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EXTRACTED VERSION

OPERATION CASTLE

Project 2.5b
Fallout Studies

Pacific Proving Grounds
March — May 1954

Headquarters Field Command
Armed Forces Special Weapons Project
Sandia Base, Albuquerque, New Mexico

February 1956

NOTICE

This is an extract of WT-916, Operation CASTLE, Project 2.5b, which remains classified SECRET/RESTRICTED DATA as of this date.

Extract version prepared for:

Director
DEFENSE NUCLEAR AGENCY
Washington, D.C. 20305

15 May 1981

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18. SUPPLEMENTARY NOTES

This report has had the classified information removed and has been republished in unclassified form for public release. This work was performed by Kaman Tempo under contract DNA001-79-C-0455 with the close cooperation of the Classification Management Division of the Defense Nuclear Agency.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Operation CASTLE
Fallout Studies
Residual Contamination
Particle Formation
Radioactive Debris

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

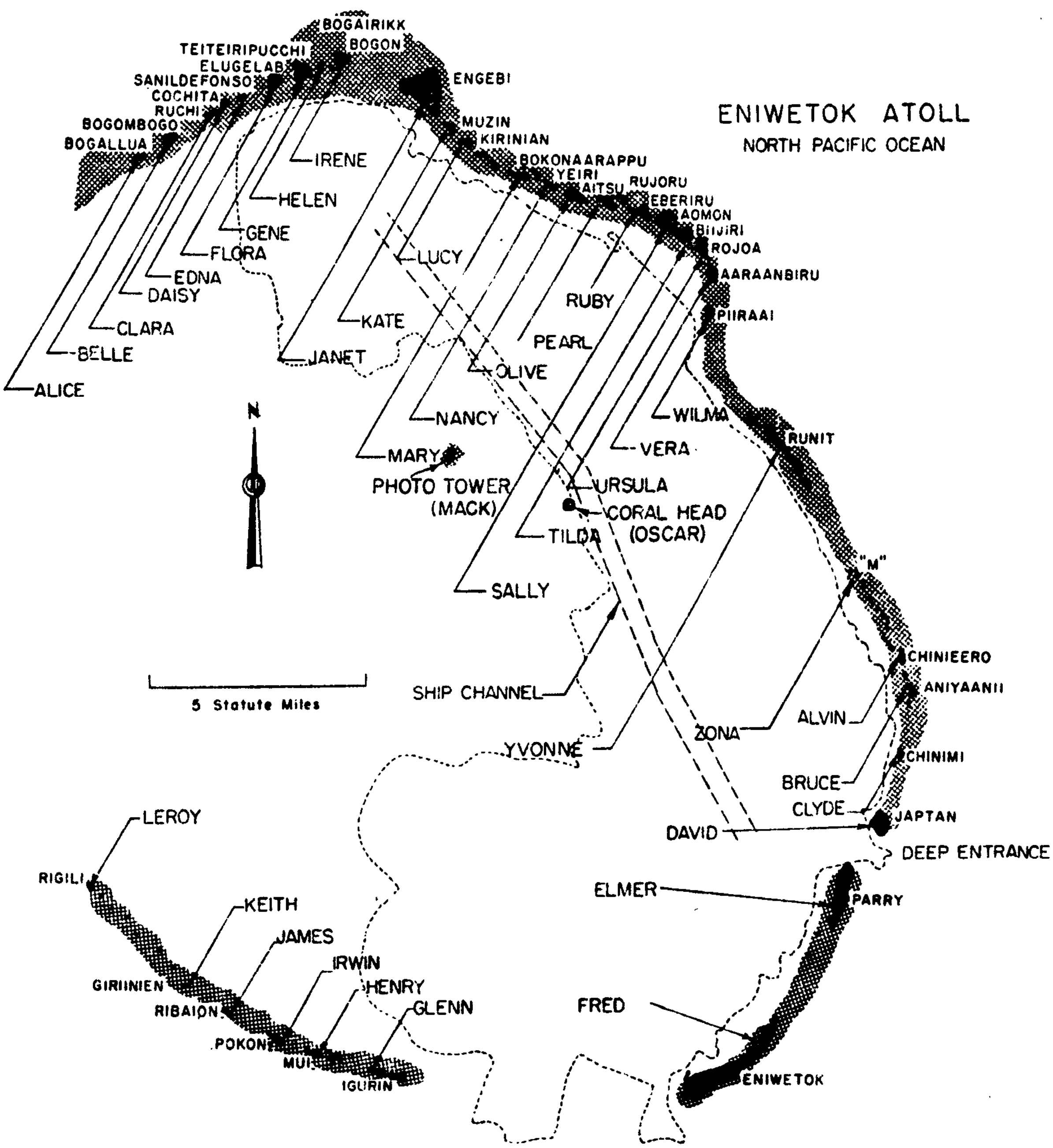
FOREWORD

This report has had classified material removed in order to make the information available on an unclassified, open publication basis, to any interested parties. This effort to declassify this report has been accomplished specifically to support the Department of Defense Nuclear Test Personnel Review (NTPR) Program. The objective is to facilitate studies of the low levels of radiation received by some individuals during the atmospheric nuclear test program by making as much information as possible available to all interested parties.

The material which has been deleted is all currently classified as Restricted Data or Formerly Restricted Data under the provision of the Atomic Energy Act of 1954, (as amended) or is National Security Information.

This report has been reproduced directly from available copies of the original material. The locations from which material has been deleted is generally obvious by the spacings and "holes" in the text. Thus the context of the material deleted is identified to assist the reader in the determination of whether the deleted information is germane to his study.

It is the belief of the individuals who have participated in preparing this report by deleting the classified material and of the Defense Nuclear Agency that the report accurately portrays the contents of the original and that the deleted material is of little or no significance to studies into the amounts or types of radiation received by any individuals during the atmospheric nuclear test program.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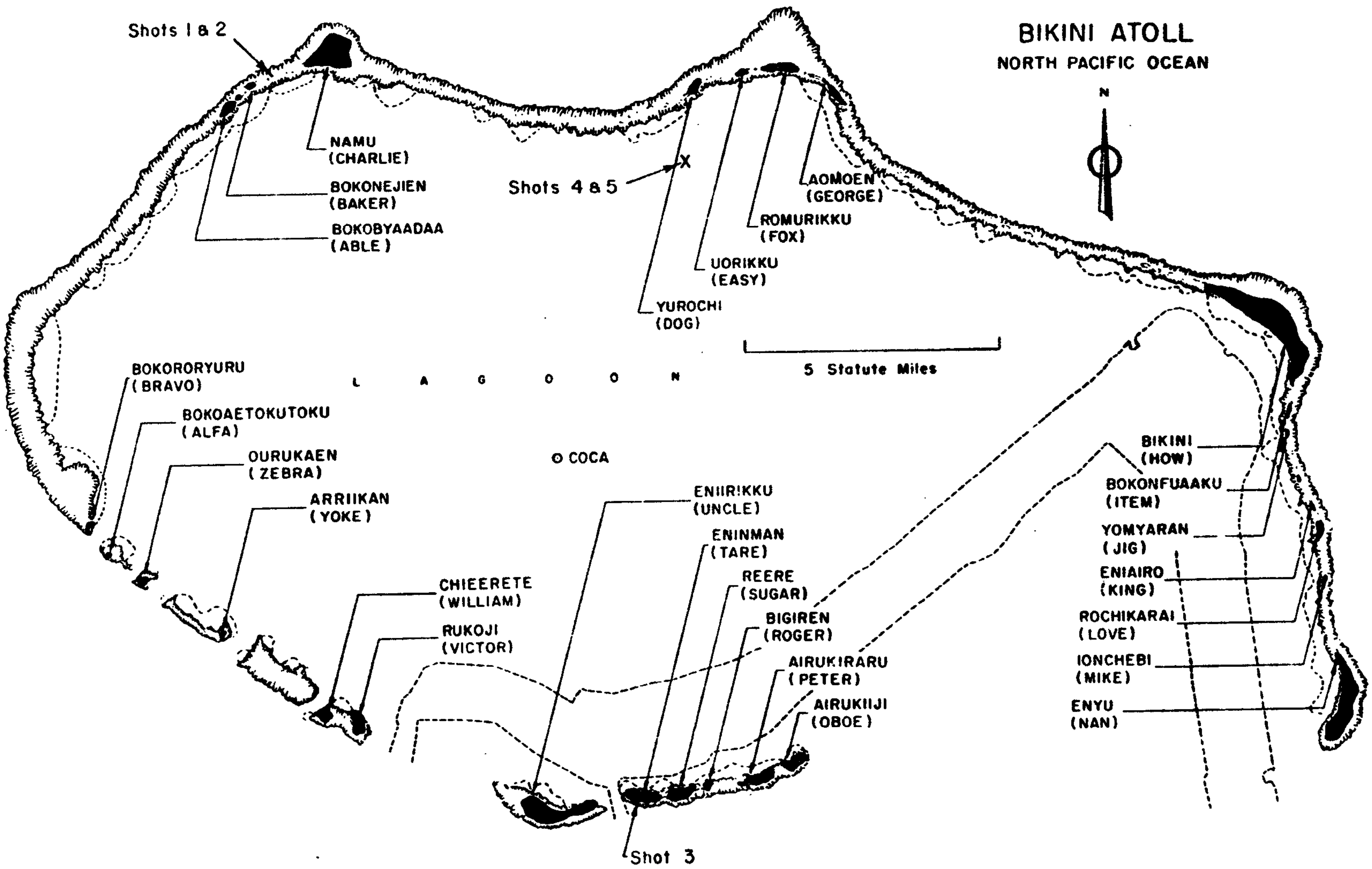
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O COCA
CHIEERETE
(WILLIAM)
RUKOJI
(VICTOR)
ENIIRIKKU
(UNCLE)
ENINMAN
(TARE)
REERE
(SUGAR)
BIGIREN
(ROGER)
AIRUKIRARU
(PETER)
AIRUKIIJI
(OBOE)
Shot 3
BIKINI
(HOW)
BOKONFUAAKU
(ITEM)
YOMYARAN
(JIG)
ENIAIRO
(KING)
ROCHIKARAI
(LOVE)
IONCHEBI
(MIKE)
ENYU
(NAN)

GENERAL SHOT INFORMATION

	Shot 1	Shot 2	Shot 3	Shot 4	Shot 5	Shot 6
DATE	1 March	27 March	7 April	26 April	5 May	14 May
CODE NAME (Unclassified)	Bravo	Romeo	Koon	Union	Yankee	Nectar
TIME*	06:40	06:25	06:15	06:05	06:05	06:15
LOCATION	Bikini, West of Charlie (Namu) on Reef	Bikini, Shot 1 Crater	Bikini, Tare (Eninman)	Bikini, on Barge at Intersection of Arcs with Radii of 6900' from Dog (Yurochi) and 3 Statute Miles from Fox (Aomoen).		Eniwetok, IVY Mike Crater, Flora (Elugelab)
TYPE	Land	Barge	Land	Barge	Barge	Barge
HOLMES & NARVER COORDINATES	N 170,617.17 E 76,163.98	N 170,635.05 E 75,950.46	N 100,154.50 E 109,799.00	N 161,698.83 E 116,800.27	N 161,424.43 E 116,688,15	N 147,750.00 E 67,790.00

* APPROXIMATE

ABSTRACT

The objective of this project was to document the characteristics of the close-in radioactive fallout resulting from the surface land or water detonations of high yield nuclear devices in order to provide information for the evaluation of:(1) the immediate hazards associated with the residual contamination from such bursts,(2) the mechanism of particle formation and distribution,and (3) the characteristics and significance of the radioactive debris distributed by base surge phenomena,provided that a significant base surge is caused by surface water bursts.

The objective was accomplished by sampling the fallout with intermittent fallout collectors and by analyzing the particulate and liquid matter for activity, decay, energies, and particle size distribution.

Fallout stations were set up in varying arrangements for Shots 1, 2, 3, 4, and 6.

When significant fallout occurred at an island after any of these shots, it apparently began to arrive there within six minutes after the detonation. The maximum activity per sampling time interval resulting from Shot 1 and other shots having yields of the same order of magnitude arrived at all sampling stations during the first hour after the detonation. Extrapolation of the beta activity had indicated rates as high as 1.3×10^{14} dpm/ft^2 1 to 6 min after the detonation.

Most of the activity had arrived at a given station within 3 to 6 hours after the detonation, with small amounts continuing to arrive up to at least 12 hours after the detonation.

Gamma dose rates at the shot atoll 1 hour after each shot were estimated to be as follows from data collected by this project and Rad Safe:

Shot 1: 1600 to 2900 r/hr along the northern islands, 160 to 630 r/hr on the eastern islands, and 15 to 43 r/hr along the southwest side of the atoll.

Shot 2: 1100 to 4700 r/hr on the northwest islands close to ground zero and 2.4 to 14 r/hr on the remaining islands.

Shot 3: 410 r/hr at Uncle, just west of ground zero, 10 to 125 r/hr on the north and northwest islands, and 0.8 to 4.5 r/hr elsewhere.

Shot 4: 160 to 440 r/hr on the north and northeast islands, and 0.1 to 23 r/hr elsewhere.

Shot 6: (At Eniwetok) Over 1000 r/hr in the immediate vicinity of ground zero, dropping to 17 to 32 r/hr on the islands westward and 1 to 6 r/hr eastward from ground zero.

Within the atoll, there was no apparent trend of radioactive particle size distribution with distance, direction,or time. The approximate number-median diameters of samples collected ranged from 5 to 20 µ. Up to forty-three per cent of these particles were under 10 µ. Shot 1 particles appeared to be coral or crystalline; those from Shot 3 appeared to be mostly crystalline, ashlike, or fused.

In particles from 149 to 1000 µ, the percentage of particles with activity on the outside generally increased directly with size, while the percentage of uniformly radioactive particles generally decreased with size. These two types of particles accounted for about 90 per cent of the radioactive particles examined. Activity was scattered randomly throughout the remaining 10 per cent of particles.

There was no apparent correlation between the location of activity on the particles and their physical appearance.

No conclusions could be drawn about the presence or absence of radioactivity in the base surge,because no samples were obtained in the base-surge region.

FOREWORD

This report is one of the reports presenting the results of the 34 projects participating in the Military Effects Tests Program of Operation CASTLE, which included six test detonations. For readers interested in other pertinent test information, reference is made to WT-934, Summary Report of the Commander, Task Unit 13, Programs 1-9, Military Effects Program. This summary report includes the following information of possible general interest.

a. An over-all description of each detonation, including yield, height of burst, ground zero location, time of detonation, ambient atmospheric conditions at detonation, etc., for the six shots.
b. Discussion of all project results.
c. A summary of each project, including objectives and results.
d. A complete listing of all reports covering the Military Effects Tests Program.

This report on close-in fallout studies at Operation CASTLE supersedes the preliminary report; ITR-916, which was issued in May 1954.

ACKNOWLEDGEMENTS

Many helpful suggestions in the planning and execution of this project were made by Lt Colonel Richard R. Entwhistle, Chemical Corps, and Lt Colonel Edward A. Martell, Director, Program 2.

Many people have made contributions to the work described herein; John Kinch and Fletcher Gabbard developed the counting techniques; Phyllis Gordon, David Rigotti, and Malcolm Gordon supervised the large amount of activity and particle size work; Robert Tompkins has contributed some of the Project 2.6b data; Capt William Home, Carl Crisco, Robert Anderson, Arnold Berman, Mrs. Frances Beals, Mrs. Ann Lieder and Miss Carmen Paul have all contributed a great deal of time and energy to the preparation of this report.

Most of the data in Appendix C was furnished by the Task Group 7.1 Radiological Safety Unit, and is used with the permission of Major John Servis, Commander, Task Unit 7.

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FIGURES

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CHAPTER 1

INTRODUCTION

1.1 OBJECTIVE

The objective of the project was to document the characteristics of the close-in radioactive fallout resulting from the surface land or water detonation of high yield nuclear devices in order to provide information for the evaluation of (1) the immediate hazards associated with the residual contamination from such bursts, (2) the mechanism of particle formation and distribution, and (3) the characteristics and significance of the radioactive debris distributed by base surge phenomenon provided that a significant base surge is caused by surface water bursts.

To accomplish the objective, the following specific physical characteristics were documented where possible.

a. Beta activity and the time at which it arrived.

b. Beta decay.

c. Maximum beta energies.

d. Gamma energy.

e. The activity per unit weight or volume of liquid and solid fallout.

f. The size distribution of radioactive particles and distribution of activity within the sized particles.

1.2 MILITARY SIGNIFICANCE OF THIS INVESTIGATION

Surface and sub-surface nuclear detonations result in the deposition of radioactive debris (fallout) on the earth's surface. The degree to which fallout may influence military operations depends upon the magnitude of the significant radiation field and upon the ability to predict the extent and location of the field. The amount and activity of the fallout is primarily a function of weapon yield and conditions of detonation, i.e., whether the detonation has taken place in the air, on the surface of land or water, or underneath the surface of land or water. This investigation seeks to extend the knowledge of such variations by studying the fallout results from high yield nuclear devices. The results from this project will aid in (1) determining the significance of fallout from surface detonations of high yield weapons, (2) predicting the fallout patterns resulting from other yields and conditions of detonation, (3) evaluating scaling parameters, (4) evaluating immediate external and internal hazards from fallout from high yield devices, and (5) evaluating the logistics involved in decontamination procedures. In addition to these basic investigations, Operation CASTLE results were expected to provide the basis of a theory for the mechanism of particle formation in the cloud and to supply data relative to the differences between fallout resulting from land and water surface detonations.

1.3 BACKGROUND

Residual contamination resulting from fallout was initially observed at Operation TRINITY 1/; subsequent atomic tests have resulted in residual contamination which was militarily significant for all types of nuclear detonations except air bursts. Experiments were designed to document the fallout from both the Operation JANGLE 2/ and Operation IVY 3/ surface shots. However, the results from these shots are of limited applicability to the CASTLE tests because the yield of the JANGLE shot was very small and in desert sand rather than coral rock, while the main downwind pattern of fallout from IVY Mike shot went out to sea and was not instrumented. The JANGLE surface shot demonstrated that a low yield weapon could cause a significant degree of contamination and definitely established the need for further work on the contamination problem and associated hazards, especially from higher yield surface detonations. Operation IVY provided the first opportunity to investigate the general fallout problem resulting from the surface land burst of a high yield nuclear device.

An unanticipated base surge was observed shortly after the CROSSROADS underwater detonation 1/. It appears that the base surge distributed some contamination from this shot, although the evidence is not entirely conclusive. Attempts to study base surge effects have since been made at JANGLE and at some high explosive tests. These experiments have not determined whether the base surge is a carrier of radioactivity. Operation CASTLE provided the first opportunity to study base surge characteristics from surface water shot.

CHAPTER 2

EXPERIMENT DESIGN

2.1 DESIGN CRITERIA

The collectors were designed to collect liquid and solid fallout samples at preset, successive time intervals which could be adjusted to between 1 min and 30 min. The samples were at least large enough to be analyzed by standard counting techniques.

Base surge estimations from work done by the Naval Ordnance Laboratory Task 152 indicated that the maximum radius of the surge from the CASTLE devices could be from 15,000 to 34,000 ft, depending upon the yield of the devices. The phenomena should be complete within 10 or 15 min after detonation. The base surge was primarily expected from the surface water shots; however, Shot 1, detonated on a reef, was instrumented for base surge samples because it was thought that the reef was so narrow that the shot would be, in effect, a water shot. Since high overpressures are encountered in the base surge region, the fallout collectors in the region were ruggedly built. These collectors were set for 1-min intervals. Experience at IVY 3/ indicated that the heaviest fallout on the atoll occurred within the first 30 min after the detonation and that fallout continued to occur more than 6 hr after the detonation, which was the maximum sampling time of the IVY collector.

Thus, two collectors were generally placed at each station: (1) one sampling at 1-or-5-min intervals for a total time of 24 min or 2 hr respectively, to document the base surge or early fallout; and (2) the other sampling at 30-min intervals for a total time of 12 hr.

Basically, the same type of instruments were used to sample fallout on the surface land and surface water shots.

2.2 THE INTERMITTENT FALLOUT COLLECTOR

The intermittent fallout collector (IFC) consisted of a circular disc (or "spider") divided into 24 sectors, a driving and timing mechanism and a housing (Figs. 2.1-2.3). Each sector contained a triangular tray 3 3/7 in. x 10 in., and 3/4 in. deep. One tray at a time was exposed to fallout through an opening of equal size in the top cover. The wide end of each tray held four glass counting cups (1 in. in diameter and 5/15 in. high), positioned in a quadralateral about $2\frac{1}{4}$ in. on a side. The cups were coated on the inside with silicone grease to produce a tacky surface. This tacky surface held almost all particles which came in contact with it; rainwater collected during the sampling interval would not wash particles from the tacky surface unless the particles themselves were soluble. An 8-oz jar was fastened beneath an opening in the bottom of the tray to collect liquid fallout (Fig. 2.4). A door covered the sampling opening both before and after the sampling time (Fig.2.5).

The instrument was started by an external timing signal. After a delay of 1 min, the cover door opened and the first tray moved into sampling position. Succeeding trays moved into position under the cover opening at set time intervals until the cycle was completed; (Fig. 2.6). The door then closed and the machine shut itself off.

At the time of the detonation an external timing signal actuated self-latching signal relay R_1 (Fig. 2.7). Current then flowed through the clock which had been pre-set for a short time delay before the door opened (Fig. 2.8). At the end of this delay microswitch C_1 in the clock was tripped, allowing the current to flow through the driving motor which in turn rotated the spider; the door opened and tray 1 moved into sampling position. Since microswitch S_3, underneath the spider rim was no longer closed by one of the cams on the spider, microswitch C_2 opened. This removed the current from the clock coil and reset the clock. The driving motor continued to run until the cam under the next tray moved over S_3. When S_3 closed, the current path to the driving motor was broken and the motor stayed off until the clock finished another cycle. Succeeding trays moved into position under the cover opening at set time intervals until the sampling cycle was completed.

At the time of detonation a spring cam was resting on a microswitch S_4, completing the circuit through the contact points of electrical latching relay R_3. As the cycle progressed, the spring cam rode over the microswitch, S_5, completing a circuit through R_3, which was thrown and latched. After the last tray was in sampling position and the door closed, the spring cam again rode over S_4, breaking the circuits and stopping the instrument.

Push-button switch, S_1, was used as a reset switch so that the operator could easily reset the entire instrument by one simple operation. Toggle switch S_2 was mounted under the clock and was used to preset the clock. This switch remained closed during the entire operation. Resistor N_1 controlled the driving motor speed to keep the trays from overshooting their position. Variable 1-ohm resistors and also lengths of nichrome wire were used.

2.3 TIMING

Where wire timing signals were available at a station, a minus 1-sec signal supplied by Edgerton, Germeshausen, and Grier (EG&G) was used to actuate the IFC. Where no wire timing signals were available at a station, an EG&G Mark III or Mark IV battery-powered bluebox was used to actuate the IFC. Wire timing signals were initially used, where available, because experience at IVY indicated that blueboxes were not always reliable. However, toward the end of this operation bluebox signals were used where feasible, because of the satisfactory performance of the modified blueboxes. At the raft stations, the IFC timing signal came from the Project 2.5a nondirectional, photoelectric, trigger mechanism.

2.4 MOUNTINGS

At the Bikini land stations, the IFC and its batteries were usually mounted in concrete foundations (Fig. 2.9). At the Bikini lagoon stations, the equipment was mounted on wooden platforms bolted to 60-man Navy life floats (Fig. 2.10). These floats were moored to floats identical to those used by Project 2.5b. The Project 2.5a floats in turn were tied to mooring buoys furnished by Holmes and Narver, Inc. At the Eniwetok land stations, the IFC and the wooden battery boxes were dug into the ground flush with the surface (Fig. 2.11).

2.5 PROJECT PARTICIPATION

This project participated in Shots 1, 2, 3, and 4 at Bikini Atoll and in Shot 6 at Eniwetok Atoll. It had been originally intended to participate in Shot 5. However, water wave damage to the stations from Shot 4 made participation in Shot 5 impractical.

Generally, IFC's were placed in groups of two at Bikini locations, and singly at the Bikini raft and Eniwetok stations. Where two IFC's were on an island or raft station, one was set to sample for 12 hr at 30-min intervals and the other was set to sample for either 24 min at 1-min intervals or for 2 hr at 5-min intervals. The 1-min samples were collected for Project 2.6b to determine the degree which the base surge was contributing to the residual contamination pattern. The 5-min interval instruments documented the early fallout and the 30-min interval instruments documented the fallout for the maximum length of time possible with this instrument. Where one IFC was located at a station or raft, it was set to sample at 30-min intervals for 12 hr.

The station locations and timing intervals are listed in Tables 2.1, 2.2, and 2.3 and shown in Figs. 2.12 and 2.16.

2.6 OPERATIONS

Operations were extremely difficult following Shot 1. Immediately following this event, the project's main base of operations at Tare was razed by fire and most spare parts, auxiliary equipment, and operational supplies were lost. The long delay before Shots 2, 4, and 6 imposed additional difficulties because the batteries readily discharged in the hot weather, requiring frequent trips to the stations with battery replacements.

Heavy seas in the Bikini Lagoon caused the cancellation of the Bikini raft station program. The rafts broke away from their moorings with distressing frequency. Locating and mooring the rafts in the lagoon proved to be dangerous to personnel. Salt spray and water made maintenance of electrical equipment on the rafts difficult. Both electrical and moving mechanical parts corroded quickly. Only a minority of project personnel were able to work at the raft stations without becoming seasick. Only two of the original nine raft stations sampled successfully during Shot 1. All raft instrumentation recoverable after Shot 1 was removed from the rafts and used at land stations.

Since no samples were obtained from predicted base surge region of any CASTLE shot, none of the desired information about the characteristics and significance of the radioactive debris distributed by base surge phenomena was obtained.

2.7 RECOVERY AND SHIPMENT OF SAMPLES

Recovery was carried out on the fourth, fifth, and ninth day after Shot 1, the first day after Shot 2, the first and second day after Shots 3 and 4, and the first day after Shot 6. A two-man team used a 10-passenger helicopter to recover samples from the land stations. A second two-man team used an LCM to recover samples from the raft stations after Shot 1. The recovery teams removed the spider assemblies from the IFC's, placed them in dust-tight boxes, and moved them to the packing area.

All locations available for packaging samples were somewhat windy and usually in contaminated areas. Packing was done on an open barge near Nan after Shot 1, in a Tare tent after Shot 2, in a Nan tent after Shot 3, on Oboe, in the rear of a closed truck turned on its side after Shot 4, and in a tent at Elmer after Shot 6. The jars were removed from the trays and capped. The trays were surveyed where possible, and a few samples selected for decay measurements at the Project 2.6b Elmer laboratory. Plastic "snap-on" caps were put on the glass cups, and the trays were sealed with aluminum foil. The trays and jars were returned to Army Chemical Center, Maryland by a special sample return plane which usually left Eniwetok one or two days after recovery was completed.

