Hot plates, Corning PC-35, 18 x 13-inch.
2. Hot plates, Lindberg #53025, 24 x 18-inch.

E. pH Meter

1. Acumet S-30009, 140 A pH meter, accuracy.

III. Counting Laboratory Equipment

A. Gross Alpha Counting - Large Air Filter

1. Large area gas proportional, 322 cm^2 active area, window face 0.85 mg/cm^2 double-coated aluminized mylar, Eberline AC-23A installed in SH-1 sample holder.

B. Gross Alpha 47 mm Filter Paper & Swipe Counter

1. Alpha scintillation counter, ZnS(Ag) powder on plastic light pipe with 2-inch photomultiplier tube and scaler/timer unit. Eberline SAC-4.

C. Gross Beta Counter - Large Air Filter

1. Large area gas proportional, 322 cm^2 active area, window face 0.8 mg/cm^2 double-coated aluminized mylar, Eberline AC23A installed in SH-1 sample holder. Complete detector and sample holder built in a 2-inch thick lead shield.

D. Gross Alpha Nose Swipe and Tritium Counter

1. Liquid scintillation system, Beckman Model LS-100C.

E. Low Background Beta Counter

1. Canberra Model 2200 gas flow counter with integral anti-coincidence guard counter and 4-inch lead shield, window 800 g/cm^2, with 7700 counter, low noise preamplifiers (1406D), high voltage power supply (3102), spectroscopy amplifier/timer single channel analyzer (2015), anti-coincidence gate/delay (2055), non-printing counter/timer (1722) and flow meter (2209).

F. Alpha Spectroscopy System

1. Detectors, silicon surfcace barrier detector 300 mm^2 area, Ortec Model BR-024-300-100.
2. Alpha Vacuum Chambers, ND B6-0534 with vacuum pump and manifold 1400B.
3. Preamplifier for alpha barrier detectors, ND 404.
4. Amplifiers for alpha barrier detectors, ND 510.

5. Power supplier for alpha barrier detectors, ND 254.
6. Gated analog routers, combined 4 alpha signals into 2048 channels of memory, ND 568 with live time clock storage channel.
7. Analog to digital converter, 8192 channel, 80 Mhz, ND 575, with 10 turn pots, for zero and threshold.
8. Multiplexer unit, allowed mixing two signals alpha and gamma into one multichannel analyzer system. ND-DX-2, #88-0141 two input multiplex module.
9. Pulse height analyzer (PHA), ND 600, with 4096 channel memory, table top CRT terminal, firmware option board ND 70-2434, ND 47-0055 intensified region peak extraction package, ND 47-0054 digital ratio option, ND 47-0056 intensified region L.D. package. Alpha signals stored in first 2048 channels of PHA.

G. Gamma Spectroscopy System

1. Intrinsic germanium detector (IG-1), large area coaxial type, approximate 25% efficiency, vertical cryostat and 30 liter dewar, Princeton Gamma-Tech Model IGC 32 with Model RG-11C preamplifier, vertical cryostat and 30 liter dewar.
2. Amplifiers-Princeton Gamma-Tech Model 340.
3. Analog to digital convertors, 8192 channel, 80 Mhz, ND 575 with 10 turn pots for zero and threshold.
4. Multiplexer unit, ND-DX-2 #88-0141 two input module.
5. Pulse height analyzer (PHA) see alpha system above.
6. Steel shields for gamma systems, 16-inch cube interiors, front opening door, 2-inch 1924 vintage steel walls with cutouts for down-looking or vertical detectors.

H. Gross Gamma System

1. Detector, 2 x 2-inch NaI(Tl) Eberline SPA-3.
2. High voltage power supply - AEC 5000.
3. Pre-amplifier, ND 404.
4. Amplifier, ND 510.
5. Single channel analyzer, ND 602.
6. Scaler/timer, ND 719.
7. Log/linear rate meter, ND 775.
8. Shield, 4-inch lead brick 2 x 4 x 8-inch, hand stacked.

I. Uninterruptible Power Supply

1. Deltec Model DSU-1810 with rack mount external battery pack #RP-1810 and DS-2000 Model solid state transfer switch. Unit rated 1500 watts for 40 minutes.

   Supplied critical items in electronics rack.

J. Gamma and Alpha PHA Readout

1. PHA serial interface digital equipment serial line Unit DL VIL Computer unit, Hewlett Packard Model 9831A with thermal printer Model 9866A, flexible disc drive Model 9885 M/s, tape memory 9877A, I/O expander Model 9878A, and serial interface units Model 98036A.

K. Calculator

1. Hewlett Packard Model 97, programmable, printing.

L. Nuclear Instrument Modules (NIM)

1. NIM bin and power supply ND 88-0346 and ND 88-0297.
2. Additional NIM modules were available and used as needed to keep the system operational.

3. Gated analog routers, ND 568.
4. Amplifiers, ND 510.
5. Clock time base, ND 88-0351.
6. Power supply AEC 5000, ND 86-0290, 0-5 kv.
7. Pulse generator and ramp generator, Berkley Model PB-4&LG-1.

IV. Instrument Trailer Equipment

A. Portable Instruments for RADLAB/DOE Operations

1. Scaler/ratemeter portable Eberline Model PRS-1.

B. Detectors

1. End window beta-gamma G. M. tube with tungsten shield, Eberline HP-210.
2. Beta-gamma G. M. hand probe Eberline HP-1776 & SP-270.
3. Alpha Scintillation probes, Eberline AC-3/7, 59 cm^2.
4. Low energy gamma probe, Eberline PG-2 (small 2-inch FIDLER).
5. Low energy gamma probe, Eberline, RD-21 (large 5-inch FIDLER), Model 20SHB63K/5021X.
6. Alpha scintillation probes, Eberline RASP-1.
7. Scintillation gamma probe 1 x 1-inch NaI(Tl) Eberline SPA-2.

C. Counter Units 110v AC

1. Scaler/timer, Eberline MS-2.
2. Stabilized assay meter, Eberline SAM-2.
3. Logic analyzer system, Hewlett Packard Model 1600A, 1607A and serial to parallel converter Model 10254A.
4. Logic probe units, Hewlett Packard logic probe 545A, logic pulser 546A, logic clip 548A, logic clip 10508A.
5. Digital current tracer 547A, logic comparator 10529A.
6. Volt-Ohm meters, Simpson Model 260-6P.
7. Mini-pulser Eberline MP-1.

D. Tool Kits for Repair

1. Jenson field engineer tool kit with VOM JTK-77.
2. Jenson precision instrument tool kit JTK-90.

E. Weight Standards

1. Balance weight set 10 mg-100 g, class S-1, Sargent-Welch Scientific Co. S-3990-B.
2. Hook on weight set 10-1000 g.

F. Flow Calibration Units

1. 150 mm Matheson-632.

G. Flow Velocity & Temperature Unit

1. Gould 4120K12.

H. Oven, Gravity Convection

1. 0.16 m^3 capacity, 50-200° C, Fisher 55-G.

I. Air Compressor

1. W. W. Grainger 7Z313.

APPENDIX D: IMP DETECTOR HISTORY

The table below gives, for each detector used in the project, the IMP in which the detector was installed, the area factor, the location measured, and comments. Blanks in a column mean that the information is the same as above. Naming an island as the IMP location means that stakes were being measured on that island during the dates shown. Inclusive dates do not necessarily mean the measurements were made on each date included. The physical location of the detector is shown. Thus, for soil screening, the location is the IMP or Crypt shed, or Belle, rather than the island from which the soil sample was obtained. The origin of the sample is sometimes noted in the comments.

The serial number of the detector in use is recorded at position 32 of the data array stored for each IMP measurement, for all measurements taken after March 28, 1978. Prior to that date, the IMP serial number, which is stored in position 8, may be used along with the tabular data, to associate detector and site measured.

Date	IMP	Area Factor	Location	Comment
		DETECTOR 386 (Radiation Lab IG2)		
		1977		
6/20	-	1.00*	PGT	Test Date
7/7		1.00	Las Vegas	Area Factor = 0.99; Shipped to Enewetak on IMP 3
8/21	3		Janet Pearl Sally Irene Vera Olive	In use on islands noted, together with detector 393
12/26-12/28	3		Enewetak	Evacuation for Typhoon Mary
		1978		
1/2-1/4	3		Sally	
1/7	3			Tropical Storm Nadine
1/12	1		Janet	
1/17-1/19	1			Replaced cables to detector
1/20-1/23	3			Detector iced up
1/24	3		IMP Shed	De-iced
1/25	1 & 3			No signal thru
1/26	1			Replaced preamp - OK on IMP 1
1/27,1/28	3		Janet	Malfunction/wide Am peak/ to Radiation Lab
1/30-1/31	3		Janet	Working but replace preamp
2/1-2/3				Bad peak shape/Adjust amplifier

*Value assigned. For area factors within 5% of the previously reported or assigned value, no change in area factor was made.

