15204

WT-942 (EX)
EXTRACTED VERSION

OPERATION CASTLE

Radiological Safety

Pacific Proving Grounds
March-May 1954

Joint Task Force Seven

August 1954

NOTICE

This is an extract of WT-942, Operation CASTLE, which remains classified SECRET/RESTRICTED DATA as of this date.

Extract version prepared for:

Director
DEFENSE NUCLEAR AGENCY
Washington, D.C. 20305

1 April 1981

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER WT-942 (EX)	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Operation CASTLE - Radiological Safety		5. TYPE OF REPORT & PERIOD COVERED
		6. PERFORMING ORG. REPORT NUMBER WT-942 (EX)
7. AUTHOR(s) J. D. Servis		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Los Alamos Scientific Laboratory Los Alamos, New Mexico		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE August 1954
		13. NUMBER OF PAGES 68
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; unlimited distribution.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

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

Operation CASTLE
Radiological Safety
Film-Badge Calibration

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

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

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.

ABSTRACT

This report contains a description of the mission, responsibilities, organization, and activities of Tast Unit 7, the Radiological Safety Unit of Task Group 7.1 during Operation Castle. The chapters are devoted to a general discussion of the organization, activities, and recommendations of the scientific sections necessary to implement a thermonuclear test radiological-safety unit.

Appendixes and illustrations contain specific details of certain operational procedures, radiological situation data, and fall-out decay curves.

As a result of Rad-Safe operations during Castle, it was determined that contamination resulting from high-yield surface bursts creates radioactive hazards over such large areas that land-based operations at the Pacific Proving Grounds are in constant jeopardy. Water-surface detonations of thermonuclear devices created less of a radiological problem than ground-surface detonations; however, the most important factor in the over-all radiological situation was the disposition of the winds between 10,000 and 60,000 ft at the time of detonation.

PREFACE

Operation Castle must be reported as the nightmare of radiological-safety test operations. The extended nature of the operation in the presence of high-level contamination in the Bikini area of the Pacific Proving Grounds, the completely shipborne operation some distance from a supply base, the decentralized system of operational control, instrument-humidity difficulties, morale problems, and poor communications tend to make this documentation an excellent guide or source of information to personnel who may be detailed or ordered to organize or work with a similar organization in possible future operations of this nature.

This report cannot be rightly attributed to any one individual since it resulted from the wholehearted cooperation and efforts of all the personnel in the unit. Their work under extremely difficult working and housing conditions is to be commended.

ACKNOWLEDGMENTS

The Radiological Safety Unit wishes to acknowledge the generous cooperation and support of a number of organizations that assisted in the accomplishment of the radiological-safety program.

Health Division, Los Alamos Scientific Laboratory (LASL)
Task Group 7.2, Joint Task Force 7
Division of Biology and Medicine, Atomic Energy Commission (AEC)
1st Radiological Safety Support Unit, Chemical Corps Training Command, Ft. McClellan, Ala.
Supply and Property Department, LASL
Las Vegas Field Office, AEC
Eniwetok Field Office, AEC
Evans Signal Laboratory, Belmar, N. J.
J-Division, LASL
Office of the Chief Chemical Officer, Washington, D. C.
Holmes and Narver, Inc., Los Angeles, Calif.

The Unit wishes to express personal appreciation to the following individuals for their close support and constructive criticism throughout the planning, operational, and roll-up phases:

Thomas L. Shipman, Health Division, LASL
Thomas N. White, Health Division, LASL
Duncan Curry, Jr., J-Division, LASL
James Terrill, U. S. Public Health Service
William Kennedy, Health Division, LASL
P. R. Schiavone, Health Division, LASL

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CHAPTER 1

TASK GROUP ORGANIZATION FOR RADIOLOGICAL SAFETY

1.1 GENERAL

A radiological-safety unit, Task Unit 7 (TU-7), was continued from Operation Ivy to accomplish the missions and responsibilities of radiological safety for Operation Castle. TU-7 operated radiological-safety centers at Parry Island, at Eniwetok Island, and aboard ships at Bikini in the accomplishment of these missions.

The concept of operations for this test series caused a change of philosophy; consequently the Rad-Safe Unit became a technical service for unit and project officers and assisted the supervisory personnel by providing technical advice and training for project personnel designated as "monitors." This practice permitted the unit to reduce its personnel requirements by 50 per cent.

TU-7 was designated the radiation-safety organization for Task Groups (TG) 7.1 and 7.5, as well as the technical Rad-Safe Unit for Joint Task Force 7 (JTF-7).

1.2 TU-7 MISSION

By direction of paragraph 1c, Annex F to Commander, Task Group 7.1 (CTG-7.1), Operation Plan No. 1-53, the Commander was to provide for:

1. Radiological protection of TG-7.1 and TG-7.5 personnel.
2. Maintenance of operational efficiency for TG-7.1 and TG-7.5 in the presence of radiological hazards.
3. Technical assistance to task force and task group commanders, program directors, and project leaders on nonmedical matters pertaining to radiological safety.

1.3 TASK UNIT RESPONSIBILITIES

To effect accomplishment of the above mission, the Commander, Task Unit 7 (CTU-7), performed the following tasks:

1. Organized and commanded a radiological-safety unit.
2. Supervised all ground-monitoring services associated with scientific missions, which included monitoring of water supplies at inhabited distant atolls and establishing suitable tables of allowable residual radiation levels for equipment, personnel, vehicles, boats, etc.
3. Furnished laboratory services and technical assistance to all task groups, including:
   a. Procurement, storage, and issuance of film badges and specified items of radiological-safety personal equipment.

b. Development and interpretation of exposed film badges.
c. Maintenance of film-badge exposure records.
d. Provision of facilities at the Parry Island Rad-Safe Center and aboard the USS Bairoko for calibration, repair, and maintenance of monitoring instruments and for storage and issuance of spare radiac-equipment parts.