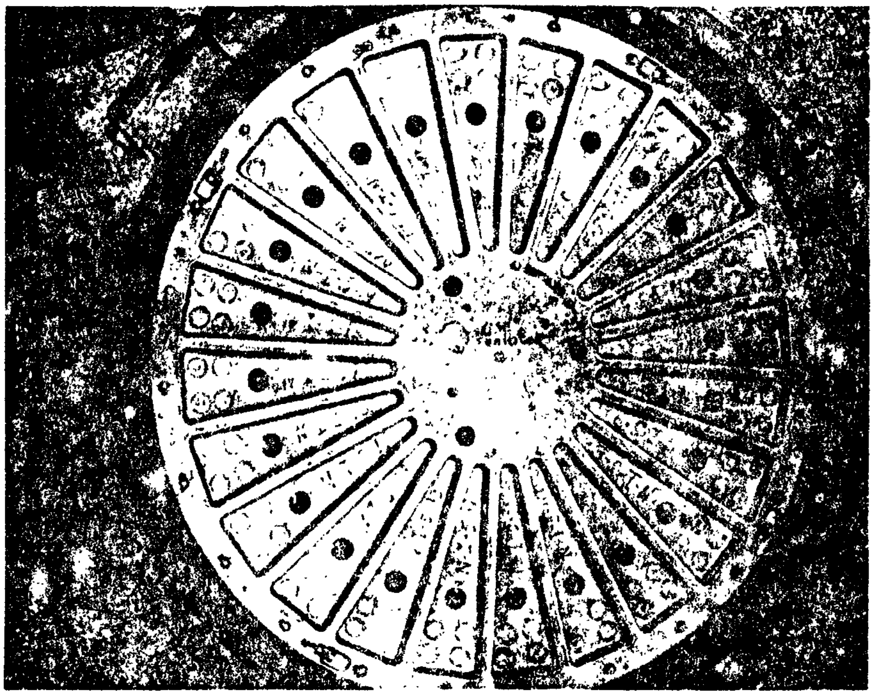

Fig. 2.1 IFC Spider and Trays with Cups

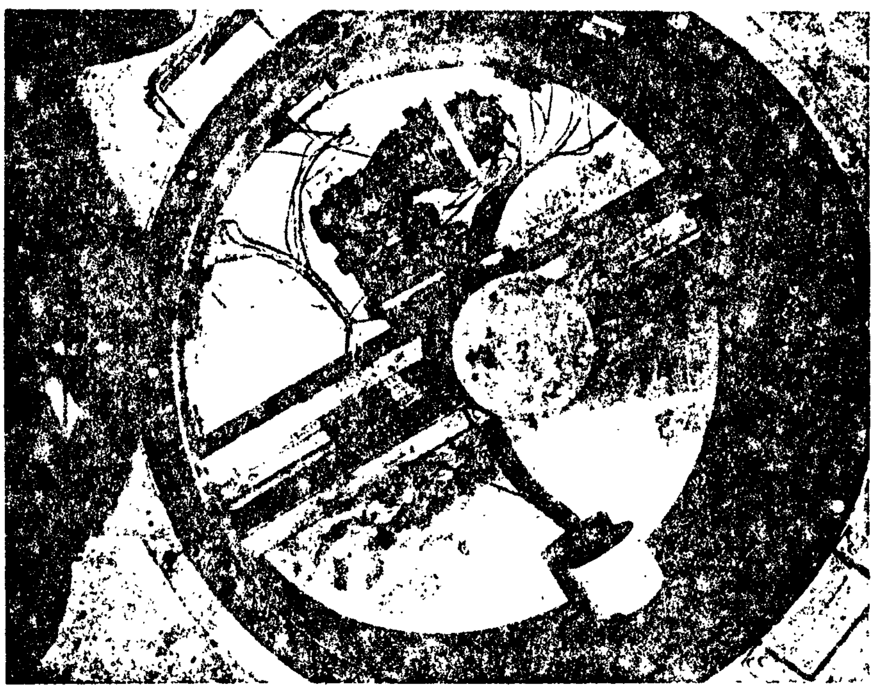

Fig. 2.2 Interior of the IFC, Showing the Motor and Gear **Reducer**

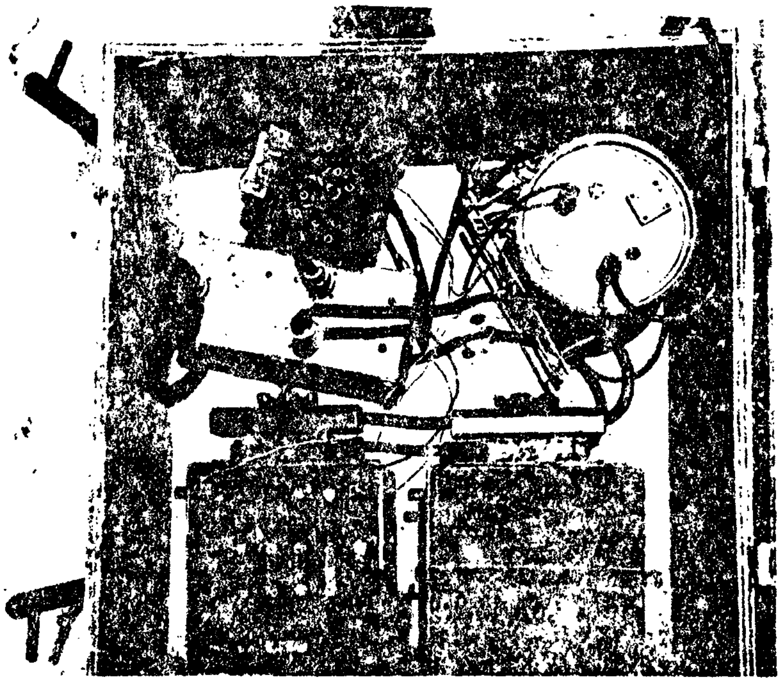

Fig. 2.3 Timer Box, Batteries, and Bluebox Mechanism

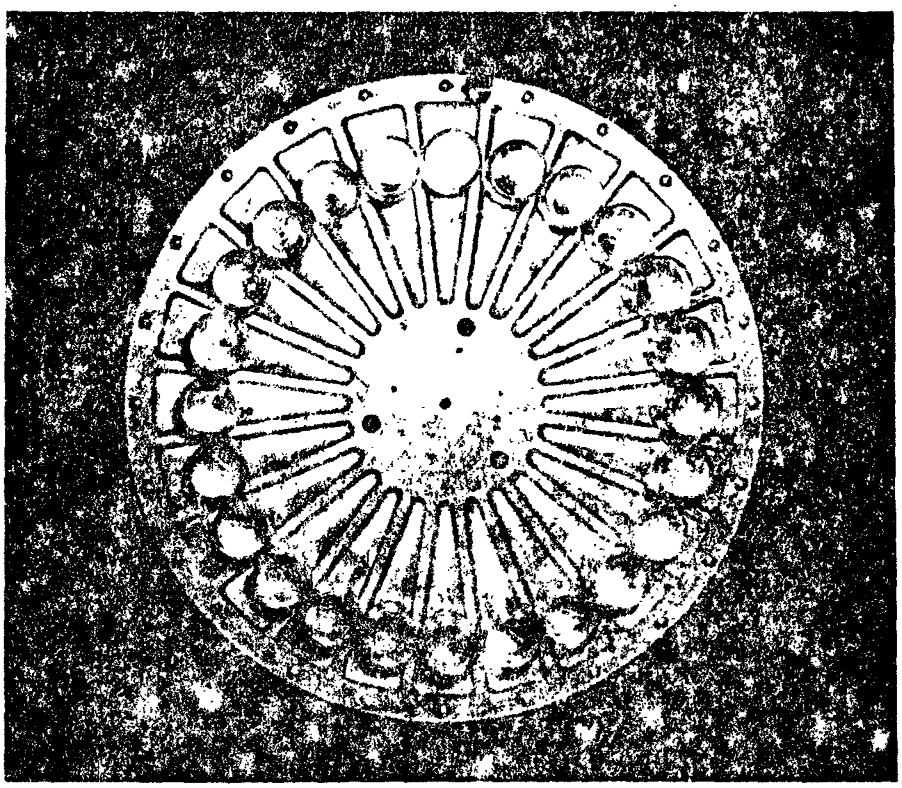

Fig. 2.4 Glass Jars for Liquid Fallout Mounted on the Underside of Spider

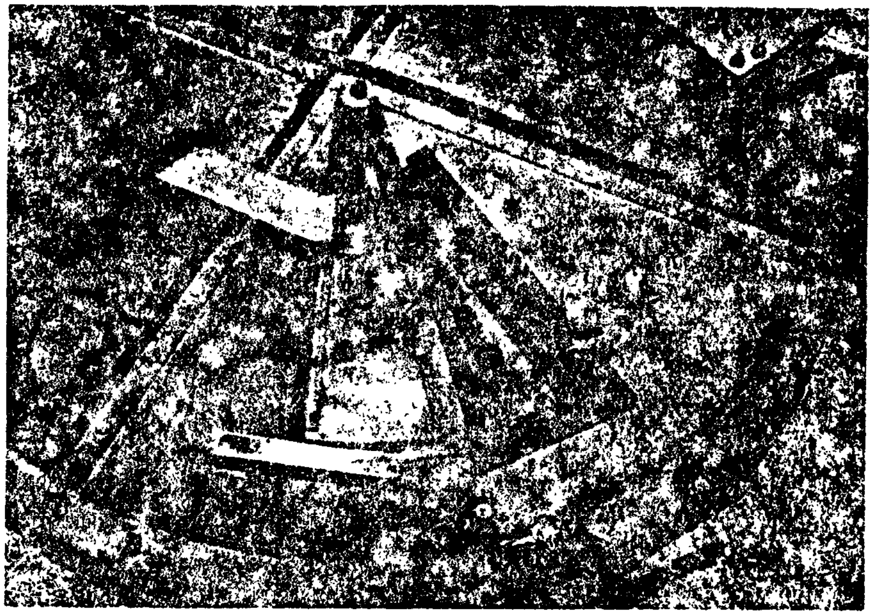

Fig. 2.5 Cover Door Closed and in Starting Position

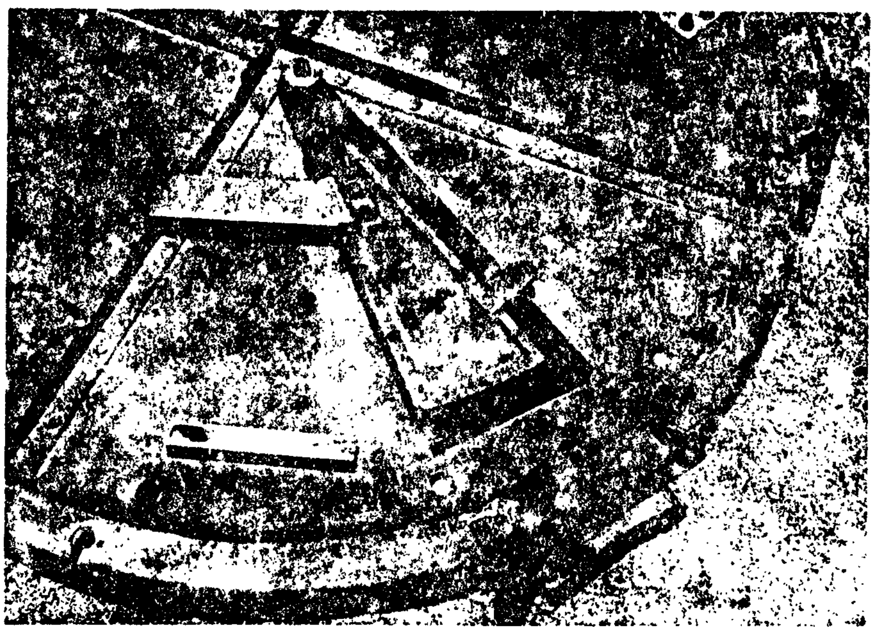

Fig. 2.6 Cover Door Open and Tray in Sampling Position

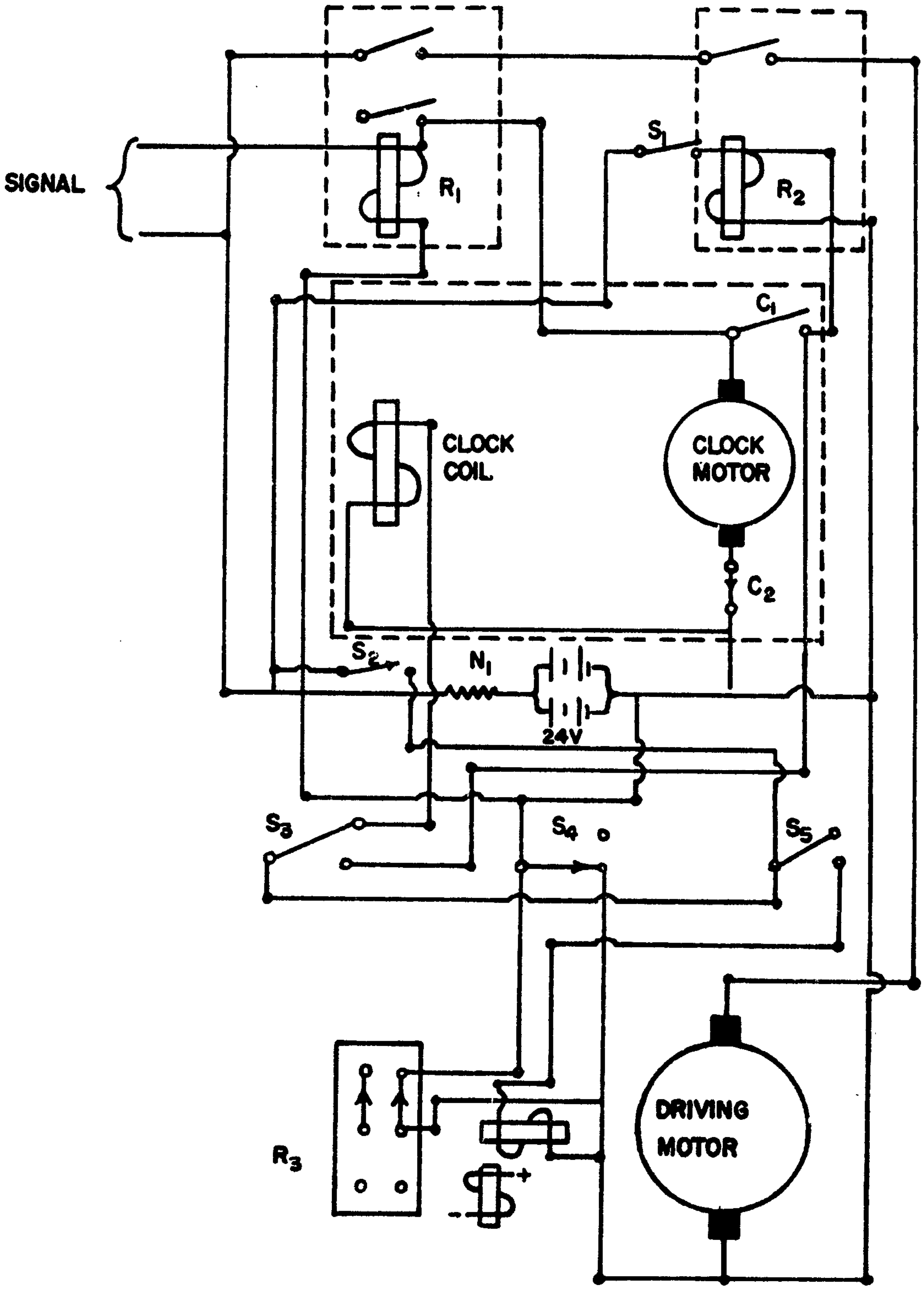

Fig. 2.7 IFC Schematic Wiring Diagram

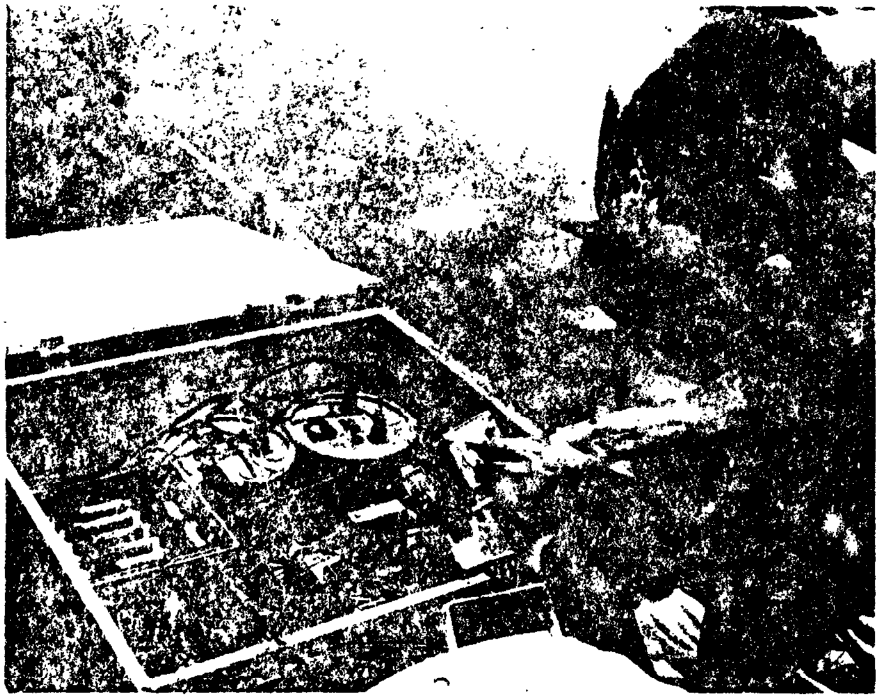

Fig. 2.8 Pre-setting Time Delay on the Clock Timer

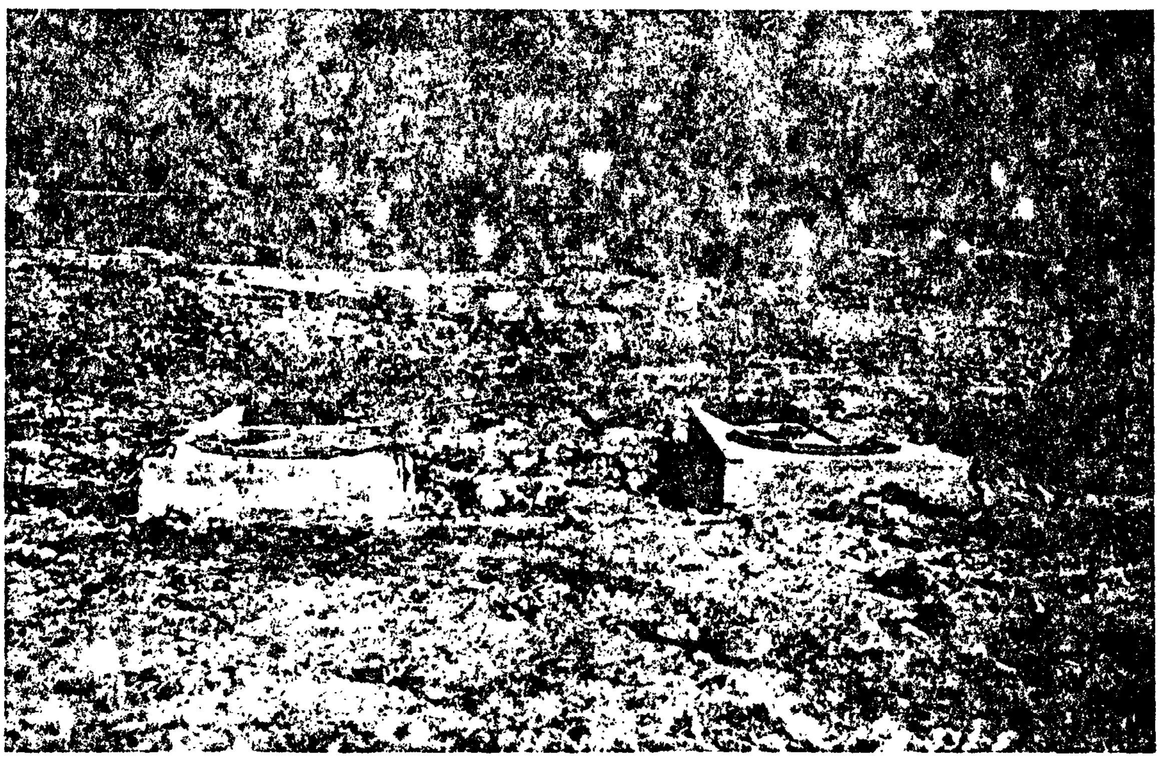

Fig. 2.9 General View of IFC Station, Victor Island, Bikini Atoll

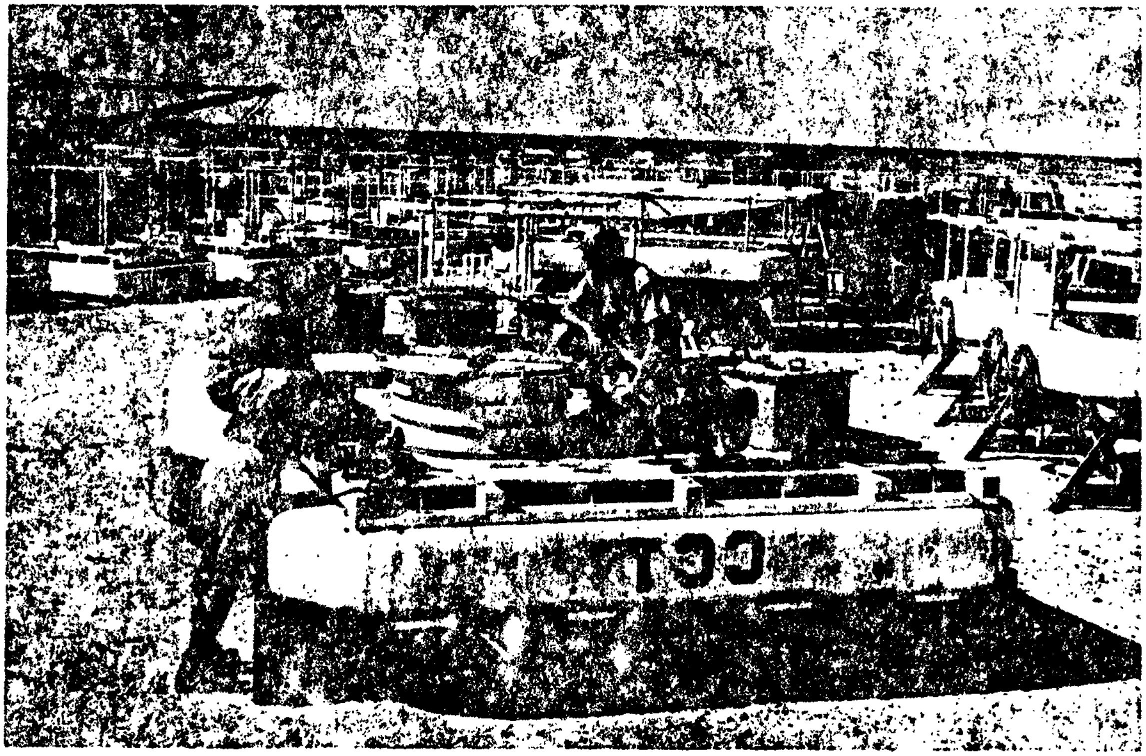

Fig. 2.10 Preparation of 2.5b Raft Stations (foreground)

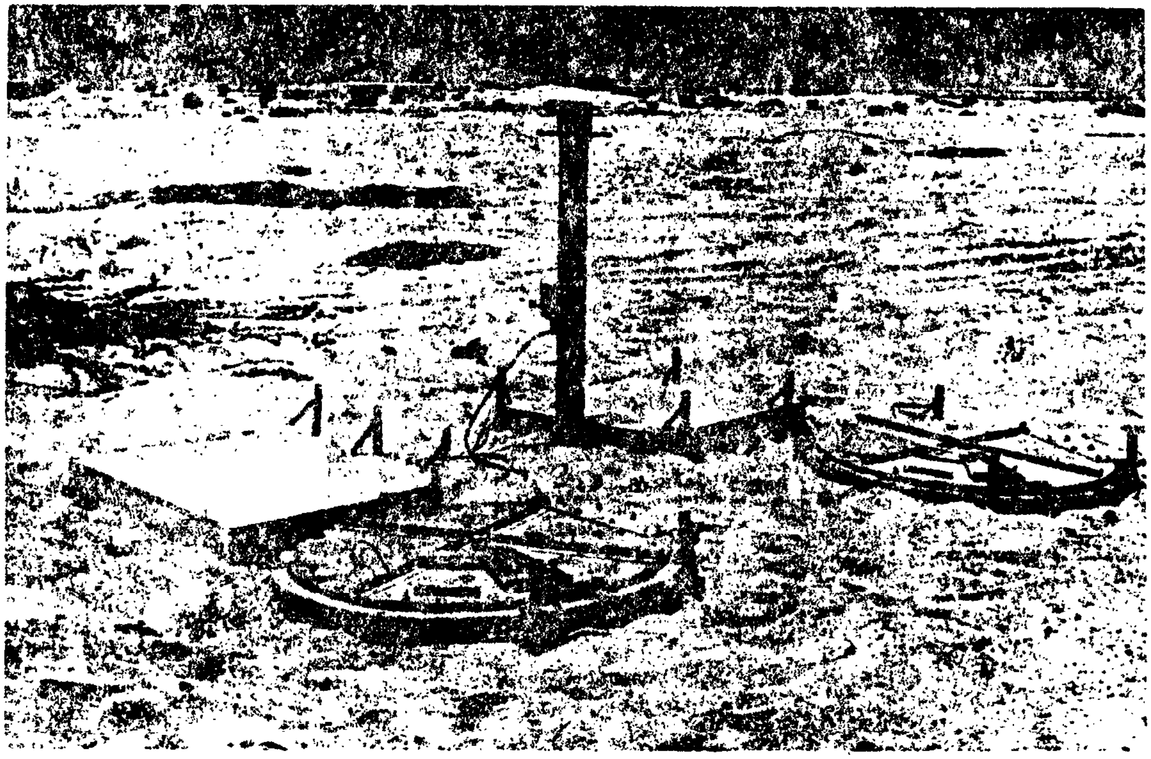

Fig. 2.11 General View of IFC Station, Irene Island, Eniwetok Atoll

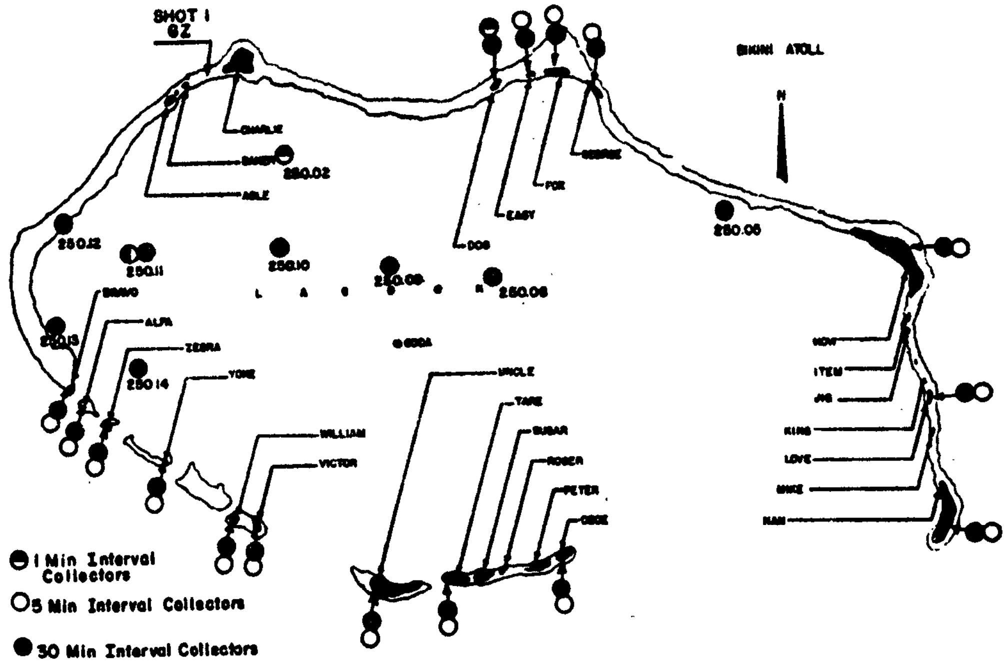

Fig. 2.12 Station Layout for Shot 1

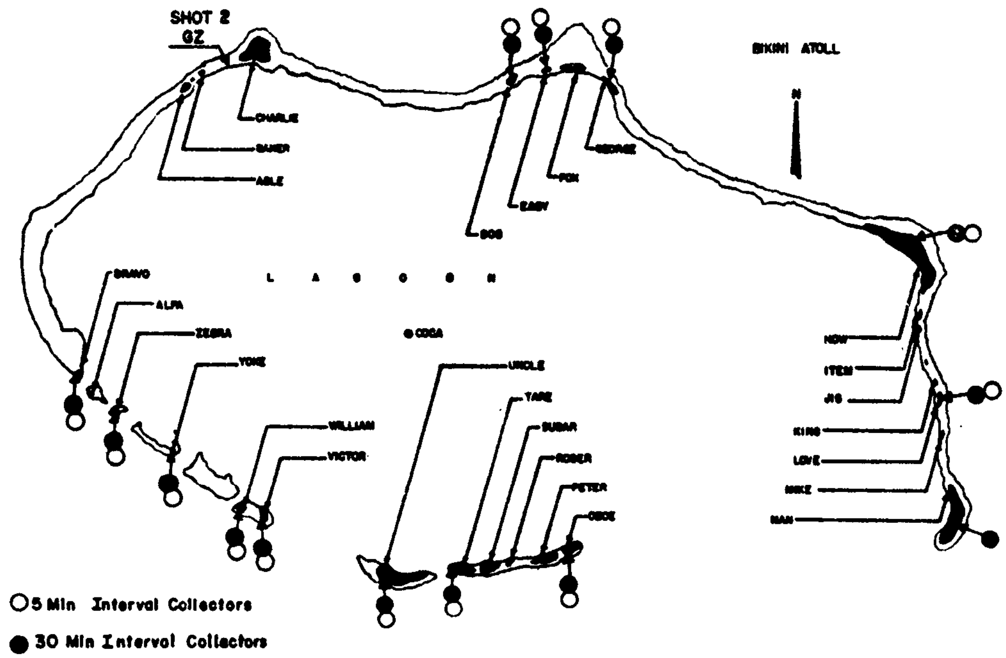

Fig. 2.13 Station Layout for Shot 2

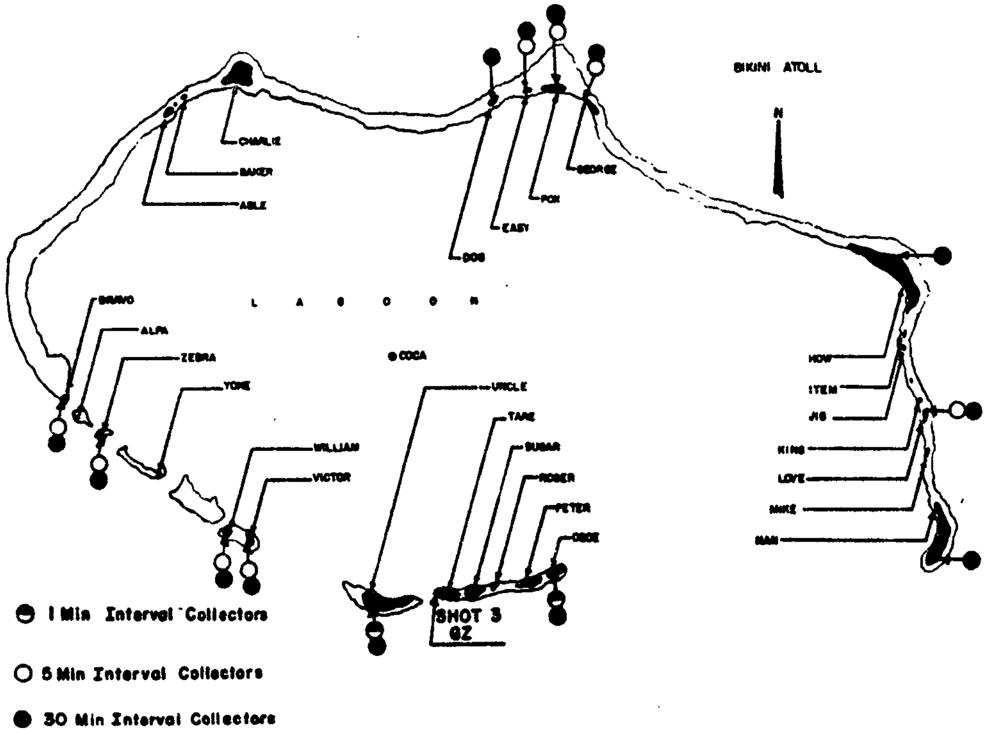

Fig. 2.14 Station Layout for Shot 3

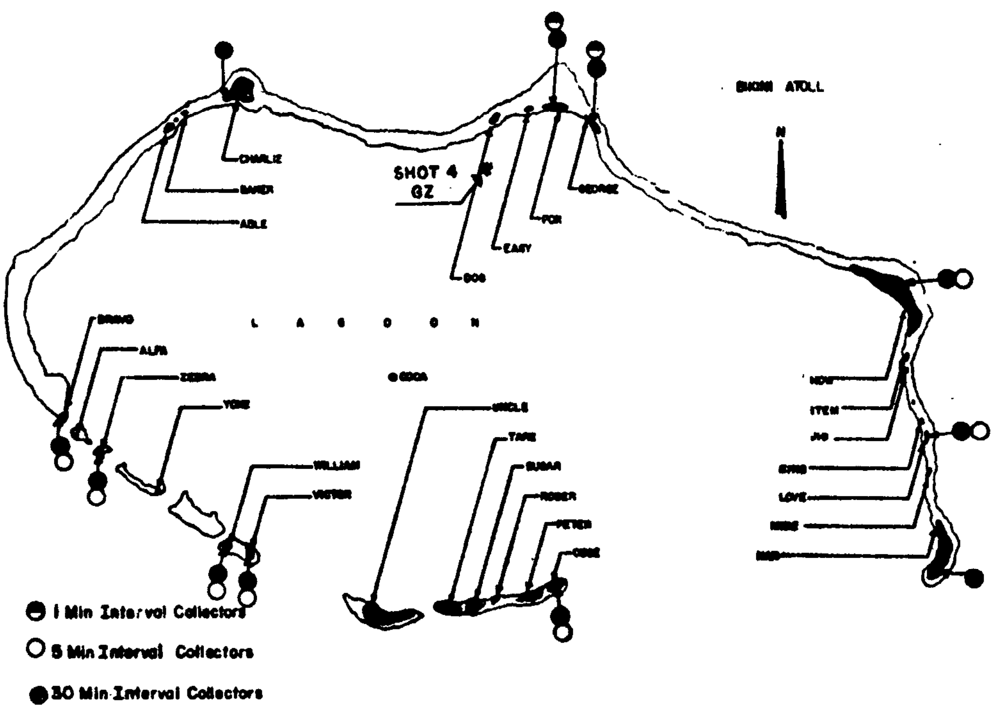

Fig. 2.15 Station Layout for Shot 4

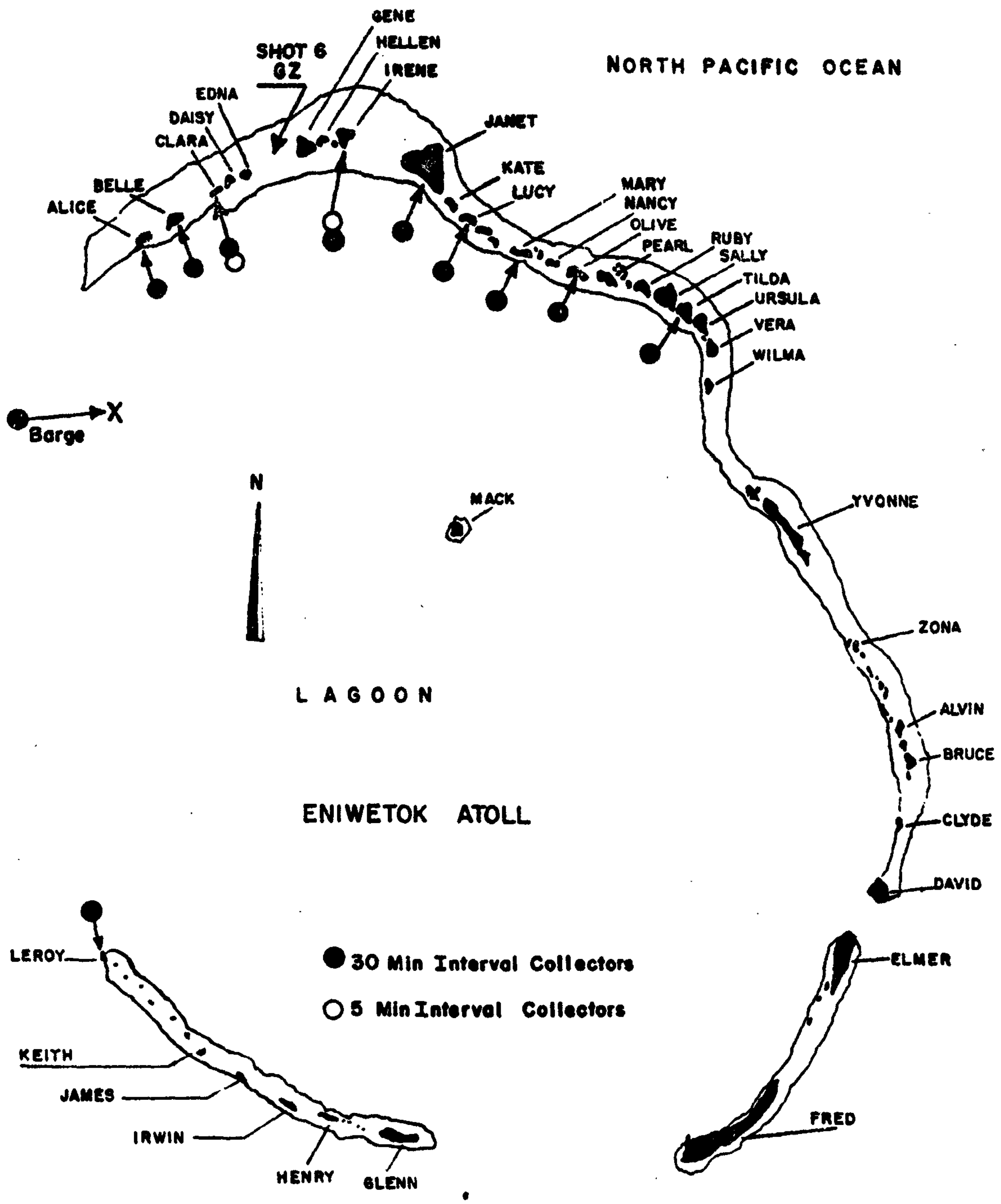

Fig. 2.16 Station Layout for Shot 6

TABLE 2.1 - Bikini IFC Land Station Data

Station		Shot 1				Shot 2		
		Distance from GZ (ft)	Time Interval (min)			Distance from GZ (ft)	Time Interval (min)	
Number	Island		1	5	30		5	30
257.14	Charlie							
252.03	Dog	41,100	xe		xe	41,100	xa	xa
257.01	Easy	45,500		xe	xe	45,500	xa	xa
252.04	Fox	50,600		xb	xb	50,600		
252.05	George	54,800		xe	xe	54,800	xe	xe
252.06	How	97,700		x	x	97,700	xb	x
252.07	Love	111,500		xb	xb	111,500	x	x
252.08	Nan	122,300		xe	xe	122,300		xce
252.09	Oboe	83,700		x	x	83,700	x	x
257.02	Tare	78,300		xb	x	78,300	x	x
252.10	Uncle	74,700		x	x	74,700	xd	xd
252.11	Victor	62,500		x	xb	62,500	xc	xc
257.03	William	65,300		x	x	65,300	xb	x
252.13	Yoke	54,500		xb	x	54,500	xd	xd
252.14	Zebra	50,000		x	x	50,000	x	x
257.04	Alfa	47,600		xb	x	47,600		
252.12	Bravo	47,000		x	x	47,000	x	x

Legend: "x" indicates the timing interval of an IFC; "a" the IFC operated prior to the event; "b" the IFC did not operate because of internal failure; "c" the IFC did not operate through the entire cycle; "d" the IFC did not operate because of water-wave damage; and "e" the IFC was triggered by an EG and G minus 1 sec wire timing signal.

TABLE 2.1 - Bikini IFC Land Station Data (Cont'd)

Station		Shot 3				Shot 4			
		Distance from GZ (ft)	Time Interval (min)			Distance from GZ (ft)	Time Interval (min)		
Number	Island		1	5	30		1	5	30
257.14	Charlie					36,200			x
252.03	Dog	69,100			x				
257.01	Easy	71,000		x	x				
252.04	Fox	72,600		x	x	13,400	xd		xd
252.05	George	71,500		xe	xbe	15,600	xd		xd
252.06	How	76,500			x	56,200		x	x
252.07	Love	72,200		x	x	71,300		xcd	xd
252.08	Nan	69,300			xe	84,500			xce
252.09	Oboe	17,000	xb		xc	58,800		xcd	xcd
257.02	Tare								
252.10	Uncle	9,800	x		x				
252.11	Victor	28,400		xc	xc	63,300		xcd	xbd
257.03	William	36,800		x	xb	64,300		xd	xd
252.13	Yoke	43,200							
252.14	Zebra	52,300		x	x	67,500		xcd	xcd
275.04	Alfa								
252.12	Bravo	59,500		x	x	69,400		xcd	xcd

Legend: "x" indicates the timing interval of an IFC; "a" the IFC operated prior to the event; "b" the IFC did not operate because of internal failure; "c" the IFC did not operate through the entire cycle; "d" did not operate because of water-wave damage; and "e" the IFC was triggered by an EG and G minus 1 sec wire timing signal.

TABLE 2.2 - Bikini Raft Stations for Shot 1

Station Number	Latitude (o ' ")	Longitude (o ' ")	Distance From Ground Zero (ft)	Remarks
250.02	11-39-40	165-17-30	16,700	Raft floor and IFC destroyed by blast. (1 min interval) Base Surge station.
250.05	11-38-40	165-28-30	75,400	Operated (30 min interval).
250.08	11-36-50	165-23-10	50,700	Electrical circuit shorted before shot. Missing after shot. (30 min interval).
250.09	11-37-00	165-20-50	37,700	Not set up because 2.5a trigger raft was missing before shot. (30 min interval).
250.10	11-37-30	165-18-10	27,500	Lost before shot. (30 min interval).
250.11	11-37-50	165-15-30	25,000	Two IFC's on raft. Lost before shot. (1 and 30 min intervals). Base surge Backup Station.
250.12	11-38-00	165-13-10	28,700	Operated (30 min interval).
250.13	11-35-50	165-13-00	39,500	Did not operate. (30 min interval).
250.14	11-35-10	165-15-20	39,000	Lost before shot. (30 min interval).

TABLE 2.3 - Eniwetok Stations for Shot 6

Station Number	Island	Distance From Ground Zero (ft)	IFC Time Interval		Remarks
			5 min	30 min	
257.05	Alice	18,200		x	
257.06	Belle	13,400		x	
257.07	Clara	8,500	x	x	Blast damaged the battery boxes, causing instrument failure.
257.08	Irene	8,500	x	x	Blast damaged the battery boxes, causing instrument failure.
257.09	Janet	16,400		x	
257.10	Lucy	22,500		x	Water wave upset equipment.
257.11	Mary	29,800		x	
257.12	Olive	35,900		x	
257.13	Tilda	50,000		x	Bluebox was not triggered by detonation flash.
257.14	Leroy	83,900		x	
	Barge	35,000		x	Located near reef SW of Alice.

CHAPTER 3

RESULTS

3.1 GENERAL

Documentation of fallout included:(1) surveying of fallout samples and the areas from whence they came; (2) studying decay; (3) extrapolating the beta activity results to estimated activities at sampling time, and (4) studying the activity per unit weight or volume, energies, particle size, and particle characteristics of the radioactive fallout.

3.2 BETA COUNTING EQUIPMENT, TECHNIQUES, AND CORRECTION

The glass counting cups were removed from the trays, externally decontaminated and counted by Tracerlab G-M tubes with window thicknesses of less than 2 mg/cm^2. The tubes were mounted in vertical lead shields, Technical Associates Model AL14 A, having a wall thickness of 2-in. lead, 0.25-in. brass, and 0.25-in. aluminum. A geometry-defining brass plate was inserted between the G-M tube and the sample. 4/ The output of the tubes was fed into Atomic Scalers Model 1060 having a characteristic resolving time of 5 microseconds.

The samples in glass cups were counted for beta activity in the following manner: samples with activities greater than 1000 cpm were counted for 10,000 counts, samples with activities less than 1000 cpm were counted for 10 min. Each sample was counted twice; in cases where the two counts did not agree within one standard deviation, a third count was taken and the three counts averaged.

It was necessary to apply several corrections in order to approximate the disintegration rate of the samples. The method most commonly used to obtain the disintegration rate of a sample is to compare the sample under consideration with a known source counted in an identical manner. However, there is no one known source which represents mixed fission products. The procedure used here evaluates the various correction factors in terms of the sample itself and thus avoids the errors associated with a direct comparison with a single-isotope standard. The procedure is as follows:

1. The raw cpm were corrected for coincidence loss. 5/

2. An 8.15-gm/cm^2 brass absorber was inserted between the sample and the tube. This absorber eliminated all beta particles with maximum energies up to 6 Mev. The purpose of this plate was to estimate the detected results of the radiation interaction in the aperture plate used for geometry definition. The absorber plate was identical to this aperture plate except for the aperture. The count thus obtained was subtracted from the original count of the sample to obtain the beta activity (A_b) of that sample.*

3. The count was corrected for geometry (G), defined as the fraction of solid angle subtended by the sensitive volume of the G-M tube. This factor was determined by using the first three terms of the Blachman Series.6/ Succeeding terms of this series are insignificant and were not used for this correction. The G values in Table A.1 appear to be low because the counting arrangement was designed in such a manner to insure the correct absorber placement.

4. Backscattering determinations (F_b) were made by mounting a tube in a hollow support of lead bricks approximately three feet from the floor. This arrangement provided negligible backscattering from the floor of the support. The geometry defining aperture tends to minimize the effects of scattering from the walls of the support. Equal aliquots of dissolved fallout from the shot under analysis were dissolved in nitric acid and pipetted into counting cups. One cup with a bottom of a very thin rubber film (0.45 mg/cm^2) was measured in the arrangement, which provided negligible backscattering, and one glass bottom cup was measured in the regular counting apparatus. The backscattering correction factor, which was obtained by dividing the count obtained in the regular apparatus by the count obtained in the arrangement with negligible backscattering, was used to correct all samples from that shot. Since the energy distribution of mixed fission products is known to be time dependent, this correction was made for various times. However, it was found that the variation was insignificant during the time the measurements were made on the concerned samples. For examples of (F_b) for various times see Table A.2.

5. A correction (F_a) was made for absorption by the air between the sample and the tube window, and absorption of the tube window itself.7/ To obtain this correction, precise absorption curves were run on a sample from each shot. A correction factor was calculated from the equation

$$F_a = \frac{n_t}{N_o} = e^{-mt} \qquad (3.1)$$

* It is now felt that the use of this absorber was not proper because the geometry factor for the aperture outweighed the geometry factor for the rest of the plate, resulting in an estimate that was too high. However, the fact that this estimate in all cases was very small (approximately 2 per cent) in comparison with the beta count indicates that the radiation interaction with the aperture is of no importance. The use of the plate has been discontinued. Regular absorption curves made with aluminum absorbers indicate that the detected gamma background is of the order of one per cent. This would be expected because of the low sensitivity of the tube to gamma radiation.

where n_t = corrected counting rate observed with thickness t between the sample and the sensitive volume

N_o = true beta counting rate at zero thickness

t = thickness of material between the source and sensitive volume

m = mass absorption coefficient expressed in cm^2/mg

$$m = \frac{1}{\Delta t} \ln \frac{n_t}{n_{t+\Delta t}} \qquad (3.2)$$

$n_{t+\Delta t}$ = counting rate at thickness $t + \Delta t$

The best straight line was drawn through the experimental points and the slope(m) was calculated accordingly. This method is applicable for any energy or group of energies as long as the first part of the absorption curve is a straight line on a semi-log plot. It can be seen from the examples given in Appendix A that this is the case and, therefore, the aforementioned determination of F_a was used.

6. Self absorption corrections for the samples in question were considered negligible, since the weight per unit area was kept in general between 5 and 10 mg/cm^2. According to Coryell and Sugarman, a radioactive sample which has a weight per unit area of 5 to 10 mg/cm^2 and has an energy greater than 0.4 Mev requires no self-absorption correction. 8/ Furthermore, according to Hunter and Ballou, the nuclides with maximum energies below this value which contribute more than 1 per cent each to the gross fission activity constitute approximately 10 per cent of the total activity of the sample at the time the measurements for this report were made, i.e. approximately at H plus 200 hr. Therefore, the error entailed by the assumption of a negligible correction should be 10 per cent or less. The practice of ignoring this correction has been further justified by comparison of the defined geometry method with four-pi counting techniques. 9/ In these comparisons the experimental error ranged from 3 to 7 per cent.

7. The sample beta activity (A_b) was treated by the above corrections to obtain the sample activity (A_d) in disintegrations per minute.

$$A_d = \frac{A_b}{F_a F_b G} \qquad (3.3)$$

A table of correction factors as well as examples of various correction determinations and the activities A_d of the samples at the time of counting are given in Appendix A.

The above method has been used to determine the disintegration rate of known mixtures of nuclides with excellent results. 10/ Its use in the determination of the disintegration rate for a mixed fission products sample is believed to result in measurements within 10 per cent of the actual rate. It is true that secondary particles (e.g. internal conversion electrons) will be detected as primary beta particles. However, the error in disintegration rate due to this source should be very small because of the inherent low energy of these secondary particles and the short half-life of most of the isotopes concerned with these processes.

3.3 EXTRAPOLATION OF BETA ACTIVITIES TO SAMPLING TIME

The activities A_d were extrapolated to the sampling time of each intermittent fallout collector tray. The method of extrapolation was determined by the amount of decay data obtained from each shot and varied for each shot.

In general, the activity consisted of fission activity decay and the decay from uranium capture products. The fission products decayed in a manner which can be represented as:

$$A_f = A_{1f} t^{-n} \quad (3.4)$$

where
A_{1f} = Activity when t = 1
A_f = Activity at later time
t = Time after shot
n = Decay Exponent

The uranium neutron capture products activity decay can be represented best as a sum of individual nuclides which can be determined by radiochemical analysis. The form of the equation would be:

$$A_c = A_{co}(\Sigma C_i e^{-u_i t}) \quad (3.5)$$

where
A_c = Activity due to capture products at time t
A_{co} = Proportionality constant such that $A_{co} \Sigma C_i = A_{oc}$

where
A_{oc} is the zero time activity of the uranium neutron capture activities
C_i = relative initial activity of nuclide
u_i = semi-log decay constant of ith nuclide

The ratio of yield of the various uranium neutron capture nuclides can be expected not to vary from sample to sample. This is because they are all uranium isotopes during the time of fallout formation. These ratios (which determine the C_i's) may be found from capture to fission ratios determined by radiochemical means.

The relative amount of the uranium neutron capture activity with respect to the fission activity varies from sample to sample. The values for A_{1f} and n of Eq. 3.4 were found from the decay curve after 2000 hours when the neutron capture activity no longer contributed significantly to the sample activity. The difference between this activity (Eq. 3.4) and the experimentally determined activity at times earlier than 2000 hours was used as a measure of uranium capture activity. From this the value of A_{co} (in Eq. 3.5) could be determined. This difference was measured at the earliest possible time when the difference was greatest.

Because the fission representation goes to infinity at zero time, the ratio of fission activity to uranium capture activity must be found at some other time. In general, the time chosen was that at which the uranium capture activity was measured. A variation in this value could be used as a method of indication of fractionation of uranium capture products with respect to fission products.

3.3.1 Shot 1

Since little experimental decay data were obtained prior to 250 hours, a composite neutron capture decay curve was constructed for times shortly after the shot. U^{237}, U^{239}, Np^{239}, U^{240}, and Np^{240} were found to be significant contributors to the decay curve. From the parent-daughter relationship

$$A_2 = A_{01} \frac{u_2}{u_2 - u_1} (e^{-u_1 t} - e^{-u_2 t}) \qquad (3.6)$$

where
A_{01} = activity of U^{239} at initial time
A_2 = activity of daughter Np^{239}
u_1 = decay constant of U^{239}
u_2 = decay constant of Np^{239}
t = time after shot

In the case of the U^{239} and Np^{239} decay scheme, u_1 is much greater than u_2 and $e^{-u_1 t}$ is much less than $e^{-u_2 t}$ at any time after initial time.

hence

$$A_2 \cong \frac{u_2}{u_1} A_{01} e^{-u_2 t} \qquad (3.7)$$

thus, setting $t = 0$

$$\frac{A_{01}}{A_{02}} \cong \frac{u_2}{u_1} \qquad (3.8)$$

The initial activity of Np^{239} can be found from Eq. 3.8, assuming a relative activity of 1 for U^{239}. Similarly, in the case of Np^{240}, it can be shown that its activity equals $u_2/(u_2 - u_1)$ times the activity of U^{240} after equilibrium is reached.

The relative activities of U^{237} to U^{239} and U^{240} to U^{239} are determined by the ratio of their decay constants multiplied by their capture yields. The relative activity and decay constants of U^{237}, U^{239}, Np^{239}, U^{240}, and Np^{240} are summarized in Table 3.1.

The composite neutron capture decay curve will then be the sum of the decay curves of U^{237}, U^{239}, Np^{239}, U^{240}, and Np^{240}, i.e.,

$$A_c = A_{co}\,(0.000416e^{-0.00431t} + e^{-1.77t} + 0.00652e^{-0.0124t} + 0.0146e^{-0.0495t})^{*} \qquad (3.9)$$

where A_c = Activity due to capture products at time t and

A_{co} = Proportionality constant

A_{co} can be determined from the ratio of neutron capture to fission activity measurements.