Date	IMP	Area Factor	Location	Comment
		1978		
2/4		1.00		Poor signal quality
2/6	-		Enewetak	To Rad Lab; OK after De-ice
5/23				Vibration sensitive; ship PGT for repair
6/21			PGT	Test Date
7/6	3		IMP Shed	Installed
7/7			Sally	Kickapoo
7/12			IMP Shed	New Preamp Installed
7/14				Area Factor = 1.01
7/17-7/18				Soil Screening
7/19			Sally	Yuma
7/21-8/3			Janet	
8/4			IMP Shed	De-Ice
8/9				Area Factor = 1.01
8/14-8/18			Janet	
8/19			IMP Shed	Replace Canister Springs
8/21-8/30			Janet	
8/31			IMP Shed	De-Ice
9/2				Area Factor = 1.02
9/4-9/7			Janet	Field Cal Source Too Close; Correct 9/6
9/11			Sally	Yuma
9/16-9/18			IMP Shed	Soil Screening
9/25-9/30	3		Janet	
10/3			IMP Shed	De-Ice; Area Factor = 1.02
10/4-10/7			Belle	
10/11-10/17			Janet	
10/18			IMP Shed	Secured for Tropical Storm Rita; came to room temp
10/21				Area Factor = 1.02
10/23-10/25			Janet	
11/4			IMP Shed	De-Iced; Area Factor = 1.01
11/6-11/10			Janet	
11/15			Janet	Changed cables to restore resolution
11/16			Janet	Preamp Feed-thru pin rusted out/ship to PGT
12/13	-		PGT	Test Date
		1979		
1/3			Radiation Lab	Operating in Enewetak Lab
2/6	2		IMP Shed	Installed
2/7,2/8			Irene	
2/8			Janet	
2/10			IMP Shed	De-Ice; Area Factor = 1.00
2/19-2/28			Runit	Intermittent Moisture Problems
3/3,3/4			IMP Shed	De-Ice; Area Factor = 1.00
3/5			Lucy	Bad Calibrations; stop measurements

Date	IMP	Area Factor	Location	Comment
			1979	
3/6			IMP Shed	Removed from IMP
3/13	-	1.00	Enewetak	Intermittent; Vibration Sensitive; Ship to EGG, Santa Barbara for troubleshooting
5/11			Enewetak	Returns; cold solder joint repaired
5/31,6/1	2		IMP Shed	Installed; Area Factor = 0.99
6/4-6/8				Soil Screening
6/9,6/11			Pearl	
6/13			IMP Shed	Wide Peak; Low Energy Noise; Remove from IMP, return to PGT for repair

DETECTOR 393 (Radiation Lab IG4)

			1977	
5/15(Approx)	-	1.00*	Las Vegas	Area Factor = 0.98; shipped to Enewetak on IMP 2
7/18	2		Janet	In use on islands noted, together with detector 386
			Pearl	
			Sally	
			Irene	
			Vera	
			Olive	
12/10(Approx)			Janet	Damaged; water in pre-amp.
12/16			Enewetak	Return for repairs; off atoll this date.
			1978	
1/2			Las Vegas	Shipped to PGT for Repair
1/30			PGT	Test Date
2/6-2/8	3		Janet	Installed; Good resolution
2/9-2/11			Daisy	
2/13-2/15			Clara	
2/21-2/25, 2/27			Runit	
2/28			Sally	
3/2	3		Sally	Comparison test w. 496
3/3			Sally	Kickapoo
3/4			IMP Shed	De-Ice
3/6				Replaced Collimator Mount
3/8-3/10			Sally	Yuma
3/13-3/17			Sally	Also monitored soil trucks; Kickapoo

*Value assigned. For area factors within 5% of the previously reported or assigned value, no change in area factor was made.

Date	IMP	Area Factor	Location	Comment
			1978	
3/18-3/23		1.00	Sally	West Spit = Cape Mixan
3/25-3/31			Sally	Kickapoo
4/3-4/4			IMP Shed	De-Ice
4/5			Sally	Kickapoo
4/8			IMP Shed	Detector Be window oxidation noted
4/13-4/19				Loss of resolution noted. De-Ice; Resolution now OK
4/19-4/21			Sally	Yuma; Went bad 4/21, suspect bad Dewar; Removed from IMP
4/27-5/23			Radiation Lab	Be window cleaned, Dewar looks OK, Loses resolution if out of air conditioned area.
4/24-7/20				In use inside lab.
7/22	1		IMP Shed	Installed; Area Factor = 1.04
7/26			Sally	Crypt Soil Screening
8/1-8/11	1		IMP Shed	Outdoor exposure test, losing effective area, De-Ice
8/15			Sally	Crypt Soil Screening
8/16			Radiation Lab	Transferred to Enewetak
10/9				High voltage applied while @ room temperature; damage suspected
11/8,11/9	1	1.20	Enewetak	Installed; Area Factor = 1.20
11/9-11/11	1		Elmer	
11/17	-		Radiation Lab	Transferred to Rad Lab.
11/25	3	1.00	IMP Shed	Installed; Area not measured; reported as 1.20 until 1/2/79
11/27-12/2			Janet	
12/5,12/9				IMP 3 malfunction; transferred to IMP 1
12/11,12/15	1		Janet	
12/18	3		IMP Shed	Transfer back to IMP 3
12/19-12/21			Janet	
			1979	
12/25			IMP Shed	De-Ice, Area Factor = 0.98
12/30			IMP Shed	De-Ice, Area Factor = 0.99
1/4				Secured for Typhoon Alice; came to room temp
1/9				No signal thru; corrosion gunk; bad Dewar; ship to PGT
3/2	-		PGT	Test date
3/14	-		Radiation Lab	For Enewetak checkout.
3/20				Report functioning OK; In use by Radiation Lab until lab shut down

Date	IMP	Area Factor	Location	Comment
		1979		
10/23		1.00	Enewetak	De-Iced
11/5		1.04	Enewetak	De-Iced
11/6			Runit	Installed
11/6-11/9			Runit	
11/11			Enewetak	Area Factor = 1.04
11/12-11/16			Runit	
11/20-11/23			Runit	
11/27-12/4			Runit	
12/15(Approx)			Las Vegas	Transferred to DRI for NTS Survey.

DETECTOR 483 (Radiation Lab IG6)*

		1977		
9/2		~1.10	Las Vegas	Used at Gnome; damaged; returned to PGT
12/29			PGT	Test Date; shipped direct to Enewetak
		1978		
1/3			Enewetak	Set up in Rad Lab; vibration sensitive; Used for few weeks
1/25			Las Vegas	Returned to PGT for repair
2/13			DRI	Transferred for NTS survey
7/24			PGT	Returned to repair slight vacuum leak; loose preamp.
8/1			PGT	Test Date
8/11			Enewetak	Arrives; Rad Lab checks out
8/16	1	1.15	IMP Shed	Area Factor = 1.15
8/21-8/25			Sally	Kickapoo and Yuma
8/29-9/1			Janet	
9/5	2		IMP Shed	Transferred, mechanical problem w IMP 1
9/6			Sally	
9/14-9/16			IMP Shed	De-Ice; Area Factor = 1.11
9/18				Soil Screening
9/19			Sally	Kickapoo Hot Strip
9/20,9/21			IMP Shed	Soil Screening
9/21-9/26			Sally	Kickapoo Hot Strip
10/2-10/4			IMP Shed	De-Ice; Area Factor = 1.10
10/5			Lojwa	Measuring background
10/18			IMP Shed	Secured for Tropical Storm Rita; came to room temp.
10/21	2		IMP Shed	De-Iced; Area Factor = 1.13

*Possibly called IG-4 in Jan 1977

Date	IMP	Area Factor	Location	Comment
			1978	
10/23-11/3		1.15	Elmer	Detector occasionally erratic
11/8	-		Radiation Lab	Transfer to Rad Lab
11/16	3		IMP Shed	Installed in IMP; Area Factor = 1.14
11/20,11/21			Janet	
11/22,11/23			Janet	Detector erratic; cables replaced
11/24			Janet	Detector fails; ship to PGT
12/18	-		PGT	Test Date
			1979	
1/11	3	1.12	IMP Shed	Installed; Area Factor = 1.12
1/25				Soil Screening - Crypt
1/29-2/1			Runit	High field calib caused by positioning error
2/12-2/15			Janet	Windrow measurements
2/21			IMP Shed	Soil Screening
3/3			Runit	
3/5-3/7			Janet	
3/8			Sally	
3/12			Janet	
3/16			Loj	
3/19-3/23			Pearl	
3/27,3/28			IMP Shed	De-ice, Area Factor = 1.08
4/2-4/6			Pearl	
4/9-4/10			Sally	Pace; Transferred, mechanical problem w. IMP 3
4/1	1		Sally	Pace
4/22,4/23			IMP Shed	De-Ice; Area Factor = 1.06
5/1	1		Sally	Crypt
5/5,5/8			IMP Shed	Soil Screening-Janet
5/10			Janet	Plow-X
5/12			IMP Shed	Soil Screening-Janet
5/19,5/20		1.11		De-Ice; Area Factor = 1.11
5/25			Sally	Crypt
5/28,5/29			Pearl	
5/30			IMP Shed	Transferred to IMP 2 then back to IMP 1 to help diagnose detector 635
6/4-6/8,6/11				Soil Screening-Irene
6/13,6/14			Runit	
6/15	2		IMP Shed	Transferred to IMP 2; Soil Screening-Pearl
6/16				Soil Screening-Irene
6/18	1			De-Ice; Area Factor = 1.08; Transferred to IMP 1
6/19,6/22				Soil Screening-Pearl
6/22,6/23			Runit	
6/26-6/30			IMP Shed	Soil Screening-Pearl

Date	IMP	Area Factor	Location	Comment
			1979	
7/5, 7/6		1.11	Runit	
7/9			Pearl	
7/10-7/12			Irene	
7/18,7/20			Runit	
7/23-7/25			IMP Shed	De-Ice; Area Factor = 1.12
7/26			Runit	
7/30-8/2			Sally	Crypt
8/17			Enewetak	Detector Dewar fails; return to PGT

DETECTOR 496 (Radiation Lab IG5)

			1977	
7/19	-		PGT	Test Date
8/2(Approx)		1.06	Las Vegas	In use for Nevada Test Site monitoring by DRI until arrival at Enewetak
			1978	
2/2	1	1.06	IMP Shed	Installed, Area Factor = 1.06 noted, Low bias voltage until 2/27, Measurements Repeated
2/3,2/4			Lucy	
2/7,2/9			Alice	
2/13,2/16			Belle	
2/21,2/24			Sally	Kickapoo
2/25			Sally	Yuma
2/27		1.10	Sally	Kickapoo; Correct Bias Used, See Tech Note 5.2
3/1			Tilda	
3/2			Sally	Comparison Test with 393
3/3			Tilda	
3/4			IMP Shed	De-Ice
3/6,3/7			Tilda	
3/9,3/10			Kate	
3/13,3/15			Nancy	
3/16,3/17			Lucy	Remeasurement
3/18			IMP Shed	Removed and Reinstalled Detector
3/21,3/22		1.28	Wilma	Field Cal Response Difference, see Tech Note 5.2
3/25			Sally	Kickapoo
3/28			Ruby	Detector No. 483 entered in error on data
3/29,3/30	1		Mary	
4/3			IMP Shed	De-Ice
4/5,4/6			Sally	Kickapoo; Detector Be window oxidation noted

Date	IMP	Area Factor	Location	Comment
		1978		
4/18,4/21		1.28	Alice	Remeasurement
4/26			Sally	Yuma
5/4			IMP Shed	Be window cleaned
5/8-5/13			Sally	Soil Screening and Truck Sampling
5/15			IMP Shed	Possible Mechanical Damage; De-Ice
5/16			IMP Shed	Detector OK; Soil Screening
5/18,5/19			Sally	Truck Sampling
5/22-5/24			IMP Shed	Soil Screening
5/25			Sally	
5/26-6/5			IMP Shed	Soil Screening
6/6,6/7			Sally	Kickapoo
6/8-6/21			IMP Shed	Soil Screening
6/22			Sally	
6/23			IMP Shed	De-Ice; Suspect Dewar Failing
6/26			Sally	Kickapoo
6/29,6/30			IMP Shed	Soil Screening
7/1			Sally	
7/3			IMP Shed	Soil Screening
7/4			Sally	
7/5,7/6			Pearl	
7/7			IMP Shed	Soil Screening
7/12			Sally	Yuma
7/14,7/15	1		IMP Shed	Area Factor = 1.28
7/20				Dewar Failure; Noted Condensation on Be Window and Neck
7/22	-			Removed to Enewetak for testing
7/25			Rad Lab	Calibrated and Operating
7/27				Malfunctioning; Dewar failure; Vibration sensitive; Return for repair
9/21			PGT	Test Date
11/11,11/13	2	1.11	Enewetak	Installed; Area Factor = 1.11
11/15-11/25			Crypt	
11/30			IMP Shed	Soil Screening
12/1-12/8			Crypt Shed	Soil Screening
12/9			IMP Shed	De-Ice
12/11		1.06		Area Factor = 1.06
		1979		
1/1-1/3	2		Crypt Shed	Soil Screening
1/4			IMP Shed	Secured for Typhoon Alice, came to room temp
1/10				De-Iced; Area Factor = 1.20
1/10-1/15		1.20	Crypt Shed	Soil Screening
1/17-1/19	2		Crypt	Spoil Pile and Debris Measurements

Date	IMP	Area Factor	Location	Comment
		1979		
1/17-1/20		1.20	IMP Shed	Soil Screening
1/23				De-Ice
1/26				Poor Resolution after De-Ice
1/27				Area Factor = 1.17
1/30,2/2				Soil Screening
2/2	2		Crypt	
2/5,2/6			Irene	Malfunction, Removed; Shipped to PGT
3/10(Approx)	-		PGT	Test Date
6/14	2		IMP Shed	Installed, low energy noise, poor resolution, transfer to IMP 1
6/15,6/16	1		IMP Shed	OK, Soil Screening
6/18	2	1.06	IMP Shed	Transfer; Area Factor = 1.06
6/18-6/20			IMP Shed	Soil Screening
6/21,6/22			Runit	Low response to field cal source; possible intermittent
6/23			IMP Shed	Soil Screening; Detector looks OK
6/26,6/27			Irene	
6/27			Belle	Set up for Soil Screening
6/28-6/30				Soil Screening; Intermittent low response to field cal source and low energy noise
7/2-7/6				Same as above
7/9			IMP Shed	Intermittent fixed; wiring problem, not detector
7/11-7/14			Irene	
7/16	3		IMP Shed	IMP 2 mechanical problems; transferred to IMP 3
7/21			Runit	
7/26-7/28			IMP Shed	De-Ice; needs to be repeated
8/3				De-Ice; Area Factor = 1.08
9/3			Enewetak	Random Point on Enewetak
10/25		1.11	Enewetak	Area Factor = 1.11
10/26-11/5			Runit	Detector fails 11/5; Return for repair

DETECTOR 513 (Radiation Lab IG3)*

		1977		
10/5	1	1.00**	Las Vegas	Received from PGT; to Enewetak with IMP 1; Area Factor = 1.02

*Mislabeled as IG 5 during period 3/10 to 3/13/78

**Value assigned. For area factors within 5% of the previously reported or assigned value, no change in area factor was made.

Date	IMP	Area Factor	Location	Comment
		1977		
11/11-12/8(Approx)		1.00	Rad Lab	In use in Rad Lab
12/9(Approx)	1		IMP Shed	Installed in IMP 1
12/12(Approx)	-		Rad Lab	IMP PHA fails; return detector to Rad Lab
12/26-12/28			Enewetak	Evacuation for Typhoon Mary
		1978		
1/6	1		Janet	
1/7				Tropical Storm Nadine
1/12				De-Ice
1/14-1/19	3		Janet	Installed in IMP 3
1/20				Malfunction; removed from IMP
1/25	-		Las Vegas	Shipped to PGT for repair
2/15			PGT	Test Date
3/18	1		IMP Shed	Installed; Area Factor about same as 496 (1.1 to 1.3); Poor resolution (tails) for Cs and Co peaks
3/21				Dewar failed
3/30	-		Las Vegas	Shipped to PGT for repair
4/11			PGT	Test Date
4/25	3		IMP Shed	Installed
4/26			Sally	Yuma
5/1-5/6	3		Sally	Kickapoo
5/8-5/13			Sally	Yuma
5/15-5/19			Sally	Truck sampling
5/23-5/27			IMP Shed	Soil Screening
5/28				De-Ice
5/29-6/5				Soil Screening
6/6,6/7			Sally	Kickapoo
6/12,6/19			IMP Shed	Soil Screening
6/21			Sally	
6/23,6/24			IMP Shed	Soil Screening
6/26,6/27			Janet	
6/28			Pearl	Data Questionable
6/30			IMP Shed	De-Ice; looks OK
7/4-7/5			IMP Shed	Soil Screening; Detector Malfunction, losing sensitivity
7/6				Soil Screening; Detector losing sensitivity during the day
7/10	-		Enewetak	Radiation Lab checkout; bad detector, return to PGT
7/24			Las Vegas	Shipped to PGT for repair
8/10(Approx)			PGT	Test Date
8/15			Las Vegas	Received from PGT; still has tailing problem
10/15(Approx)			DRI	Transferred for NTS Survey

Date	IMP	Area Factor	Location	Comment
		DETECTOR 635		
		1978		
7/5	-	1.10	Las Vegas	Received from PGT; transferred to DRI for NTS survey
10/15(Approx)				Returned to PGT for repair; resolution degrades w. time (had been observed by PGT March to July)
		1979		
1/8			Las Vegas	Received from PGT
1/12			DRI	Transferred to DRI for NTS survey
3/3			Enewetak	Radiation Lab; considerable difficulty in starting up reported
3/12	2	1.14	IMP Shed	Installed; Area Factor = 1.14
3/17				Soil Screening - Crypt
3/19,3/20			Kate	
3/23			Janet	
3/26-4/11			Runit	
4/18-4/20			Janet	
4/30-5/4		1.19	IMP Shed	De-Ice, Area Factor = 1.19
5/5				Soil Screening - Kickapoo
5/8-5/12				Soil Screening - Janet and Cactus Crater lip
5/14-5/25			Pearl	
5/26-5/28			IMP Shed	De-Ice; poor signal afterwards
5/30				Malfunction, no signal thru, return to PGT
6/12	-		Las Vegas	Return to PGT for repair

APPENDIX E: RADIOLOGICAL ASPECTS OF OPLAN 600-77

This appendix contains an extract of selected passages from FCDNA OPLAN 600-77. This OPLAN described the concept and provided guidance for the cleanup project at the time it was issued in April 1977. Although the basic plan was followed in most major respects, some deviations did occur when the work was performed to adapt to conditions and problems experienced in the field.

The foregoing pages describe the way ERSP actually carried out its assignments. For background and the historical record, portions of the OPLAN relevant to ERSP are quoted below, although it is important for the reader to realize some changes were made in the way activities were actually conducted.