TABLE 3.1 - Initial Relative Activities of U^{237}, U^{239}, Np^{239}, U^{240}, and Np^{240}

The Shot 1 decay curve will then be the sum of Eq. 3.4 and Eq. 3.9. The experimentally determined ratio of uranium capture products to fission products can then be used to find the value of A_{co} if it is remembered that A_{1f} has already been determined.

$$\frac{A_c|250}{A_{1f}(250)^{-n}} = 0.8 \qquad (3.10)$$

$$0.8\,A_{1f}(250)^{-n} = A_{oc}(\Sigma C_i e^{-u_i t}) \qquad (3.11)$$

The curve was then normalized (set equal to 1) to 400 hours, at which time the activity data were known.

The equation for the extrapolation of **fission** and neutron induced activities to sampling time is then

$$A = 1350\,t^{-1.26} + 2200(0.000416e^{-0.00431t} + e^{-1.77t} + 0.00652e^{-0.0124t} + 0.0146e^{-0.0495t}) \qquad (3.12)$$

This composite curve is shown in Fig. 3.1.

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* The last term includes the activity of both U^{240} and Np^{240}

TABLE 3.2 - Beta Decay Exponents of Samples from Shot 1*

Station	Timing Interval (min)	Tray	n	Station	Timing Interval (min)	Tray	n
Dog	1	1	-1.22	George	30	1	-1.31
Dog	1	2	-1.25	George	30	22	-0.99
Dog	1	8	-1.19	George	30	24	-1.32
Dog	1	13	-1.34	George - Island Sample			-0.94
Dog	1	17	-1.30	How	5	1	-1.33
Dog	1	18	-1.22	How	5	6	-1.01
Dog	30	1	-1.30	How	5	7	-1.23
Dog	30	14	-1.28	How	5	12	-1.29
Dog	30	15	-1.23	How	30	1	-1.34
Dog	30	18	-1.22	How	30	3	-1.31
Dog - Island Samples			-0.94	How	30	6	-1.28
			-0.86	How	30	7	-1.20
Easy	5	5	-1.27	How	30	11	-1.26
Easy	5	6	-1.31	How	30	15	-1.09
Easy	30	2	-1.28	How	30	24	-1.45
Easy	30	3	-1.30	How - Island Sample			-1.01
Easy	30	4	-1.30	Nan	5	1	-1.05
Easy	30	5	-1.33	Nan	30	6	-1.04
Easy	30	19	-1.27	Nan	30	7	-1.31
Easy	30	21	-1.32	Nan	30	8	-1.28
Easy	30	23	-1.33	Oboe	5	9	-1.24
Easy - Island Samples			-1.05	Oboe	5	13	-1.39
George	5	1	-1.26	Oboe	5	18	-0.98
George	5	5	-1.10	Oboe	5	20	-1.06
George	5	6	-1.30	Oboe	30	1	-1.37
George	5	7	-1.24	Oboe	30	4	-1.18
George	5	8	-1.28	Bravo	5	4	-0.80
George	5	11	-1.29	Raft	30	9	-1.36
George	5	12	-1.28	250.05			
George	5	14	-1.30	Raft	30	1	-1.27
George	5	15	-1.33	250.12			
George	5	16	-1.29	Raft	30	24	-0.66
George	5	18	-1.32	250.12			
George	5	20	-1.32				
George	5	22	-1.30	Shot 1 Average			-1.26

* The decay exponent is the exponent of t in the decay expression $A = A_1 t^{-n}$ for the period of 2000 to 4000 hr after the shot.

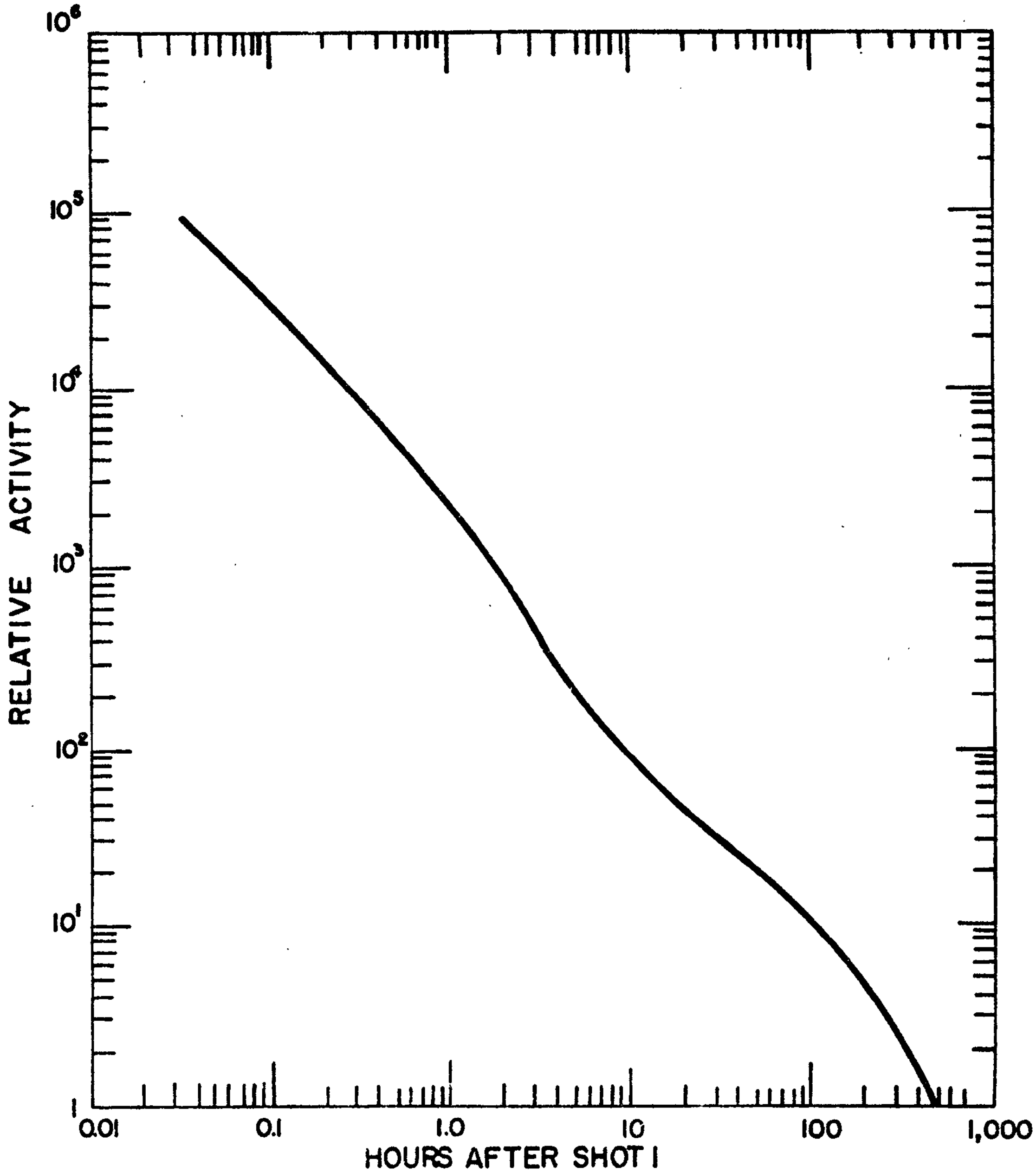


Fig. 3.1 Shot 1 Average Composite Decay Curve

Decay data of a Shot 1 size graded sample are presented in Table 3.3 from work done by Project 2.6b.[12] The rate of decay of all fractions is the same for all but one fraction at times from 5 to 30 days after the shot. The absolute value of the decay exponent decreased at later times but the smaller fractions exhibited relatively higher rates of ddcay.

3.3.2 Shot 2

The Shot 2 decay-curve slopes, as plotted on log-log paper, increased with time when the time scale was based upon Shot 2. This phenomenon is unlike fission decay either with or without uranium capture products. The curves as plotted on a Shot 1 zero-time scale appear to be normal fission decay. The activity collected during the Shot 2 sampling period could have come from contamination already on the ground around the collectors either by the action of winds, shock wave, or by contamination which was displaced from the Shot 1 crater by the Shot 2 detonation. Undoubtedly, some contamination caused by the Shot 2 detonation fell on some Bikini land areas. However, in the few determinations made, the total amount of fallout activity on the islands was too small to materially affect the decay rate attributable to Shot 1.

The decay of Shot 2 samples can be represented by:

$$A = A_1(t + 623)^{-n} \qquad (3.13)$$

where
A = Activity at any time t
A_1 = Activity when t = 1
t = Time in hours after Shot 2
623 = The time in hours between Shots 1 and 2
n = The decay exponent

Shot 2 decays are presented in Table 3.4. The data from one sample plotted to both Shot 1 and 2 times are shown in Fig. 3.3.

The Shot 2 average decay exponent is about -1.4 between 600 and 1200 hr and about 1.25 between 1500 and 4000 hr. These values are in fairly good agreement with Shot 1 values. Because of the paucity of Shot 2 decay data, the Shot 2 activities were corrected to sampling time by the use of the Shot 1 composite decay curve described in the preceding section.

3.3.3 Shot 3

Extrapolation of most Shot 3 activities was similar to that of Shot 1 activities. The activity due to U^{237}, U^{239}, and Np^{239}, respectively, can be represented by:

$$A_c = A_{co}(0.0007e^{-0.00431t} + e^{-1.77t} + 0.00652e^{-0.0124t}) \qquad (3.14)$$

TABLE 3.3 - Beta-Decay Exponents of Shot 1
Size Graded Samples*

NMD of Fraction µ **	Decay Exponent 5 to 30 Days After Shot 1 n	Decay Exponent 110 to 170 Days After Shot 1 n
1.1	-2.0	-1.32
3.2	-2.0	-1.20
22	-2.0	-1.31
27	-2.0	-1.09
38	-2.0	-1.13
56	-2.0	-1.09
79	-2.0	-1.14
69	-2.0	-1.18
98	-2.0	-1.22
103	-2.0	-1.17
160	-2.0	-1.15
171	-2.0	-1.18
195	-2.0	
225	-1.8	-1.20

* Project 2.6b results from How Island
** Project 2.6b reports the fractions as the mean volume diameter of the particles

The terms for U^{239} and Np^{239} were derived as in Eq. 3.9. The ratio of U^{237} activity to U^{239} activity, 0.0007, was determined in this case by a solution of simultaneous equations using actual decay curves because capture to fission ratios were unavailable for this shot. However, because of its short half-life, U^{240} cannot be calculated similarly. The fission activity component was:

$$A_f = A_{1f} t^{-1.3} \qquad (3.15)$$

where the exponent was determined from decay data after 2000 hr.

A few decay determinations from early-interval samples of Easy, Fox, and George show that a high percentage of activity originated prior to Shot 3, probably from Shot 1. The decay from these samples follows the relationship:

$$A = A_1 (t + 998)^{-n} \qquad (3.16)$$

where 998 hr is the time elapsed between Shots 1 and 3 and n is the Shot 1 decay exponent during this period.

The activity values from the first two 30-min intervals and the first 5-min interval were extrapolated to sampling time by Eq. 3.16. All other activities were extrapolated using Eq. 3.14 and 3.15.

Shot 3 decay exponents are listed in Table 3.4. A typical decay curve is shown in Fig. 3.2.

3.3.4 Shot 4

The activities of Shot 4 samples were corrected to sampling time by the relation:

$$A = A_1 t^{-1.4} \qquad (3.17)$$

where 1.4 is the average of the Shot 4 decay exponents.

The decay curves for this shot are more nearly straight lines on log-log paper than the curves from Shots 1 and 3, indicating that the neutron capture activities in samples from Shot 4 are small or absent; therefore, no corrections were made for these neutron capture activities. Shot 4 decay values are shown in Table 3.4 and a typical curve is illustrated in Fig. 3.4.

3.3.5 Shot 6

Shot 6 activities were corrected to sampling time by the relationship:

$$A = A_1 t^{-1.2} \qquad (3.18)$$

The curves show little or no neutron capture activity and no correction was made for neutron capture activities. The value of -1.2 is the average of Shot 6 decays. Values of individual samples are shown in Tables 3.4 and a representative decay curve is illustrated in Fig. 3.4.

TABLE 3.4 - Beta Decay Exponents of Samples from Shots 2,3,4, and 6*

Shot	Station	Timing Interval (min)	Tray	n
2	Dog	30	5	-1.22
2	Easy	5	1	-1.18
2	Easy	30	23	-1.20
2	Easy	30	24	-1.22
2	George	5	24	-1.18
2	George	30	1	-1.33
2	George	30	11	-1.22
2	George	30	23	-1.16
2	George	30	24	-1.14
2	Shot 2	Avg		-1.25
3	Easy	5	1	-1.24
3	Fox	30	15	-1.14
3	George	5	7	-0.98
3	George	5	9	-1.32
3	George	5	11	-1.30
3	George	5	15	-1.35
3	George	5	16	-1.23
3	George	5	18	-1.19
3	George	Island	Sample	-1.02
3	How	Island	Sample	-0.83
3	Love	Island	Sample	-0.81
3	Uncle	1	1	-1.32
3	Uncle	1	16	-1.32
3	Uncle	30	2	-1.39
3	Uncle	30	4	-1.28
3	Uncle	30	5	-1.27
3	Uncle	30	8	-1.25
3	Uncle	30	9	-1.24
3	Uncle	30	12	-1.25
3	Uncle	30	22	-1.25

* The decay exponent is the exponent of t in the decay expression $A_t = A_1 t^{-n}$. The Shot 2 exponents are for the period of 2000 to 4000 hr, Shot 3 from 1500 to 3500 hr, except the island samples which are from 700-4500 hr, Shot 4 from 167 to 2036 hr (except the Nan 30 min exponents, which are from 1530 to 3064 hr), and the Shot 6 exponents, from 400 to 1800 hr.

TABLE 3.4 - Beta Decay Exponents of Samples from Shots 2,3,4, and 6* (Cont'd)

Shot	Station	Timing Interval (min)	Tray	n
3	Uncle	30	23	-1.33
3	Shot 3	Avg		-1.3
4	George	30	6	-1.53
4	How	5	1	-1.40
4	How	5	2	-1.42
4	How	5	7	-1.50
4	How	5	8	-1.44
4	How	5	9	-1.35
4	How	5	10	-1.36
4	How	5	12	-1.38
4	How	5	13	-1.38
4	How	30	2	-1.38
4	How	30	9	-1.34
4	How	30	12	-1.41
4	How	30	17	-1.34
4	Love	30	6	-1.53
4	Nan	30	7	-1.11
4	Nan	30	8	-1.13
4	Shot 4	Avg		-1.4
6	Alice	30	1	-1.46
6	Alice	30	21	-1.19
6	Alice	30	24	-1.11
6	Belle	30	1	-1.44
6	Belle	30	3	-1.28
6	Belle	30	21	-1.30
6	Belle	30	24	-1.33
6	Janet	30	2	-1.32
6	Janet	30	9	-1.13
6	Olive	30	2	-1.55
6	Olive	30	3	-1.60
6	Shot 6	Avg		-1.2

* The decay exponent is the exponent of t in the decay expression $A_t = A_1 t^{-n}$. The Shot 2 exponents are for the period of 2000 to 4000 hr, Shot 3 from 1500 to 3500 hr, except the island samples which are from 700-4500 hr, Shot 4 from 167 to 2036 hr (except the Nan 30 min exponents, which are from 1530 to 3064 hr), and the Shot 6 exponents, from 400 to 1800 hr.

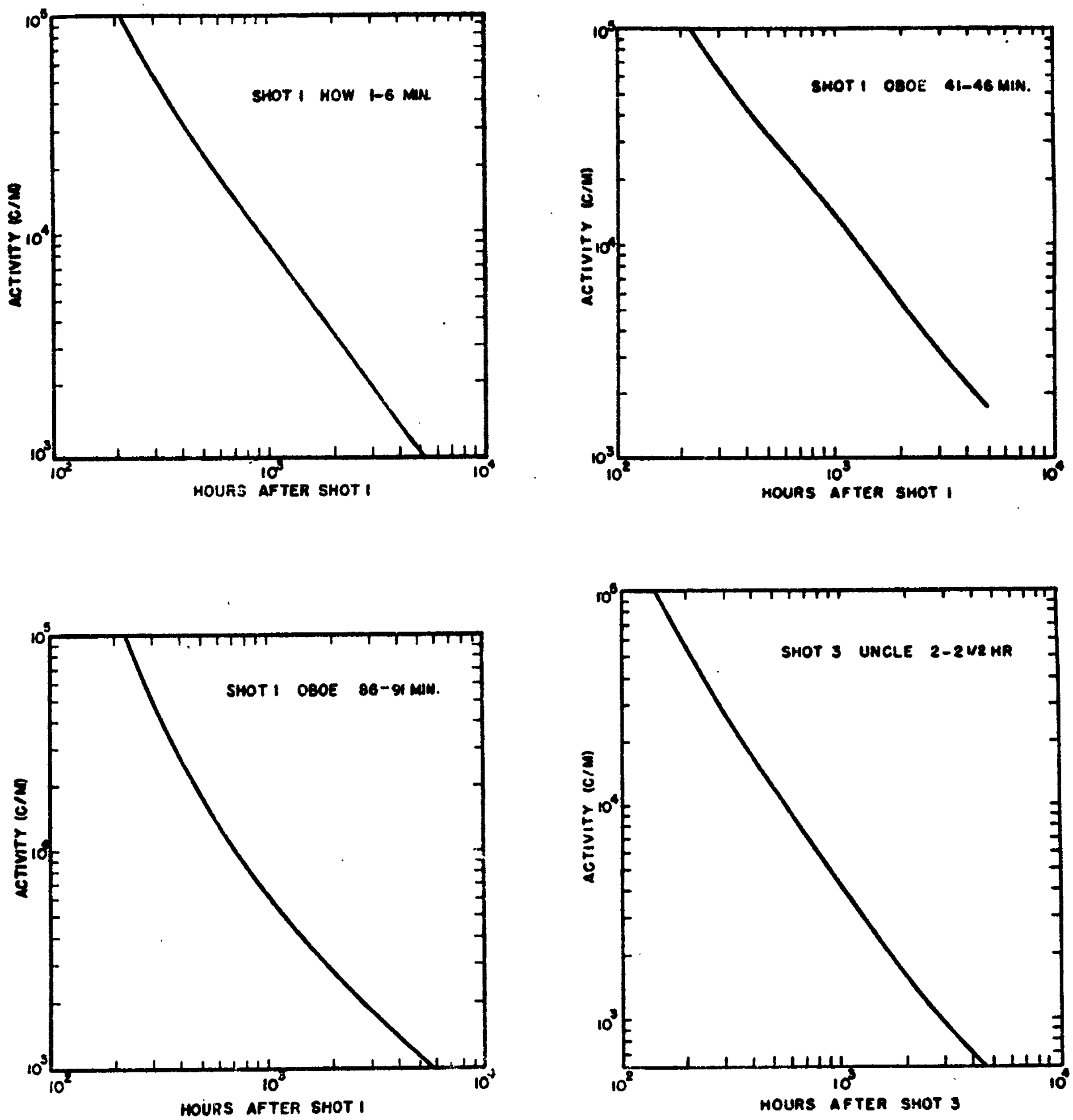


Fig. 3.2 Shots 1 and 3 Representative Decay Curves

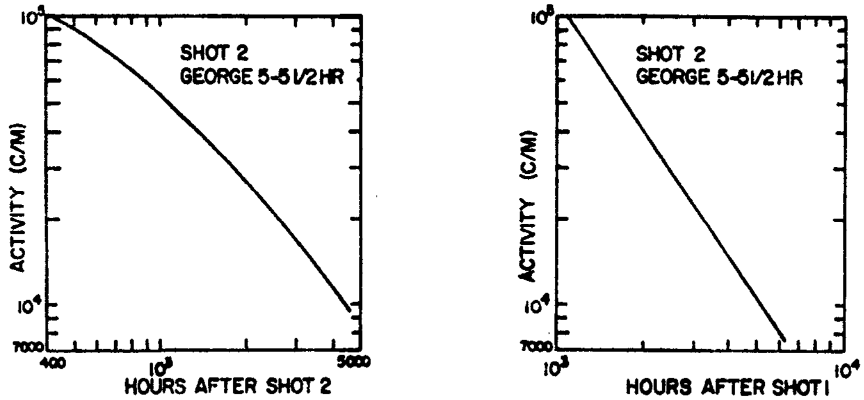


Fig. 3.3 Example of Shot 2 Decay Curve Plotted to Shots 2 and 1 Zero Times

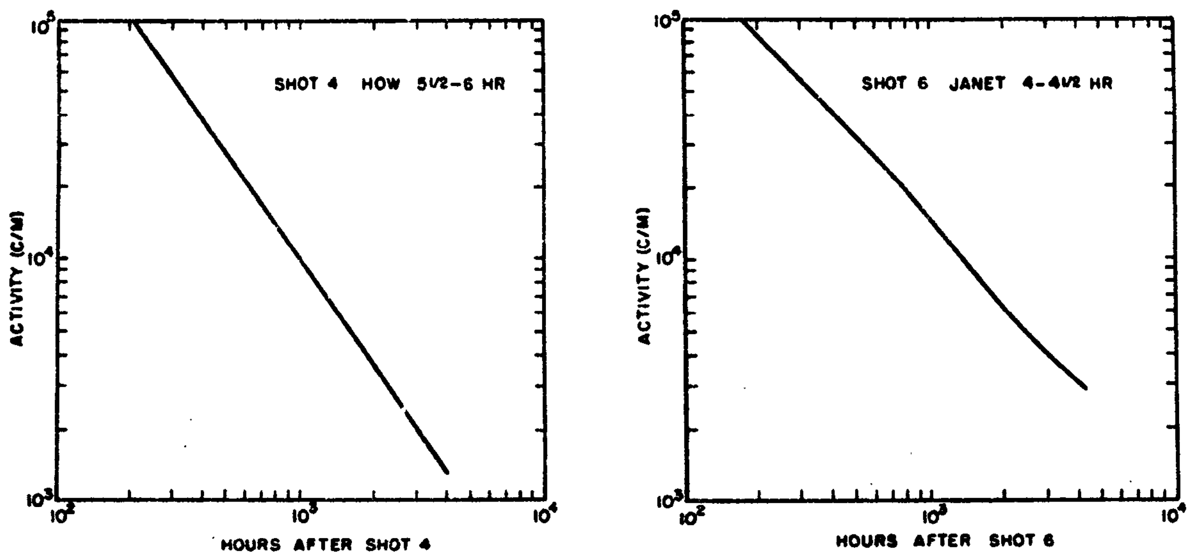


Fig. 3.4 Shots 4 and 6 Representative Decay Curves

3.3.6 Decay Exponent Variations

The variation in decay exponent from sample to sample results from a real or apparent variation in the zero time activity of various nuclides. This may result from changes in fission yield because of different fission processes, from differential deposition of various nuclides (fractionation), geographic limitations of the station layout, and limitations of the collecting instruments themselves. However, no one of these factors has been determined to be the primary cause of these decay variations.

3.4 BETA ACTIVITY

3.4.1 Interval and Cumulative Activities from Intermittent Fallout Collector Samples

The activities of the IFC samples were corrected to the midpoint of each sampling time by the methods described in Section 3.3 and calculated in terms of activity in disintegrations per min per 0.6 in.^{2}. The averaged activity values are based upon samples having a total area of 2.4 in.^{2}. Figures 3.5 through 3.17 present these data. It is to be noted that in many of these graphs the early intervals of the 1-and-5-min interval collectors show higher initial fallout activities than the first intervals of the 30-min interval collectors on the same island. The correction for decay is reflected in these results. Obviously, the midpoint of the sampling intervals for the first few 1-and-5-min intervals is much closer to the actual time of detonation than the midpoint of the first 30-min interval. However, it is believed that the method used is a reasonable method of showing the relative activity at about the actual time of sampling.

Activity results from Shots 1 and 3 were more complete than from the other shots. Data from selected intervals from these two shots can be expressed in approximate units of disintegrations per minute per square foot, using the relation:

$$\text{activity } \frac{\text{dpm}}{\text{ft}^2} = 1.67 \frac{\text{dpm}}{0.6 \text{ in.}^2} \times \frac{144 \text{ in.}^2}{\text{ft}^2} \qquad (3.19)$$

These results (in Tables 3.5 and 3.6) indicate the concentration of beta activity which could be expected over land areas, assuming that the material falling into the collector trays fell uniformly over the land mass being considered.*

The results indicate that when significant fallout occurred at an island on the shot atoll after any of these shots, it apparently began to arrive there within six minutes after the detonation. The maximum activity per sampling time interval resulting from Shot 1 and

* This assumption has not been investigated extensively. Several groups of two IFC's ten feet apart and with identical timing intervals were set up at IVY. 3/ There was a variation in the results of the two instruments; it was much less pronounced where the station was subject to heavy fallout than where fallout was sparse. At CASTLE, no instruments were available to check this assumption.

other shots having the same order of magnitude arrived at all sampling stations during the first hour after the detonation. Extrapolation of the beta activity indicated rates as high as 1.3×10^{14} d/min, 1 to 6 minutes after the detonation.

Cumulative residual activity levels, which are calculated values reflecting the activity arriving during an interval as well as the decay of residual activity deposited in previous intervals, are also shown in Figures 3.5 to 3.17. The cumulative activity levels indicate that if personnel were in such areas of fallout at later times, they would generally not be subject to an activity level and also a dose rate greater than that which existed at the beginning of fallout.

These results are considered to exclude the small percentage of activity with energies below 0.4 Mev; also, all activity detected is considered a primary beta particle. The results also do not include gamma activity in the fallout; it can be assumed that such gamma activity will be roughly proportional to the beta activity. In general, most of the activity had arrived at a given station within 3 to 6 hours after the detonation, with small amounts continuing to arrive up to at least 12 hr after the detonation.

Any fallout occurring at a station 12 hr after a detonation is, in general, not reflected in the IFC activity results. It is known, for example, that light fallout occurred on the Oboe-Tare chain the night after Shot 2. It is possible that such fallout may have arrived elsewhere at the atoll both after Shot 2 and after the other shots; however, such fallout at late times should generally be minor.

There is a possibility that some of the activity collected during the later time intervals had reached the ground during earlier times and was redistributed by the wind. It is also possible that the shock wave from a detonation would also raise fallout from earlier shots off the ground. This fallout could then be redistributed by the wind. Such an effect was quite possible on the Dog-George chain after Shot 2 and possible at both other Shot 2 stations and after Shot 4 at all stations. It is believed that this effect from Shot 3 is remote because of the low yield of the device which would produce correspondingly low shock waves. Shots 1 and 6 locations and sampling stations were in essentially uncontaminated locations.

3.4.2 Cloud Action Based upon Cloud Photography and Wind Vectors

Project 9.1 photography indicated that the Shot 1 cloud expanded horizontally very rapidly during the first few minutes after the detonation; it was 7.2 miles in diameter 1 min after the shot and 70 miles in diameter 10 min after the shot.13/ Such rapid expansion may be the reason that fallout was observed so soon after the detonation. The fallout intensity was greatest at the downwind stations on the north and east sides of the shot atoll. As would be expected from observing the wind vectors for Shot 1 (Appendix B), fallout was much less intense at the cross-wind stations.

The clouds and/or stems from Shots 2, 4 and 6 spread almost as rapidly as the Shot 1 cloud, 13/ but the wind vectors existing during Shots 2 and 6 (Appendix B) precluded the possibility of much sig-

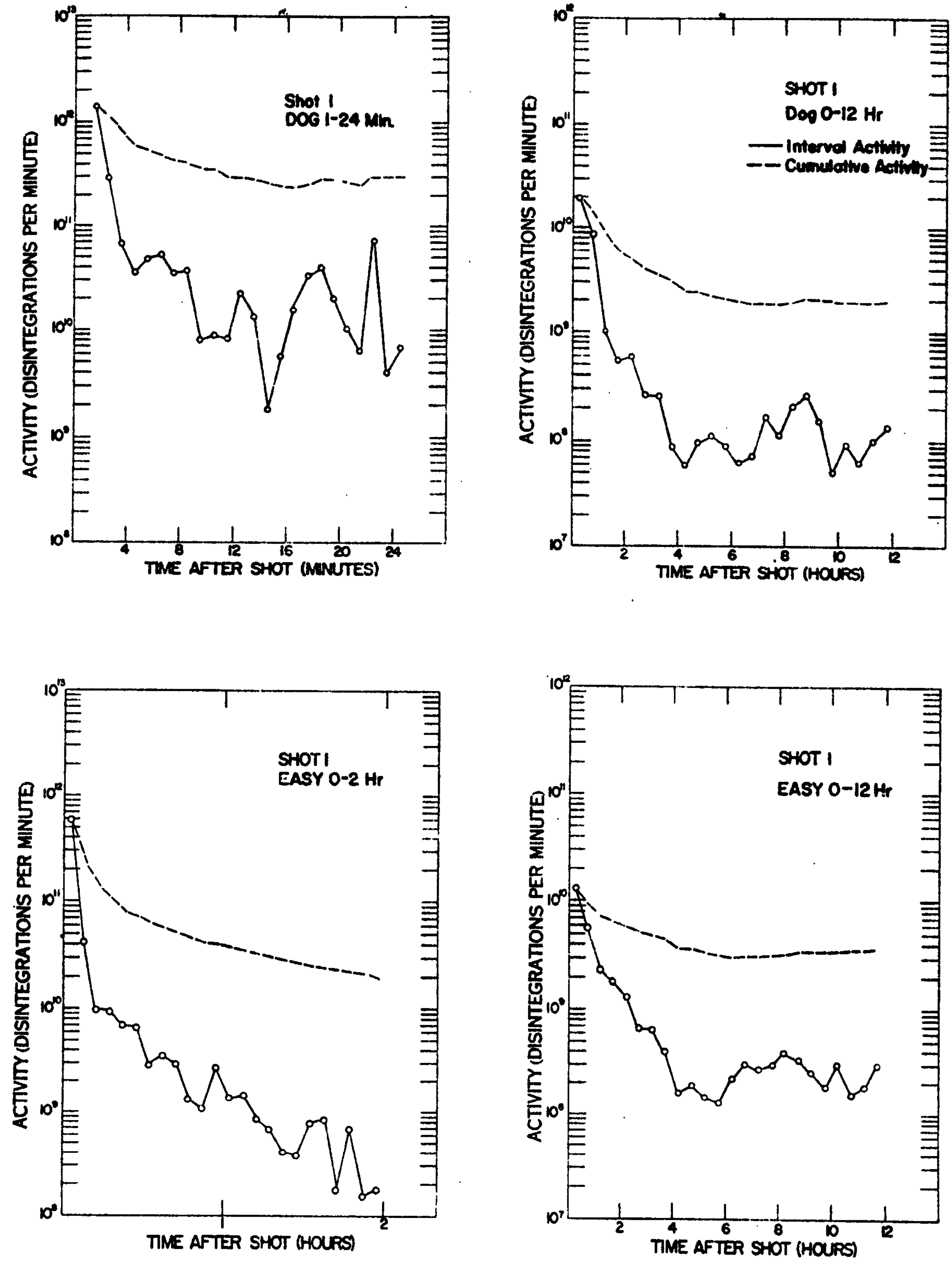


Fig. 3.5 Variation of Beta Activity with Time, Shot 1, Dog 1-24 min, Dog 0-12 hr, Easy 0-2 hr, Easy 0-12 hr.

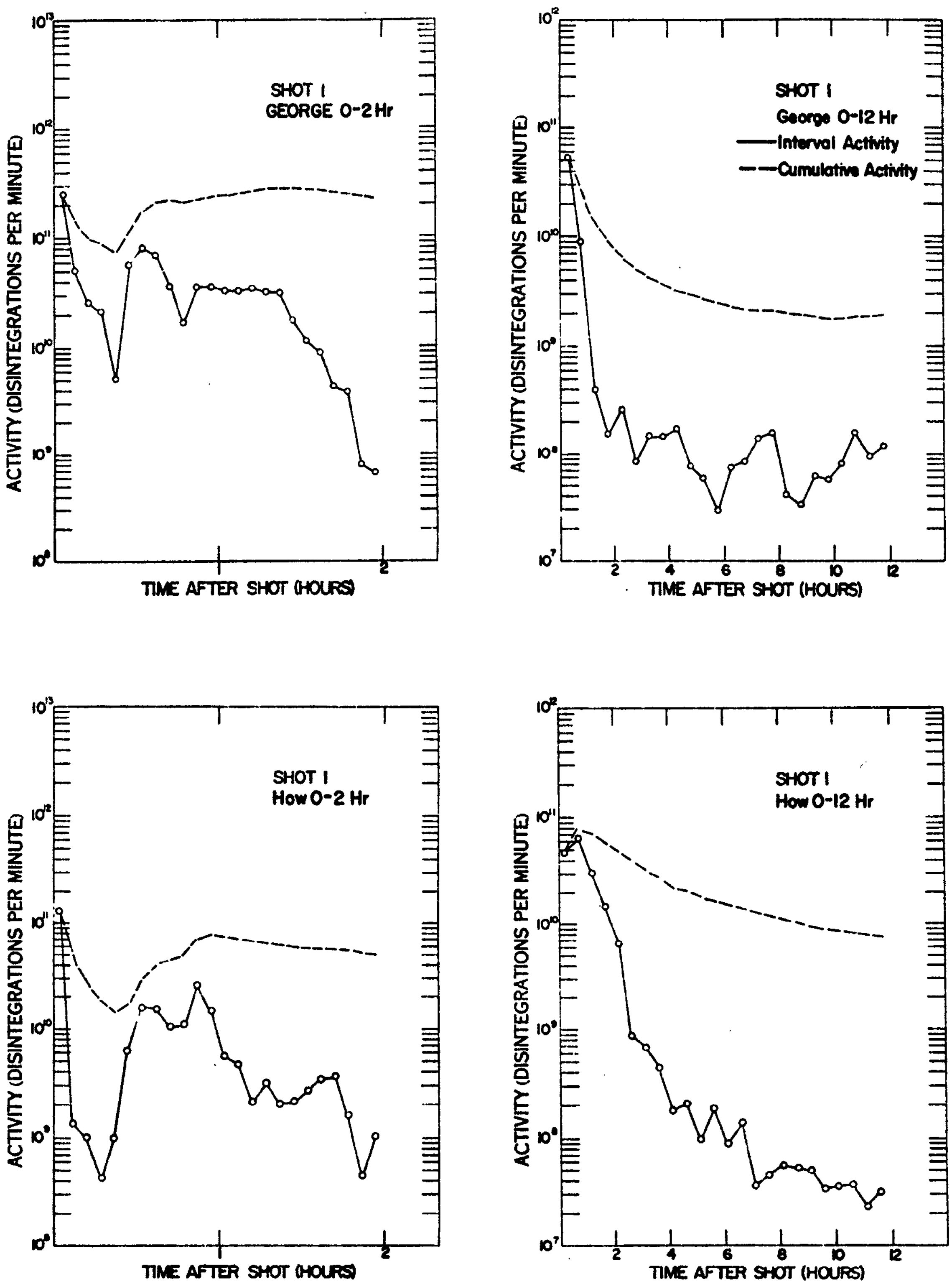


Fig. 3.6 Variation of Beta Activity with Time, Shot 1, George 0-2 hr, George 0-12 hr, How 0-2 hr, How 0-12 hr.

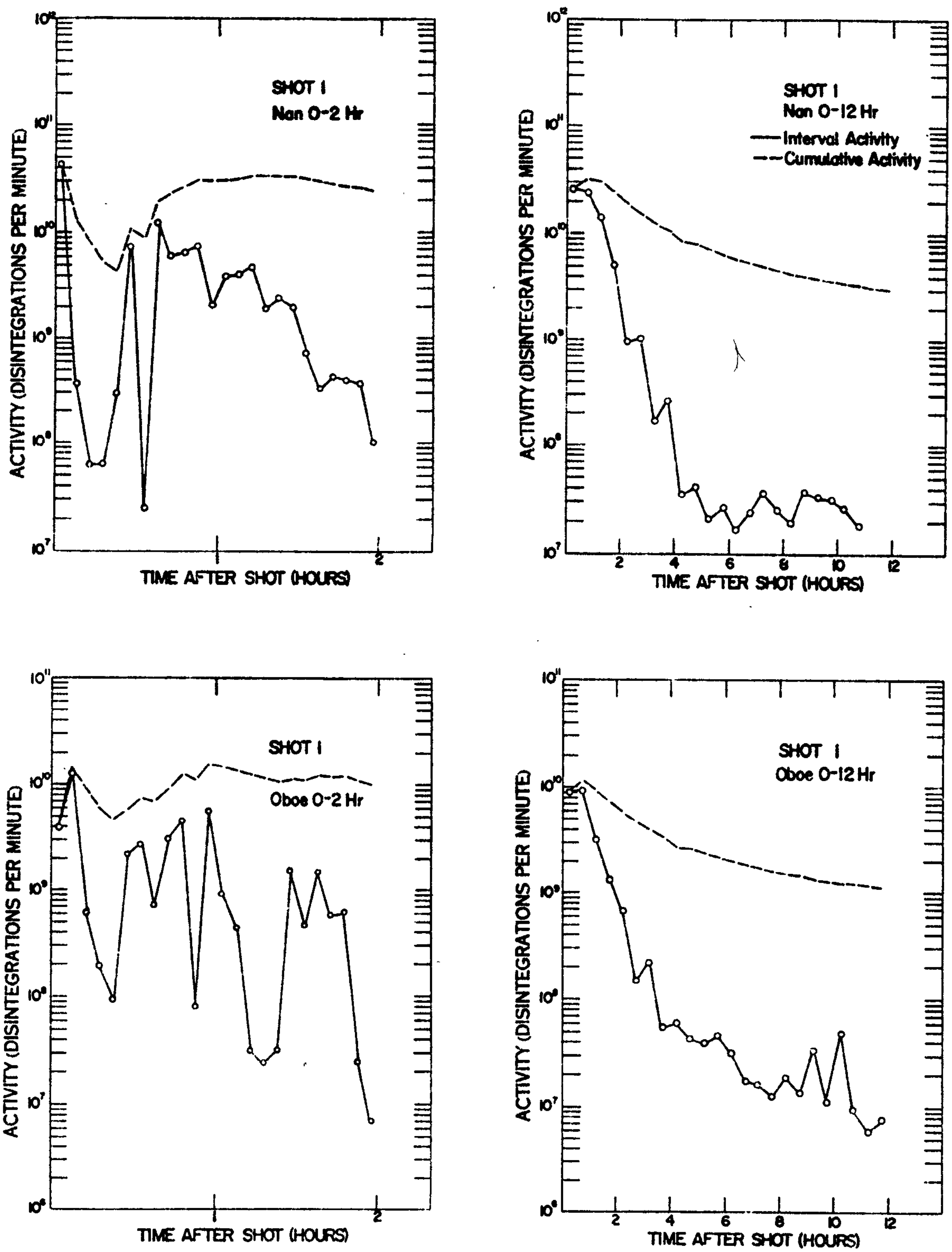


Fig. 3.7 Variation of Beta Activity with Time, Shot 1, Nan 0-2 hr, Nan 0-12 hr, Oboe 0-2 hr, Oboe 0-12 hr.