OPLAN 600-77

The final version of OPLAN 600-77, including the demobilization annex, is about 700 pages in length. Of this total, only 27 pages deal with radiological aspects of cleanup involving DOE. This Appendix is reproduced from numerous parts of OPLAN 600-77, with only minor editorial modifications (or introductory remarks in parentheses) to provide continuity. Where actual practice differed significantly from OPLAN specifications, a footnote has been added to explain, or just to note, the difference.

(Figure C-4-1, shown herein as Figure E-1, portrays the overall Enewetak Cleanup Operation Schedule as envisioned 29 April 1977. Note that the radiation survey was at that time expected to take 4.5 months. Details of the Mobilization Phase applicable to the ERSP are presented in Figures E-2 and E-3. The following paragraph outlines the general responsibilities assigned to ERDA/DOE. The next following paragraph summarizes the removal of contaminated soil, then details of soil cleanup are presented. Underlined numbers in parentheses preceding each section identify the location of the text within OPLAN 600-77.)

(3.b.(5)(c) pg. 19) ERDA has established a project manager organization (Enewetak Radiological Support Project (ERSP)) which will work closely with the JTG Commander and his staff for the satisfactory accomplishment of radiological cleanup operations. The ERSP will also provide advice to the Commander in radiological safety and other radiation related matters. Additionally, ERDA, through its Pacific Area Support Office, administers the base support contract (H&N). The Task Organization for the ERDA element is shown in Figure A-6-1 (Figure E-4 herein).

(C.3.a.(2)(c)) Removal of Contaminated Soil. Before soil removal can begin, the northern islands will be radiologically surveyed by air and the ERDA field in situ vans supported by the FRST and Army engineers. The survey party will identify the contaminated soil and physically mark these areas on the ground. Once these areas have been marked, the engineer team with appropriate equipment can begin the soil removal. Depth of soil removal cuts will be recommended by ERDA personnel based upon detailed cleanup objectives set by the JTG Commander. After the soil has been removed, the area will be resurveyed and if the surface soil concentration does not meet the objective, another cut will be made. This iterative process will continue until the objective has been met. The contaminated soil will be placed in dump trucks and covered with tarps for transport to Runit (Yvonne). Care must be taken by the work force to avoid the contamination of areas designated as noncontaminated. Upon final radiological certification by ERDA, engineer equipment will be utilized to eliminate unusual and uneven soil irregularities in the area.

(Annex C, App. 2, Para 3.) SOIL CLEANUP:

a. General

(1) The identification, collection and removal of Pu contaminated soil will be called "soil cleanup." An ERDA developed in situ gamma ray measurement and calculation method will be used to quantify Pu contamination of soil. The "in situ method" will also be the primary method used by ERDA for certification (See Tab E).

(2) The in situ method measures the flux density (the number of gamma rays per unit area time) of the prominent gamma ray from americium (Am), a radioactive decay product of Pu, at a point in air above the ground. The average Am concentration in the soil at the

APPENDIX 4 TO ANNEX C TO FC DNA OPLAN 600-77
ENEWETAK CLEANUP OPERATIONS SCHEDULE

FIELD COMMAND
DEFENSE NUCLEAR AGENCY
KIRTLAND AFB, NEW MEXICO 87115
29 APRIL 1977

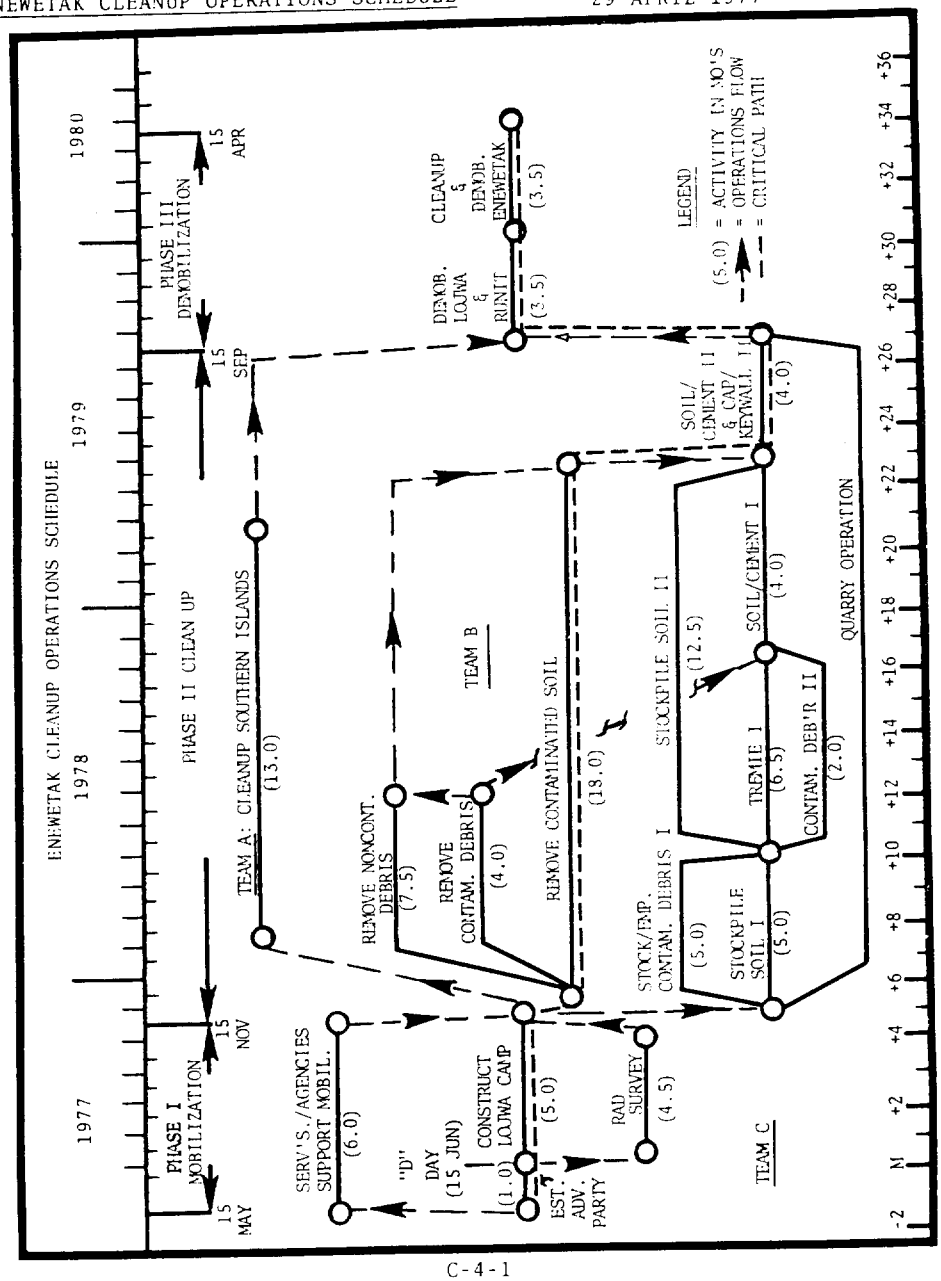


FIGURE E-1. ENEWETAK CLEANUP OPERATIONS SCHEDULE, OPLAN 600-77

C-4-1

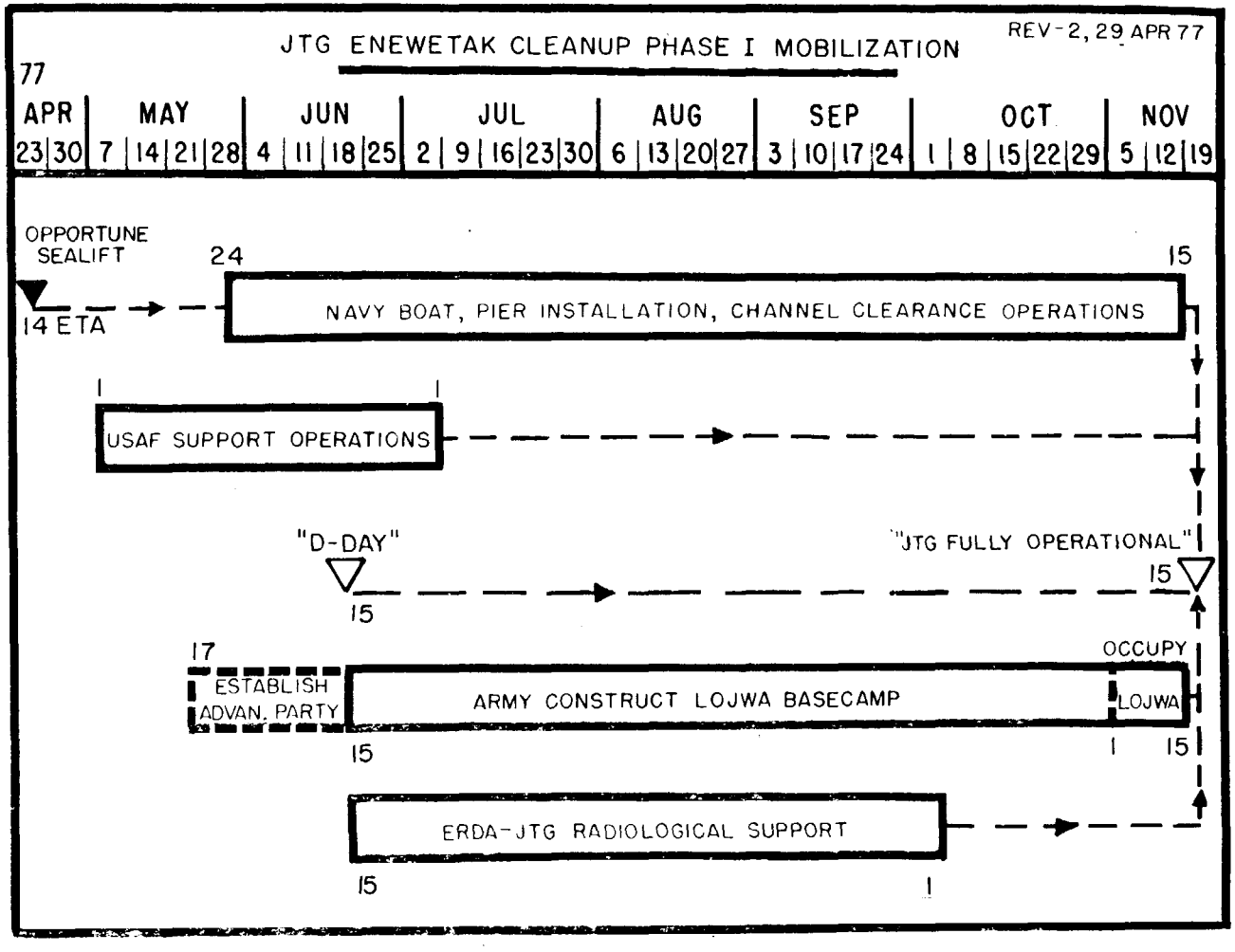


FIGURE E-2. JTG ENEWETAK CLEANUP PHASE I MOBILIZATION, OPLAN 600-77

TABLE II

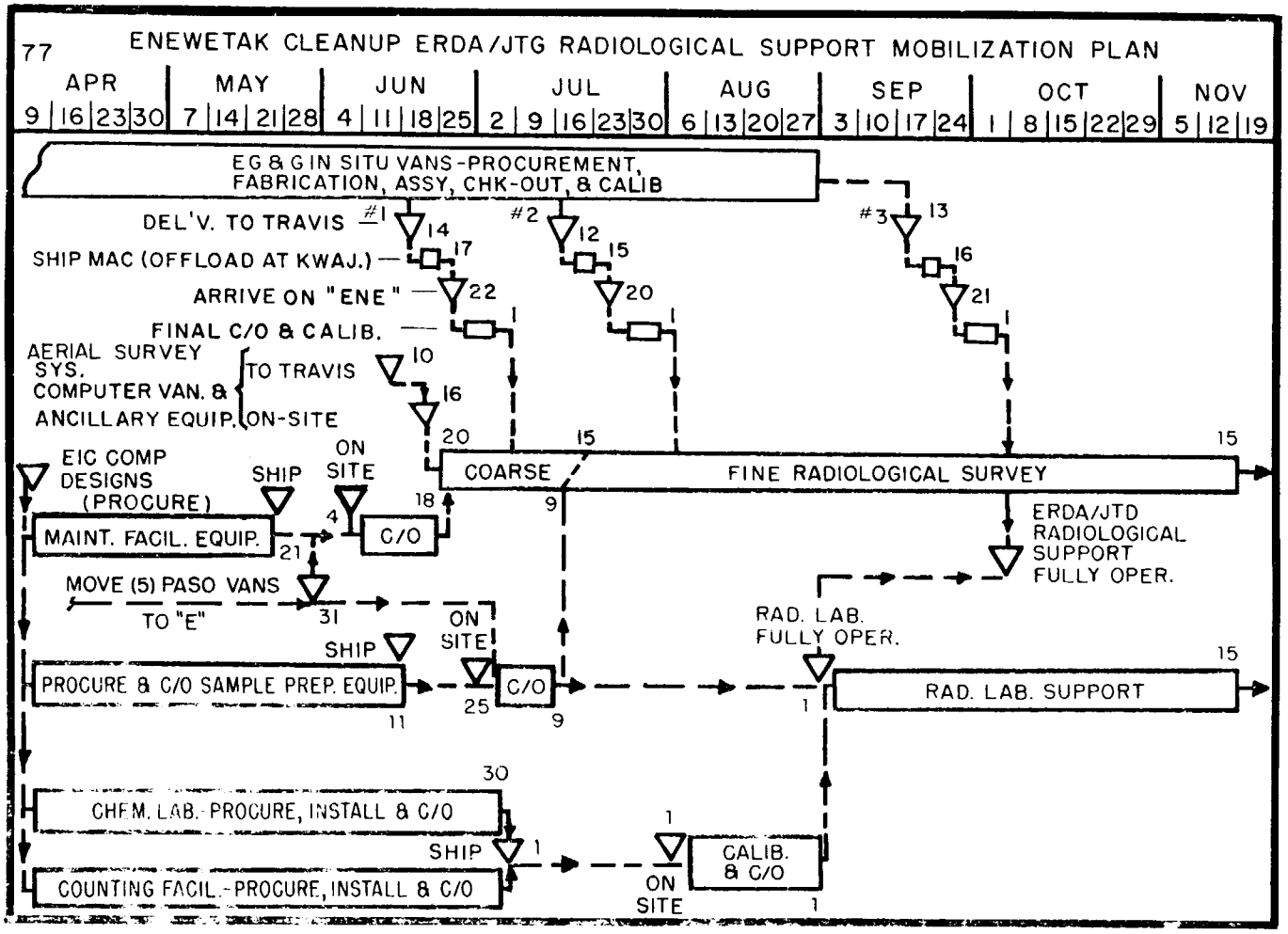


FIGURE E-3. ENEWETAK CLEANUP ERDA/JTG RADIOLOGICAL SUPPORT MOBILIZATION PLAN, OPLAN 660-77

APPENDIX 6 TO ANNEX A TO FCDNA OPLAN 600-77
TASK ORGANIZATION - ERDA ELEMENT

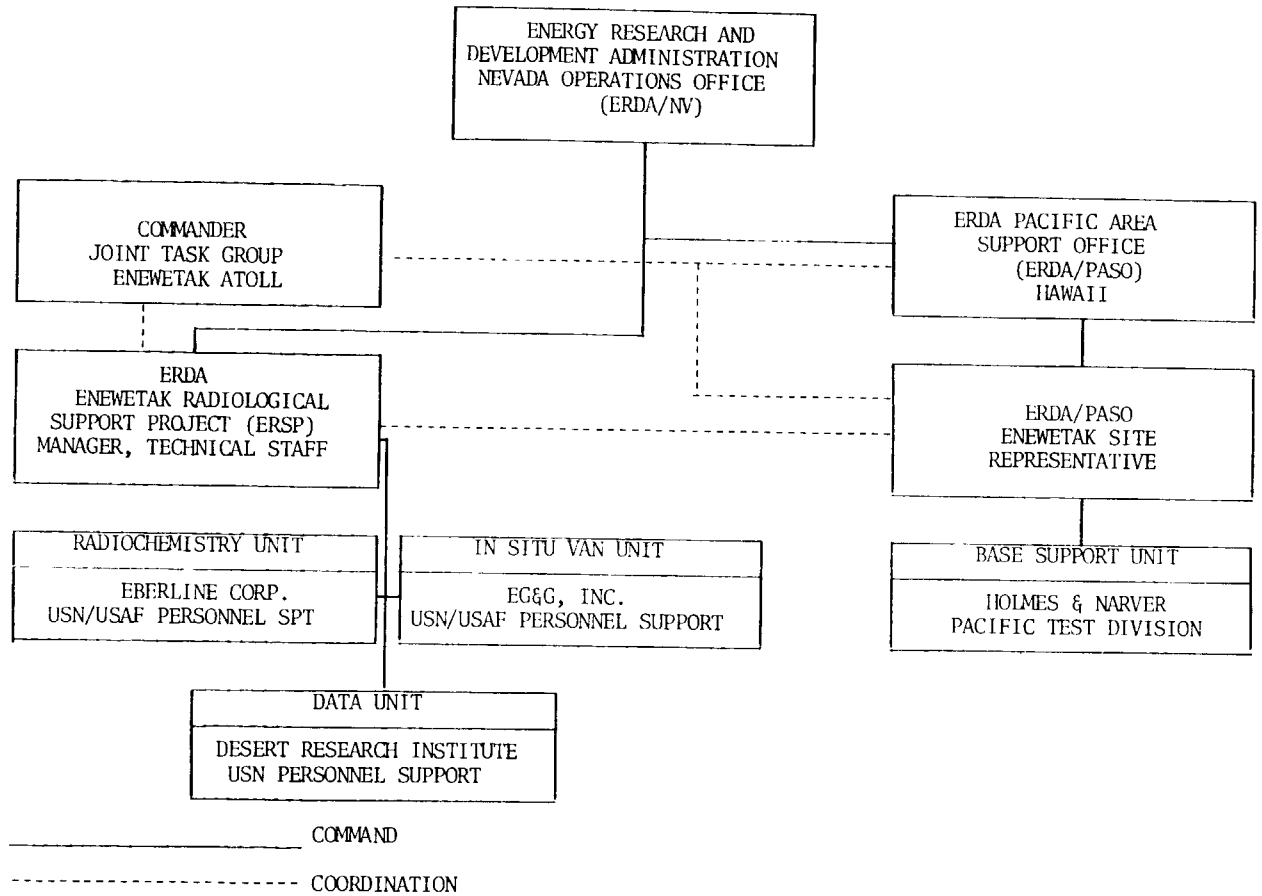


FIGURE E-4. TASK ORGANIZATION—ERDA ELEMENT, OPLAN 600-77

ground surface is calculated using this flux density measurement together with depth distribution and soil density data obtained from an analysis of soil samples by the radiochemistry laboratory (Tab D). The average Pu concentration over an area of soil is derived from the calculated Am concentration and the Pu/Am ratio which has been determined by laboratory radiochemical analysis.

b. Execution

(1) The in situ measurements by helicopter and by van (including Pu/Am ratios, densities and depth profiles) and data analysis will be performed by ERDA, using available DoD personnel for assistance as needed. The Field Radiation Support Team (FRST) will conduct radiological safety monitoring as necessary during soil cleanup. Radiological counting facilities (FCDNA provided) will be managed by the FRST to provide the radiological safety support services.