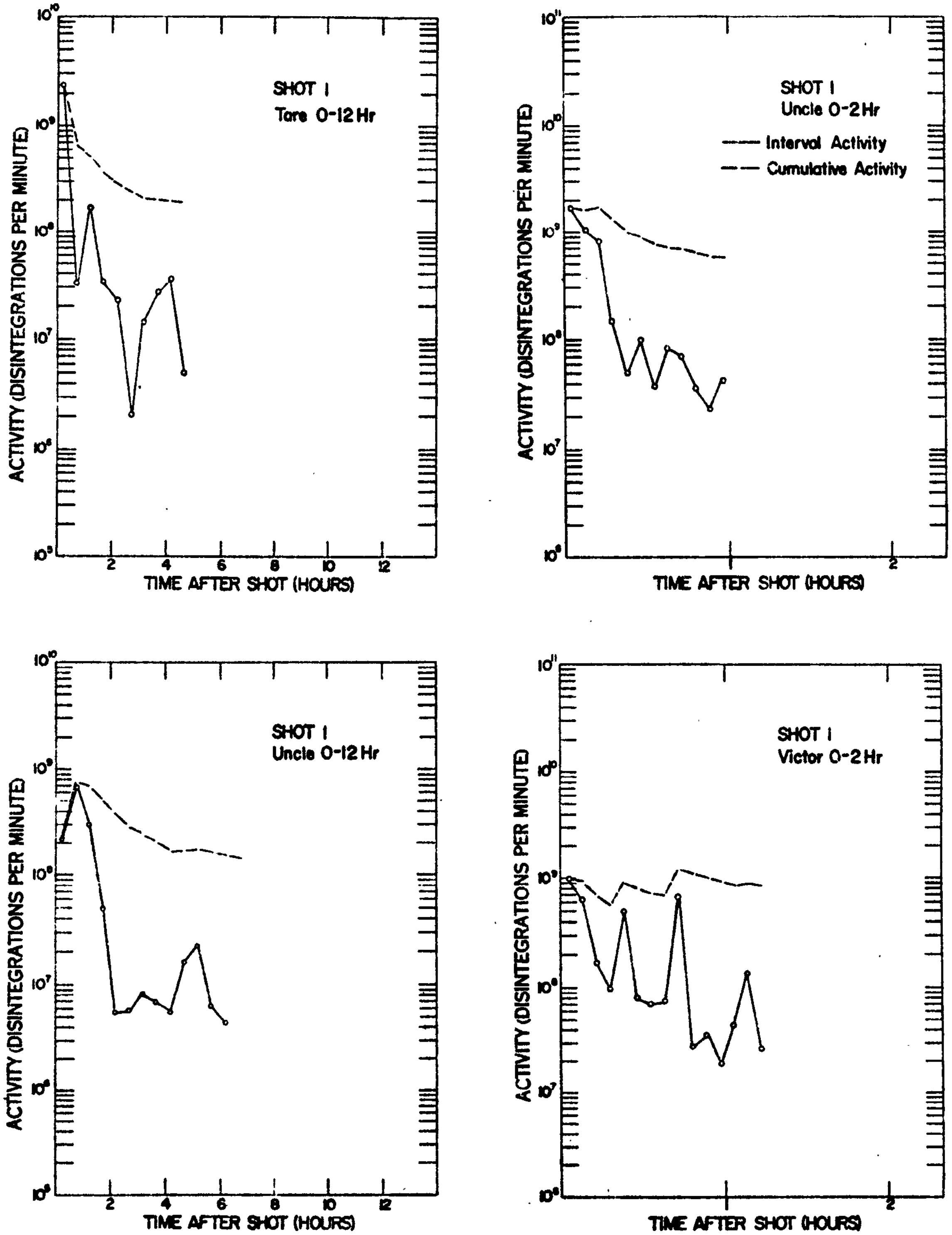


Fig. 3.8 Variation of Beta Activity with Time, Shot 1, Tare 0-12 hr, Uncle 0-2 hr, Uncle 0-12 hr, Victor 0.2 hr.

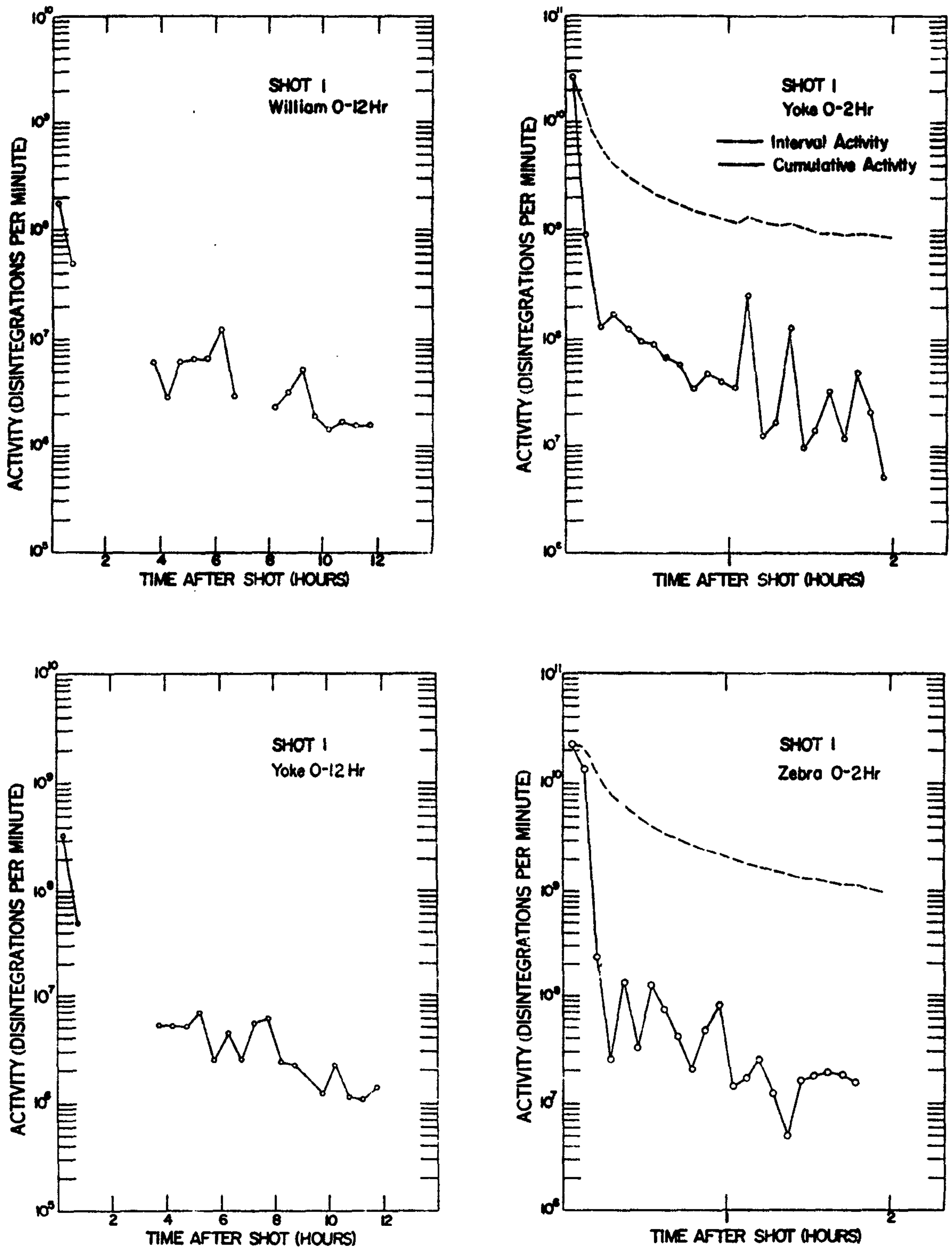


Fig. 3.9 Variation of Beta Activity with Time, Shot 1, William 0-12 hr, Yoke 0-2 hr, Yoke 0-12 hr, Zebra 0-2 hr.

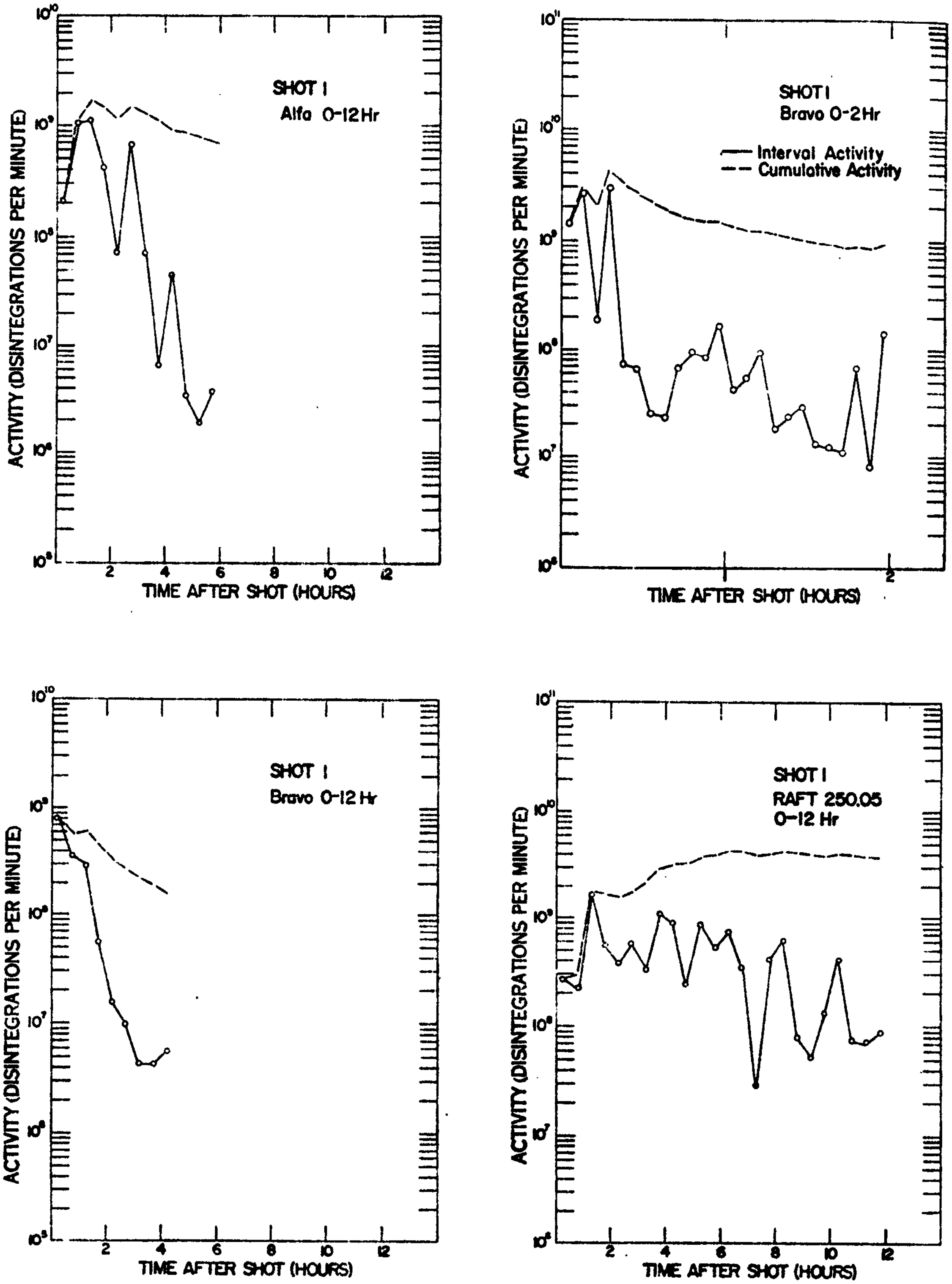


Fig. 3.10 Variation of Beta Activity with Time, Shot 1, Alfa 0-12 hr, Bravo 0-2 hr, Bravo 0-12 hr, Raft 250.05 0-12 hr.

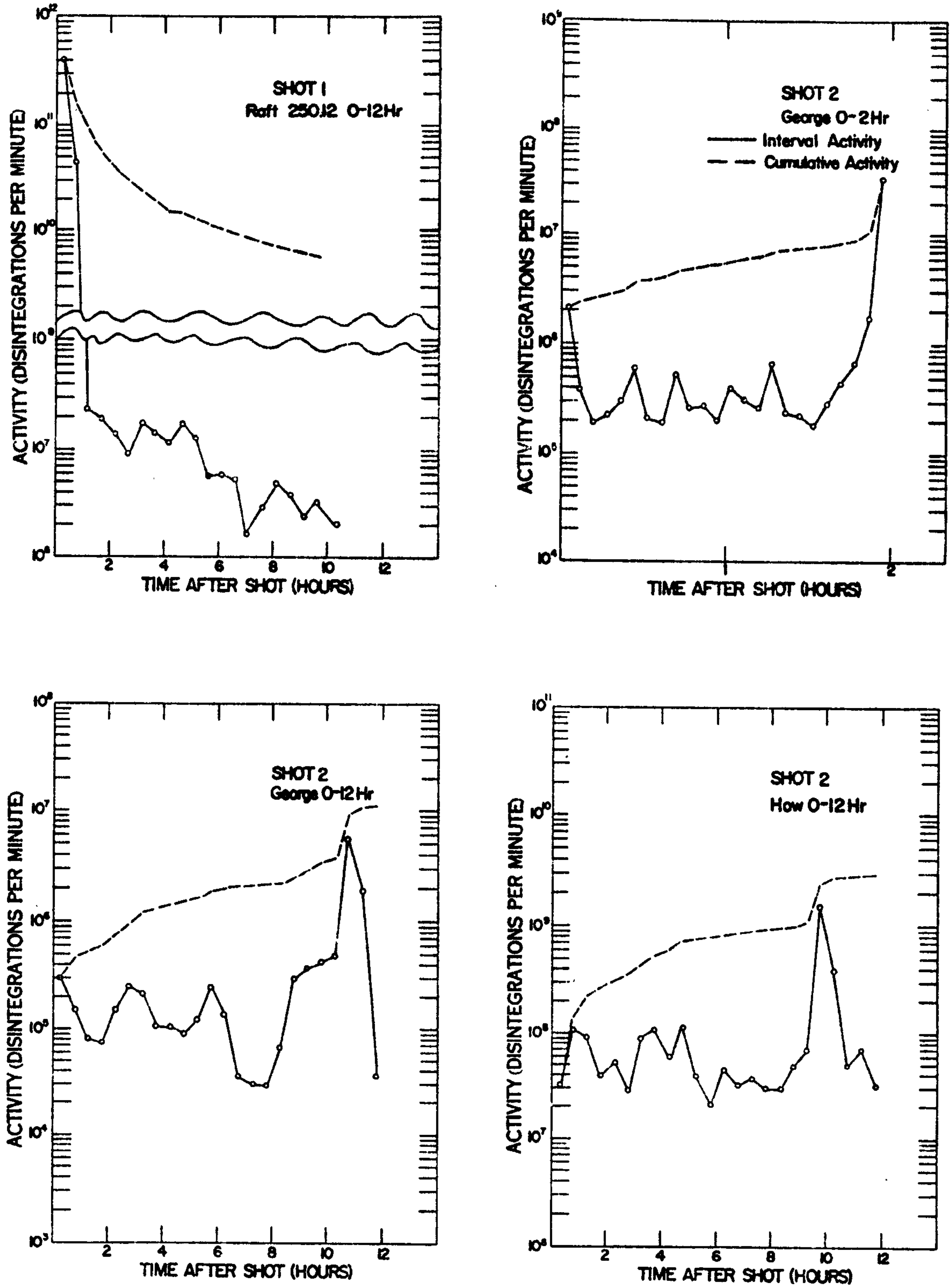


Fig. 3.11 Variation of Beta Activity with Time, Shot 1, Raft 250.12 0-12 hr, Shot 2, George 0-2 hr, George 0-12 hr, How 0-12 hr.

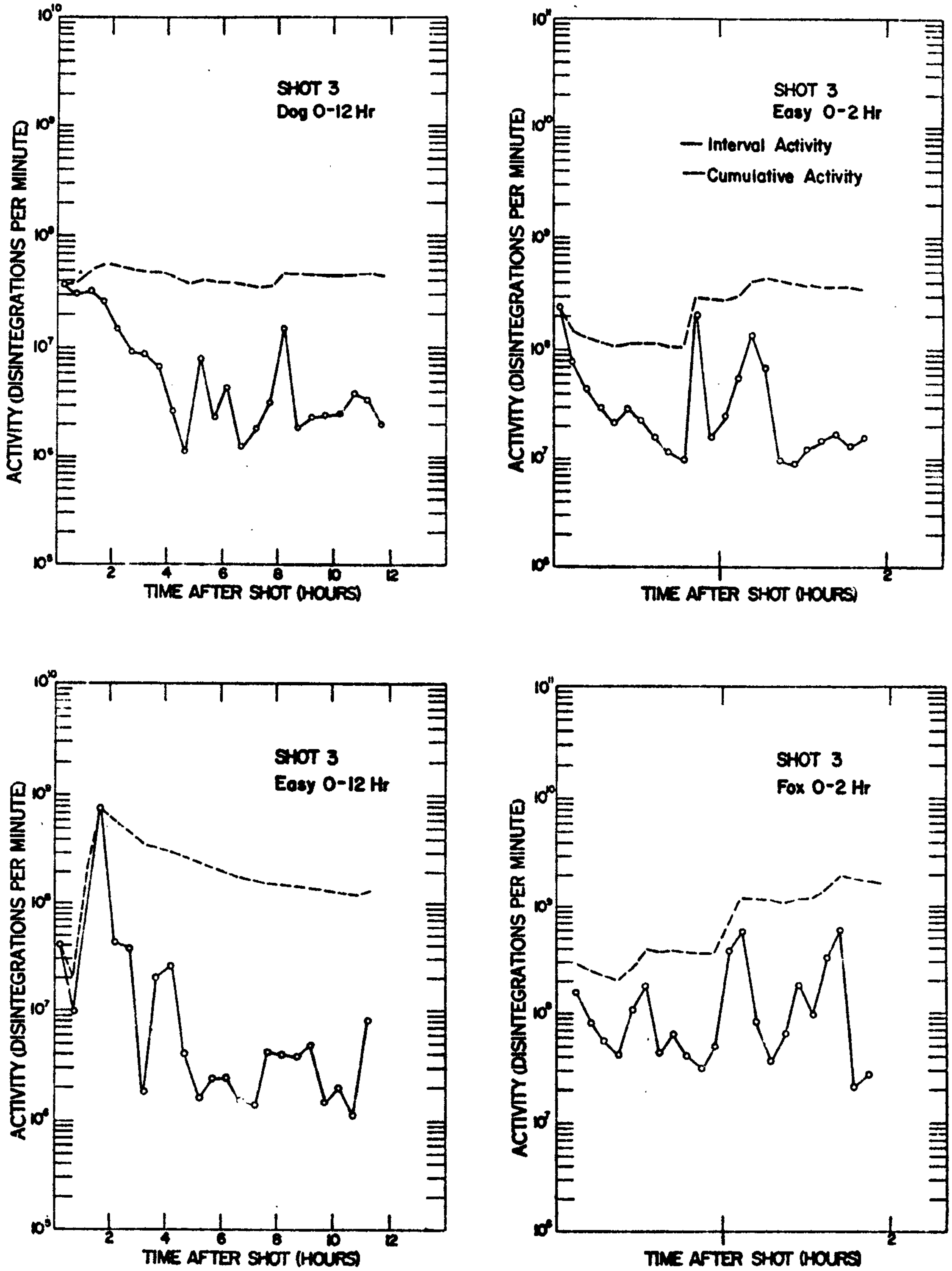


Fig. 3.12 Variation of Beta Activity with Time, Shot 3, Dog 0-12 hr, Easy 0-2 hr; Easy 0-12 hr, Fox 0-2 hr.

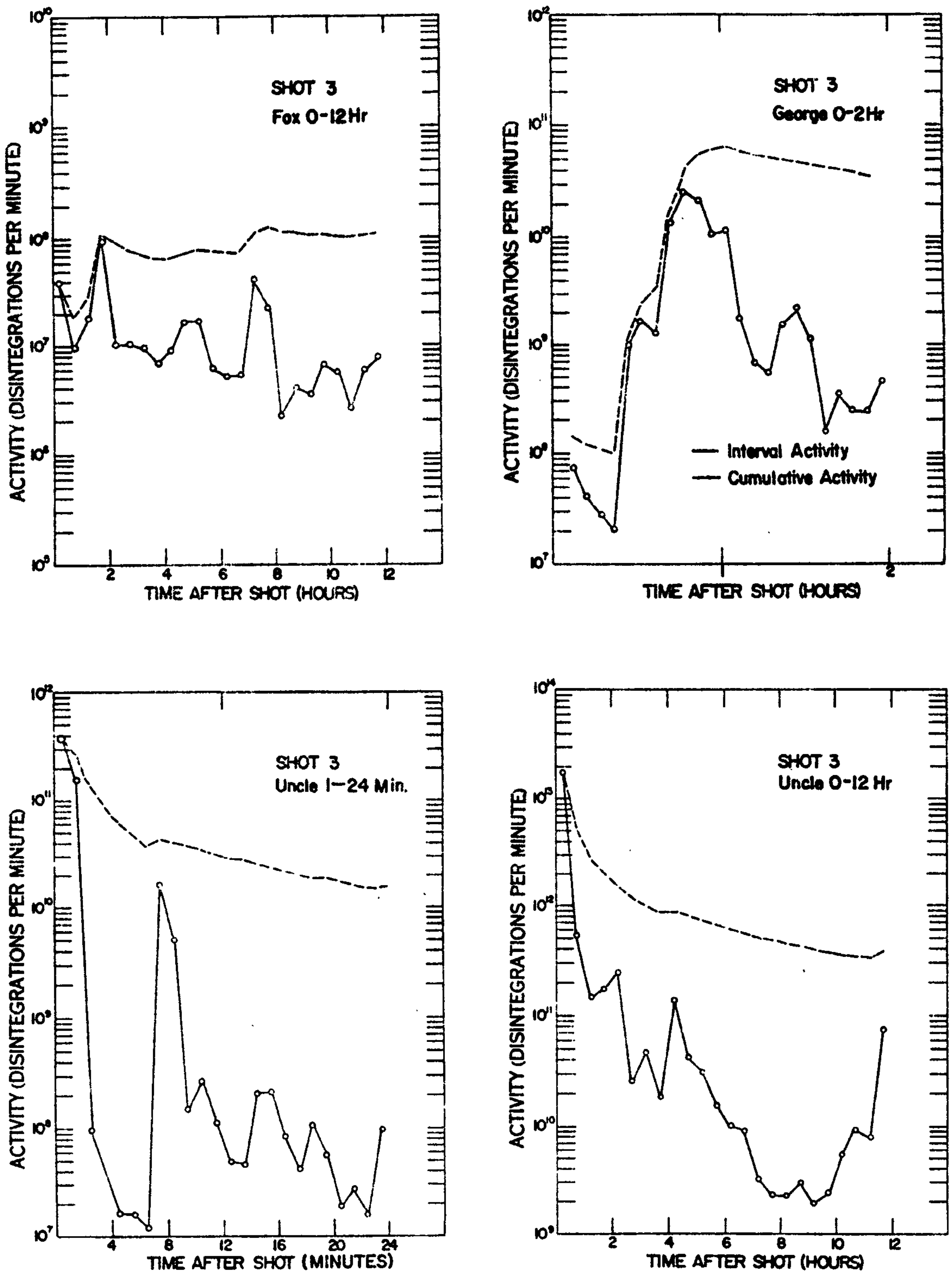


Fig. 3.13 Variation of Beta Activity with Time, Shot 3 Fox 0-12 hr, George 0-2 hr, Uncle 1-24 min, Uncle 0-12 hr.

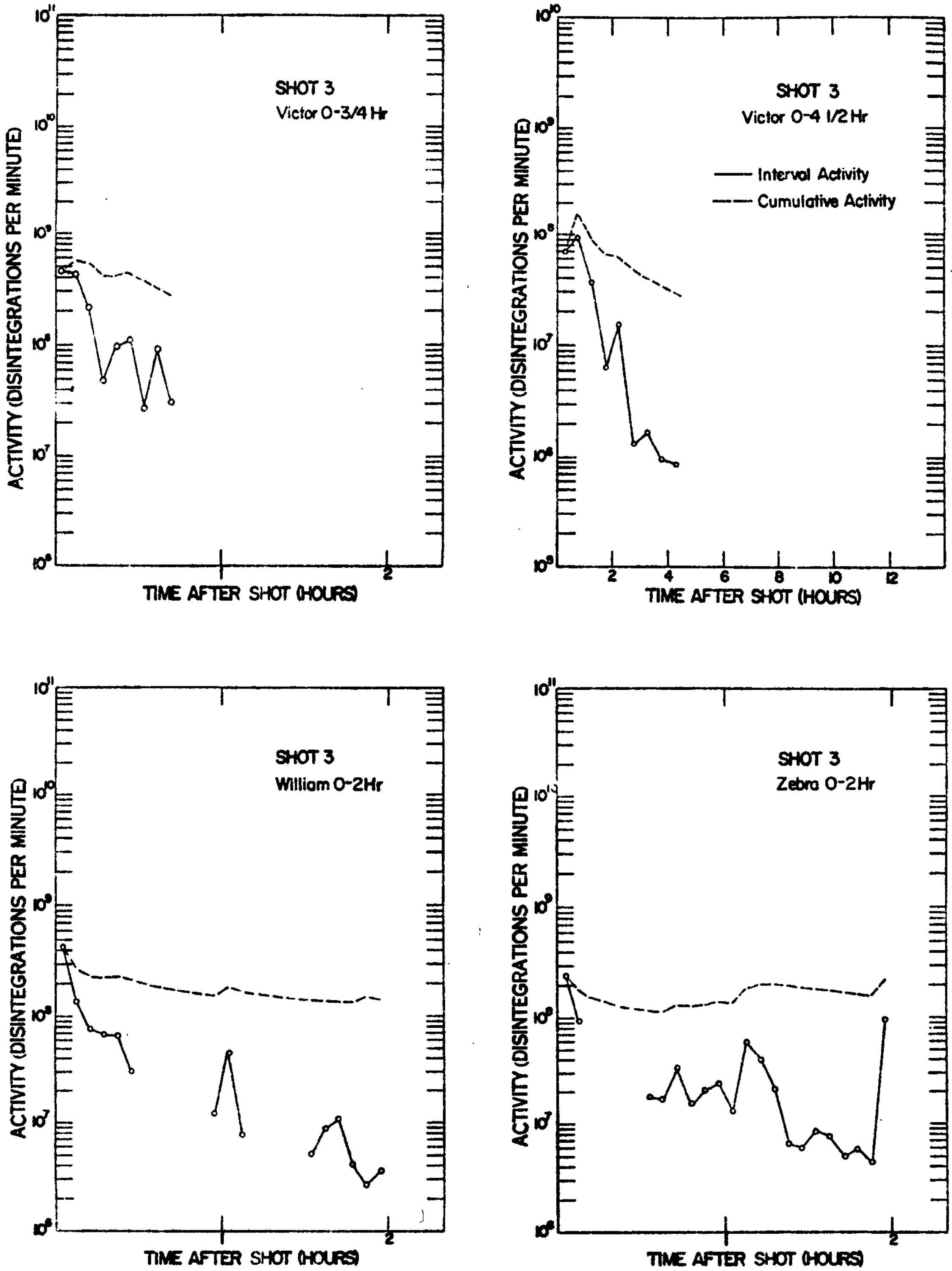


Fig. 3.14 Variation of Beta Activity with Time, Shot 3, Victor 0-3/4 hr, Victor 0-4 ½ hr, William 0-2 hr, Zebra 0-2 hr.

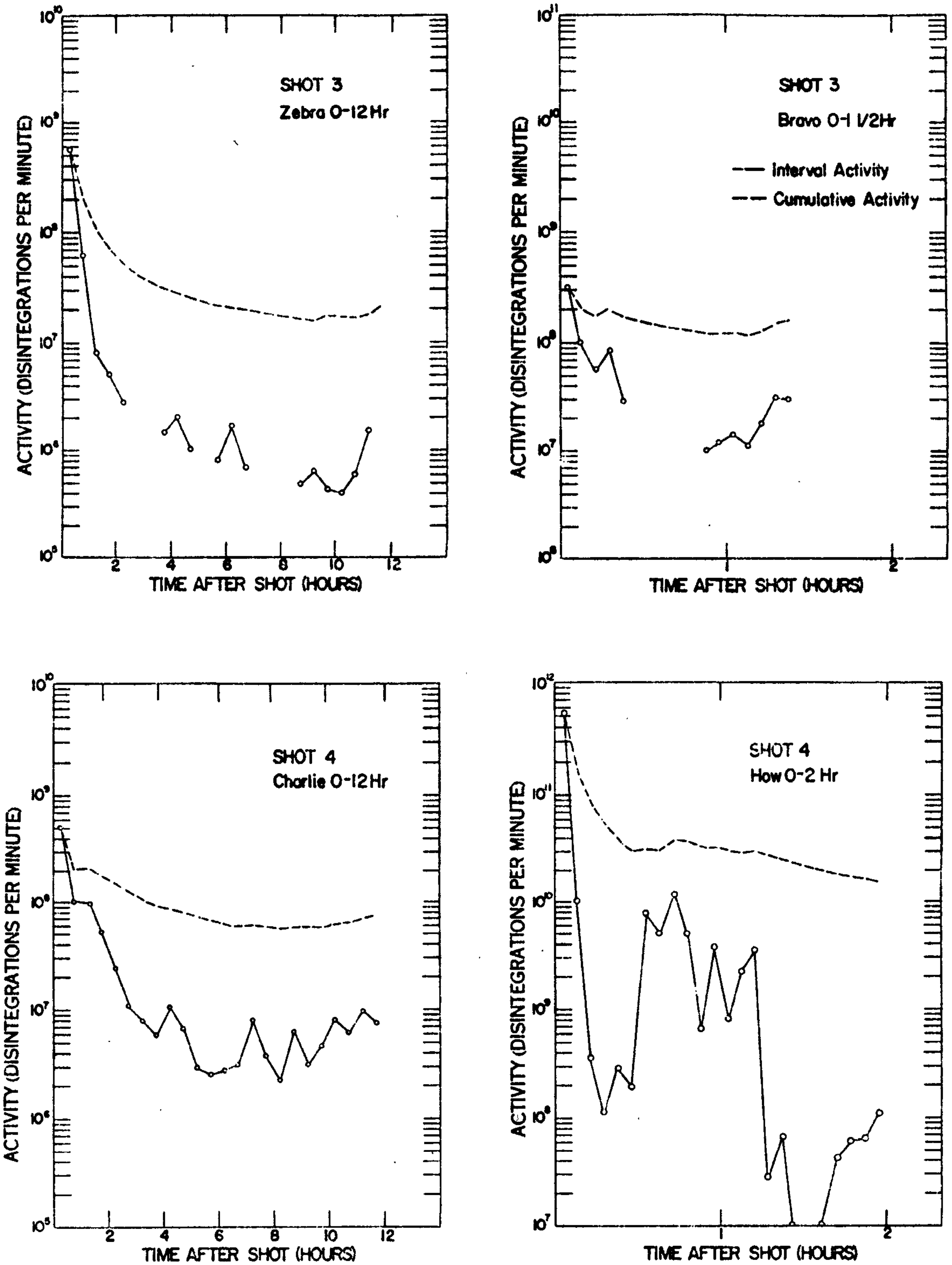


Fig. 3.15 Variation of Beta Activity with Time, Shot 3, Zebra 0-12 hr, Bravo 0-1½ hr; Shot 4, Charlie 0-12 hr, How 0-2 hr.

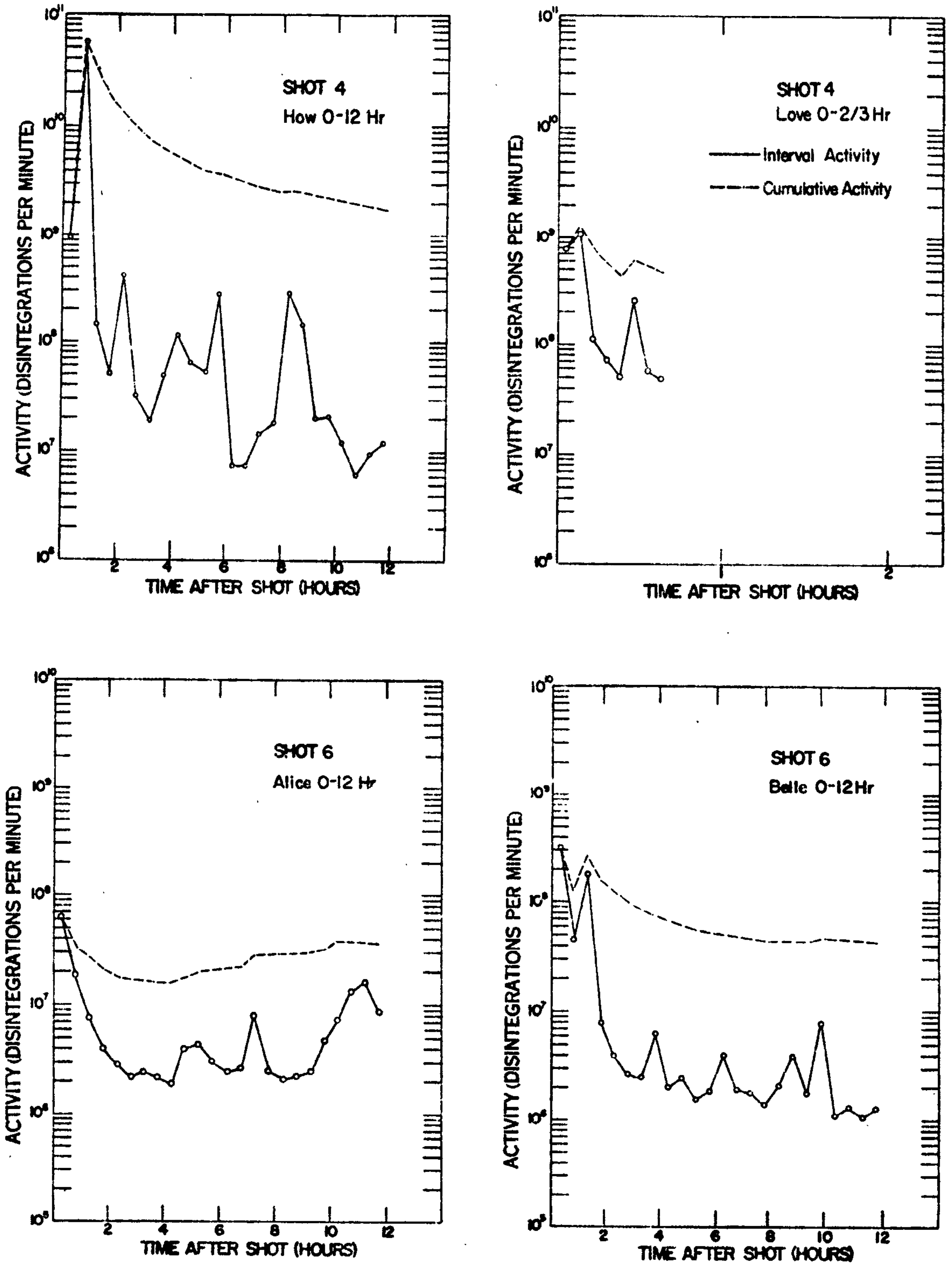


Fig. 3.16 Variation of Beta Activity with Time, Shot 4, How 0-12 hr, Love 0-2/3 hr; Shot 6, Alice 0-12 hr, Belle 0-12 hr.

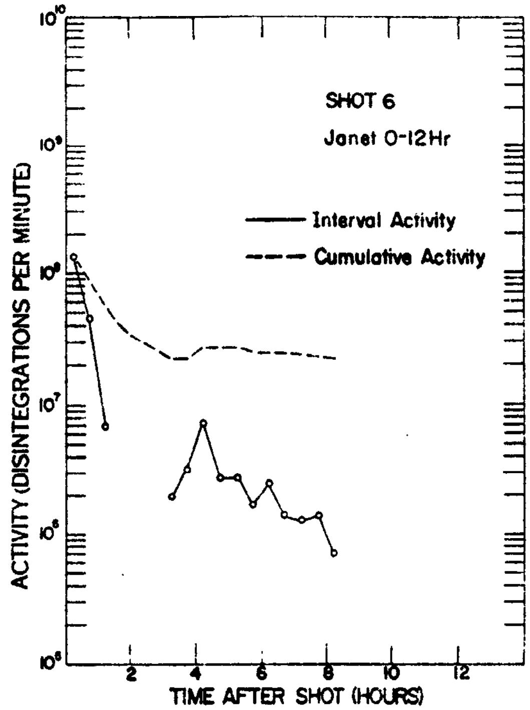


Fig. 3.17 Variation of Beta Activity with Time, Shot 6, Janet 0-12 hour

nificant fallout from these shots being deposited over most land areas of the shot atolls. Shot 4 fallout was significant from Dog through How and light or non-existent on the other islands.

No photographs of the Shot 3 cloud were obtained.13/ The Shot 3 yield was relatively much lower than the yields from the other shots and it can be postulated that the resultant cloud was much smaller and did not cover the entire shot atoll. Deposition of Shot 3 fallout at Bikini Atoll may be accounted for by examining the wind vectors at shot time. (Appendix B). Surface and low altitude winds carried intense activity to the stations immediately to the west of ground zero immediately after the detonation. Winds at altitudes above 6000 ft transported the cloud to the downwind stations 14 miles to the north of ground zero 1/2 to 1 1/2 hr after the shot.

3.4.3 Activity in the Base Surge

No evidence of base surge activity from Shots 1 and 4 was found by this project, because all base surge sampling stations were made inoperative either by blast pressures or by heavy waterwaves. The Director, Program 2, has stated that no evidence of a base surge was found from any CASTLE shot but that secondary disturbances at the base of the column of the surface water shots (in shallow water) have been observed in photographs.

TABLE 3.5 - Shot 1 Beta Activity at Sampling Time

Units of 10^{10} dpm/ft^2

Island	Time After Shot											
	1-6 Min	6-11 Min	0-½ Hr	½-1 Hr	1-1½ Hr	1½-2 Hr	2½-3 Hr	3½-4 Hr	4½-5 Hr	5½-6 Hr	7½-8 Hr	9½-10 Hr
Dog			466	209	24.4	13.1	6.2	2.1	2.2	2.1	2.7	1.2
Easy	13800	1020	311	133	5.6	44.4	15.5	0.9	4.4	0.3	7.1	0.4
George	5770	1200	1290	207	8.9	3.6	1.9	0.3	1.7	0.07	3.6	1.3
How	3110	31.1	1020	1420	666	311	1.9	1.0	4.4	4.2	10.2	0.8
Nan	1040	9.6	666	622	355	129	26.6	0.7	10.4	0.7	0.6	0.8
Oboe	95.5	311	204	202	71	31.1	3.3	1.2	10.0	1.0	0.3	0.2
Tare			54.8	0.8	4.0	0.8	0.05	0.6	BKG	BKG	BKG	BKG
Uncle	37.7	22.2	46.6	15.5	6.7	1.1	0.1	BKG	0.4	0.2	BKG	BKG
Victor	24	16.4										
William			BKG	BKG	BKG	BKG	BKG	0.2	0.2	0.2	BKG	0.04
Yoke	622	20.9	82.1	BKG	BKG	BKG	BKG	0.1	0.1	0.06	0.2	0.03
Zebra	533	311	66.6	BKG	BKG	BKG	BKG	BKG	BKG	BKG	BKG	0.01
Alpha			4.9	26.6	2.9	10.4	16.9	0.2	0.08	BKG	BKG	BKG
Bravo	33.3	64.4	18.7	8.2	6.9	1.3	0.2	0.1	BKG	BKG	BKG	BKG
Raft 250.05			6.0	4.9	36.2	12.0	12.4	2.33	5.1	11.5	8.7	2.9
Raft 250.12			8260	932	0.5	0.4	0.2	0.3	3.8	0.1	0.06	0.07

TABLE 3.6 - Shot 3 Beta Activity at Sampling Time
Units of 10^9 dpm/ft^2

Island	Time After Shot									
	0-½ Hr	½-1 Hr	1-1½ Hr	1½-2 Hr	2½-3 Hr	3½-4 Hr	4½-5 Hr	5½-6 Hr	7½-8 Hr	9½-10 Hr
Dog	9.32	7.55	8.21	6.66	2.22	1.71	0.29	0.58	0.82	0.60
Easy	9.32	2.22	48.8	149	8.66	4.66	0.89	0.53	0.93	0.31
Fox	9.32	2.22	4.22	22.2	2.44	1.64	4.00	1.47	5.33	1.60
How	2.00	2398	71.0	1.07	0.33	0.40	1.62	0.27	0.29	0.78
Uncle	41700	1230	320	393	57.7	40.0	93.2	35.5	5.11	5.33
Victor	16.6	22.20	8.66	1.55	3.33	0.22				
Zebra	126	13.90	1.84	1.15	0.49	0.33	0.24	1.89	0.13	0.10

3.4.4 Fallout at Elmer

Secondary fallout was detected by beta laboratory background counters at Elmer at about 24 hr after Shot 1; 11 to 16 hr and 45 to 100 hr after Shot 2; 4 to 6 hr after Shot 4; and 12 to 14 hr after Shot 6. The activities found were generally not over 50 times background and were not high enough to constitute a real hazard to personnel.

3.5 GAMMA ACTIVITY

The Rad Safe Gamma ground readings (Appendix C) measured shortly after each shot and which were apparently representative ground readings were corrected back to one hour after each shot, the time by which the peak of significant activity had been reached. This time was estimated from the time of arrival results obtained from the intermittent fallout collector. The correction is made by the expression

$$A_1 = A_2\left(\frac{t_2}{t_1}\right)^{1.2} \qquad (3.20)$$

where A_2 is the observed activity at time, t_2
A_1 is the activity calculated at time, t_1

The exponent 1.2 is an approximation. In the absence of the actual exponent associated with the gamma decay its use lies within the accuracy associated with the actual ground readings obtained and the relatively short period of time involved in the extrapolation. The survey readings resulting from contamination from previous shots were subtracted as background in determining the level of activity associated with a subsequent detonation. These dose rates are shown in Figs. 3.18 to 3.22. Segments of isodose rate lines have been drawn as solid lines where island dose rate readings, together with wind vector data, make such approximations reasonable. Where no data was available, the isodose rate lines are shown as dashed lines.

Infinite gamma dosages, based on Rad Safe ground readings, were also calculated; they indicate the hazard associated with permanent occupation of an area with the same degree of contamination. These values are underlined in Figs. 3.18 to 3.22.

3.6 BETA ACTIVITY CONCENTRATIONS

The total beta activity per unit weight or volume associated with a sample composed of mixed nuclides is defined as the activity concentration. It refers to the plus the low energy gamma activity detected by the beta counting equipment. As used here, the activity concentration can be thought of as being similar to what is usually referred to as the "specific activity" of a particular isotope in a sample.

The activity concentration of the liquid phase collected in the 8-oz jars was determined by counting an aliquot portion of the filtrate after it had been evaporated to dryness. The activity con-

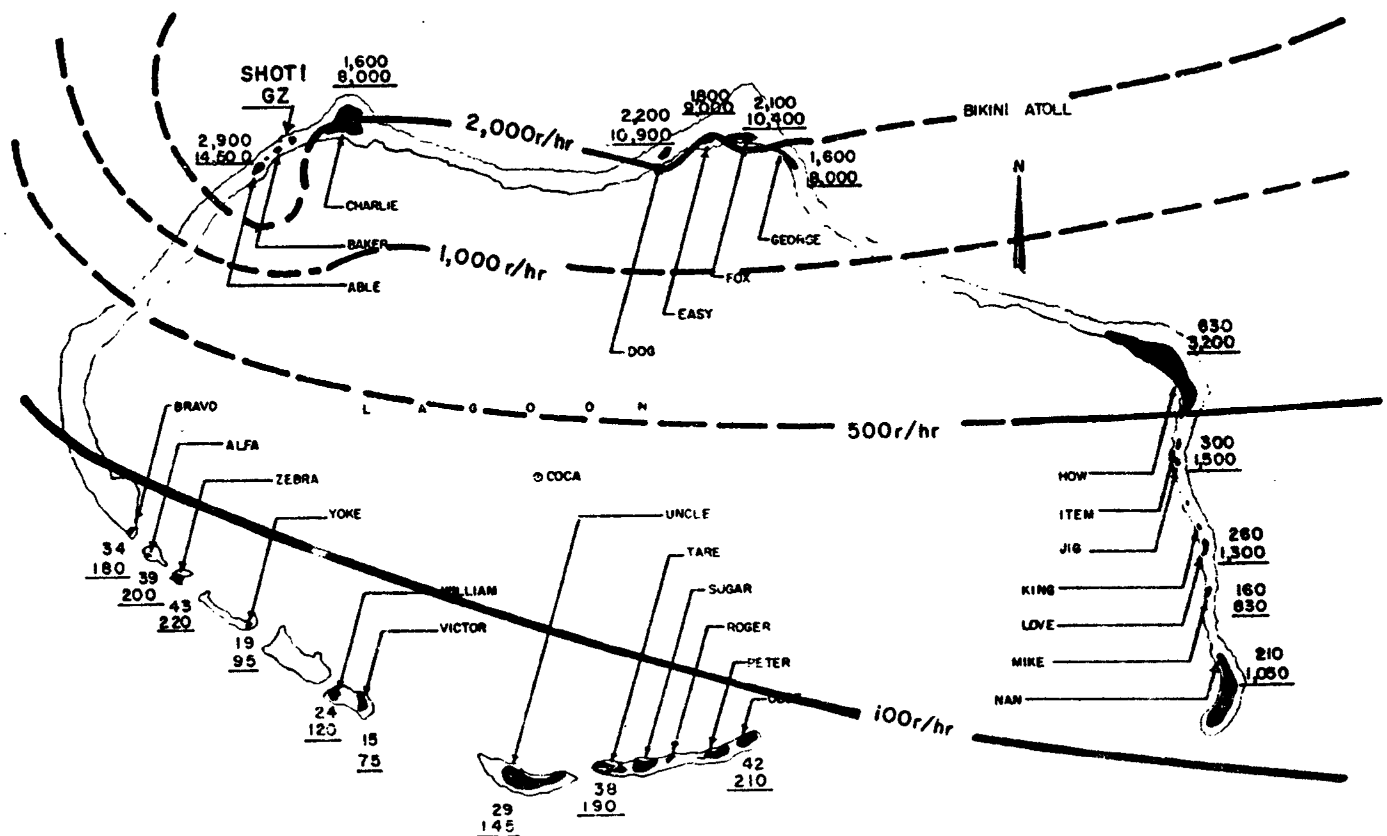


Fig. 3.18 Gamma Dose Rates in Roentgens/hr of Shot 1 Fallout 1 hr after Shot Time. Infinite dosages (underlined) in roentgens are based upon these dose rates.

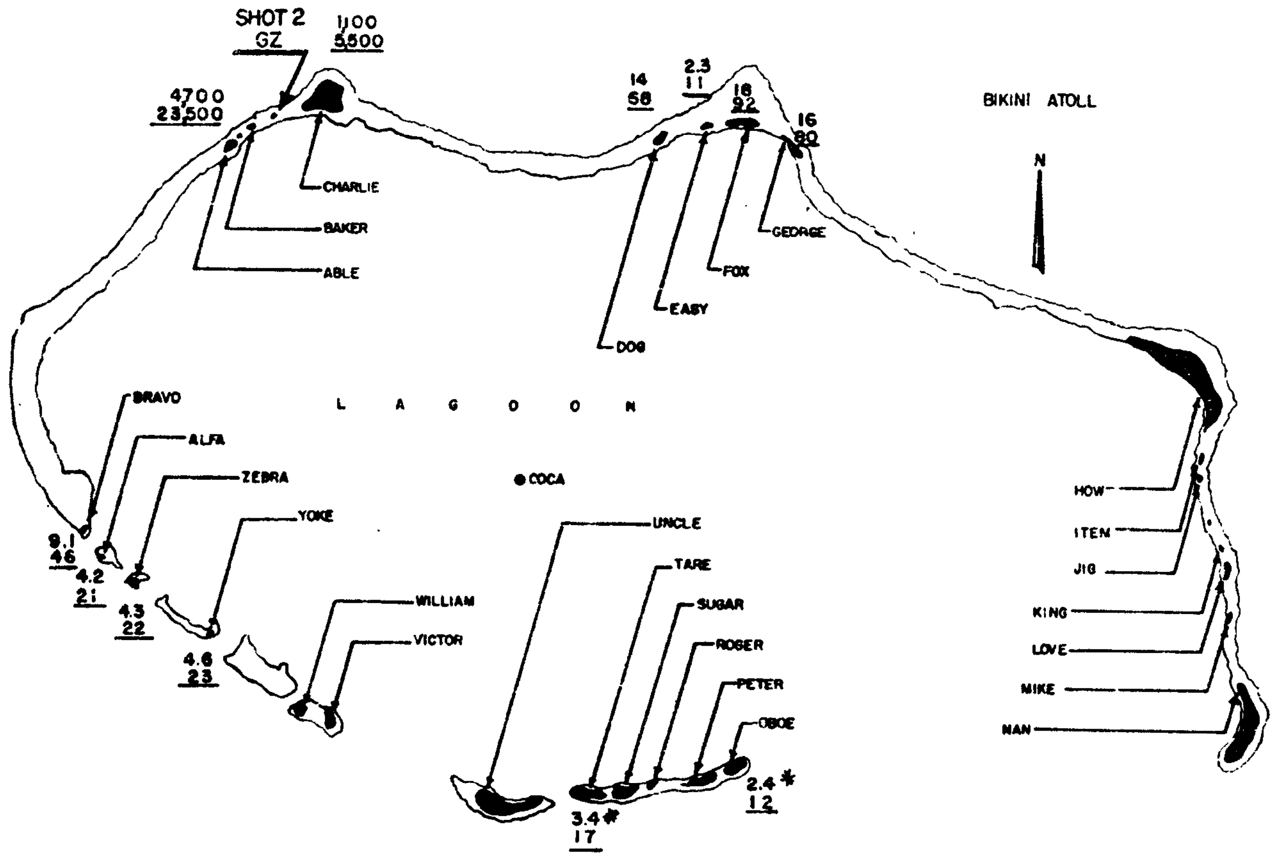


Fig. 3.19 Gamma Dose Rates in Roentgens/hr of Shot 2 Fallout 1 hr After Shot Time. Infinite dosages (underlined) in roentgens are based upon these dose rates. There was light fallout at the two islands marked with asterisks during the night after Shot 2; dose rates on the latter islands are based on readings after the secondary fallout was completed.

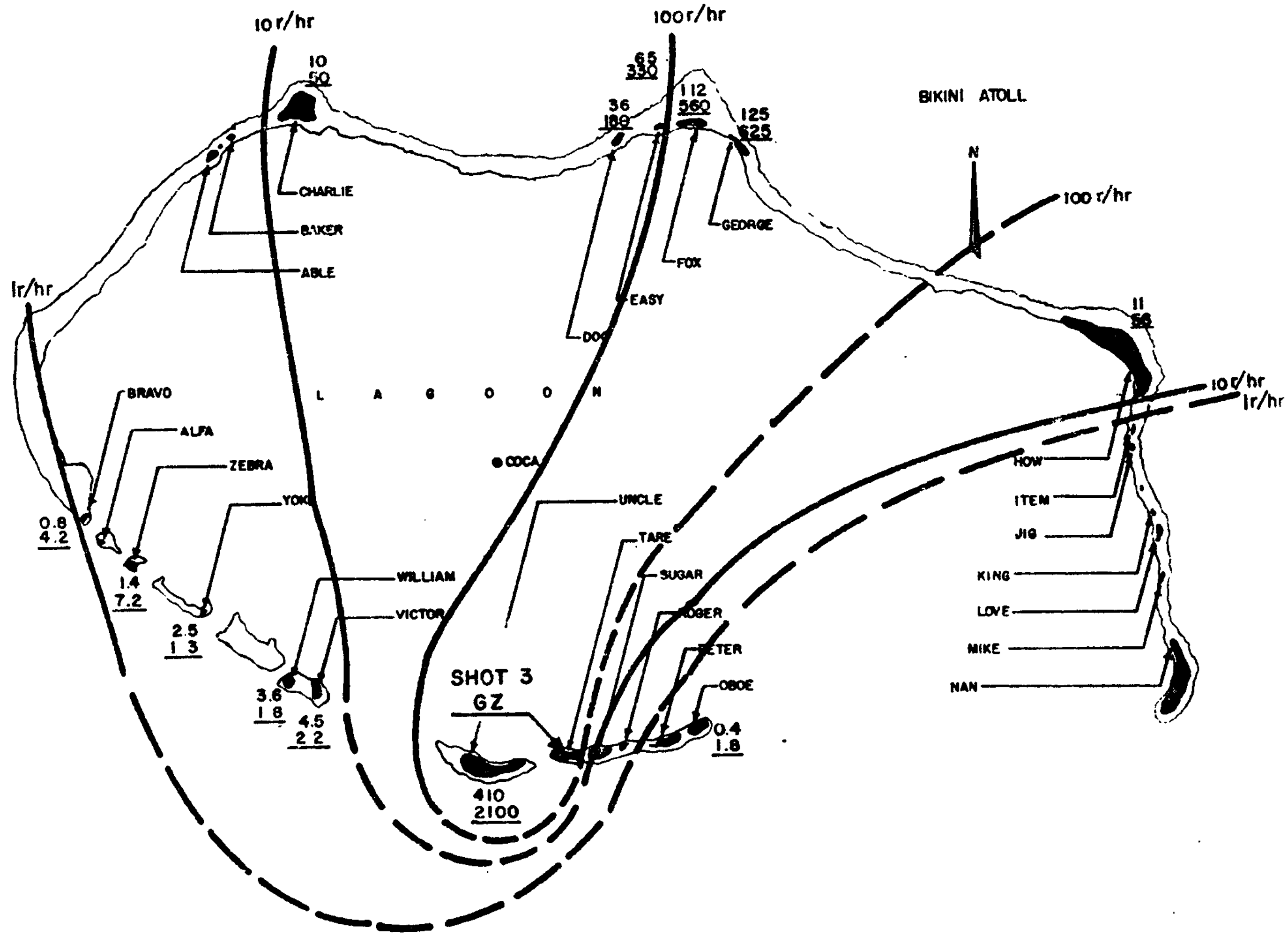


Fig. 3.20 Gamma Dose Rates in Roentgens/hr of Shot 3 Fallout 1 hr After Shot Time. Infinite Dosages (underlined) in roentgens are based upon these dose rates.

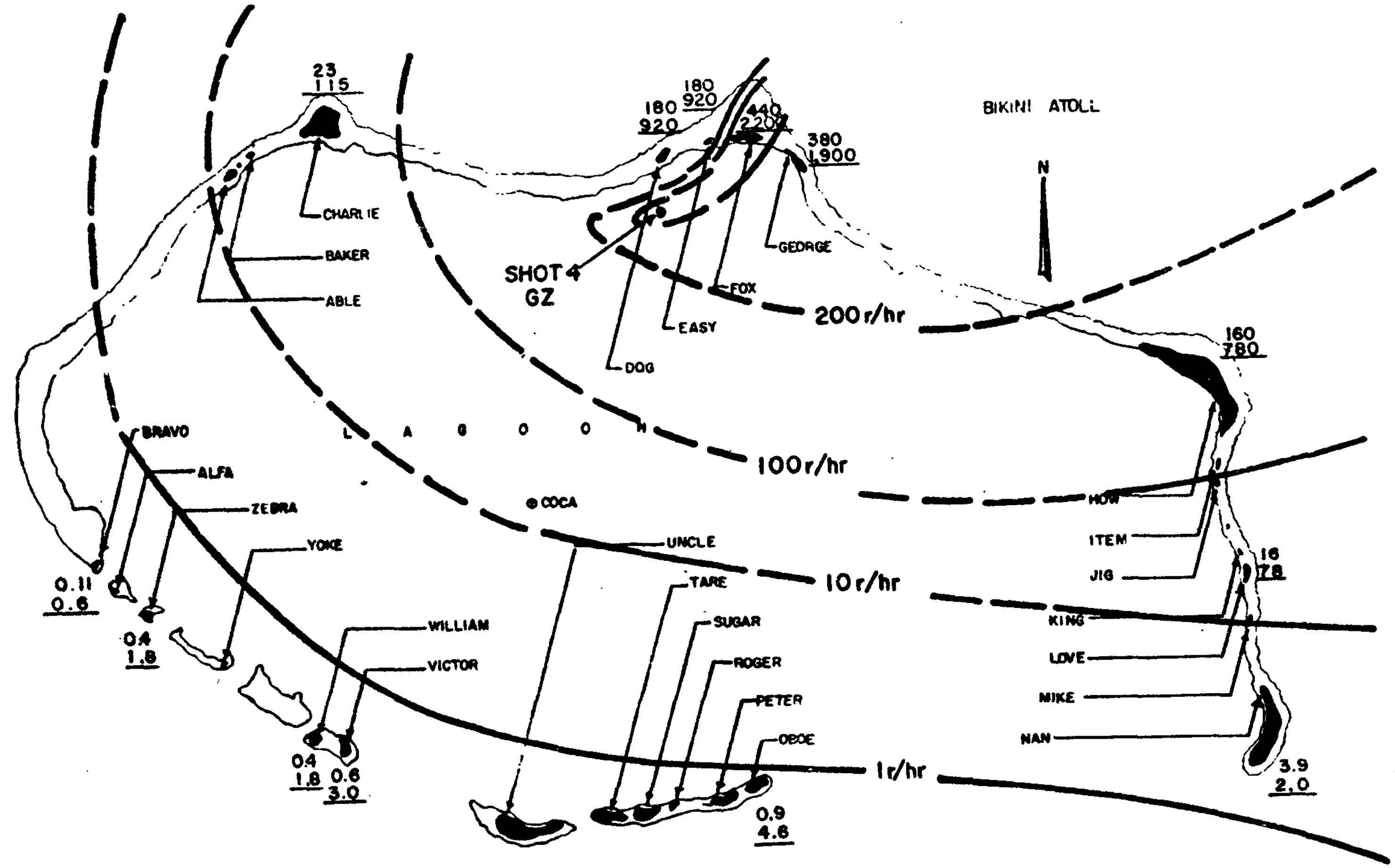


Fig. 3.21 Gamma Dose Rates in Roentgens/hr of Shot 4 Fallout 1 hr after Shot Time. Infinite Dosages (underlined) in roentgens are based upon these dose rates.

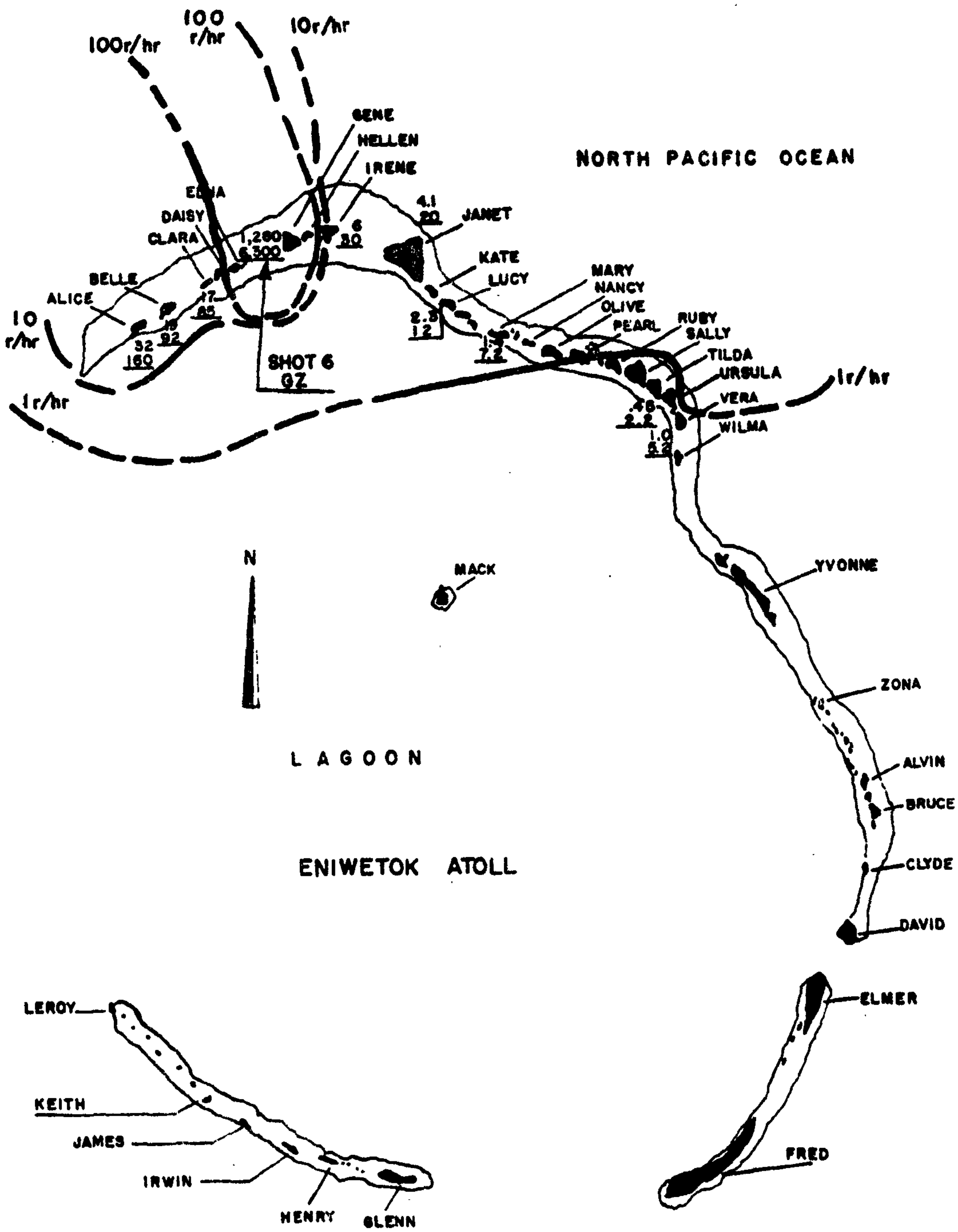


Fig. 3.22 Gamma Dose Rates in Roentgens/hr of Shot 6 Fallout 1 hr after Shot Time. Infinite dosages (underlined) in roentgens are based upon these dose rates.

centration in the solid phase was found by dissolving the solid in nitric acid (to make a sample with uniform activity for counting) and proceeding as above. The activity corrections discussed in Section 3.2 were applied and the results, expressed in d/min/gm or d/min/ml, were corrected to 15 min after shot time by methods similar to those discussed in Section 3.3.1.

The Shot 1 fallout as collected was not sufficient to enable a study to be made of the activity concentration as a function of time after the shot. However, enough sample was obtained from a few collectors to determine the activity concentrations over the entire time cycle. The results, presented in Table 3.7, indicate that the concentration of activity per unit weight of the solid material was of the same order of magnitude for all samples and independent of time and distance within the area sampled. A slightly smaller concentration is indicated for particles collected during the first two hours than for those collected during the 12-hr period after the shot. The concentration of activity in the liquid is much less than that of the solid. It should be pointed out that not much data are available and categorical conclusions should not be made.

Liquid fallout samples were collected in the 30-min collector at How after Shot 4. The liquid exhibited considerable activity. The beta concentration as a function of time was determined 4 days after Shot 4 at the Project 2.6b laboratory at Elmer. The results are shown in Table 3.8. Absorption and backscattering corrections were not determined, hence the activity concentration is expressed in c/min/ml. The table indicates that the beta concentration increased gradually up to 9 hr after Shot 4 and then dropped of sharply.

Activity concentrations in the remaining samples of collected liquid fallout were too low to be significant. The volume of liquid collected for all samples is listed in Appendix D. Activity concentrations of a Shot 1 size-graded solid sample are shown in Table 3.15.

TABLE 3.7 - Activity Concentrations of Shot 1 Fallout

Sample	Time of Collection	Type	Activity Concentration
How	0 to 2 hr	Solid	7.1×10^7 d/min/gm
Nan	0 to 12 hr	Solid	8.2×10^7 d/min/gm
Raft 250.12	0 to 12 hr	Solid	9.3×10^7 d/min/gm
Raft 250.12	0 to 12 hr	Liquid	0.79×10^7 d/min/ml

TABLE 3.8 - Activity Concentration of Shot 4, How, Liquid Fallout

Time After Shot (hr)	Activity Concentration (c/min/ml)
$1\frac{1}{2}$ - 3	3.2×10^4
$3\frac{1}{2}$ - 5	4.3×10^4
8 - 9	5.0×10^4
9 - 10	7.2×10^3
10 - 11	7.9×10^3
11 - 12	1.8×10^4

3.7 BETA ENERGY MEASUREMENTS

Aluminum absorbers, inserted between the sample and tube window very near to the tube window, were used on selected samples to determine the maximum range and energy of the beta radiation. A plot was made of activity vs absorber thickness; sufficient absorbers were used to obtain the gamma background associated with the beta activity. A sample plot is shown in Fig. 3.23.

The maximum range, R, of the beta radiation was determined by visual inspection of the point on the curve where the gamma contribution ceased to be the sole contributor to the total activity. The beta energy, E, was calculated using the relation.14/

$$E = 1.85R + 0.245 \qquad (3.21)$$

where E = maximum energy in Mev
R = maximum range in aluminum in mg/cm^2

The results are presented in Table 3.9.

Absorption methods for the determination of beta energies for fission product samples are subject to error due to the presence of a significant amount of gamma activity which overshadows the activity of high energy beta emitters present in the samples. Determination of the range by visual inspection of the curves when gamma backgrounds are present will yield an apparent range which is less than the actual range.

The data indicate that the apparent maximum beta energy of several Shot 1 samples increased from 1.7 Mev to 2.2 - 2.5 Mev during the period from 9 to 70 days after the shot. The Hunter-Ballou curves15/ indicate that 9 days after fission the contributors having the highest energies are La^{140} (1.7 Mev) and Pr^{144} (2.97 Mev). La^{140} contributes 12 per cent and Pr^{144} 0.3 per cent of the total activity at the time. Shot 1 absorption data taken 9 days after the shot indicate the presence of La^{140}. As the time after the detonation increased, the curves indicated that the contribution of Pr^{144} to the total activity increased (i.e., 0.9 per cent and 2.4 per cent at 24 and 70 days

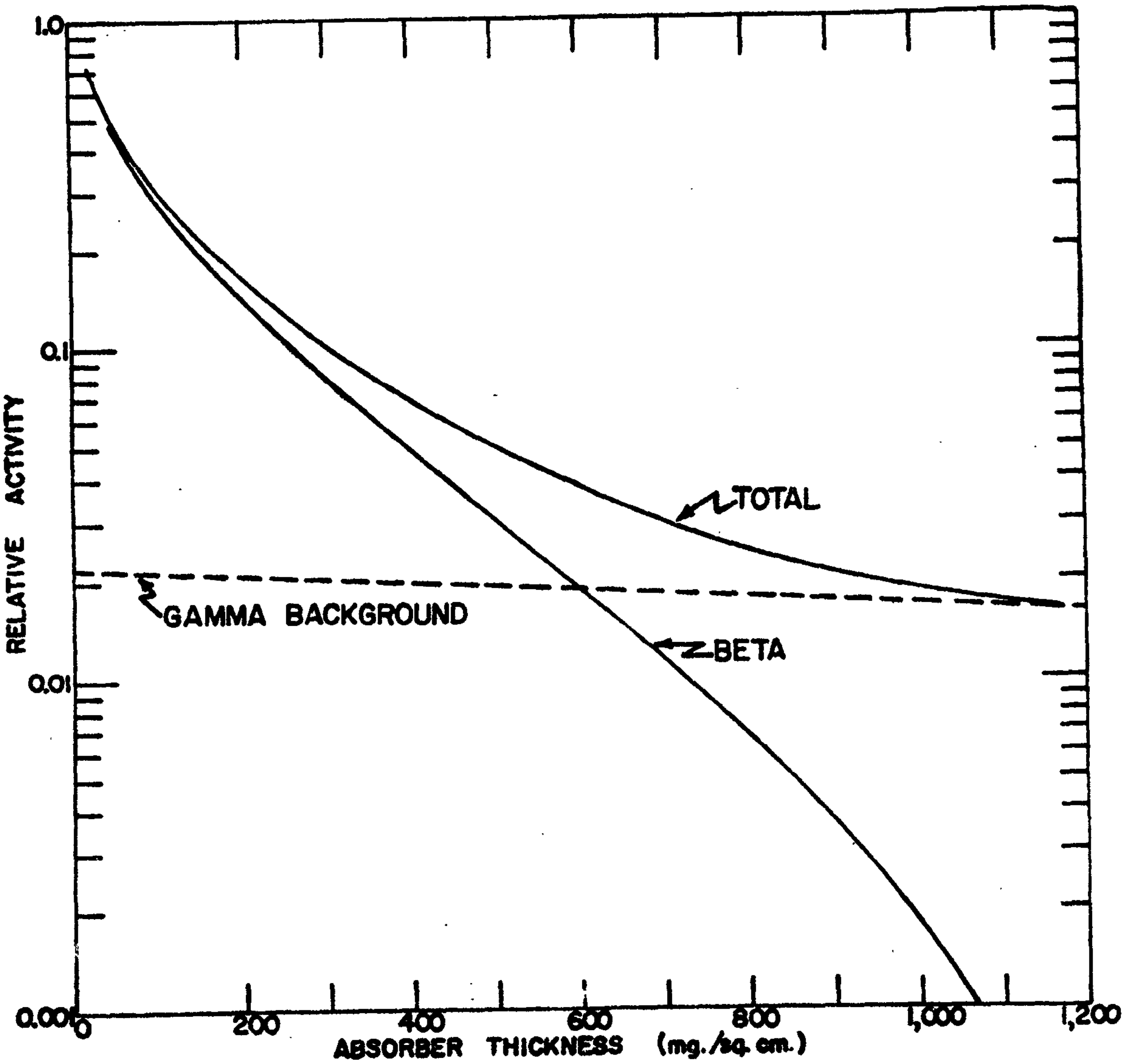


Fig. 3.23 Example of Beta Range Measurement, Shot 1, How 2 - 2½ hr Sample.

respectively.) The increasing contribution of Pr^{144} is reflected in the increase of the maximum energies shown in the tables. Contributions of higher energy isotopes, such as Rh^{106}, during this time are negligible.

Since fission product samples contain many nuclides contributing to the total beta activity of the sample, each of which has its own energy spectrum associated with it, no conclusions should be drawn from these data as to the average beta energies of these samples.

TABLE 3.9 - Beta Range Measurements

Shot	Station and Collection Time Interval		Days After Shot	Range (mg/cm^2)	Energy (Mev)
1	How	½ - 1 hr	9	780	1.7
1	How	½ - 1 hr	50	1170	2.4
1	How	½ - 1 hr	73	1180	2.4
1	How	½ - 1 hr	101	1180	2.4
1	How	2 - 2½ hr	9	780	1.7
1	How	2 - 2½ hr	15	820	1.8
1	How	2 - 2½ hr	25	1080	2.2
1	Nan	1 - 1½ hr	9	780	1.7
1	Nan	1 - 1½ hr	15	840	1.8
1	Nan	1 - 1½ hr	25	1040	2.2
1	Nan	1 - 1½ hr	73	1120	2.3
1	Nan	1 - 1½ hr	101	1200	2.5
3	Uncle	0 - ½ hr	14	940	2.0
4	How	½ - 1 hr	16	800	1.7

3.8 GAMMA ENERGY SPECTRUM

The gamma energy and decay spectrum of a ground sample picked up at George after Shot 4 was investigated with a scintillation spectrometer. Individual isotopes were identified where possible and their activities corrected back to the time of detonation.

Work similar to that done here has been carried out for previous operations by Bouquet et al. 16/ The method assigned the most energetic photopeak to a specific nuclide or gamma ray for which a standard spectrum was available or could be estimated. Since the area under the photopeak is directly proportional to the intensity of the radioactivity, a quantitative measure of the amount of the nuclide of gamma ray present in any sample can be made. By normalizing the standard spectrum of the assigned nuclide or gamma ray to the intensity observed in the fallout sample, its contribution to the total sample spectrum was subtracted. This subtraction exposed the next most energetic photopeak to the same treatment and the cycle was repeated.

3.8.1 Gamma Counting Equipment and Techniques

The sensing element of the scintillation spectrometer was a $1\frac{1}{2}$ in.-diameter, 1-in. thick cylindrical crystal of NaI(Tl). The crystal was mounted with a powdered MgO reflector on the photo-cathode of a selected RCA 5819 photomultiplier tube. The voltage supplying the photomultiplier was well stabilized, being kept constant to a few tenths per cent during a particular run. The output of the photomultiplier was coupled to an Atomic 204-B pulse amplifier. The linear high level output of the amplifier went to an Atomic 510 single channel pulse height analyzer, the outpout of which was recorded with a standard-type scaler. Background was reduced by using a $\frac{1}{2}$ in. lead shield surrounding the NaI(Tl) crystal.

Several grams of fallout, consisting largely of coral-like material, made up the sample to be analyzed. The material was ground to a powder and for the first series of runs a 0.0246 gram sample was used. The sample was placed about 9/16 in. from the face of the NaI(Tl) crystal. There was 1/8 in. of aluminum between the source and crystal to stop the high-energy beta rays coming from some of the decaying isotopes. A channel width of one volt was chosen for the pulse height analyzer as a compromise between good statistics and resolution. Data were obtained by moving the pulse height analyzer in one volt steps over the whole pulse height spectrum, counting for a given length of time at each point. Before each run the pulse height dial of the spectrometer was calibrated for energy using the 0.511 Mev annihilation radiation from the decay of Na^{22} positrons. Data on each run were taken for the above energy scale. In addition, the amplifier gain was increased by a factor of 4 and the spectrum rerun to examine the low energy end of the spectrum. The pulse height spectrum obtained 10 days after shot time is shown in Figs. 3.24 and 3.25.

3.8.2 Procedure Used in Analysis of Curves

Analysis of the experimental data is based on four facts: (1) the gamma decay schemes of most isotopes are known with a reasonable degree of accuracy, (2) the shape of the spectrum for any one isotope remains unchanged for varying amounts of the isotope, (3) the photo-peak of the highest energy gamma in a spectrum is not affected by any other reaction in the crystal, (4) the area of a photo-peak is a valid measure of the amount of the gamma producing that peak. Additional aids in the assignment of specific photo-peaks to individual isotopes were found in decay data from the sample spectra, and the information covering the major contributing fission products at any given time after the fission of U^{235}.15/

The photo-peak and part of the Compton distribution of the 1.6 Mev gamma ray of La^{140} appeared to be uncontaminated by other gamma rays. La^{140} is the 40 hr daughter of 12.8 day Ba^{140}. According to the table of isotopes,17/ these two isotopes have peak gamma rays at 2.51 and 3.00 Mev. The 1.6 Mev photo-peak suggested the possibility of normalizing the known scintillation counter spectrum of Ba^{140} and La^{140} to that of the fallout sample. Then, by point-by-point subtraction of the spectrum, one would remove the effect of the Ba^{140} and

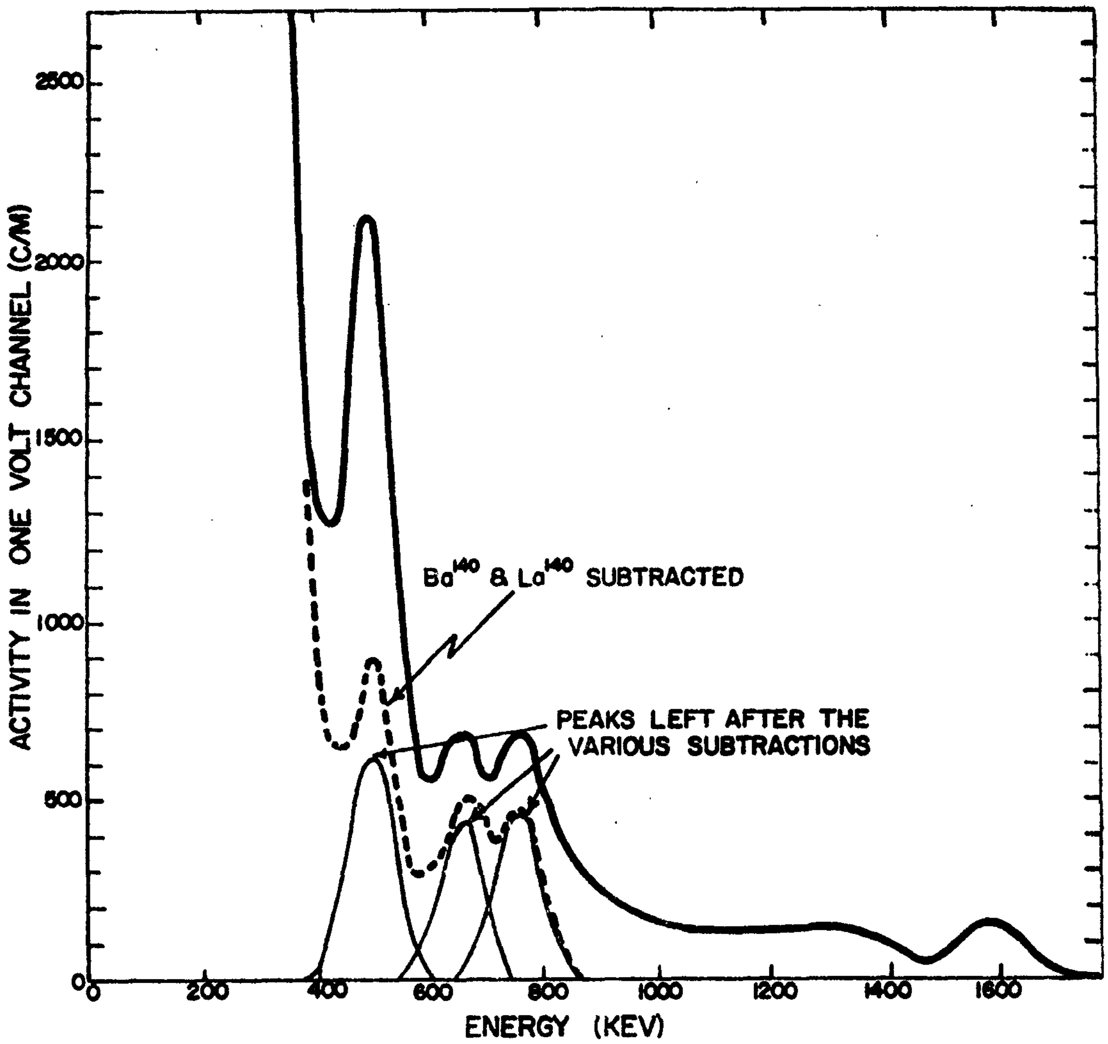


Fig. 3.24 High Energy NaI(Tl) Scintillation Counter Spectrum of 0.0246 g. of Fallout 10 Days after Shot 4.

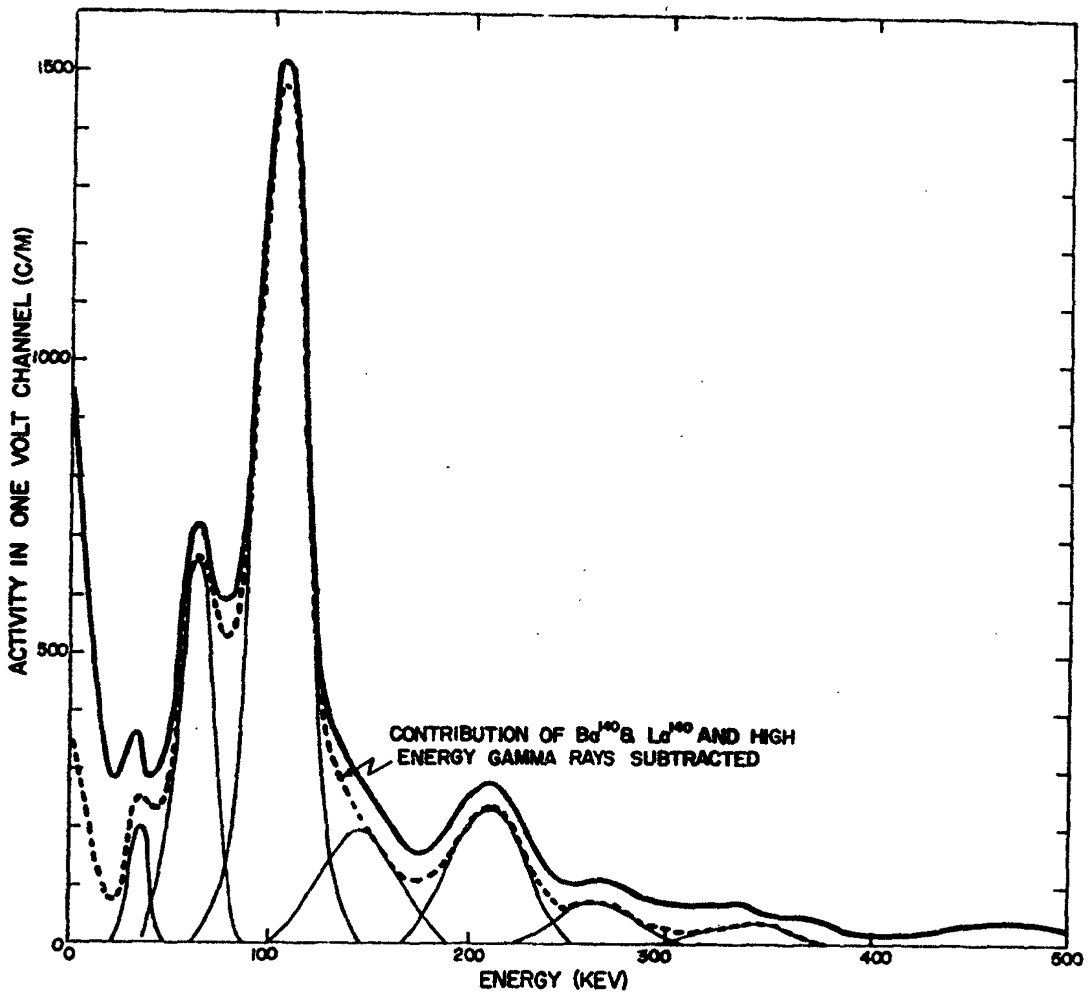


Fig. 3.25 Low Energy NaI(Tl) Scintillation Counter Spectrum of 0.0246 g of Fallout 10 Days after Shot 4

La^{140}.

Accordingly, a chemical separation of Ba^{140} was made from a fallout sample. Nine days after the separation, Ba^{140} had come to transient equilibrium and a scintillation spectrometer pulse-height distribution was obtained. This distribution was used in the analysis of all the fallout spectra.