(2) In situ measurements will be made on the islands listed in Tab A. (Ed. Note: Tab A, not included herein, listed islands Alice through Yvonne.) Initial measurements will be based on data derived from the AEC Survey and the aerial radiological survey. When measurements show Pu concentration levels sufficient to require, or likely to require soil cleanup, soil samples will be taken and/or additional measurements will be made on successively finer and finer grids until boundaries of the elevated Pu concentrations in soil can be well established. Soil cleanup will proceed iteratively until an acceptable concentration level is attained (See Tab E).

(3) The in situ method probably will not be suitable for locating Pu contaminated soil which is buried. Thus, suspected burial sites of Pu contaminated soil (Tab B, listed Irene, Ruby, Sally, and Yvonne) will be investigated by means of a truck-mounted auger or coring device capable of drilling into the ground to depths up to 3 meters.* Material will be removed from the auger as it penetrates the ground and assayed for Am by the in situ gamma ray spectrometer. If the presence of buried Pu bearing soil is indicated, further sampling and analysis will be required to define the limits and levels of contamination and to determine appropriate cleanup actions.

(4) The Pu contaminated soil which is collected will be transported to Runit (Yvonne) by trucks of sufficient integrity to prevent any loss of contaminated materials. This soil will be stockpiled on Runit for subsequent crater placement. Trucks will be monitored periodically and decontaminated as appropriate.

(The OPLAN contained the following section describing the purpose and operations of the Radiochemistry Laboratory. Chapter 4 of this Report provides details of actual operations.)

(Annex C, App. 2, Tab D) RADIOCHEMISTRY LABORATORY

1. PURPOSE: A radiochemistry laboratory (RAD LAB) will be established to support the Atoll radiological protection program and the plutonium soil assay operations.

2. CONCEPT OF OPERATIONS:

a. This laboratory complex will have a capability to prepare samples for radiochemistry assay, and to analyze prepared samples for alpha, beta, and gamma radiation including isotopic identification and quantification. The laboratory will have a maintenance capability to repair and calibrate its own radiation measuring equipment as well as the portable radiation instruments used during the Cleanup. It will also be capable of supporting the in situ van measurement operations.

b. All work done by the RAD LAB including maintenance work, will be pursuant to the direction of the ERDA ERSP Manager.

*This method was used only at the Aomon Crypt. Other subsurface investigations utilized a backhoe to dig a small trench for sidewall profiling.

3. CONDUCT OF OPERATIONS:

a. The Field Radiation Support Team, in its capacity of implementing the radiological protection program discussed in Tab C (not included herein), will collect urine samples, air sample filters, nose swipes, etc., which may be analyzed by the RAD LAB for fast turn around results. These samples will be sealed in appropriate containers, e.g., plastic bottles or plastic bags. Samples are to be supplied with proper identification and accompanied by completed data forms. They will be delivered to the sample preparation trailer in the RAD LAB complex. Soil samples taken on the northern islands also will be sealed and identified in appropriate containers, and delivered to the sample preparation trailer.

b. All samples received will be bagged and prepared for analysis. Soil samples will be processed so that the sample will be homogenized. An aliquot will be taken from the processed sample for analysis by wet chemistry. The remainder of the homogenized sample will be stored for the duration of the project in case additional analysis is required.

c. The chemistry trailer is a minimal facility equipped to handle an estimated 10 soil samples/day. Chemistry techniques will be applied to prepare these and other samples for subsequent counting.

d. The radiation measurements trailer will have two multichannel analyzers which can be applied to two of four available detection systems: intrinsic germanium, sodium iodide, alpha spectrometer, and FIDLER. The trailer will also contain low level alpha and beta counting, liquid scintillation, and large area alpha and beta counting systems. The radiological counting of a sample will be performed by one or more of these systems. Appropriate mathematical calculations will be performed to convert sample counts to the desired units. This facility will be equipped with health physics equipment to support the laboratory operations and other limited functions on the Atoll.

e. Samples will be processed in batches so that blind samples of spiked blanks and splits may be processed simultaneously for purpose of quality control. A written quality assurance manual for RAD LAB operations will be developed for the approval of the ERDA ERSP Manager. Quality control results will be documented.

f. A written procedures manual, approved by ERDA, for sample preparation, chemistry, and counting, will be developed and maintained. Analysis will conform to this manual or to approved modification.*

g. Two FRST team members will be assigned to the function of instrument maintenance. If required, they will be supplemented by personnel from the maintenance trailer. There will be operational equipment spares in the forward area (northern islands), however, the major inventory of spares for FRST team instrument support will be maintained in the maintenance trailer.

h. All radioactive calibration sources, other than license exempt, will be controlled by the RAD LAB in accordance with the procedures of appropriate chapters of the ERDA Manual. An inventory of these sources will be furnished the Enewetak Radiological Protection Officer (RPO).

i. The ERDA contractor, Eberline, will be responsible for the RAD LAB and instrument maintenance facilities. Military personnel will be employed in these facilities. (See chart C-2-D-1-1, shown herein as Figure E-5.)

j. The instrument maintenance facility will support the field in situ van operation for repair and calibration as required. This will include appropriate test equipment and ordinary spare parts. Unique spares for the system will be furnished by the ERDA in situ van contractor (EG&G).

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*See Appendix B of this report.

ENCLOSURE 1 TO TAB D TO APPENDIX 2 TO ANNEX C TO FCDNA OPLAN 600-77
RADIOCHEMISTRY LABORATORY ORGANIZATION AND MANNING

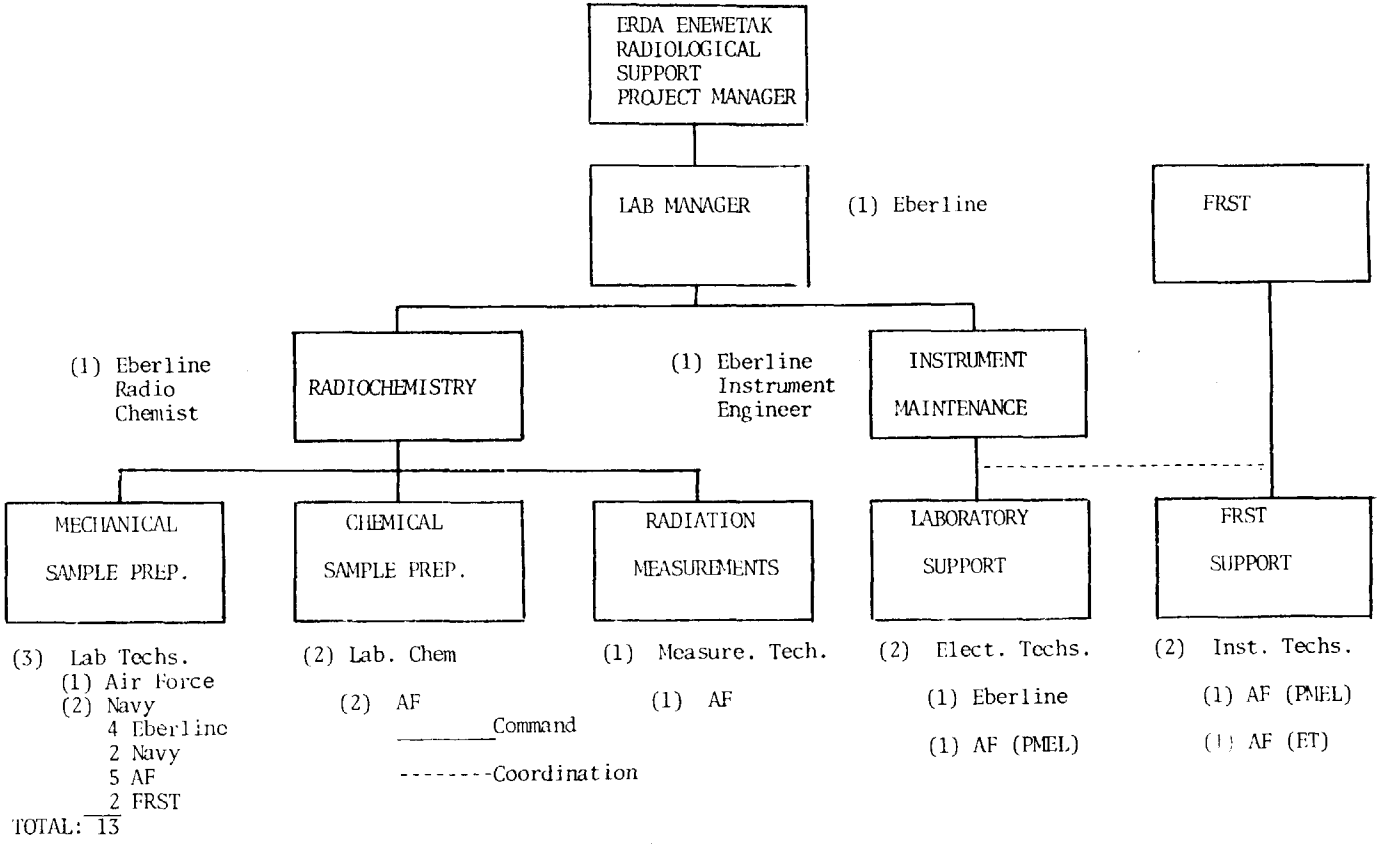

FIGURE E-5. RADIOCHEMISTRY LABORATORY ORGANIZATION AND MANNING, OPLAN 600-77

k. Maintenance of the RAD LAB equipment will be accomplished by the ERDA contractor maintenance facility.

l. The RAD LAB facility, including an instrument maintenance trailer, will be located on existing pads number 46, 47, and 48 on Enewetak (Fred) Island.

m. ERDA will be responsible for establishing, ordering and storage requirements and a distribution schedule for liquid nitrogen.

(Field in-situ operations and Pu survey criteria are described in the following sections from the OPLAN. Chapter 3 of this report documents actual field in-situ operations while Pu criteria are discussed in Section 2.2.4 of this report.)

(Annex C, App. 2, Tab E) FIELD IN SITU OPERATIONS

1. GENERAL: The in situ van is a mobile soil assay system in a tracked vehicle. It is self-contained to the extent that all radiological data can be acquired and most of the data processed by the in situ van in the field. Final data processing and map overlays, etc., will be done in the Data Reduction Trailers on Lojwa (Ursula)* and Enewetak (Fred).

2. CONCEPT OF OPERATIONS:

a. The in situ van is designed to detect gamma-ray emitting radionuclides in the soil. It will accomplish this by means of a solid state radiation detector suspended above the soil by means of a boom at the rear of the vehicle. A complete survey of an island will require roughly ten to one hundred measurement locations depending upon the island size. These measurement locations will initially be spaced 50-100 meters apart in an approximately rectangular grid covering an island. To facilitate access, measurement locations may require some clearing and will be identified by survey markers. These locations will eventually be referenced to a permanent set of coordinates for documentation.

b. Initially, the undisturbed soil will be looked at in an area cleared of vegetation.**. This will allow a decision to be made concerning location and extent of soil removal operations. Additional measurements will be made after each soil lift to plan future work. Finally, a set of measurements will be made to document the radiological condition of the islands at the termination of cleanup operations.

3. CONDUCT OF OPERATIONS:

a. A typical sequence of operations would be:

(1) Off-load in situ van from inter-island transport boat.

(2) Drive to first measurement location.

(3) Deploy boom and detector to operating position (approximately 10 meters above soil surface).

(4) Acquire data. (Acquisition time will vary.)

(5) Secure boom and detector.

(6) Drive to next location. This typical sequence is expected to result in an overall average rate of one measurement location per hour.***

*Data processing and construction of maps and overlays was all done by DRI in the Enewetak facility.
**Early experience indicated that vegetation could not be economically cleared without disturbing the soil. See Chapter 6 for details on vegetation clearing.
***In average circumstances, two locations per hour were measured.

b. During the in situ van measurements, areas will be selected where representative soil samples will be taken. These soil samples will be transported to Enewetak for analysis by the Radiochemistry Laboratory. The americium (Am) and plutonium (Pu) concentration data from these soil samples will be used to complete the data chain for calculation of plutonium soil concentrations from the in situ van measurements. A maximum of 100 soil samples may be sent to McClellan Central Laboratory* for analysis during July/August, (results required by 30 August) depending upon the availability of the Radiochemistry Laboratory on Enewetak presently scheduled to become operational in August.

c. Soil sampling is an important part of the in situ van operation since the Pu and Am data derived from the soil samples provides the basic van detector calibration. For this reason, careful sampling procedures will be used to assure the validity and accuracy of surface concentration data, and of the gradient of concentration with depth.

d. After all measurement locations have been visited and data acquired, a complete set of data for that island will be sent to the Data Reduction Trailer. These data, together with the Am and Pu data from the soil samples, will be used to generate isopleth map overlays showing plutonium soil concentration contours. Soil sample analysis may take three to four days and the basic data processing is expected to take one to two days.

e. The first plutonium contours will be used as a guide to determine which areas need to be cleared further for a more detailed survey grid. After this clearing is complete and a new grid surveyed in to fit the area, the in situ van will be used to provide a more detailed set of plutonium concentration contours. These contours will then be used to direct soil removal operations.

f. After the initial soil removal, the in situ van will re-survey the removal area. Analysis of additional soil samples may be required and will be done by the Radiochemistry Laboratory at Enewetak. This reevaluation will result in a new set of plutonium soil concentration contours that will be used to guide additional soil removal operations. Upon completion of the final soil lift, the in situ van will be used to document the then existing concentrations and a final set of plutonium concentration contours will be drawn. It is important that the documentation, which will be essential to ERDA certification, be referenced to permanent coordinates.**

g. The concept of phased operations presents the opportunity to make an initial gross survey of the islands to identify those with the highest probability of soil removal. These data will greatly assist in developing working estimates of soil to be removed.

h. An ERDA aerial survey system will be fielded as early as possible (i.e., shipped in mid-June and operational shortly thereafter). This aerial system would proceed to survey the islands where soil removal possibilities exist.

i. The first van will be shipped approximately 1 July and become operational in mid-July, a second van, will be operational in August and both will commence with the fine surveys. By the August/September time frame, sufficient fine surveys can be completed to allow soil removal to begin in the planned mid-November time frame.*** As noted in 3.b above, the initial soil samples for van calibrations will be sent to McClellan AFB for analysis. The Radiochemistry Laboratory is expected to become operational on Enewetak in August.

j. A third van is expected to be on Enewetak at the end of September. This van is intended as an operating spare replacement for the operating vans.

*No samples were sent to this laboratory.

**Reference points were not recovered or established on some islands, so this aspect of the documentation is incomplete.

***Soil removal operations did not start in November.

4. PU SURVEY CRITERIA:*

a. The AEC Task Group recommendations and guidance were by design, general in nature. Subsequently, criteria have been developed by ERDA to guide the in situ soil assay.

b. A case-by-case evaluation by the CJTG (with the advice of the RCC) of the requirements for soil removal, taking into consideration the location (island), planned use, economics and the AEC/ERDA Task Group recommendations, will be required for each of the islands where contamination is found to exist. The resulting evaluation should lead to one of the four following conditions which have been recommended by ERDA.

(1) Condition A. When an assay area/1 is determined by either direct measurement or extrapolation, to exceed 400 pCi/g (at the 67 percent confidence level/2), the following actions will be taken:

(a) The area will be fine surveyed and isopleths drawn which define the region which exceeds local background/3.

(b) Vertical soil profiles will be taken to evaluate the effectiveness of excavation as a means of reducing the resuspension potential/4.

(c) An iterative excavation plan will be executed to:

1. Reduce the assay area average concentration below 400 pCi/g/5.

2. Reduce the average concentration of the "defined region" to some lower number which shall be determined by cost-benefit considerations but will usually not be below local background.

(d) The region will be resurveyed and the results documented.

(2) Condition B. When a half hectare is determined by either direct measurement or extrapolation to exceed 100 pCi/g (at the 67 percent confidence level), the following actions will be taken:

(a) The area will be fine surveyed and isopleths drawn which define the region which exceeds local background.

(b) Vertical soil profiles will be taken to evaluate the effectiveness of excavation as a means of reducing the Resuspension Potential.

(c) An iterative excavation plan will be executed to:

1. Reduce the half hectare area average concentration below 100 pCi/g.

2. Reduce the average concentration of the "defined region" to some lower number which shall be determined by cost-benefit considerations but will usually not be below local background.

(d) The region will be resurveyed and the results documented.

(3) Condition C: When a quarter hectare is determined by either direct measurement or extrapolation to exceed 40 pCi/g (at the 67 percent confidence level number), the following actions will be taken:

(a) The area will be fine surveyed and isopleths drawn which define the region which exceeds local background.

(b) Vertical soil profiles will be taken to evaluate the effectiveness of excavation as a means of reducing the Resuspension Potential.

*See Section 2.2.4 of this Report for final criteria.

(c) An iterative excavation plan will be executed to:

1. Reduce the quarter hectare area average concentration below 40 pCi/g.

2. Reduce the average concentration of the "defined region" to some lower number which shall be determined by cost-benefit considerations, but will usually not be below local background.

(4) Condition D: An assay area whose average Pu concentration is any 5 cm thickness of soil below the surface layer when measured /6 (at the 67 percent confidence level) to exceed 400 pCi/g will be excavated and measured iteratively until its average Pu concentration in the new 5 cm layer is found by measurement (at the 50 percent confidence level) to be reduced in the defined region to some lower number which shall be determined by cost-benefit considerations, but will usually not be below local background.

Footnotes:

/1 Assay Area. The field of view of the in situ detector in its normal operating position; typically a 28 meter diameter circle of 3 - 5 cm in depth. Scattered measurement can be used to estimate average concentrations between such measurements by means of a linear estimator program known as "Kriging."