Upon subtraction of the Ba^{140} and La^{140}, a peak at about 750 kev was found. Since Zr^{95}-Nb^{95} yielded only one major photo-peak at about 750 kev with only an insignificant peak at 235 kev, a standard curve for Zr^{95}-Nb^{95} was obtained and a subtraction procedure similar to that for Ba^{140}-La^{140} was used. Similarly, a peak at 500 kev was found after the subtraction of Ba^{140}-La^{140} and Zr^{95}-Nb^{95}. This peak was assigned to Ru^{103}. A standard curve was also obtained for Ru^{103}. Two standard spectrometer curves at the two amplifier gains used for the fallout spectra were obtained for each of the isotopes mentioned.

At gamma-ray energies of a few hundred kilovolts or more, two pulse-height distributions per gamma ray are obtained, a bell-shaped distribution called a photo-peak and a broad, nearly flat, distribution due to Compton effect. At lower energies the amount of Compton effect becomes increasingly small compared to photo-effect, so that at about 100 kev the Compton effect is negligible. In addition, there are secondary scattering effects which throw counts normally in the Compton distribution into the photo-peak which for low gamma-ray energies results in a great reduction in the theoretical Compton distribution. This effect is illustrated in Fig. 3.26 by the theoretical and experimental curves of the ratio of the photo-peak to total area.

At the low gamma-ray energies the procedure was to work first with the highest energy photo-peak left from the subtraction of known isotopes. The photo-peak was fitted with a Gaussian curve and its area determined. The Compton effect is found from the experimental curve of ratio of photo-peak to total peak. The Compton distribution was then subtracted from the peaks of lower energy and the procedure repeated.

At energies below about 200 kev the photo-peak of the various gamma rays overlapped. As an aid in the subtraction procedure it was assumed that the width of the peaks at one-half maximum followed the $E^{\frac{1}{2}}$ law, 18/ where E is the energy of the gamma ray producing the photo-peak. Thus, three conditions were imposed upon the photo-peaks, (1) all available counts were used, (2) the peaks were Gaussian in shape, and (3) the width of the peak followed the $E^{\frac{1}{2}}$ law.

3.8.3 Detection Efficiency of the Scintillation Spectrometer

Assume that the gamma-ray source emits gamma rays of one energy only. The number, N_t, of these gamma rays detected by the crystal are

$$N_t = N_o e^{-u(E)_{Al} X_{Al}} \left(1 - e^{-u(E)_{NaI} X_{NaI}}\right) \frac{\phi}{4} \qquad (3.22)$$

where N_o = source strength

$u(E)_{Al}$ = energy dependent absorption coefficient of aluminum

X_{Al} = thickness of aluminum which gamma rays must penetrate

$u(E)_{NaI}$ = energy dependent absorption coefficient of NaI

ϕ = effective solid angle the source subtends at the crystal

X_{NaI} = thickness of NaI crystal

if A_{pe} = the area of the photo-peak and A_t = the total area of the pulse height distribution, then the number of counts N_{pe} in the photo-peak will be:

$$N_{pe} = \frac{A_{pe}}{A_t} N_o e^{-u(E)_{Al}X_{Al}}\left(1-e^{-u(E)_{NaI}X_{NaI}}\right)\frac{\phi}{4} \quad (3.23)$$

It is assumed that ϕ is independent of energy which is only true to a good approximation. The absorption in NaI at low energies is much greater than at high energies so that the gamma rays are absorbed largely near the incident face of the crystal. This results in an increased solid angle over that for the higher energies. Tests indicate that this effect is of little importance in the analysis of the present data.

The above formula has been used to determine the relative detection efficiency. Use was made of the experimental A_{pe}/A_t curve. As a partial check, sources of Na^{22} and Cs^{137} were counted in a G-M counter so as to get their relative source strengths. From the known decay schemes the number of gamma rays per beta were determined and an efficiency curve plotted which was in excellent agreement with the above curve.

Absolute calibration of the spectrometer was attempted in order to perform absolute analysis for various isotopes. Products of the slow neutron fission of a U^{235} sample that had been recently irradiated at Brookhaven National Laboratory were available. The neutron flux was known and it was possible to calculate the yield of the various isotopes.

The Project 2.6b report discusses the methods of obtaining Zr^{95}-Nb^{95}, Ce^{141}, and Ce^{144}-Pr^{144} standards from the thermal neutron fission of U^{235}; it also discusses the Zr and Ce calibration procedure.12/ The samples were mounted under the same conditions as the fallout samples (described in Sec. 3.2) and gamma spectra were taken for the known sources. The gamma rays of Zr^{95} are 730 kev, those of Ce^{141} are 145 kev, and Ce^{144} are 134 kev. The Ce gamma rays were predominantly due to Ce^{141} as it has a 33-day half life compared with 282 days for Ce^{144}. To determine the amount of Ce^{141} present, use was made of the known U^{235} fission yields of 5.7 percent for Ce^{141} and 5.3 percent for Ce^{144}. 19/

Experimentally the intensity of a given gamma ray was determined through the area of its photo-peak. The abscissa of the curve is in volts and the ordinate in counts per minute so that the area of the photo-peak is in the units of count-volts per minute. To obtain the correction factor for converting count-volts per minute to gamma

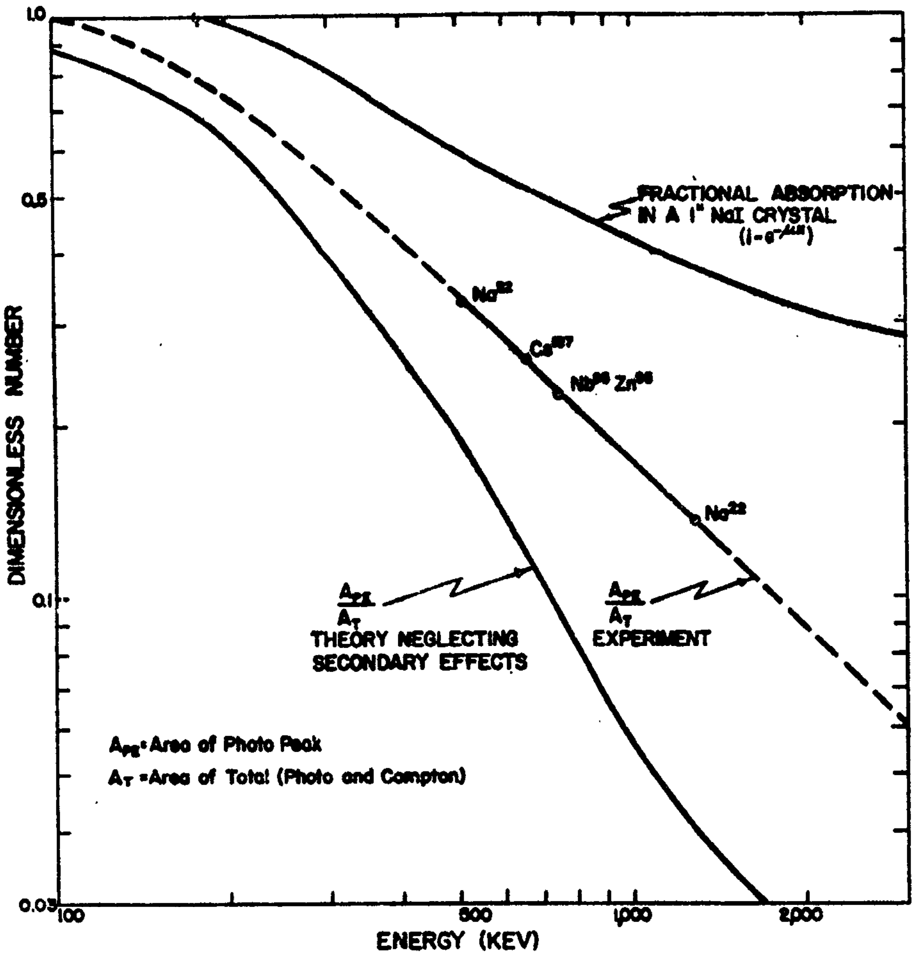


Fig. 3.26 Theoretical and Experimental Ratios of the Area of the Photopeak to Total Area and Fractional Absorption in a 1-in. NaI Crystal

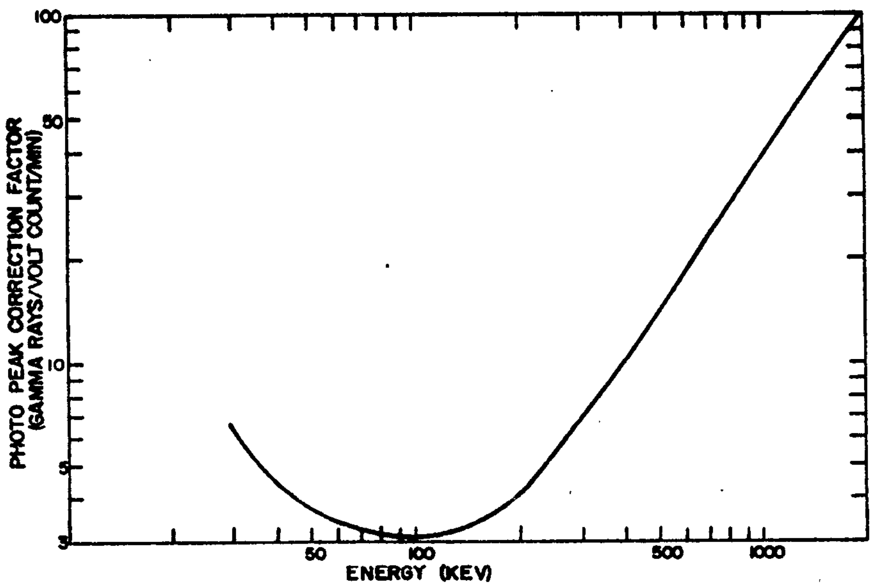


Fig. 3.27 Factor to Convert Area of Photopeak in Gamma Rays/Volt Count/min into Number of Gamma Rays/min

rays per minute the reciprocal of the efficiency was employed and put on an absolute basis with the Ce-and-Zr data. For the geometry used in this work Ce gave 3.70 gamma rays per volt count per min at 145 kev and Zr 23.6 gamma rays per volt count per minute at 730 kev. The curve shown in Fig. 3.27 was normalized to these values.

3.8.4 Results

The area of the photo-peaks of the various gamma rays was plotted as a function of time on semi-log paper and extrapolated back to shot time. Figure 3.28 shows such a curve for the decay of the 1600-kev gamma ray in La^{140}. The slope of the curve is in excellent agreement with the accepted value of the parent Ba^{140}. The decay schemes of Ba^{140} and La^{140} are known, which enabled the gamma contribution of the other gamma rays from the 1600-kev peak to be calculated (Table 3.10).

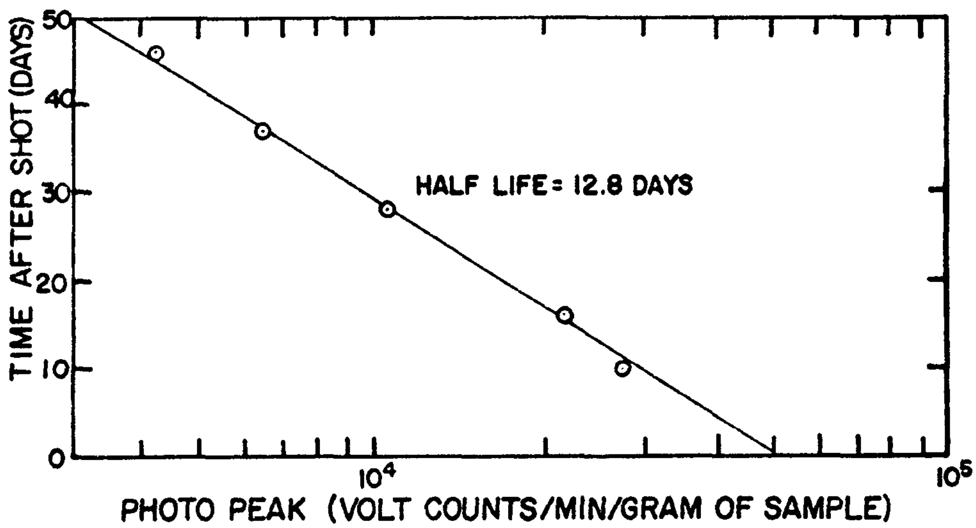


Fig. 3.28 The La^{140} 1.6 Mev Photopeak as a Function of Time

The experimental results are given in Table 3.11. The results are recorded as the number of gamma rays per minute per gram of fall-out. The quoted errors represent the reproducibility of the method or the precision with which the intensity of a particular gamma ray is known in the sample. These errors were judged from the fit of the experimental decay points to the best straight line represented by the points. No estimate is made of the absolute accuracy of the data. However, when varying mixtures of Zr^{95}-Nb^{95}, Ba^{140}-La^{140}, and Ce^{144} - Pr^{144} were synthesized and analyzed by the technique, the maximum error between the actual composition and the gamma spectral analysis

TABLE 3.10 - Derived Values from Known Intensity Ratio of 1600 kev Gamma Ray in La^{140} to the Other Gamma Rays in La^{140} and Ba^{140}*

Isotope	Energy (kev)	Gamma Activity at Time of Shot 10^6 Gamma Rays/min/gm
From La^{140}	335	0.195 ± 0.015
"	490	1.4 ± 0.12
"	820	1.0 ± 0.09
"	2510	0.195 ± 0.015
From Ba^{140}	30	4.0 ± 0.3
"	162	2.4 ± 0.2
"	304	0.51 ± 0.03
"	537	1.2 ± 0.1

*$La^{140}Ba^{140}$ are assumed to be in secular equilibrium with a half-life of 12.8 days.

TABLE 3.11 - Important Gamma Contributors to Shot 4 Activity*

Gamma Ray Energy (kev)	Half-Life Days	Gamma Activity at Time of Shot 10^6 Gamma Rays min/gm	Possible Isotope
35 and 64**	8	9.3 ± 0.9	Not identified
104	5	40 ± 3	U^{237} and Np^{239}
145	6	11.4 ± 1.0	Not identified
145	33	0.095 ± 0.05	Ce^{141}
209	5.5	13 ± 3	U^{237} and Np^{239}
264	5	6 ± 3	U^{237} and Np^{239}
340	6	3.8 ± 1.1	U^{237} and Np^{239}
500	11	2.4 ± 0.5	Nd^{147} ?
500	40	0.25 ± 0.05	Ru^{103}
700	4	8.1 ± 1.4	Not identified
750	7	3.9 ± 0.3	Not identified
750	35	0.57 ± 0.23	Not identified
1600	12.8	3.6 ± 0.3	La^{140}

* At times greater than 10 days after the shot
** Combined

was only 5.8 per cent. This correlation was maintained even when the relative concentration of the nuclides were changed by a factor of 20. Subsequent analysis of the fallout from TEAPOT indicate a variation of less than 14 per cent between a radiochemical separation of Ba^{140} - La^{140} and the gamma spectral analyses.

The peak at 750 kev remaining after subtraction of Ba and La decayed as if an isotope of 7-day half-life and an isotope of 35-day half-life were present. Both activities are unassigned.

The peak at 500 kev left after subtracting the contributions due to the higher-energy gamma rays decayed with half lives of 11 and 40 days. These activities are assigned to $Nd^{147}$and Ru^{103}.

At low energies, peaks were found at 104, 209, 264, and 340 kev, decaying with an average half-life of about 5.5 days. These gamma rays are believed due to the combined effects of 6.7-day U^{237} and 2.3-day Np^{239}. The predominant peak at 104 kev is due to the 105-kev gamma ray reported for Np^{239} and to the x-rays following the internal conversion of a gamma ray of 207-kev in U^{237}. Unfortunately, data earlier than 10 days were not available and the data covering the period 10 to 40 days were not extensive enough to permit the separation of the two isotopes. Because of the 29-kev energy difference and about equal decay half lives, the peak at 35 kev is believed to be the iodine x-ray escape peak of the 64-kev gamma ray. Also, the related number of counts in the two peaks is in agreement with that expected from the theoretical calculations of Axel.20/ These calculations predicate a ratio of escape to non-escape of 0.14 compared with the present result of 0.15.

Below the 35-kev peak there is seen a sharp rise in the pulse-height distribution. These counts are believed to be due to the Bremsstrahlung radiation formed in stopping high-energy beta particles. Since the beta rays were stopped in aluminum rather than in some more dense material the number was kept to a minimum. The actual amount formed has not been evaluated.

This work indicates that, within limitations, isotopic analysis can be carried out on fallout through a study of the gamma-ray spectrum. In future work, use should be made of the fact that short lived isotopes almost invariably emit the higher-energy gamma rays. For instance, Na^{24}, which is produced in large quantities in a nuclear detonation near sea water, has a 2.76 kev gamma ray and 15-hr half life. At a time of about one day after the shot this is the only gamma ray of appreciable intensity in this energy region. About ten days after a shot, Ba^{140} and La^{140} are in transient-equilibrium. La^{140} emits a 1.6-Mev gamma which is the only gamma ray in that energy region at that time after the shot. At a period of about 60 days after a shot, Zr^{95} may be analyzed with a gamma ray at 730 kev. Also, at this time, an analysis can be made of Ru^{103} with a gamma energy of 498 kev by subtraction procedures.

The external radiation hazard, (gamma dose rate) is an energy dependent phenomenon, with the effects of gamma rays increasing as the energy increases. Analysis of the gamma spectrum of fallout used in conjunction with the known decay schemes of the individual isotopes could yield data showing the contribution of the gamma dose rate from all isotopes of any consequence in fallout. Not enough isotopes were analyzed here to perform such an analysis.

3.9 RADIOACTIVE PARTICLE SIZE ANALYSIS

The dried samples from all trays of each collector were combined, weighed, and then sieved through a 44-μ sieve. The weight of each fraction was determined and a weighed portion of each fraction was used for radioautography.

These fractions were washed from the weighing dishes with toluene onto the backside of Eastman NTB stripping film which was previously mounted on 4-in. plastic rings. The transfer was done in dim light. Canada balsam, which was added before the toluene evaporated to form a uniform adhesive medium for the particles, did not interfere with microscopic observation. The celluloid backing separated the particles from the emulsion so that during processing the particle medium was not disturbed (Fig. 3.29). The NTB film has a 10-μ thick emulsion and a 7-μ thick backing.

The radioautographs were exposed for the empirically determined time of 15 hr for samples measuring 100,000 cpm, 25 hr for samples counting 50,000 cpm, 60 hr for 25,000 cpm, etc. All exposures were started 6 to 9 days after each shot. The radioautographs were developed in Eastman Kodak D-19 Developer for 5 min at 20° C., then rinsed and fixed for 10 min. All developing operations were done without disturbing the particle medium. The particles were projected at a magnification of 1000 times with a micro-projector which consisted of a Bausch and Lomb research microscope mounted on a micro-projector base with carbon arc illumination. The particle images were projected at a magnification of 1000X. Radioactive particles only were measured. The limitations of the optical microscope precluded the observation of particles below about 1 μ.

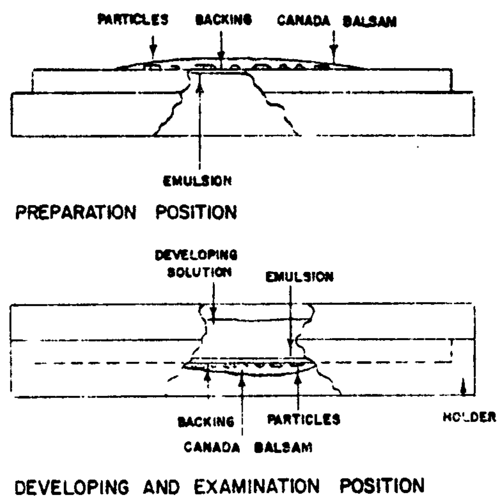


Fig. 3.29 Preparation of Particle Medium; Developing and Examination Position of Stripping Film

The number median diameter (NMD), geometric standard deviation (σ_g), and average diameter (D_{avg}) were obtained for each sample analyzed.

The NMD is defined as that size such that 50 per cent of the number of the particles are smaller and 50 per cent are larger than the stated size. The value is obtained by interpolation of two values bracketing the 50 per cent line on a cumulative graph of number distribution.

The geometric standard deviation (σ_g) is a measure of the degree of homogeneity of the sample. It is defined by either of the following relationships.21/

$$\sigma_g = \frac{\text{cumulative 84.14 percent particle size on log-probability plot}}{\text{cumulative 50 percent particle size on log-probability plot}} \quad (3.24)$$

$$\sigma_g = \frac{\text{cumulative 50 percent particle size on log-probability plot}}{\text{cumulative 15.87 percent particle size on log-probability plot}} \quad (3.25)$$

The range from 15.87 percent to 84.13 percent is one standard deviation. σ_g may theoretically be any value from 1 to infinity. Values near 1 indicate a homogeneous sample. As the value increases, samples are indicated as being more hetrogeneous. In practice, values rarely are higher than 4 to 6 for field samples. 22/

The average diameter $D_{avg} = \frac{\sum D_n}{\sum n}$ (3.26)

where $\sum D_n$ is the sum of the diameter of all of the particles

$\sum n$ is the sum of the number of particles

Particles as large as 3000 μ were found during the analysis. The procedure of separating each sample into two fractions eliminated the requirement of a common exposure time for both small and large particles and the smaller particles were more easily distinguished than they would be in an unfractionated sample. Since a gross particle size distribution was not made, the data from both fractions of each sample could not be recombined to give one NMD for each station. However, the number of particles in the larger fraction was found by microscopic examination to be only a small percentage of the number of particles in the gross sample; hence, the small fraction NMD would not be raised by any great extent, if it had been possible to combine the two fractions. Thus, the NMD of the small fraction may be considered to be the approximate NMD of the entire sample. It should be pointed out that the use of sieves in fractionating particles may have some tendency to break up agglomerated particles into their smaller components, although some experimental evidence indicates that this effect is minor. Particle size results are presented in Tables 3.12 and 3.13 and are summarized as follows:

SHOT 1: The NMD of the small fraction ranged from 5 to 17.5μ. The NMD of the large fraction ranged from 61 to 118μ.

TABLE 3.12 - Shot 1, Radioactive Particle Analysis Results

Station	Time Duration (hr)	Under 44 µ			Over 44 µ		
		NMD	σ_g	D_{avg}	NMD	σ_g	D_{avg}
Dog	0.4	14.5	1.76	17.0	94	2.35	153
Dog	12	13.3	2.56	16.1	80	2.38	123
Easy	2	16.1	2.24	19.0	81	3.21	170
Easy	12	13.8	2.38	16.4	85	2.13	131
George	2	15.0	2.53	17.9	111	1.78	143
George	12				112	1.96	144
How	2	16.5	2.79	18.9	84	2.02	120
How	12	16.5	2.12	18.7	94	2.66	196
Nan	2	5.2	2.54	8.0	108	2.69	186
Nan	12	17.0	2.09	19.1	118	2.20	170
Oboe	2	10.8	3.33	14.8	81	3.40	186
Oboe	12	13.1	2.06	15.8	105	3.52	182
Uncle	2	8.4	2.50	11.9	94	2.98	184
Uncle	12	8.0	2.94	12.4	66	1.98	96
Victor	2	Insufficient Sample			73	2.41	121
Victor	12	5.0	2.00	6.6	63	1.75	80
William	2	12.0	2.58	16.7	61	2.62	116
Yoke	2	10.8	2.13	13.9	Insufficient Sample		
Yoke	12	11.5	3.16	15.0	86	1.75	110
Zebra	2	12.5	2.32	15.1	Insufficient Sample		
Zebra	12	10.7	2.66	14.1	70	2.70	182
Alpha	12	9.7	2.27	13.3	74	2.23	186
Bravo	2	13.2	2.88	17.3	112	1.88	146
Bravo	12	11.8	2.12	14.8	Analytical Sample Broken		
Raft 250.05	12	11.5	2.70	16.0	117	1.75	171
Raft 250.12	12	14.7	2.11	17.9	100	2.30	149
Average	2	12.5	2.58	15.4	89	2.55	152
Average	12	10.9	2.39	15.1	90	2.25	149

SHOT 2 Only one station, George, collected enough fallout to be analyzed. The small fraction NMD's were 12.6 and 10.7 μ for the 2-hr and 12-hr collectors, respectively. Not enough of the large fraction sample was collected to be analyzed. It appears (Sect. 3.3.2) that these particles were largely remains of Shot 1 fallout which had been redistributed during Shot 2.
SHOT 3 The small fraction NMD's ranged from 9.4 μ to 20.0 μ; large fractions varied from 77 μ to 127 μ.
SHOTS 4 AND 6 Not enough radioactive material was collected from these two shots to be analyzed for particle size distribution.

There was not enough fallout material in each collector interval for a meaningful analysis; so the fallout from all intervals in each collector was mixed together and analyzed. The only timing intervals which can be compared are the entire cycling times of each collector. On the basis of these cycles (2-hr and 12-hr) there is no trend of particle size with time after shot, within the limits of sampling time. Neither is there a trend of particle size with distance or direction from ground zero within the limits of the area covered by the collectors.

The behavior of the cloud, which is discussed in Section 3.4.2, is believed to account for the lack of trends of particle-size data. The particle-size data obtained indicates that the Shot 1 cloud and the Shot 3 cloud particles were both fairly homogeneous within the limits of the area sampled. Lack of data from Shots 2,4, and 6 preclude any statements about the particle size distribution characteristics from these shots.

A difference was noted between the radioactive particle-size distributions of Shot 1 and those of Shot 3. The samples collected from Shot 1 were found to have 20 per cent of the particles under 5 μ, which was 2½ times as many as those collected from Shot 3 (Table 3.14).

TABLE 3.13 - Shots 2 and 3 Radioactive Particle Analysis Results

Shot	Station	Time Duration (hr)	Under 44 μ			Over 44 μ		
			NMD μ	σ_g	D_{avg} μ	NMD μ	σ_g	D_{avg} μ
2	George*	2	12.6	1.83	15.1	Insufficient		Sample
2	George*	12	10.7	2.00	13.2	"		"
3	Easy	2	17.5	1.77	19.4	101	1.57	125
3	Easy	12	9.4	2.02	12.3	112	1.47	141
3	George	2	16.8	2.01	19.9	107	1.69	140
3	Uncle	0.4	11.8	1.82	14.9	127	1.77	160
3	Uncle	12	16.7	1.98	17.4	118	1.64	145
3	Victor	2	20.0	2.10	21.5	95	1.49	111
3	Zebra	2	13.0	2.00	16.2	95	1.65	115
3	Zebra	12	12.7	1.93	15.7	77	2.66	138
3	Average	2	15.8	1.97	19.0	105	1.60	123
3	Average	12	12.9	1.98	15.1	102	1.92	106

* These particles probably originated at Shot 1 and were redistributed by Shot 2

TABLE 3.14 - Averages of Cumulative Per Cent of Radioactive Particles Under Stated Size Ranges

Shot	Under 5 μ	Under 10 μ	Under 20 μ
1	20	43	74
3	8.8	31	68

The Shot 1 particles were also found to have 43 per cent of the particles under 10 μ, which was about 1½ times as many particles in the same size range as those collected from Shot 3. However, the percentage of particles under 20 μ was approximately the same (about 70 per cent) in the samples collected from both shots. Apparently, Shot 1 produced a larger percentage of particles under 5 μ and 10 μ than did Shot 3. The size range under 5 μ is the range of particles which is most likely to be deposited at some point in the respiratory system, 1/ except for particles below 0.1 μ or 0.2 μ, which tend to be exhaled. 23/ These results also indicate that Shot 1 particles would be harder to decontaminate than particles from Shot 3. The Shot 1 percentages are higher than those that have been found at previous tests and may be due to improvements in analytical technique, but it is felt that the difference in the results is more likely to be due to the differences of the particle characteristics themselves.

3.9.1 Activity in Size-Fractionated Particles.

The percentage of total activity of each fraction of a size fractionated sample, which was collected from How Island after Shot 1, was determined by Project 2.6b. 12/ It should be pointed out that these particles were primarily fractionated for radiochemical analysis. Particles below 44 μ were separated by a roller analyzer so some agglomerates were probably broken up. The particles above 44 μ were fractionated by sieves so fewer agglomerates were probably broken up. Table 3.15 presents data which is a by product of the radiochemical analysis procedures. The per cent of total activity in the two smallest fractions is about 23.4 per cent of the activity found in the entire sample and second only to the activity in the largest fraction (32.9 per cent). The activity in these two smallest fractions would constitute the principal pulmonary hazard in this fallout. However, the internal hazard caused by these particles is almost always overshadowed by the external radiation hazard existing in the same region and so the internal respiratory hazard may be relatively unimportant. It should also be pointed out that these results are based mostly on activity which has condensed or become connected to Pacific Island coral or sand particles and the results may not be applicable to other types of environment. Activity information for each of several isotopes in each fraction are presented in the Project 2.6b report.

TABLE 3.15 - Per Cent of Total Activity of Shot 1 Size Graded Samples from How Island*

NMD of Fraction μ**	Weight (gm)	Per Cent of Total Weight ***	Total Activity of Fraction in Arbitrary Units at D+ 7 Days	Per Cent of Total Activity in Fraction
1.1	2.901	9.47	7.31	17.8
3.2	0.975	3.19	2.29	5.59
22	0.112	0.366	0.323	0.788
27	0.923	3.02	2.45	5.98
38	0.597	1.95	1.96	4.78
56	1.031	3.36	3.22	7.86
69	0.400	1.71	1.16	2.83
79	0.522	1.31	1.30	3.17
98	0.408	1.33	0.950	2.32
103	0.646	2.11	1.45	3.54
160	0.691	2.26	1.56	3.81
171	0.757	2.47	1.58	3.86
195	0.983	3.21	1.98	4.83
>225	19.662	64.20	13.5	32.9
TOTAL	30.608	100	41.0	100

* Project 2.6b results 12/

** Project 2.6b reports the fractions as the mean volume diameter of the particles, not as the number mean diameter

*** Both radioactive and non-radioactive particles in the fraction

3.10 PARTICLE CHARACTERISTICS

The average density of all particles was about 2.6 g/cc. The index of refraction of all Shot 1 particles was about 1.544.

The fallout material from Shots 1, 2, and 3, which remained after the removal of samples for particle-size analysis, were mixed and sieved through 420, 210, 149, 105, 74 and 44 micron sieves. (Not enough fallout was collected from Shots 4 and 6 to make these analyses). Each fraction from each shot was separated into two groups.

3.10.1 Particle Appearance

The particles from one group were radioautographed for the minimum practicable length of time. Those which were found to be radioactive were classified according to appearance. The results are presented in Table 3.16. Representative particles are illustrated in Figures 3.30 to 3.36. The large particles from Shots 1 and 2 appeared to be coral, whereas the smaller particles had a more crystal-like appearance. Fallout from Shot 3 had a smaller percentage of coral particles, most of which were in the larger size ranges; the remaining particles had a fuzed, porous, or ashlike appearance.

3.10.2 Location of Activity in the Particle.

The particles from the second group were treated by the method employed by Cadle[24] to determine their internal activity distribution. This process could not resolve the location of activity on particles below 149 μ. These data are presented in Table 3.17 and selected radioautographs are illustrated in Figures 3.37 through 3.39. Activity on the Shot 1 particles was on the surface in 60 to 70 per cent of the number examined, evenly distributed throughout 21 to 36 per cent of the particles and unevenly distributed throughout 1 to 8 per cent of the particles examined. The activity on the outside of the Shot 3 particles varied from 32 to 97 per cent. Uniformly radioactive particles varied from 3 to 55 per cent and activity was unevenly distributed in zero to 13 per cent of the particles. The percentage of particles with activity on the outside generally increased directly with size, while the percentage of uniformly radioactive particles generally decreased with size. No trends were noted in the small group where the activity was scattered randomly throughout the particle.

There was no apparent correlation between the location of activity on the particles and their physical appearance.

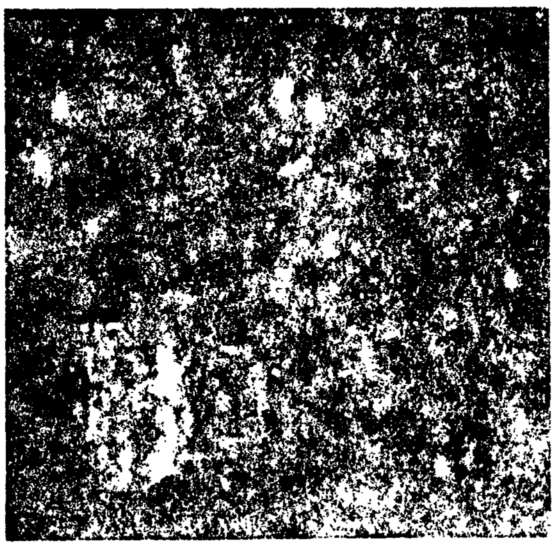


Fig. 3.30 Shot 1 Transparent Crystalline Particle 49-149 μ.

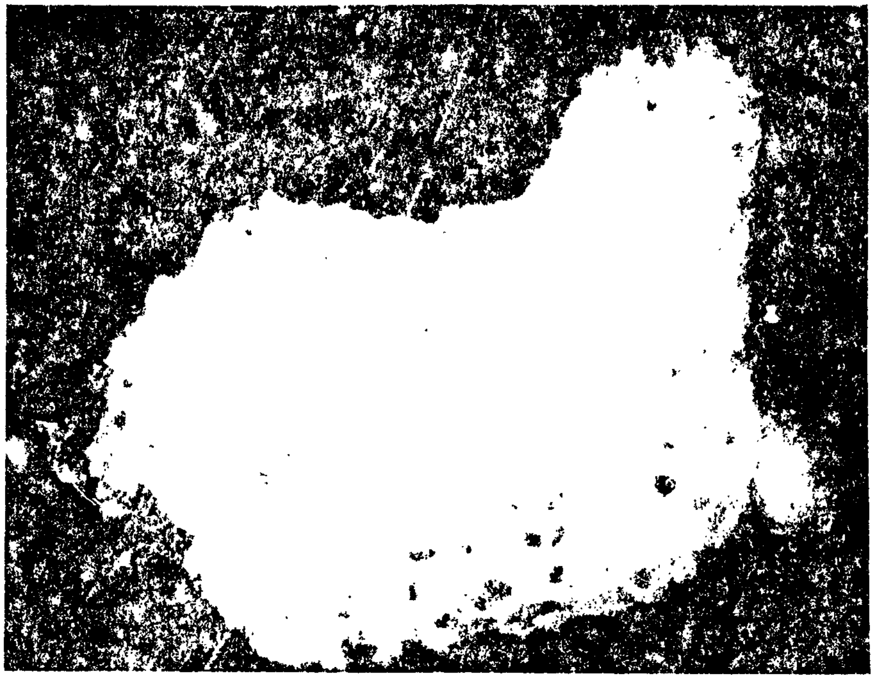


Fig. 3.31 Shot 1 Milky Translucent Particle 149-210 μ.

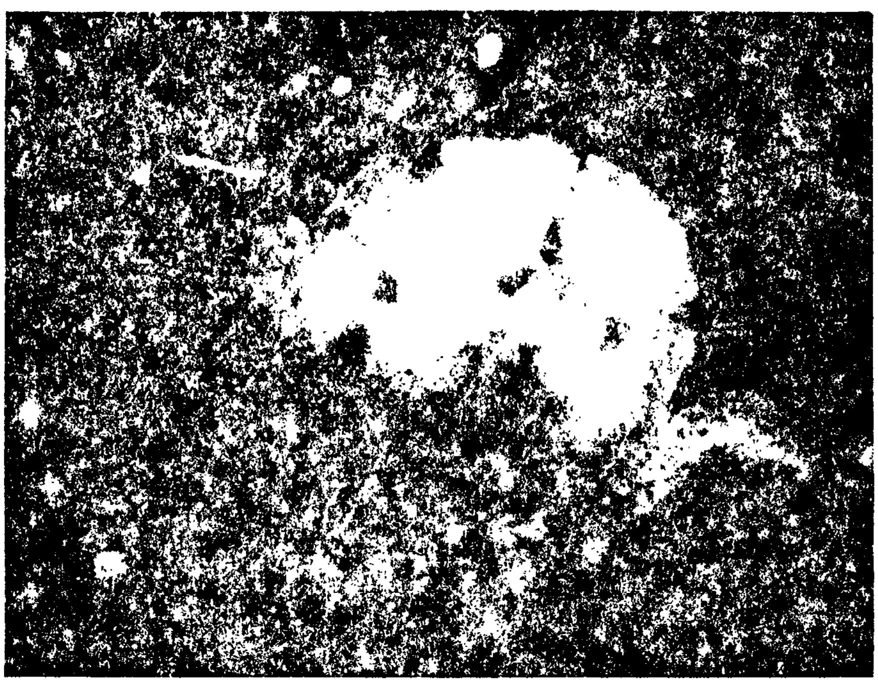


Fig. 3.32 Shot 1 Coral Particle 420-1000 μ.

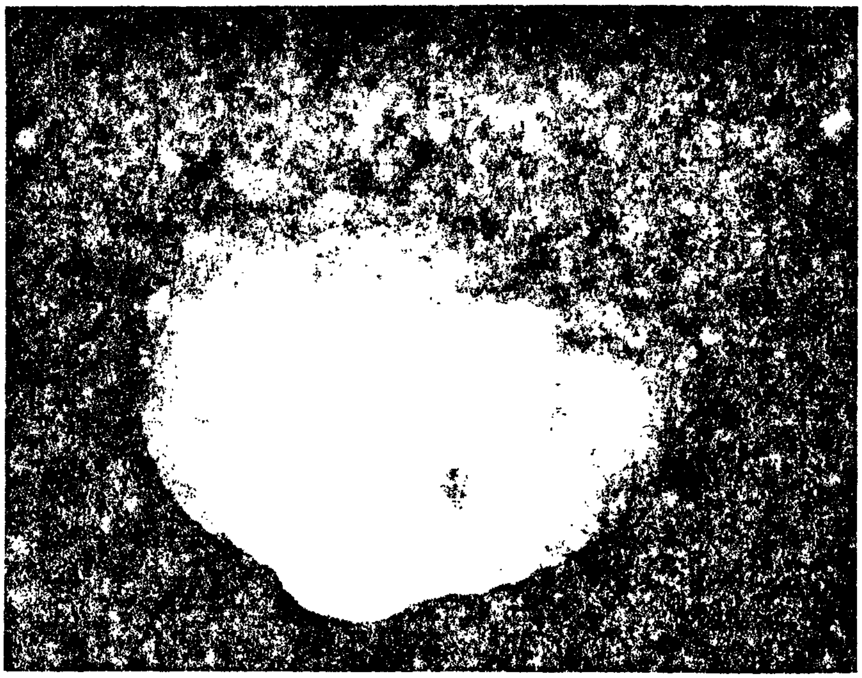


Fig. 3.33 Shot 3 Translucent Fused Particle 49-149 μ.

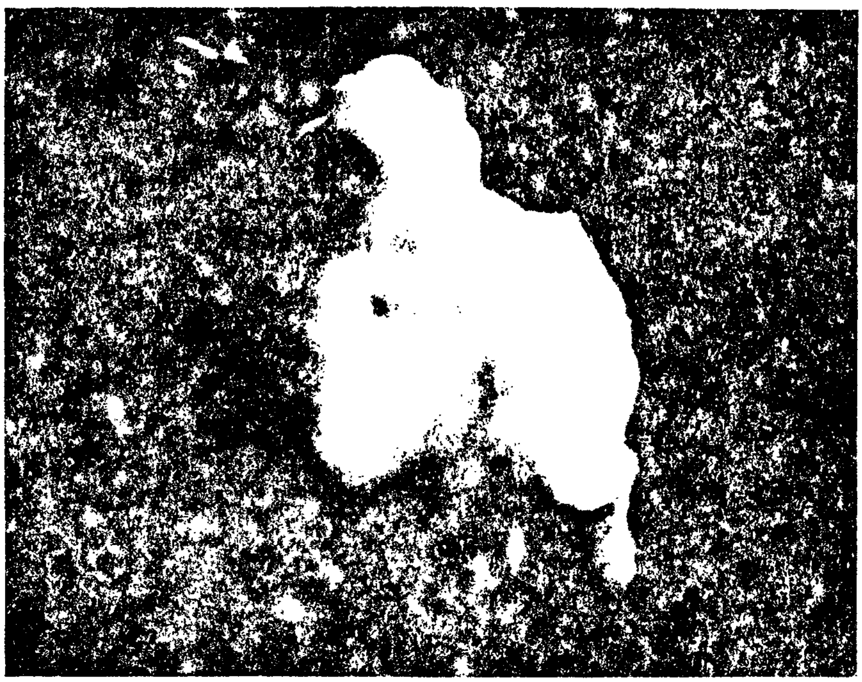


Fig. 3.34 Shot 3 White Fused Particle 210-420 μ.

Fig. 3.35 Shot 3, Grey, Ashlike, Irregular, and Porous Particle 210-420 μ.