/2 Statistically, two-thirds of the time the actual concentration will be below the guide number. One-third of the time the actual concentration may exceed the number by some percentage which must be empirically determined (up to 20-30 percent, as an estimate). This is similar to using a 50 percent confidence level with a numerical guide 20-30 percent (estimated) lower. If a 90 percent confidence level were used with the numerical guide, the equivalent guide at a 50 percent confidence level would require a 40-50 percent (estimated) reduction of the numerical number. For example, if the guide number were 400 pCi/g, cleanup would be required at 400- σt, where σ is the standard deviation of the measurement and t is the "student t" value, about 0 for 50 percent, .5 for 67 percent, 1.5 for 90 percent and 2.0 for 95 percent. The current estimate without data for a typical is 30-50 percent of the measurement (data and experience at Enewetak will be necessary to measure the sigma). Therefore, a 50 percent confidence level would require cleanup above 400 pCi/g, 67 percent would require cleanup at 320 pCi/g (estimated), and 90 percent would require cleanup at 250 pCi/g (estimated).

/3 Local Background. In this plan, local background is defined as the average surface soil concentration which is expected to remain in the undisturbed region surrounding a cleaned up area. Identification of the surrounding region (which may be a portion of an island or at most an entire island) will result from examination of coarse survey data, evaluation of potential land use and accessibility, and economic and logistic factors. Thus, the decision as to what surface concentration is to be assumed in each case as local background is judgemental and is a key element in setting detailed cleanup objectives.

/4 Resuspension Potential. The product of an area multiplied by the average surface concentration of Pu over that area, hence the inventory of Pu readily available to be resuspended. Resuspension potential is an index which has no meaning in terms of hazard. It serves only to compare areas as being worthy of the expenditure of cleanup resources.

/5 Surface Concentration. The apparent concentration on the surface, as viewed by the in situ detector. In reality, this is a complex function of the distribution of Pu in the top few cm of soil. Normally expressed in pCi/g.

/6 Soil profiles will (approximately 2 or more) be needed to estimate the assay area below the surface.

(Predeployment Radiological Training is presented in the following section from the OPLAN. This Report has no counterpart sections.)

(Annex C, App. 2, Tab H) PREDEPLOYMENT RADIOLOGICAL TRAINING

1. GENERAL:

a. The military personnel of the Field Radiation Support Team (FRST) and those supporting the ERDA contractor Radiochemistry Laboratory (RAD LAB) and the field in situ van operation must be able to perform specialized duties in such areas as radiological monitoring, air sampling, radiochemistry or soil sampling. The military training system does not routinely train personnel in these skills; therefore, a special training program must be established to prepare the assigned individuals for their tasks.

b. The USAF will provide 33 personnel for the FRST and 7 for the RAD LAB/in situ van. The USN will provide eight for the RAD LAB/in situ van operation.

2. REQUIREMENTS:

a. FRST. The personnel identified for the FRST need to be fully qualified in radiological health principles, use of survey instruments and other areas unique to the cleanup operation. Therefore, some period of intensive training is required for those personnel who will be FRST members. Minimum areas to be covered would include basic radiation, sources of radiation on the islands, biological hazards of radiation exposure, principles of radiation detection, bioassay methods, personnel monitoring and principles of decontamination and protection.

b. RAD LAB and In Situ Van. The USAF personnel from the McClellan Central Laboratory will be fully qualified to function as laboratory chemists. Indications are that the other personnel supporting the RAD LAB and in situ van may not be fully qualified. They will have to be trained in radiochemistry techniques, laboratory radiation measurement procedures, and computer programming in support of in situ operations or radiological soil sampling.

c. Because the radiological support to the cleanup is at minimum strength with frequent rotation, complete on-site training is not feasible. Another consideration is that Enewetak Atoll does not have the classroom facilities to support an academic training program. Discussion with the Services and contractors indicate that personnel should receive specialized training before arrival with proficiency acquired during the overlap period on-site.

3. PROPOSED TRAINING PROGRAM:

a. FRST. A training program will be established at the CBR School, Schofield Barracks, Hawaii to provide the necessary training for the USAF personnel assigned to the FRST. Upon completion of the training, the personnel should deploy to Enewetak for field training. This cycle will be repeated at approximately 6 month intervals as new FRST personnel are assigned to Enewetak. The program will be reviewed and revised as necessary after each cycle. The training program outline is as follows:

(A summary of the topics and number of hours devoted to each is presented below)

SUMMARY OF TRAINING PROGRAM

TOPIC	HOURS
Basic Science Concepts and General Background	3
History and Radiological Background of Enewetak Atoll	2
Radiation Biology	1
Biohazards of Enewetak Cleanup Operation	1
Radiation Detection and Instrumentation	1
Laboratory Training in Use of Survey Instruments	3

SUMMARY OF TRAINING PROGRAM (Continued)

TOPIC	HOURS
Hot Line Procedures	2
Decontamination Procedures	1
Soil Sampling	2
Personnel Monitoring	1
Bioassay	1
Forward Support Labs	2
Field and Laboratory Exercises and Review	20
	40

b. RAD LAB and In Situ Van.

(1) The first part of the program outlined below, addressed to the USN personnel, is intended not only to provide the necessary skills but also to sort out the group, on the basis of individual abilities, to the three major tasks to be accomplished; i.e., radiochemistry laboratory operations, in situ van support and soil samping operations.

(2) In situ operations. Initial training in this program will be provided by the contractor at the contractor's location.* Depending on the subgroup, follow-on training will be at location as indicated:

(a) Basic training and screening program.

1 Provided by EG&G, two days, at Las Vegas for all RAD LAB USN personnel.

2 Covers program orientation, basic computer skills.

(b) Advanced computer techniques.

1 Provided by EG&G, and the Desert Research Institute (DRI) five days, for three Navy personnel at the Nevada Test Site (NTS).

2 Covers specialized Enewetak computational methods on Hewlett-Packard computers.

(c) Soil sampling techniques and laboratory procedures. Three days on soil sampling provided by EG&G and DRI at Nevada Test Site (NTS) on soil sampling for remaining individuals.

(3) Radiochemistry operations. Five (5) days of laboratory and laboratory-related procedures including sample preparation, sampling, record keeping, radiochemistry procedures, measurement systems and data reduction. This can be accomplished in a five (5) day period for the USN group (six (6) people maximum at a time) at McClellan Central Laboratory, McClellan AFB, CA, using existing radiochemical laboratory staff and a contractor supplied training outline. It can be repeated as necessary to include a total group of twelve (12). Direct coordination with McClellan Central Laboratory for this training class is authorized.

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*No Air Force or Navy personnel received training by EIC at Santa Fe or by EG&G or DRI at Las Vegas or the NTS.

(4) USN personnel not holding the basic NEC 9591 skill code must obtain equivalent military training in this area prior to entering this program.*

(5) Air Force Technical Applications Center (AFTAC) will use the radiochemistry and measurement procedures specified by the RAD LAB contractor and will train the three RI99106 technicians prior to embarkation. The remaining four USAF technicians are one Laboratory technician, one PMEL specialist and two Aerospace Ground Equipment (AGE) mechanics. Only laboratory technician specialists require laboratory and measurement equipment training. The AGE specialists will receive training on the Atoll by the EG & G contractor.

(6) Laboratory specialists coming from stations in the Pacific can be given orientation and familiarization training for the Radiochemistry Laboratory duty using an enroute TDY at Yokota AB, Japan. Since the individuals will work for fully qualified and experienced supervisors, a three day training program at Yokota AB enroute to Hickam AFB and then Enewetak Atoll, is adequate. A training course will be developed by AFTAC and provided to the instructor for use. This training can be repeated at Yokota AF for follow-on replacements during the total project. If sourcing is from CONUS or USAFE, identical training can be provided at the McClellan Central Laboratory, McClellan AFB, CA as an enroute TDY prior to departure from Travis AFB, CA.

(7) The Services will pay per diem and travel costs associated with the training of their personnel. The two AF PMEL specialists (one in the radiochemistry lab and one of the FRST) will be enroute TDY to Eberline Instrument Corp., Santa Fe, NM for five (5) days training in the maintenance of radiation measurement equipment.

(The OPLAN contained this section on Radiological Laboratory Support. Project funding is discussed in Section 2.2.2 of this report.)

(Annex M, App. 5) RADIOLOGICAL LABORATORY SUPPORT

1. GENERAL:

a. Purpose. This Appendix provides information supporting the MILCON cost estimated for radiological laboratory support during the period shown in Annex C, Operations.

b. Users. The funds indicated herein will be used by ERDA for radiological support of the cleanup.

2. COST CATEGORY FOR ERDA RADIOLOGICAL SUPPORT: ($1,500,000)

This service will be provided by the Energy Research and Development Administration on a reimbursable basis pursuant to a 10 September 1975 agreement between the Defense Nuclear Agency and the Energy Reseach and Development Administration. This category includes deployment and operation of a mobile radiochemistry laboratory, in situ soil vans and related technical support. MILCON funds in the amount of $1,500,000 have been identified in this plan for ERDA radiological support. Reference OASD (COMP) MEMO, Subject: "Enewetak Cleanup Project, dated 22 March 1977." ERDA will budget for, and fund, complete radiological effort over and above the $1,500,000 provided from MILCON funds.

*The majority of USN personnel assigned to the RAD LAB did not have the background or training indicated.

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28. Fission Product Data Base Results
29. IMP (in-situ gamma scan) Measurements
30. Surface Soil Sample Analysis Results
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