Fig. 3.36 Shot 3, White, Opaque, Porous, Irregular Particle 420-1000 μ,

TABLE 3.16 - Particle Appearance

Shot	Fraction (μ)	White, Opaque, Irregular Porous (Coral)	White, Opaque, Irregular Fused	Milky, Translucent Crystalline	Crustaceous (Shell-like)	Grey, Ashlike, Irregular, Porous	White, Fused	Pink, Porous, Opaque, Irregular (Very radioactive)	White, Porous, Opaque, Irregular	Red, Grey, and Brown Ash	Black, Fused, Irregular	Fused, Glassy, Translucent to Brown	Translucent, Fused	Transparent, Crystalline	White, Crystalline	Coral, (Grey Streaked)
		Percent of Total No. Observed in Each Fraction for Various Particle Types														
1	420 - 1000	100														
	210 - 420	80	5	15												
	149 - 210	35		65												
	44 - 149	25		25										50		
2*	420 - 1000	100														
	210 - 420	100														
	149 - 210	65														
	44 - 149	15		85											35	
3	420 - 1000	33			18	15	7									
	210 - 420							40	35	25						25
	149 - 210							28	23	30	22	17				
	44 - 149						20	8	9	15	3		45			

* Some and perhaps most of these particles originated from Shot 1 and were redistributed by Shot 2

TABLE 3.17 - Activity Distribution Within Individual Particles

Shot	Size Range (μ)	Number of Particles Examined	Total Number of Particles with Activity on the Surface (pct)	Total Number Particles With Activity Evenly Distributed Throughout Particles (pct)	Total Number Particles With Activity Scattered Throughout the Particle(%)
1	420-1000	95	70	28	1
	210-420	144	69	21	8
	149-210	327	60	36	4
	49-149		Indistinguishable		
2*	420-1000	113	67	20	12
	210-420	75	53	36	11
	149-210	75	20	80	
	44-149		Indistinguishable		
3 (dry sample)	420-1000	62	87		13
	210-420	33	97	3	
	149-210	80	60	40	
	44-149		Indistinguishable		
3 (wet sample which was dried)	420-1000	85	85	5	11
	210-420	53	53	40	7
	149-210	44	32	55	13
	44-149		Indistinguishable		

* Some and perhaps most of these particles probably originated from Shot 1 and were redistributed by Shot 2

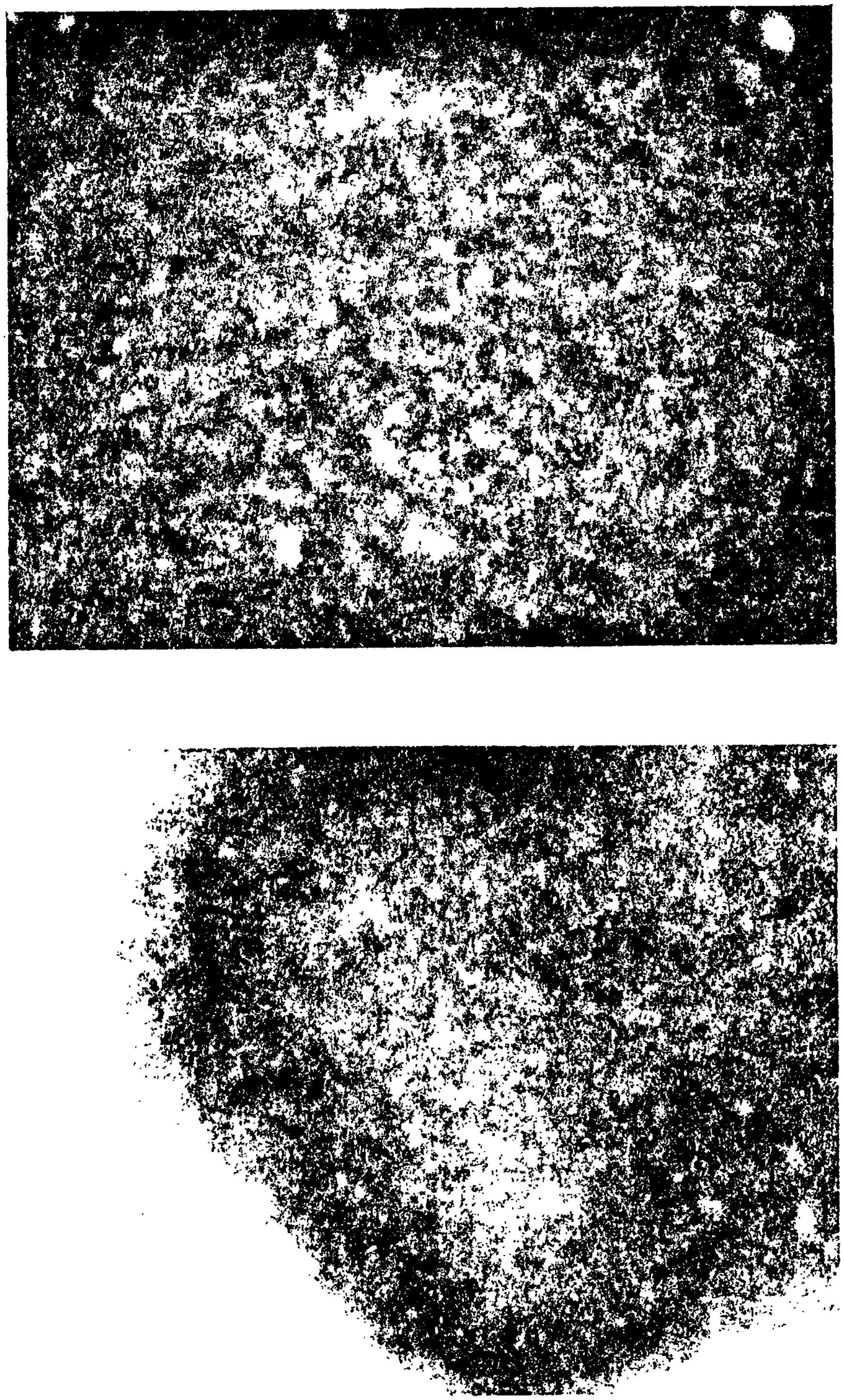
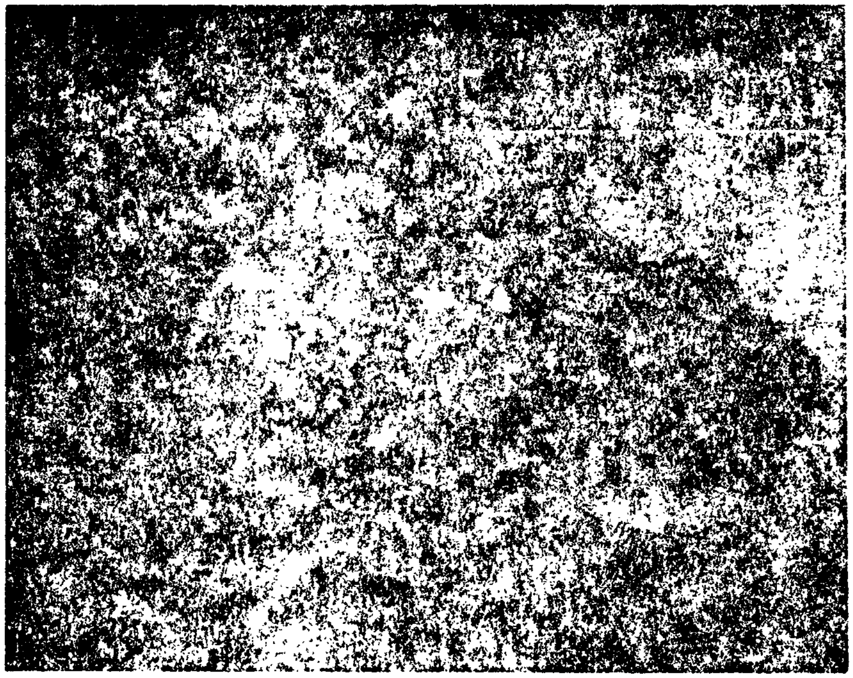


Fig. 3.37 Example of a Sliced Particle with Activity only on the Outside. The particle is at the top and its radioautograph at the bottom.



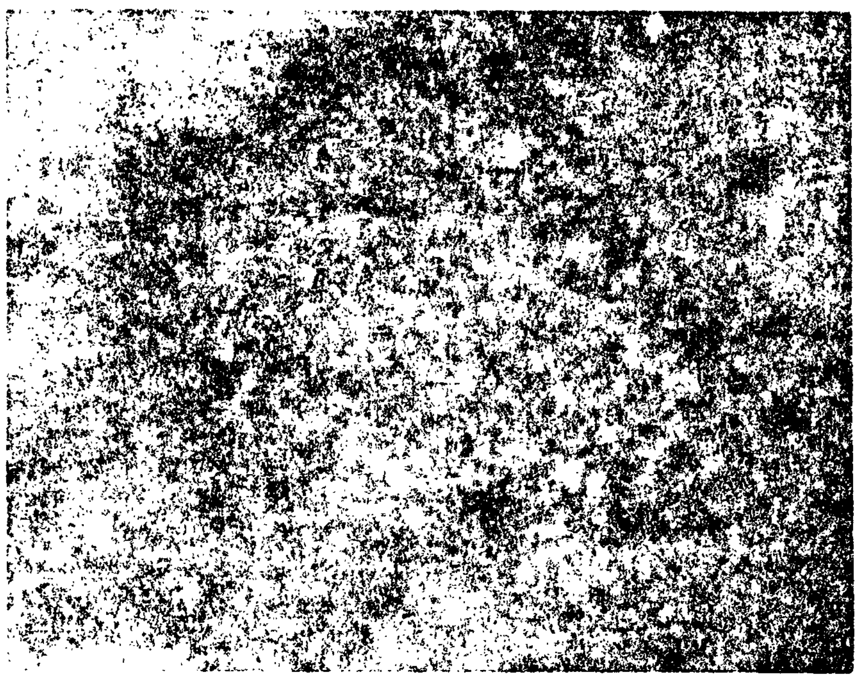


Fig. 3.38 Example of a Sliced Particle with Activity Distributed Irregularly Throughout it. The particle is at the top and its radioautograph at the bottom.

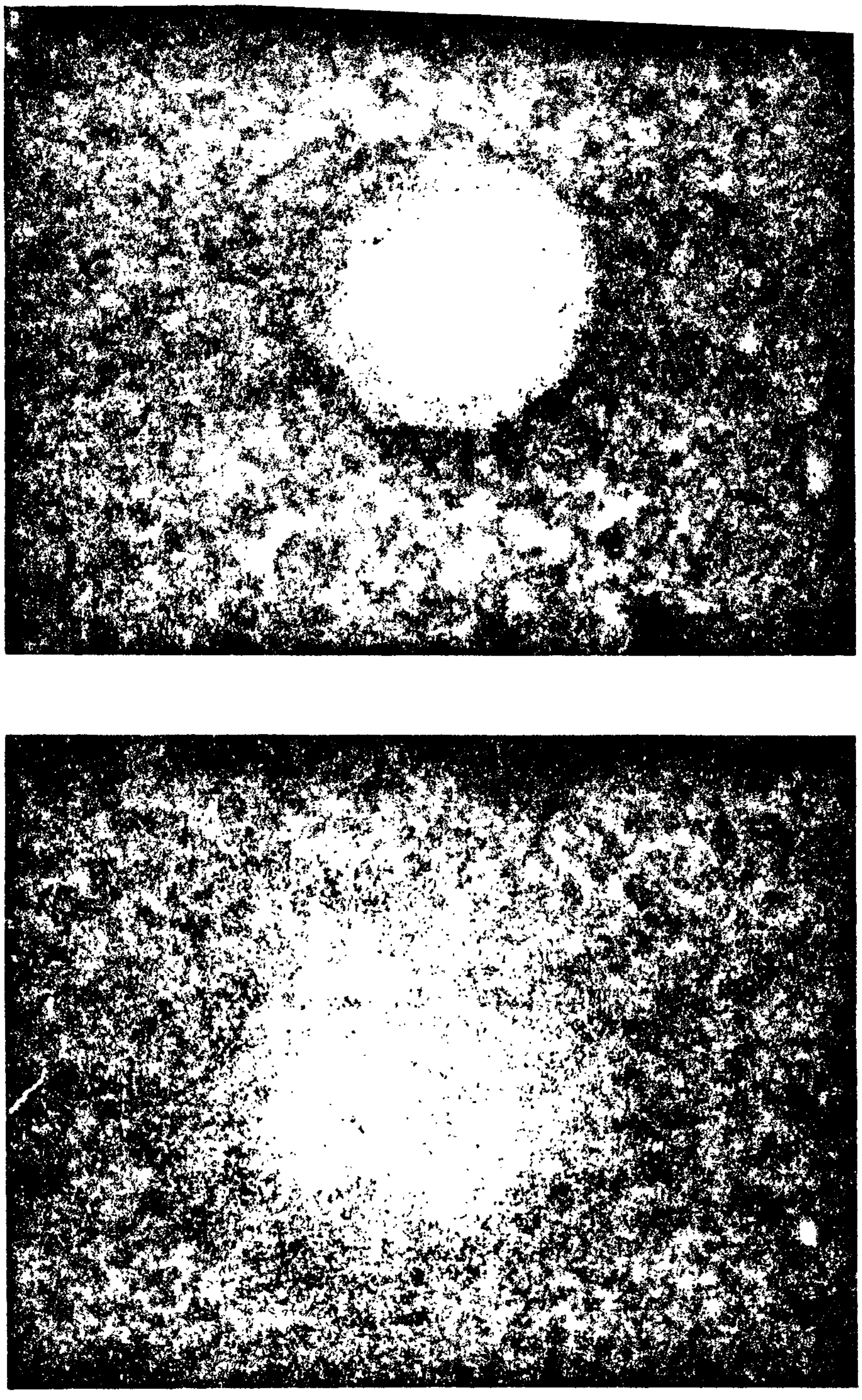


Fig. 3.39 Example of a Sliced Particle which was Uniformly Radioactive. The particle is at the top and its radioautograph at the bottom.

CHAPTER 4

CONCLUSIONS AND RECOMMENDATIONS

In order to completely document the hazardous fallout activity resulting from the fission products and uranium neutron capture products on Operation CASTLE, one would have had to anticipate the widespread contamination that was produced. The scope of this project was limited to documentation (primarily on land and secondarily on water) at the shot atolls. Documentation on water, as it was done by this project, was not practical and was discontinued after the first shot.

Fallout stations were set up in varying arrangements for Shots 1, 2, 3, 4, and 6.

When significant fallout occurred at an island after any of these shots, it apparently began to arrive there within six minutes after the detonation. The maximum activity per sampling time interval resulting from Shot 1 and other shots having yields of the same order of magnitude arrived at all sampling stations during the first hour after the detonation. Extrapolation of the beta activity has indicated rates as high as 1.3×10^{14} dpm/ft^2, 1 to 6 min after detonation.

The major part of the activity had arrived at a given station within 3 to 6 hours after the detonation, with small amounts continuing to arrive up to at least 12 hours after the detonation.

Gamma dose rates due to each shot at the shot atoll 1 hour after each shot were estimated from data collected by this project and Rad Safe to be as follows:

Shot 1: 1600 to 2900 r/hr along the northern islands, 160 to 630 r/hr on the eastern islands and 15 to 43 r/hr along the southwest side of the atoll.

Shot 2: 1100 to 4700 r/hr on the northwest islands close to ground zero and 2.4 to 14 r/hr on the rest of the atoll.

Shot 3: 410 r/hr at Uncle, just west of ground zero, 10 to 125 r/hr on the north and northeast islands, and 0.8 to 4.5 r/hr elsewhere.

Shot 4: 160 to 440 r/hr on the north and northeast islands, and 0.1 to 23 r/hr elsewhere.

Shot 6: (At Eniwetok) Over 1000 r/hr in the immediate vicinity of ground zero, dropping to 17 to 32 r/hr on the islands westward and 1 to 6 r/hr eastward from ground zero.

Within the atoll, there was no apparent trend of radioactive particle size distribution with distance, direction, or time. The approximate number median diameters of samples collected ranged from 5.2 to 20 μ. Up to forty-three per cent of these particles were under 10 μ in diameter.

Shot 1 particles appeared to be coral or crystalline; those from Shot 3 appeared to be mostly crystalline, ashlike, or fused.

In particles from 149 to 1000 μ, the percentage of particles with activity on the outside generally increased directly with size, while the percentage of uniformly radioactive particles generally decreased with size. These two types of particles accounted for about 90 per cent of the radioactive particles examined. Activity was scattered randomly throughout the remaining 10 per cent of particles.

There was no apparent correlation between the location of activity on the particles and their physical appearance.

No conclusions could be drawn about the presence or absence of radioactivity in the base surge, because no samples were obtained in the base surge region.

4.1 TECHNICAL RECOMMENDATIONS

The properties and effects of fallout from new and untried types of detonations should continue to be studied at future operations.

The time and rate of arrival of primary fallout should be determined at the great distances at which fallout can be a hazard to human life, as well as at close-in locations.

When a base surge is predicted as one of the effects of a detonation, attempts should again be made to determine whether radioactivity is carried in that base surge.

The differences in characteristics of fallout between land and water shots should be more thoroughly determined at future tests.

Rates of beta and gamma activity should be known with more certainty at early times, and hence, efforts should be made to observe and study decay at early times after the detonation.

The characteristics of fallout particles, particularly from water shots, should be investigated at future tests.

The presence or absence of an internal radiological respiratory hazard should be established when new type detonation conditions become available.

Systematic recording of gamma radiation levels should continue to be made at varying distances from ground zero.

Ground level activities around ground zero should be determined by employing helicopter aerial survey system or other means.

4.2 OPERATIONAL RECOMMENDATIONS

When devices to be detonated have a yield of the order of magnitude of the larger CASTLE shots, documentation of fallout should cover extensive areas.

Fallout sampling stations should be located in areas which are most likely to receive significant fallout. Determination of such areas should be made in consultation with those who are responsible for deciding what weather conditions are required to detonate a device. If the predominant direction of fallout cannot be determined, then sampling stations should be located in all directions from ground zero. Such an array should be avoided where possible because of the large amount of work required to maintain the resulting large number of stations.

Water-based stations should be used at the Pacific Proving Grounds to provide proper area coverage to document the fallout. Land stations at the shot atoll do not by themselves provide enough fallout documentation.

Larger bases, such as barges, should be used where practicable as instrument platforms in the lagoon rather than the rafts used at CASTLE. The rafts used at CASTLE were inadequate bases on which to mount fallout collectors. Seas in the lagoon are generally so rough that it is difficult for personnel to moor rafts to buoys, transfer equipment from boats to rafts, and work on the rafts.

New types of fallout collectors should be designed to sample fallout in locations subject to more or less continuous salt water spray and occasional immersion before and after the instrument has operated. Present fallout collectors, though adequate to keep ordinary rains from working parts, are not adequate when mounted on low rafts at sea stations and at land stations subject to water waves from close-by nuclear detonations.

APPENDIX A

COUNTING CORRECTION FACTORS AND ORIGINAL COUNTING DATA

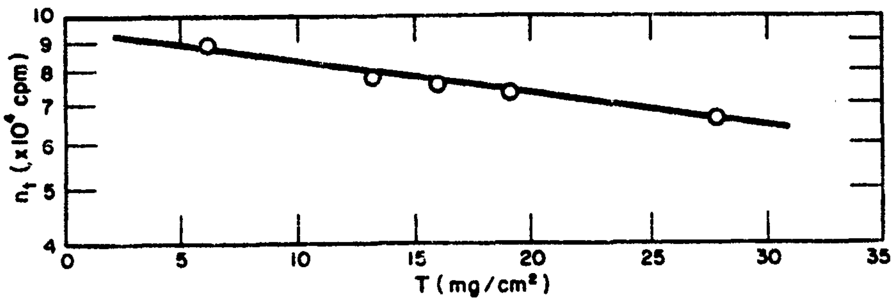


Fig. A.1 Absorption Correction Curve - Shot 1 How ½ - 1 hr
m = 0.01343

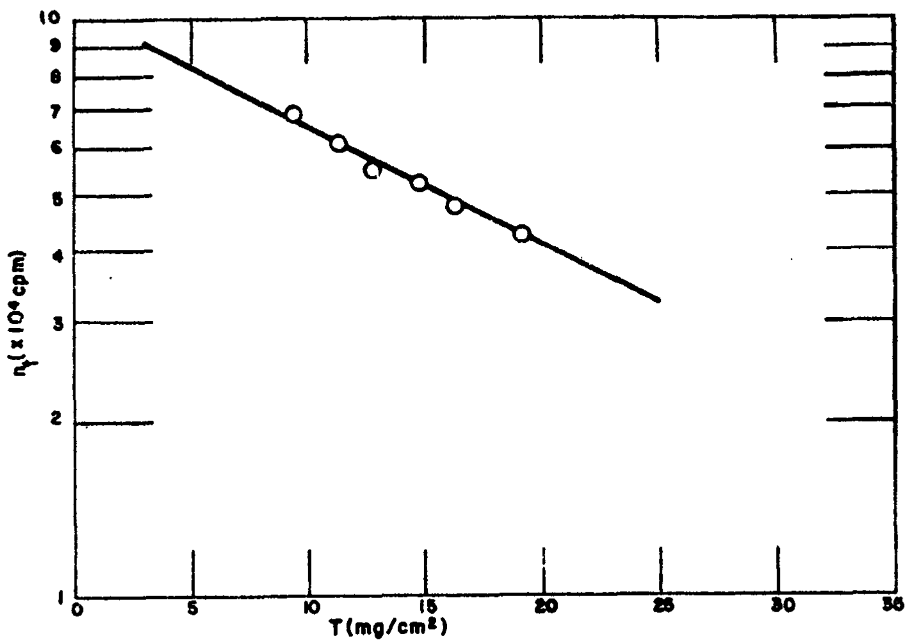


Fig. A.2 Absorption Correction Curve - Shot 3 Mixture
m = 0.05080

TABLE A.1 - Counting Correction Factors

Shot	Shelf	Absorption (F_a)					Back Scattering (F_b)	Geometry (G)		
		Tube Window Thickness, mg/cm^2						Aperture 1	Aperture 2	Aperture 3
		1.5	1.6	1.7	1.8	1.9				
1 and 2	2	0.925	0.923	0.922	0.922	0.920	1.14	0.00675		
	3	0.902	0.900	0.899	0.898	0.897	1.11	0.00420	0.00650	
	4	0.879	0.877	0.876	0.875	0.874	1.11	0.00180	0.00318	0.00685
	5	0.856	0.855	0.854	0.852	0.852	1.10	0.00102	0.00190	0.00397
3	2	0.900	0.898	0.897	0.895	0.894	1.10	0.00675		
	3	0.870	0.867	0.865	0.864	0.864	1.02	0.00420	0.00650	
	4	0.840	0.838	0.837	0.835	0.834	1.02	0.00180	0.00318	0.00685
	5	0.812	0.810	0.808	0.807	0.806	1.00	0.00102	0.00190	0.00397
4 and 6	2			0.842			1.18	0.00675		
	3			0.796			1.16	0.00420	0.00650	
	4			0.753			1.14	0.00180	0.00318	0.00685
	5			0.713			1.10	0.00102	0.00190	0.00397

TABLE A.2 - Backscattering Corrections for Various Times

Shelf	Aperture	Correction			
		Hours After Shot 1			
		287	624	1392	1440
2	1	1.284	1.262	1.187	1.177
3	2	1.183	1.180	1.133	1.117
4	3	1.136	1.143	1.116	1.083
5	3	1.077	1.091	1.061	1.053

TABLE A.3 - Beta Activities at 400 Hours After Shot 1, 5 min Interval Collectors*
(Units of 10^5 Disintegrations/Min)

Interval	STATION								
	How	Nan	Oboe	Uncle	Victor	William	Yoke	Zebra	Bravo
1	20.5	6.94	0.635	0.253	0.166		4.15	3.62	0.226
2	0.310	0.0866	3.00	0.231	0.154			3.05	0.614
3	0.854	0.0548	0.507	0.636	0.155		0.105		0.161
4	0.550	0.0831	0.244	0.166	0.133			0.0318	3.79
5	1.73	0.518	0.163	0.0767	0.891			0.0227	0.124
6	13.4	16.7	4.76		0.184			0.0703	0.144
7	41.6	0.0695	7.35	0.0933				0.325	0.0678
8	48.2	40.7	2.21		0.253			0.230	0.0727
9	38.2	22.8	11.0		2.55	0.1168		0.147	0.243
10	46.6	28.6	19.1	0.141	0.126	0.270	0.141	0.0853	0.400
11	119	37.0	0.378	0.101	0.179		0.213	0.216	0.397
12	78.4	11.1	29.6		0.106	0.360		0.414	0.879
13	33.4	23.7	5.53		0.279	0.750		0.0847	0.250
14	31.6	27.7	2.86		0.945	0.196	1.59	0.108	0.363
15	15.3	35.9	0.231				0.865	0.178	0.683
16	24.8	15.7	0.188				0.123	0.0969	0.144
17	17.6	21.1	0.271				1.05	0.0419	
18	20.5	18.9	14.0			0.288	0.0912	0.149	0.268
19	26.4	7.44	4.52		0.194	0.503	0.137	0.175	0.132
20	36.9	3.51	15.5		0.256	0.178	0.351		0.131
21	41.5	4.91	6.37		0.357	0.157	0.131		0.126
22	19.3	4.84	7.25		0.583	0.192	0.577		0.798
23	17.1	14.5	0.938		0.434	0.184	0.778	0.0664	0.305
24	41.1	4.06	0.273		0.828		0.197	0.176	5.59

* Refer to Table A.5 for Easy and George 5 min collector activities

TABLE A.4 - Beta Activities at 400 Hours After Shot 1, 30 min Interval Collectors*
(Units of 10^5 disintegrations/min)

Interval	STATION					
	How	Nan	Oboe	Tare	Uncle	William
1	45.0	28.5	9.02	2.42	0.213	
2	232	102	33.1	0.128	2.52	
3	207	109	21.5	1.23	2.02	
4	154	62.4	14.4	0.383	0.529	
5	95.0	16.3	10.1	0.359	0.0846	
6	16.5	22.7	2.89	0.0431	0.114	
7	16.2	4.61	5.44	0.368		
8	12.4	8.38	1.59	0.0810		
9	6.38	1.44	2.15	0.137		0.117
10	7.85	1.79	1.71		0.631	0.270
11	4.33	1.04	1.72		1.01	
12	9.00	1.44	2.25		0.319	0.360
13	4.82	0.996	1.69		0.242	0.750
14	8.12	1.59	1.02			0.196
15	2.31	2.58	1.05			
16	3.13	2.01	0.882			
17	4.13	1.65	1.39			
18	4.13	3.28	1.09			0.288
19	4.27	3.21	2.91			0.503
20	3.15	3.24	1.02			0.178
21	3.44	2.84	4.66			0.157
22	3.69	2.05	0.969			0.192
23	2.54		0.641			0.184
24	3.59		0.863			

* Refer to Table A.5 for Dog, Easy and George 30 min collector activities

TABLE A.4 (Cont'd) - Beta Activities at 400 Hours After Shot 1, 30 min Interval Collector
(Units of 10^5 disintegrations/min)

Interval	STATION					
	Yoke	Zebra	Alfa	Bravo	Raft 250.05	Raft 250.12
1	0.360	2.91	0.217	0.824	0.269	365
2			4.33	1.33	0.810	152
3			8.66	2.09	1.11	0.156
4			5.02	0.603	0.581	0.198
5			1.24	0.240	0.550	
6			14.7	0.199	1.09	0.171
7			1.96	0.108	0.787	0.409
8	0.170		0.212	0.127	2.97	0.392
9			1.85		3.16	0.399
10	0.218		0.147		0.875	0.645
11	0.335		0.0925		3.67	0.554
12	0.133				2.48	0.262
13	0.264			0.165	3.85	0.310
14	0.165				1.93	0.307
15	0.391				0.180	0.0744
16	0.460				2.67	0.197
17			0.0673	0.150	4.47	0.369
18			0.0525		0.609	0.288
19	0.152		0.0717	0.127	0.437	0.200
20	0.126	0.0308			1.18	0.295
21	0.242			0.182	3.72	0.201
22	0.127		0.166	0.139	0.720	
23	0.127	0.0499	0.233	0.139	0.712	0.329
24	0.168	0.418	0.243	0.121	0.420	

*Refer to Table A.5 for Dog, Easy and George 30 min collector activities

TABLE A.5 - Beta Activities at 800 Hours After Shot 1
(Units of 10^5 disintegrations/min)

Interval	1 Min Interval Station	5 Min Interval Collectors Station		30 Min Interval Collectors Station		
	Dog	Easy	George	Dog	Easy	George
1	30.9	36.1	15.1	8.04	5.29	22.2
2	11.0	3.82	4.43	13.2	8.41	13.0
3	3.92	3.31	8.13	2.85	6.51	1.06
4	2.83	4.69	9.98	2.43	8.05	0.658
5	4.56	4.70	3.23	3.63	8.16	1.54
6	6.28	5.70	45.6	2.09	5.29	0.647
7	5.13	3.07	79.7	2.53	6.38	1.41
8	6.37	4.47	82.1	1.03	4.60	1.67
9	1.62	4.19	48.8	0.860	2.36	2.41
10	1.90	2.22	26.0	1.50	3.00	1.15
11	2.14	2.05	62.0	1.97	2.56	1.01
12	6.18	5.57	69.1	1.80	2.57	0.556
13	4.04	3.15	71.8	1.37	4.84	1.58
14	0.618	3.58	79.3	1.73	7.24	2.00
15	2.11	2.46	90.2	4.38	7.03	3.46
16	6.24	2.14	91.8	3.18	8.45	4.30
17	13.9	1.38	98.8	6.36	12.0	1.24
18	17.8	1.42	58.5	8.35	10.9	1.06
19	9.31	3.10	42.4	5.27	8.79	2.09
20	5.36	3.64	34.4	1.85	6.80	2.07
21	3.47	0.797	17.4	3.67	12.0	3.51
22	40.0	3.32	16.4	2.54	6.25	6.24
23	2.45	2.32	11.1	4.29	7.98	3.96
24	4.33	2.80	9.60	6.18	13.7	5.24

TABLE A.6 - Beta Activities 165 Hours After Shot 2, 5 min Interval Collectors
(Units of 10^5 disintegrations/min)

Interval	STATION			
	George	Love	Zebra	Bravo
1	16.71	0.379	0.2032	0.2140
2	3.231	3.7860	0.1918	0.1930
3	1.630	0.1760	0.8170	0.1906
4	1.878	0.1760	0.1932	0.1921
5	2.512	0.1760	0.1932	0.1921
6	5.005	0.1760	0.1932	0.1921
7	1.782	0.2292	0.1932	0.1921
8	1.616	0.1775	0.1932	0.1921
9	4.421	0.2975	0.1945	0.1921
10	2.209	0.2433	0.1945	0.1921
11	2.318	0.1789	0.1945	0.1921
12	1.718	0.1789	0.1945	0.1936
13	3.384	0.1789	0.1945	0.1936
14	2.686	0.1995	0.1945	0.1936
15	2.220	0.3519	0.1945	0.1936
16	5.643	0.1995	0.1945	0.1936
17	2.014	0.1995	0.1945	0.1936
18	1.938	0.1995	0.2478	0.1936
19	1.566	0.1995	0.2016	0.1936
20	2.441	0.1995	0.2295	0.2128
21	3.780	0.1995	0.1987	0.1989
22	5.685	0.1995	0.1987	0.1950
23	14.42	0.1995	0.1987	0.2369
24	194.0	0.1995	0.2805	0.1966

TABLE A.7 - Beta Activities at 105 Hours After Shot 2, 30 Min Interval Collectors
(Units of 10^5 disintegrations/min)

Interval	STATION						
	George	How	Love	Nan	Oboe	Victor	Zebra
1	2.130	0.2401	0.4038	0.5308	0.4000	0.1981	0.6478
2	1.060	0.8188	2.687	0.2209	0.4431	0.1981	0.1770
3	0.5637	0.6928	0.5678	0.2209	0.2178	0.4035	0.1783
4	0.5010	0.2936	0.4525	0.2780	0.2178	0.3280	0.1783
5	1.024	0.3830	0.2209	0.2209	0.2178	0.2033	0.1783
6	1.731	0.2168	0.2209	0.2209	0.2178	0.2033	0.1783
7	1.429	0.6793	0.4221	0.2240	0.3576	0.2033	0.1796
8	0.7372	0.8182	0.2174	0.6808	0.2281	0.5736	0.1796
9	0.7236	0.4378	0.2174	0.2240	0.2209	0.5314	0.1796
10	0.6152	0.8727	0.2174	0.2240	0.2209	0.2056	0.1810
11	0.8379	0.2989	0.2240		0.2209	0.2056	0.1810
12	1.687	0.1535	0.2514		0.2209	0.2056	0.1810
13	0.9452	0.3306	0.2643		0.2209	0.2056	0.2280
14	0.2372	0.2388	0.3278		0.2548	0.2056	0.1823
15	0.2002	0.2768	0.2072		0.2240	0.3735	0.1823
16	0.2002	0.2152	0.2072		0.2240	0.2071	0.1823
17	0.4434	0.2170	0.2072		0.2240	0.2071	0.1823
18	2.090	0.3536	0.2072		0.2240	0.2071	0.1823
19	2.590	0.5079	0.2072		0.2240	0.2071	0.4147
20	2.944	9.728	0.3019		0.2240	0.3979	0.2357
21	3.300	2.880	0.2898		0.2240	0.2058	0.1863
22	36.40	0.3632	0.3321		0.2240	0.2058	0.1863
23	12.90	0.5164	0.7084		0.2240	0.2058	0.1942
24	0.2137	0.2284	2.582		0.3228	0.2058	0.8453

TABLE A.8 - Beta Activities at 200 Hours After Shot 3, 1 and 5 Min Interval Collectors
(Units of 10^5 disintegrations/min)

Interval	1 Min Interval Collector	5 Min Interval Collectors						
		STATION						
	Uncle	Easy	Fox	George	Victor	William	Zebra	Bravo
1	54.16	680.0			0.1964	0.1691	1.038	0.1294
2	46.63	1.282	5.828	22.63	0.5674	0.1691	0.1149	0.1294
3	44.88	1.004	0.3368	16.63	0.5040	0.1648	0.1149	0.1294
4	24.38	0.2948	0.6527	16.28	0.1635	0.2202	0.1149	0.2741
5	13.12	1.638	0.6807	12.24	0.4465	0.2914	0.1149	0.1294
6	15.80	0.1700	0.3427	6.112	0.6584	0.1691	0.1149	0.1294
7	14.46	0.1626	0.6772	12.32	0.1964	0.1691	0.1204	0.1294
8	22.51	0.1430	0.1908	11.46	0.8257	0.1691	0.1412	0.1302
9	7.905	0.1137	0.3172	139.9	0.3152	0.1691	0.3178	0.1311
10	27.02	0.1137	0.2334	307.5		0.1691	0.1695	0.1203
11	55.46	2.734	0.2441	304.1		0.1691	0.2615	0.1311
12	24.60	0.2691	0.3928	165.4		0.1691	0.3331	0.1688
13	12.00	0.4038	3.246	197.9		0.6916	0.2152	0.2236
14	12.31	1.034	5.680	34.04		0.1353	1.023	0.1983
15	60.32	2.668	0.8793	14.20		0.1353	0.7777	0.3465
16	69.52	1.472	0.4285	12.29		0.1353	0.4453	0.6513
17	28.90	0.2286	0.8147	37.31		0.1353	0.1487	0.7114
18	15.78	0.2286	2.497	58.50		0.1353	0.1487	0.5394
19	41.60	0.3381	1.411	31.80		0.1353	0.2305	0.2121
20	23.43	0.4383	5.072	4.895		0.2490	0.2222	0.1093
21	8.252	0.5363	10.11	11.29		0.3324	0.1513	0.1626
22	12.51	0.4444	0.3884	8.707		0.1353	0.1770	0.1626
23	7.950	0.5625	0.5355	9.043		0.8956	0.1540	0.1626
24	50.76		2.531	18.97		0.1353	3.650	0.1626

TABLE A.9 - Beta Activities at 200 Hours After Shot 3, 30 Min Interval Collectors
(Units of 10^5 disintegrations/min)

Interval	STATION						
	Dog	Easy	Fox	How	Uncle	Victor	Zebra
1	2.217	0.4738	0.7078	4.492	447.0	0.1773	1.363
2	0.3260	1.470	0.4772	102.8	50.60	0.9838	0.6000
3	0.6903	3.868	0.3617	6.092	26.95	0.7381	0.1556
4	0.8849	19.98	3.099	0.1442	52.87	0.2084	0.1546
5	0.7307	1.858	0.4620	0.2066	105.7	0.7321	0.1224
6	0.5940	2.214	0.6399	0.08359	13.75	0.08351	0.1224
7	0.7318	0.1347	0.7377	0.08359	33.72	0.1288	0.1254
8	0.6575	1.766	0.6312	0.1493	15.58	0.08703	0.1300
9	0.3078	2.451	0.9715	0.1610	136.0	0.09103	0.1930
10	0.1505	0.4630	2.059	0.08359	48.02		0.1240
11	1.223	0.2071	2.356	0.08359	40.44		0.1240
12	0.3780	0.3554	0.9628	0.1702	22.70		0.1240
13	0.7986	0.4069	0.8991	0.8340	16.68		0.2834
14	0.2546	0.2716	1.018	5.887	16.18		0.1268
15	0.3714	0.2745	9.000	0.7705	6.346		0.1268
16	0.7684	0.8880	5.177	0.2712	4.787		0.1268
17	3.952	0.9167	0.5571	0.09753	5.302		0.1268
18	0.5278	0.9106	1.000	0.09753	7.227		0.1268
19	0.7181	1.322	1.009	0.09753	5.101		0.1765
20	0.7595	0.3997	2.009	0.09753	6.604		0.1279
21	0.8738	0.6201	1.792	0.2419	16.41		0.1279
22	1.384	0.3569	0.8584	0.09753	29.16		0.1963
23	1.320	2.650	2.116	0.2854	26.11		0.5359
24	0.8470		2.942	0.6248	271.9		2.780

TABLE A.10 – Beta Activities, Shots 4 and 6
(Units of 10^5 disintegrations/minute)

Interval	Shot 4 - 5 min Interval Collectors		Shot 4 - 30 min Interval Collectors		Shot 6 - 30 min Interval Collectors		
	How*	Love*	Charlie*	How*	Alice**	Belle**	Janet**
1	21.63	0.0311	0.1900	0.3065	0.2079	1.057	0.4481
2	1.463	0.1763	0.1756	83.43	0.2320	0.5523	0.5399
3	0.0996	0.03162	0.3440	0.4420	0.1555	3.724	0.1354
4	0.0492	0.03162	0.3020	0.3147	0.1345	0.2642	0.1354
5	0.1445	0.03162	0.1920	2.920	0.1354	0.1800	0.1354
6	0.1546	0.2274	0.1165	0.2920	0.1354	0.1532	0.1354
7	7.635	0.6381	0.1080	0.2716	0.1808	0.1744	0.1354
8	6.000	0.0654	0.0970	0.6768	0.1955	0.5298	0.2716
9	16.64		0.2085	1.920	0.1862	0.1980	0.6880
10	8.128		0.1530	1.265	0.4421	0.2702	0.2957
11	1.265		0.0782	1.194	0.5674	0.1988	0.3492
12	7.853		0.0782	7.185	0.4488	0.2617	0.2336
13	1.942		0.0782	0.1740	0.3722	0.6265	0.4238
14	6.063		0.1188	0.2397	0.4638	0.3288	0.2332
15	10.22		0.3296	0.5150	1.518	0.3316	0.2332
16	0.0937		0.1750	0.7150	0.5153	0.2819	0.2775
17	0.2394		0.1134	12.10	0.4587	0.4474	0.2332
18	0.035		0.3411	6.890	0.5193	0.9024	0.2332
19	0.0547		0.1820	0.9743	0.6218	0.4478	0.2332
20	0.0501		0.2964	1.114	1.226	2.053	0.2332
21	0.2052		0.5433	0.6938	2.080	0.3118	0.2332
22	0.3186		0.4472	0.3758	0.3991	0.3843	0.2332
23	0.3568		0.7417	0.6650	0.5023	0.3286	0.2332
24	0.6591		0.6260	0.8452	0.2863	0.4144	0.2332

* At 400 hrs
** At 200 hrs

APPENDIX B

WIND VECTORS

The following wind vector representations (Figs. B.1 to B.5) are drawn from data furnished by the Joint Task Force Seven Air Weather Service at Eniwetok to Task Group 7.1. These drawings represent the wind vectors taken at 2000-ft vertical intervals up to 20,000-ft and 5000-ft vertical intervals from 20,000 ft up to the altitude at which data were no longer taken. These vectors show the general wind conditions existing in the vicinity of the shot atolls at about the time of each shot. Contamination on the shot atoll can be adequately explained by observing these wind vectors. More refined patterns based on particle settling rates are not applicable to this experiment, since within the relatively small area sampled no trends of particle size with distance from ground zero or with time after shot were found in the analysis of the samples.

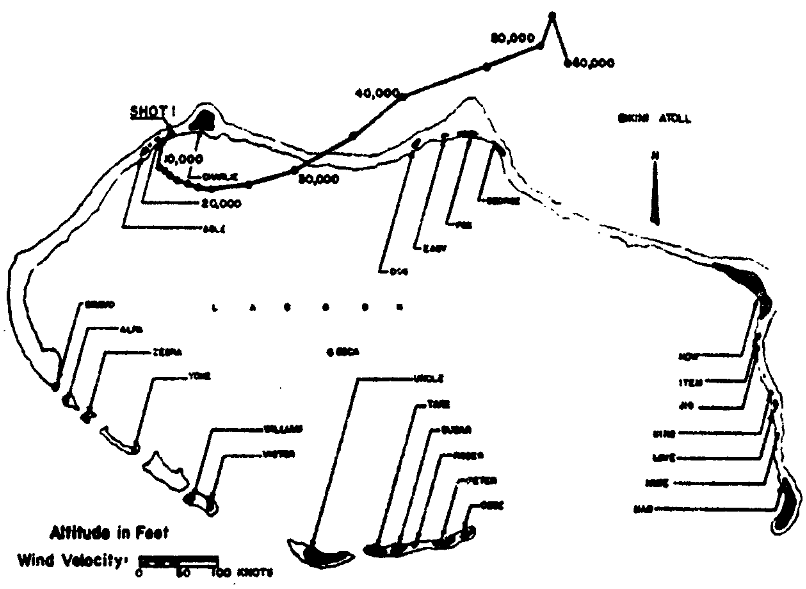


Fig. B.1 Vertical Profile of Wind Vectors at Bikini, Shot 1.
Observations started at 0600 local time.

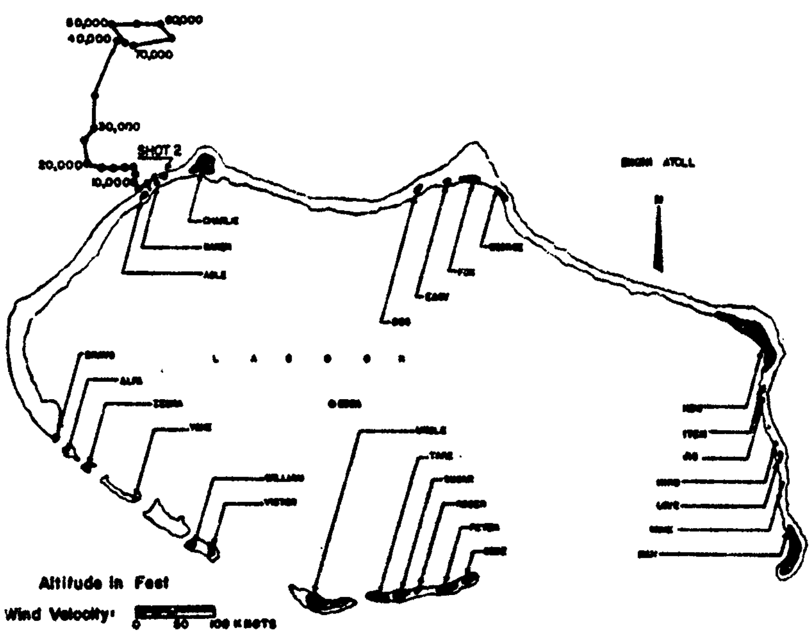


Fig. B.2 Vertical Profile of Wind Vectors at Bikini During Shot 2.
Observations started at 0600 local time.

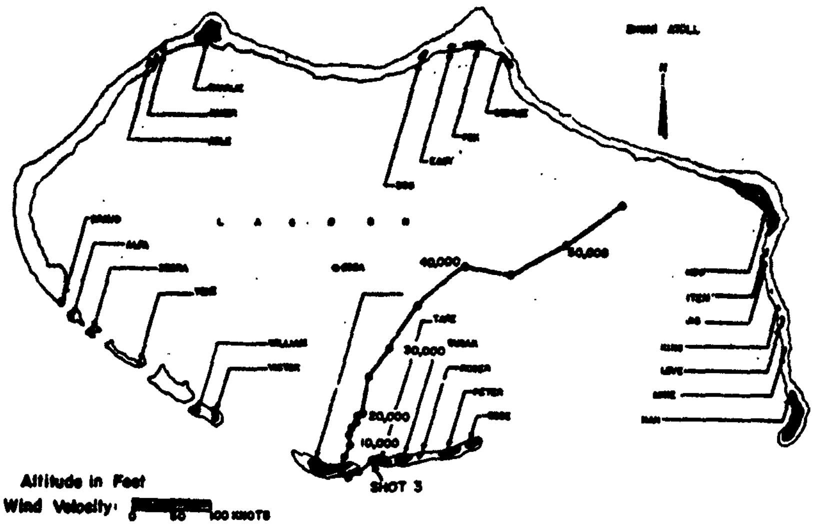


Fig. B.3 Vertical Profile of Wind Vectors at Bikini During Shot 3. Observations started at 0620 local time.

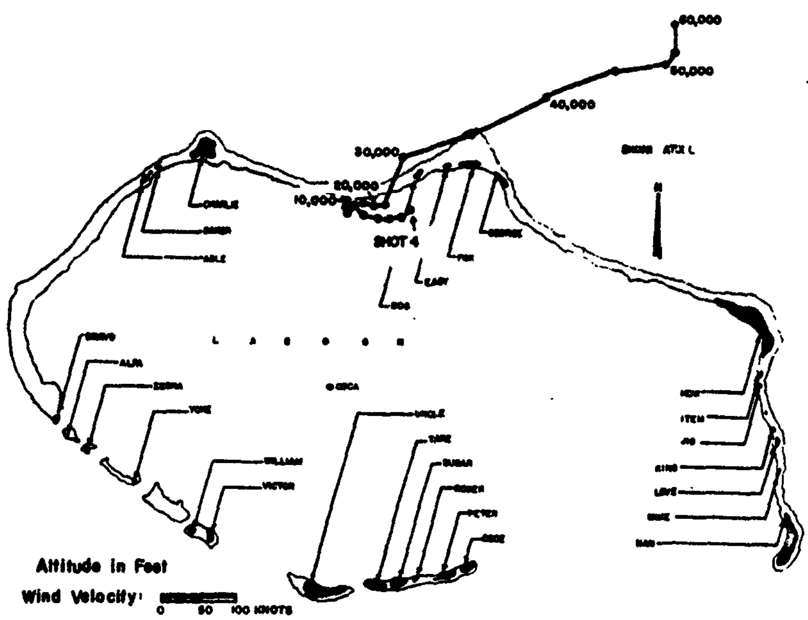


Fig. B.4 Vertical Profile of Wind Vectors During Shot 4. Observations started at 0610 local time.

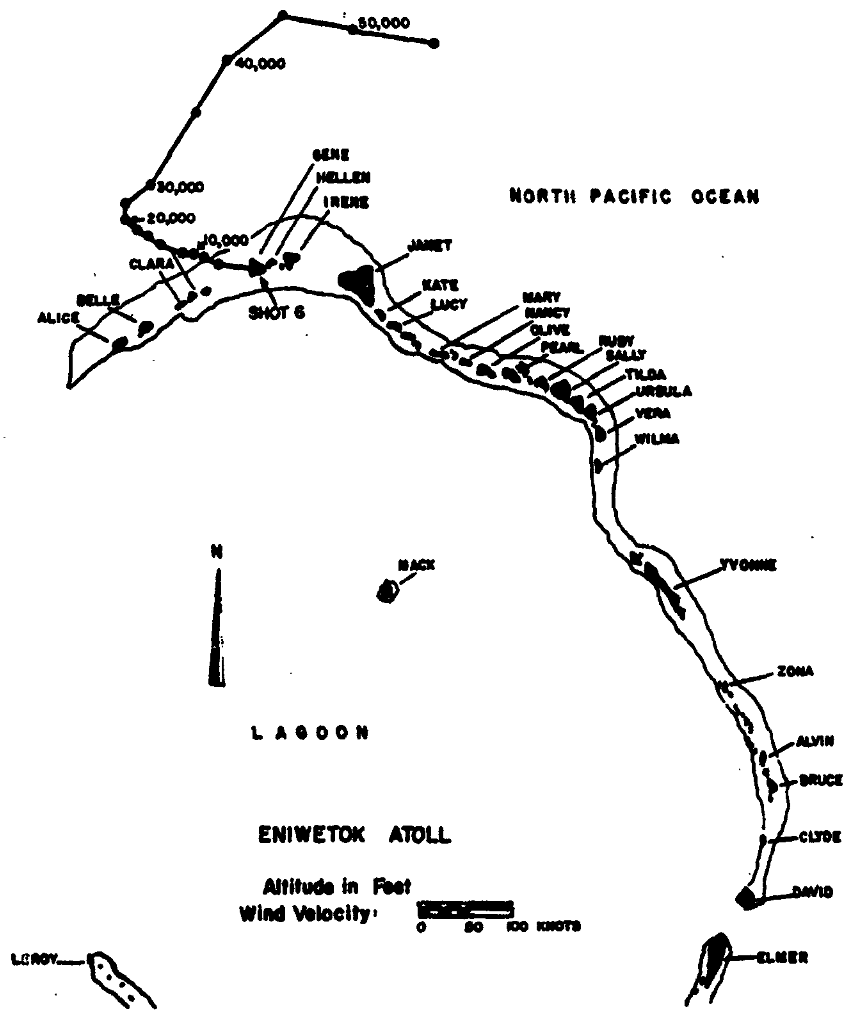


Fig. B.5 Vertical Profile of Wind Vectors at Eniwetok During Shot 6. Observations started at 0600 local time.

APPENDIX C

RAD SAFE GAMMA SURVEY READINGS

The following tables contain a fairly complete list of gamma residual radiation readings as obtained by the Task Group 7.1 Radiological Safety unit. These readings were primarily intended to be used as a guide for the Rad Safe Unit Commander to determine the conditions for access of personnel to contaminated areas during the field phase of the operation. The readings were subject to a multitude of variables, as was to be expected in field measurements of this type: readings were not always taken at the same location on or above the island; winds may have moved the debris around and concentrated it in "hot spots" and conversely, "cold spots"; rain may have leached some of the activity from the debris; and the AN/PDR-39 gamma survey meters which were used for the surveys were subject to both instrumental and operational errors.

In the field, Rad Safe used a rough "rule of thumb" to convert the air readings taken from helicopters to ground readings which could be used as a guide for recovery and working parties in contaminated areas. The readings at 50 ft or higher above the ground were multiplied by 3 to estimate the corresponding ground readings, and readings taken at 25 ft were multiplied by 2 to estimate the corresponding ground readings. It must be borne in mind that these readings are subject to a variety of influences such as the energies of the radioactive nuclides in the contaminated area, which may vary with time after the shot, the size of the island and the radiation field from it, and the radiation field which may come from the water surrounding the island. As an example of the latter, note the 25 ft readings on Yoke, Zebra, Alfa, and Bravo on three days after Shot 2. The 25-ft readings are from 2.3 to 5 times higher than the land ground readings as a result of the contamination in the water around these islands. It should also be noted that secondary fallout occurred on the Oboe-Tare chain during the night following Shot 2.

These data are used here with the permission of the Task Group 7.1 Radiological Safety Unit Commander and are included in this report because they provide a background for understanding the results of the fallout and residual contamination projects. Where several readings were available from one island on the same day, an average of the readings was usually made. An asterisk by a reading denotes a reading made by Project 2.5b personnel at the Project 2.5b station on that island.

TABLE C.1 - Rad Safe Gamma Survey Readings After Shot 1

Island	Activity in mr/hr at Various Heights Above Ground			
	Days After Shot 1			
	0	2	3	4
Able		20,000 at 50'	6,000 at 0' 1,000 at 50'	4,000 at 50'
Charlie		7,000 at 50'	2,000 at 50'	5,000 at 0' 6,000 at 50'
Dog	At H/12 hr 80,000 at 0'	10,000 at 50'	10,000 at 0' 5,000 at 50'	3,600 at 50'
Easy				3,200 at 50'
Fox		20,000 at 0'	8,000 at 0' 4,000 at 50'	2,900 at 50'
George	50,000 at 100' H/5 hr	2,500 at 50'	6,000 at 50'	4,000 at 0' 3,000 at 25'
How	30,000 at 450' H/5 hr	3,000 at 25'	3,000 at 0'	800 at 50'
Item			900 at 50'	
Jig			800 at 50'	460 at 50'
King			800 at 50'	
Love			600 at 50'	420 at 50'
Mike			800 at 50'	350 at 50'
Nan	10,000 at 25' H/6 hr	2,000 at 0' 600 at 75'	1,500 at 0'	500 at 0' 310 at 50'
Oboe	3,500 at 25'	400 at 0' 260 at 50'	475 at 0' 120 at 50'	360 at 0'* 110 at 50'
Peter		220 at 10'	250 at 50'	110 at 50'
Roger		300 at 10'	100 at 50'	
Sugar	1,500 at 25'	220 at 10'		80 at 50'
Tare		300 at 0' 220 at 15'	150 at 0' 120 at 50'	130 at 0' 80 at 50'
Uncle		120 at 50'	100 at 50'	120 at 0'* 50 at 50'
Victor		120 at 0'	125 at 0' 80 at 50'	40 at 50' 42 at 75'
William		120 at 0'	75 at 0' 80 at 50'	100 at 0'* 42 at 75'
Yoke		100 at 0'	150 at 0' 80 at 50'	80 at 0'*
Zebra		120 at 0'	80 at 50'	180 at 0'*
Alfa		100 at 0'	160 at 0' 100 at 50'	160 at 0'*
Bravo		150 at 0' 125 at 50'	150 at 0' 80 at 50'	150 at 0'*

* Project 2.5b station readings

TABLE C.1 - Rad Safe Gamma Survey Readings After Shot 1 (Cont'd)

Island	Activity in mr/hr at Various Heights Above Ground					
	Days After Shot 1					
	5	6	7	8	9	10
Able	1000 at 50'	1000 at 50'	5000 at 50'	2000 at 50'	6000 at 25'	4000 at 0' 4600 at 25'
Charlie	1500 at 50'	3500 at 0' 1600 at 15'	1400 at 50'	1200 at 25'	2000 at 25'	2200 at 0'* 1200 at 25'
Dog	2700 at 50'	9000 at 0' 4000 at 25'	3000 at 50'	2400 at 25'	3500 at 0' 2500 at 25'	4000 at 0' 2100 at 25'
Easy	2000 at 50'	3300 at 25'	1500 at 50'	2200 at 25' 2100 at 50'		2000 at 25' 2500 at 0'*
Fox	2000 at 50'	2600 at 50'	2500 at 50'	2100 at 25'	3500 at 0'	2200 at 0'* 2200 at 25'
George	2700 at 50'	4200 at 0' 3000 at 25'	2500 at 50'	1900 at 25'	2000 at 0' 2000 at 25'	1600 at 25'
How	2000 at 0'	1500 at 0'	750 at 50'	900 at 25'	500 at 25'	550 at 0' 290 at 50'
Item	420 at 50'			360 at 50'	350 at 25'	260 at 25'
Jig	400 at 40'	700 at 20'		360 at 25' 340 at 50'	350 at 25'	240 at 25'
King	300 at 50'	400 at 20'		280 at 25' 340 at 50'		
Love	450 at 50' 800 at 0'	530 at 20'	325 at 50'	280 at 50'	500 at 0' 300 at 25'	200 at 25'
Mike		380 at 10'	250 at 50'	200 at 50'	250 at 25'	160 at 25'
Nan	600 at 0'* 290 at 50'	300 at 50'	390 at 0'	250 at 0'	270 at 0'	250 at 0'
Oboe	250 at 0' 50 at 15'	160 at 0'	175 at 0'	100 at 0'	120 at 0'	90 at 0'
Peter		175 at 0'				
Roger		50 at 20'				
Sugar		70 at 50'				
Tare	120 at 0'	110 at 0'	100 at 0'	90 at 0' 40 at 25'	60 at 0'	44 at 0'
Uncle	150 at 0'	40 at 50'	30 at 50'	30 at 25' 32 at 50'	38 at 0'	20 at 25'
Victor	40 at 50'	35 at 50'	27 at 50'	30 at 25' 28 at 50'	15 at 35'	22 at 25'
William	40 at 50'	45 at 0' 30 at 50'	50 at 0'	32 at 25'	30 at 0' 22 at 35'	20 at 25'
Yoke	70 at 0' 40 at 20'	35 at 20'	85 at 0' 20 at 50'	18 at 25'	15 at 0' 18 at 40'	16 at 25'
Zebra	70 at 0' 40 at 20'	25 at 25'	33 at 50'	45 at 0' 28 at 50'	30 at 0'	20 at 25'
Alfa		35 at 50'	25 at 50'	12 at 25'	35 at 0' 30 at 25'	22 at 25'
Bravo	45 at 10'	50 at 20'		22 at 25'	30 at 0' 30 at 25'	40 at 25'

*Project 2.5b station readings

TABLE C.1 - Rad Safe Gamma Survey Readings After Shot 1 (Cont'd)

	Activity in mr/hr at Various Heights above Ground					
Island	Days After Shot 1					
	12	13	14	15	16	17
Able		2000 at 25'	2400 at 0' 1200 at 25'	1500 at 25'		1200 at 0' 600 at 25'
Charlie		700 at 0' 700 at 25' 600 at 50' 900 at 100' 400 at 200' 180 at 400'	900 at 0' 800 at 25' 420 at 50' 320 at 100' 200 at 200' 110 at 400'	800 at 25'		420 at 0' 360 at 25' 240 at 40' 240 at 100' 100 at 200' 80 at 400'
Dog	2100 at 0'	1800 at 25'	2000 at 0' 1600 at 25'	1600 at 0' 1000 at 25'		1200 at 0' 800 at 25'
Easy	2100 at 0'			1000 at 25'		
Fox		2200 at 0' 1300 at 25' 1200 at 50' 1000 at 100' 500 at 200' 140 at 400'		1400 at 0' 1000 at 25'		900 at 0'
George	1900 at 0'	1400 at 0'	1400 at 0' 1200 at 25'	1200 at 0' 1000 at 25'	900 at 0'*	1000 at 0' 600 at 25'
How			380 at 0' 290 at 25'	290 at 0' 220 at 25'	250 at 0'*	240 at 0' 180 at 25'
Item			270 at 0' 170 at 25'	130 at 25'		320 at 0' 120 at 25'
Love			260 at 0' 130 at 25'	160 at 25'		170 at 0' 100 at 25'
Mike			150 at 0' 100 at 25'	60 at 0' 80 at 25'		80 at 0' 70 at 25'
Nan	100 at 0'	150 at 0' 130 at 25' 100 at 50'		100 at 0' 70 at 25'	90 at 0'*	90 at 0' 70 at 25'
Peter						30 at 0'
Roger						20 at 0'
Tare	26 at 0'	34 at 0'	26 at 0'	18 at 0' 19 at 25'	30 at 0'	19 at 0' 12 at 25'
Uncle		16 at 25'	20 at 0' 14 at 25'	14 at 25'		10 at 0' 8 at 25'
Victor		14 at 25'	14 at 0' 12 at 25'	11 at 25'		8 at 0' 6 at 25'
William		20 at 0' 14 at 25' 6 at 50'		12 at 25'		
Yoke			19 at 0' 10 at 25'	8 at 25'		2 at 0' 4 at 25'
Zebra			18 at 0' 13 at 25'	9 at 25'		10 at 0' 8 at 25'
Alfa			22 at 0' 13 at 25'	12 at 25'		14 at 0' 10 at 25'
Bravo			20 at 0' 14 at 25'	11 at 25'		14 at 0' 10 at 25'

TABLE C.1 - Rad Safe Gamma Survey Readings After Shot 1 (Cont'd)

Island	Activity in mr/hr at Various Heights Above Ground					
	Days After Shot 1					
	19	20	21	23	24	25
Able	1200 at 0' 600 at 25'		1100 at 20'	600 at 15'	600 at 15'	500 at 25'
Charlie	700 at 0' 420 at 25'		500 at 25'	500 at 15'	500 at 15'	250 at 25'
Dog	500 at 0' 480 at 25'		800 at 0'	800 at 10'		440 at 25'
Easy	360 at 0'		500 at 25'	700 at 10'		400 at 25'
Fox	1200 at 0' 340 at 75'		800 at 0'	900 at 0' 700 at 10'		390 at 0'
George	1000 at 0' 400 at 100'	700 at 0'	250 at 0'	600 at 10' 300 at 0'	400 at 0'	220 at 0'
How	200 at 0' 100 at 75' 90 at 125'		140 at 0'	140 at 0'	140 at 0'	195 at 0'
Item	80 at 25' 120 at 0'		80 at 25'			
Jig			70 at 25'			
King				80 at 10'		
Love	90 at 0' 60 at 25'		60 at 25'			
Mike	60 at 25'		50 at 25'			
Nan	80 at 0' 20 at 25'	60 at 0'	60 at 0'	42 at 0'	42 at 0'	30 at 0'
Oboe	19 at 0' 30 at 50'		15 at 0'	9 at 0'		
Tare	12 at 0' 6 at 25'		12 at 0'	8 at 0'		
Uncle	14 at 0'		6 at 25'	8 at 0'		
Victor			5 at 25'	5 at 25'		2.6 at 25'
William	10 at 0'		4 at 25'	4 at 25'		4.2 at 25'
Yoke	10 at 0'		2 at 25'	4 at 10'		2.5 at 25'
Zebra	14 at 0'		5 at 25'	6 at 10'		4.5 at 25'
Alfa	15 at 0'		8 at 25'			
Bravo	16 at 0'		6 at 25'	8 at 10'	8 at 10'	12 at 25'

TABLE C.2 - Rad Safe Gamma Survey Readings After Shot 2

Island	Activity in mr/hr at Various Heights Above Ground				
	Days After Shot				
	0	1	2	3	4
Able		50,000 at 200'	75,000 at 25' 2,000 at 400'	26,000 at 25'	20,000 at 0' 9,000 at 25'
Baker		12,000 at 15'		28,000 at 25'	
Charlie	1100 at 300'	2,900 at 300'	6,000 at 400'	32,000 at 25'	5,000 at 0'
Dog	900 at 0'	900 at 0'* 500 at 25'	340 at 50'	800 at 0'* 440 at 25'	680 at 0'
Easy	1100 at 0'	800 at 0'* 500 at 25'	280 at 50'	800 at 0'* 330 at 25'	480 at 0'
Fox	1600 at 0'	600 at 25'	240 at 50'	800 at 0'* 360 at 25'	500 at 0'
George	800 at 0'	700 at 0'*	240 at 50'	800 at 0'* 360 at 25'	420 at 0'
How	120 at 0'	115 at 0'*	130 at 0' 80 at 25'	175 at 0'* 32 at 25'	100 at 0'
Item		60 at 25'	90 at 25'		
Jig		60 at 25'	95 at 25'		
King		60 at 25'	90 at 25'		
Love		70 at 0'* 44 at 25'	60 at 25'	80 at 25'	
Mike			50 at 25'	60 at 25'	
Nan	35 at 0'	28 at 0'*	60 at 0' 50 at 25'	60 at 0'* 30 at 25'	35 at 0'
Oboe			34 at 0' 30 at 25'	30 at 0'	
Peter				20 at 0'	
Roger		4 at 25'		22 at 25'	
Sugar		4 at 25'		26 at 25'	
Tare	4 at 25'	6 at 25'	42 at 0' 28 at 25'	40 at 0'	
Uncle	4 at 50'	8 at 0'	32 at 0' 24 at 25'	25 at 0'* 21 at 25'	
Victor	2 at 25'	1.5 at 0'*	26 at 25'	20 at 0'* 18 at 25'	25 at 0' 20 at 25'
William	4.5 at 25'	6 at 0'	26 at 25'	28 at 0'* 20 at 25'	
Yoke	4 at 25'	100 at 0'*	125 at 25'	20 at 0'* 90 at 25'	
Zebra	4 at 25'	100 at 0'* 200 at 10'	80 at 25'	30 at 0'* 70 at 25'	18 at 0'
Alfa	10 at 25'	100 at 0'*	120 at 25'	42 at 0'* 200 at 25'	
Bravo		200 at 0'*		40 at 0'* 100 at 25'	45 at 0'

* Project 2.5b station readings

TABLE C.2 - Rad Safe Gamma Survey Readings After Shot 2 (Cont'd)

Island	Activity in mr/hr at Various Heights Above Ground				
	Days After Shot 2				
	5	6	7	8	9
Able	25,000 at 0'	4000 at 400'			
Charlie		2000 at 400' 4000 at 0'			
Dog		380 at 25' 400 at 0'	600 at 0'	380 at 0'	470 at 0'*
Easy		360 at 25'			480 at 0'*
Fox		400 at 0' 350 at 25'	350 at 0'	300 at 25'	470 at 0'*
George		320 at 25'	310 at 0'	200 at 0'	500 at 0'*
How	125 at 0'	120 at 0'		70 at 25'	100 at 0'*
Love		50 at 25'			46 at 0'*
Mike		35 at 25'			
Nan	45 at 0'	20 at 0' 30 at 25'		40 at 0'	22 at 0'*
Oboe	30 at 0'	14 at 0' 12 at 25'		15 at 0'	20 at 0'*
Tare	20 at 0'	14 at 0' 12 at 25'	18 at 0'	10 at 0'	
Uncle		20 at 0' 10 at 25'	10 at 0'	10 at 0'	10 at 0'*
Victor		14 at 25'		9 at 25'	6 at 0'*
William		14 at 25'		40 at 0' 7 at 25'	6 at 0'*
Yoke		10 at 25'		12 at 25'	8 at 0'*
Zebra		14 at 25'		14 at 25'	8 at 0'*
Alfa		16 at 25'		20 at 0' 12 at 25'	12 at 0'*
Bravo		16 at 25'		30 at 0' 14 at 0'	18 at 0'*

*Project 2.5b station readings

TABLE C.3 - Rad Safe Gamma Survey Readings After Shot 3

Island	Activity in mr/hr at Various Heights Above Ground — Days After Shot 3: 0	1	2	5	6
Able		3600 at 25'	180 at 400'	300 at 0'	
Charlie		15000 at 25'	1500 at 0' 12000 at 0'	300 at 25'	700 at 0'
Dog	500 at 300'	1200 at 0'* 460 at 25'	600 at 0' 300 at 200'	600 at 0'	
Easy	600 at 200'	1800 at 0'*	150 at 200'		
Fox	300 at 600'	3000 at 0'* 800 at 25'	150 at 200' 180 at 400'	1000 at 0'	900 at 0'*
George	4000 at 25'	3000 at 0'* 1200 at 25'*	410 at 0' 180 at 400'	700 at 0' 700 at 25'	600 at 0'*
How	1300 at 0' 500 at 300'	440 at 0'*	180 at 0'	120 at 0' 120 at 25'	110 at 0'*
Item		44 at 25'			
Jig		42 at 25'			
Love		48 at 0'* 27 at 25'	100 at 0'	80 at 0'	
Mike		26 at 25'			
Nan	20 at 0'	28 at 0' 15 at 25'	30 at 0'	21 at 0'	20 at 0'
Oboe	40 at 0'	20 at 0'*	10 at 0'	4 at 0'	
Peter	5 at 25'	10 at 25'	4 at 0'	7 at 0'	
Roger	15 at 25'	9 at 25'			
Sugar	10 at 0''	9 at 25'			
Tare	11000 at 500' H+7 hr crater 3000 at 200' H+2 hr on island	50000 at 200'	1000 at 500'		
Uncle	15000 at 100' H+8 hr	2300 at 100'	3900 at 0'*	2400 at 0'	800 at 0'
Victor	120 at 25'	100 at 0'* 28 at 25'	50 at 0'	28 at 0'	
William	100 at 25'	80 at 0'* 28 at 25'	45 at 0'	22 at 0'	
Yoke	46 at 25'	18 at 25'	30 at 0'	10 at 0'	
Zebra	28 at 25'	40 at 0'* 18 at 25'	22 at 0'*	16 at 0'	
Alfa	33 at 0'	18 at 25'	22 at 0'	8 at 0'	
Bravo	40 at 0'	32 at 0'*	24 at 0'	10 at 0'	

* Project 2.5b station readings

TABLE C.3 - Rad Safe Gamma Survey Readings After Shot 3 (Cont'd)

Island	Activity in mr/hr at Various Heights Above Ground				
	Days After Shot 3				
	7	10	12	15	16
Able	8000 at 25'		4500 at 25'	3000 at 25'	
Charlie	5000 at 25'	800 at 0'*	2500 at 25'	850 at 100' 1000 at 25'	
Dog	250 at 25'		260 at 25'	400 at 0' 175 at 25'	
Easy	300 at 25'		260 at 25'	300 at 0' 160 at 25'	
Fox	435 at 25'	825 at 0'*	450 at 0'	1000 at 0' 210 at 25'	
George	180 at 0' 180 at 25'	900 at 0'*	320 at 25'	310 at 0' 200 at 25'	
How	75 at 0' 60 at 25'	85 at 0'*	60 at 0' 40 at 25'	32 at 0' 40 at 25'	40 at 0'*
Item	35 at 25'		25 at 25'		
Jig	40 at 25'		25 at 25'		
King	40 at 25'		20 at 25'		
Love	35 at 25'	29 at 0'*	25 at 25'		25 at 0'*
Mike	35 at 25'		6 at 25'		
Nan	20 at 0' 18 at 25'	20 at 0'*	13 at 25'	15 at 0'	
Oboe	10 at 25'	12 at 0'	7 at 25'	8 at 0'	
Peter	10 at 25'				
Roger	11 at 25'				
Sugar	7 at 25'		6 at 25'		
Tare	21000 at 25'		16000 at 25'	45000 at 100'	
Uncle	400 at 25'		500 at 25'	900 at 0'	450 at 0'*
Victor	15 at 25'	12 at 0'	5 at 25'	4 at 25'	
William	15 at 25'	11 at 0'*	5 at 25'	5 at 25'	
Yoke	7 at 25'		7 at 25'	2 at 25'	
Zebra	9 at 25'	8 at 0'*	5 at 25'	4 at 25'	
Alfa	9 at 25'		6 at 25'	5 at 25'	
Bravo	9 at 25'	8 at 0'*	13 at 25'	4 at 25'	

*Project 2.5b station readings

TABLE C.4 - Rad Safe Gamma Survey Readings After Shot 4

Island	Activity in mr/hr at Various Heights Above Ground					
	Days After Shot 4					
	0	1	2	4	6	8
Able		200 at 100'		2200 at 0'	2000 at 0'	2000 at 0'
Charlie		1100 at 100' 1100 at 0'*		2000 at 0'	1000 at 0'	500 at 0'
Dog	7000 at 200' 1800 at 500'	4000 at 100' 5000 at 25'	2000 at 25'	1000 at 0'	8000 at 0'	1000 at 0'
Easy		3000 at 100' 4000 at 100'	3200 at 25'	1000 at 0'	800 at 0'	250 at 0'
Fox		4000 at 100'	4500 at 0'* 3800 at 25'	2400 at 0'	700 at 0'	900 at 0'
George	3000 at 500' 8000 at 200'	3000 at 100'	3800 at 0'*	2000 at 0'	1300 at 0'	1000 at 0' 300 at 25'
How	9000 at 0' 2600 at 200' 1800 at 400'	3500 at 0' 1600 at 100'	1500 at 0'* 600 at 100'	800 at 0'	420 at 25'	320 at 0'
Item		1000 at 25'				
Jig	1000 at 200'	800 at 25'			240 at 0'	150 at 0'
King			140 at 25'	250 at 25'	100 at 0'	
Love		260 at 25'	180 at 0'* 140 at 25'	80 at 50'	100 at 0'	
Mike		100 at 25'	60 at 25'	60 at 50'	40 at 0'	27 at 0'
Nan	280 at 0' 240 at 25'	100 at 0'* 160 at 100'	50 at 0'	30 at 0'	20 at 0' 30 at 25'	24 at 0'
Oboe	18 at 0'	20 at 0'* 4 at 25'			2.6 at 0'	3 at 0'
Roger				4 at 0'		
Sugar		6 at 25'				4 at 0'
Tare	18 at 0' 6000 at 600' Crater	1600 at 100' Crater		2.6 at 0' 2000 at 25' Crater	5000 at 0' Crater	3000 at 25' Crater
Uncle		200 at 50'		100 at 0' 130 at 25'	38 at 25'	20 at 0'
Victor		13 at 0'* 3 at 25'		5 at 50'	2 at 0'	5 at 0'
William		8 at 0'* 5 at 25'			4 at 0'	8 at 0'
Yoke		8 at 25'		300 at 25'	20 at 0'	80 at 0'
Zebra		6 at 25' 8 at 0'*		280 at 25'	15 at 0'	8 at 0'
Alfa		18 at 25'		220 at 25'	12 at 0'	160 at 0'
Bravo		25 at 0' 6 at 25'		500 at 0'	15 at 0'	12 at 25'

* Project 2.5b Station Readings

TABLE C.5 - Rad Safe Gamma Survey Readings After Shot 5

Island	Activity in mr/hr at Various Heights Above Ground					
	Days After Shot 5					
	0	1	2	3	4	6
Able	800 at 500'					450 at 25'
Charlie	120 at 200'					500 at 25'
Dog		20,000 at 25'	1200 at 25'		2600 at 25'	1200 at 25'
Easy		3,800 at 25'	500 at 25'			700 at 25'
Fox		2,500 at 0'	600 at 25'		600 at 25'	600 at 25'
George	20,000 at 100'	5,000 at 0'	600 at 25'		500 at 25'	400 at 0'
How	18,000 at 200'	9,000 at 40'	3200 at 0'	2,600 at 15'	1400 at 25'	1400 at 25'
Item		2,600 at 25'	1100 at 25'	1,000 at 25'	40 at 50'	400 at 25'
Jig		4,100 at 25'	1400 at 25'	1,200 at 25'		
King		3,400 at 25'		1,000 at 25'		600 at 25'
Love			800 at 25'	1,000 at 25'		600 at 25'
Mike		2,600 at 25'	1100 at 25'	1,000 at 25'	240 at 100'	400 at 25'
Nan	8,000 at 25' 800 at 500' 3,400 at 100'	2,000 at 0'	180 at 25' 400 at 100'	500 at 0' 300 at 25'	100 at 5' 140 at 100'	220 at 25'
Oboe	5 at 0'	10 at 0'	6 at 25'	5 at 0'		
Sugar				5 at 0'		
Tare				1500 at 25' Crater		
Uncle	35 at 100'	4 at 0'	25 at 25'	60 at 25'		
Victor	30 at 100'	8 at 100'	15 at 25'			5 at 25'
William	30 at 100'	12 at 0'				10 at 25'
Yoke	200 at 100'	120 at 25'	160 at 25'			50 at 25'
Zebra		110 at 100'				40 at 25'
Alfa	200 at 100'	100 at 100'	250 at 25'			50 at 25'
Bravo		300 at 100'	300 at 25'			

TABLE C.6 - Rad Safe Gamma Survey Readings After Shot 6

Island	Activity in mr/hr at Various Heights Above Ground			
	Days After Shot 6			
	0	1	2	3
Alice	2200 at 100'	230 at 25' 700 at 0'*	300 at 0'	180 at 0'*
Belle		220 at 25' 400 at 0'*	180 at 25'	170 at 0'*
Clara		400 at 25'	180 at 25'	100 at 0'* (The water's edge at Clara read 3000 at 0'*)
Daisy		4000 at 25'	500 at 25'	
Edna		4000 at 25'	12,000 at 0' 2,000 at 25'	
Gene		3400 at 25'	3,500 at 25'	
Helen	1100 at 100'	110 at 25'	300 at 25'	
Irene	850 at 100'	60 at 25' 130 at 0'*	70 at 25'	40 at 0'*
Janet	350 at 100'	40 at 25' 90 at 0'*	70 at 25'	30 at 0'*
Kate	60 at 400'	24 at 25'	30 at 25'	
Lucy		20 at 25' 50 at 0'*	22 at 25'	
Mary		12 at 25' 30 at 0'*	14 at 25'	
Nancy	40 at 400'	11 at 25'	12 at 25'	
Olive	60 at 400'	8 at 25'	14 at 25'	
Pearl		6 at 25'	12 at 25'	
Ruby		11 at 25'	12 at 25'	
Sally		11 at 25'	10 at 25'	
Tilda	28 at 400'	7 at 25' 10 at 0'*	8 at 25'	
Ursula	22 at 400'	6 at 25'	10 at 0'	
Vera	12 at 400'	5 at 25'	4 at 25'	
Wilma	5 at 400'	3 at 25'	3 at 25'	
Leroy	2 at 100'			
Project 6.5 Barge	2.5 at 0'			

* Readings Taken at Project 2.5b Stations

APPENDIX D

TABLE D.1 - Liquid Fallout Collected in IFC Trays

Shot	Station	Time After Shot	Milli-liters	Shot	Station	Time After Shot	Milli-liters
1	Yoke	1 - 6 min	115	3	Victor	4 - 4½ hr	2
1	Yoke	6 - 11 min	225	3	Yoke	0 - ½ hr	3
1	Yoke	11 - 16 min	225	3	Yoke	½ - 1 hr	72
1	Yoke	16 - 21 min	30	3	Yoke	1 - 1½ hr	76
1	Yoke	116 - 121 min	63	3	Yoke	11½-12 hr	22
3	Dog	0 - ½ hr	13	3	Zebra	11½-12 hr	92
3	Easy	2 - 2½ hr	11	3	Alfa	0 - ½ hr	96
3	Easy	2½ - 3 hr	16	3	Alfa	½ - 1 hr	16
3	Easy	11½ - 12 hr	8	3	Alfa	11½-12 hr	14
3	Fox	11 - 11½ hr	3	3	Bravo	11½-12 hr	49
3	Fox	11½ - 12 hr	2	4	How	1½ - 3 hr	75
3	Oboe	0 - ½ hr	220	4	How	3½ - 5 hr	5
3	Oboe	½ - 1 hr	90	4	How	8 - 9 hr	250
3	Oboe	1 - 1½ hr	145	4	How	9 -10 hr	400
3	Oboe	1½ - 2 hr	6	4	How	10 -11 hr	275
3	Oboe	2 - 2½ hr	2	4	How	11 -12 hr	5
3	Oboe	11½ - 12 hr	205	6	Janet	0 - ½ hr	140
3	Uncle	0 - ½ hr	50	6	Janet	½ - 1 hr	140
3	Uncle	½ - 1 hr	22	6	Janet	11½-12 hr	27
3	Uncle	1 - 1½ hr	9	6	Mary	3½ - 4 hr	47
3	Uncle	1½ - 2 hr	20	6	Olive	0 - ½ hr	5
3	Uncle	3½ - 4 hr	4	6	Olive	½ - 1 hr	51
3	Uncle	4 - 4½ hr	20	6	Olive	1 - 1½ hr	4
3	Victor	2½ - 3 hr	5	6	Olive	11½-12 hr	13
3	Victor	3 - 3½ hr	31	6	Barge	10½-11 hr	170
3	Victor	3½ - 4 hr	12	6	Barge	11½-12 hr	17

APPENDIX E

PERSONNEL ROSTER

The following people participated in the project at the test site:

- Robert Beckelheimer
- Nicholas Capasso
- Pfc Harry Crawford
- Carl Crisco
- Lt Col Richard Entwhistle
- Pfc Donald Hamilton
- Luther Hardin
- J. P. Mitchell
- Pvt Louis Nidus
- Cpl Roger Stenerson
- Pfc Walter Tallon
- Edward Wilsey

In addition, groups from Projects 2.6b and 2.5a aided this project in the installation and maintenance of the 2.5b and 2.6b land stations and the 2.5b raft stations.

The following personnel carried out the activity and particle size analysis:

- Cpl William Andrews
- Pfc Arnold Berman
- Cpl Leonard Bird
- Henry Chambers
- Pfc John Daley
- Pfc Robert French
- Pfc Fletcher Gabbard
- Malcolm Gordon
- Phyllis Gordon
- Pfc Paul Grant
- Pfc Howard Holler
- Sgt Francis Holley
- Cpl John Kinch
- Pfc John Kish
- Pfc Paul Michael
- Cpl Dean Miller
- Dora Meyers
- Cpl Leroy Ornella
- David Rigotti
- Cpl James Sauers
- Murray Schmoke
- Pfc John Shewell
- Pfc Daniel Smith
- Robert Smith
- Martha Stickel
- Mayme Talbott
- Cpl Semour Tarras
- Pfc Harry West
- Cpl Bruce Whitlock

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