4. Procured radiological-safety clothing for JTF-7 personnel.
5. Procured and issued special high-density goggles to specified personnel of JTF-7.
6. Provided decontamination facilities for personnel and equipment.
7. Conducted laboratory studies to determine the nature of radiological hazards.

1.4 UNIT ORGANIZATION

The organizational chart for TU-7 is shown in Fig. 1.1.

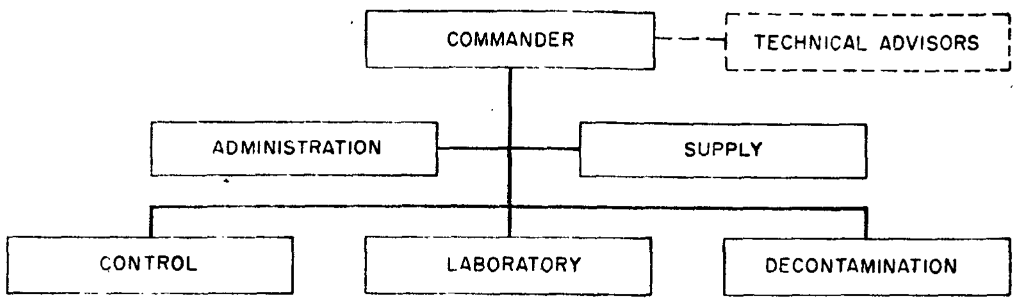


Fig. 1.1 TU-7 organizational chart.

Two radiological-safety centers were established for Operation Castle, one at Parry Island and one aboard the USS Bairoko in the Bikini lagoon. Each center was equipped so as to accomplish the unit mission independently. TU-7 personnel were transferred freely between the two centers, according to the radiological situation and the extent of personal exposure.

Subcenters of the Bikini Rad-Safe Center were established aboard a barge adjacent to the USNS Ainsworth, aboard the USS Curtiss, and aboard the USS Estes. These substations acted primarily as control and personnel-decontamination points for TG-7.1 and TG-7.5 projects.

Since the establishment of subcenters had not been anticipated in the preliminary personnel-procurement planning, TU-7 personnel were very thinly scattered throughout. This extension of personnel reduced the effectiveness of TU-7 in some areas but permitted decentralized and controlled recovery operations.

Communications between the Bairoko Rad-Safe Center and the subcenters were maintained through the task group administrative net and a special frequency Rad-Safe net. These nets permitted direct communication between control points and the dosimetry record unit aboard the USS Bairoko.

1.5 CONCLUSIONS AND RECOMMENDATIONS

1.5.1 Conclusions

1. The organization for radiological safety at Operation Castle was adequate in structure but inadequate in number of personnel.

2. The responsibilities of procuring, developing, and interpreting film badges and the maintenance of film-badge exposure records should be delegated to the individual task groups.

3. The responsibility of providing special high-density goggles should be delegated to the various task group supply sections.

1.5.2 Recommendations

1. The task force should incorporate within the Operation Plan the directives that each task group will be responsible for its dosimetric program and records and that the methods of dosimetry will be specified in a task force standing operating procedure.
2. The task force should direct each task group to be responsible for the procurement of adequate numbers of special high-density goggles.

CHAPTER 2

PROCUREMENT OF PERSONNEL

2.1 SOURCES OF PERSONNEL

As in the past, primary sources for technically qualified health physics personnel are the Health Division, Los Alamos Scientific Laboratory (LASL) and special organizations within the Department of Defense. In the interim period between Ivy and Castle, the Department of the Army authorized the Chief Chemical Officer to establish the 1st Rad-Safe Support Unit (RSSU) with a mission of supporting test operations at the Nevada and Pacific Proving Grounds. This organization was established at the Chemical Corps Training Command, Ft. McClellan, Ala., in the summer of 1953. This activity provided the bulk of Army personnel for TU-7.

The technically trained Navy personnel were provided from the National Naval Medical Center; Special Weapons Unit, Pacific Fleet; Sandia Base, Armed Forces Special Weapons Project (AFSWP); and the Naval Radiological Defense Laboratory. One Marine Corps noncommissioned officer was obtained from the second Marine Division, FMF.

2.2 METHOD OF PROCUREMENT

In January 1953, TU-7 advised the J-1 Section of an anticipated personnel requirement of 86 enlisted men and 14 officers. After a conference with the Scientific Deputy and the Task Group Commander, a revised personnel request was submitted late in March 1953 for 36 enlisted men and 12 officers. This reduction in personnel was directed by the adoption of a policy in which:

1. Training programs would be initiated by the Task Group Rad-Safe Officer to qualify program and project personnel in radiological-safety principles and techniques of monitoring.
2. Consolidation of the radiological-safety organizations of TG-7.1 and TG-7.5 would be accomplished.
3. An increase of the military-support mission of CTG-7.2 would be made so that the following services could be provided to TG-7.1 and TG-7.5: (a) Support of the over-all radiological-safety program by training and providing radiological-safety monitors as needed and (b) support of the over-all radiological-safety program by training and providing decontamination personnel as needed.

In early April JTF-7 was requested by CTG-7.1 to procure from the military services, prior to 1 September 1953, 1 executive officer, 7 control officers, 4 laboratory officers, 10 monitors, 4 laboratory technicians, 8 photodosimetry technicians, 4 radiological-instrument repairmen, 3 supply clerks, 1 supply sergeant, and 6 clerk-typists.

In mid-August the 1st RSSU received its first notice of TU-7 personnel requirements. This created a strain on the organization since the RSSU had only nine men available for duty.

Additional difficulties were being encountered by the release of experienced men from the military service. In spite of these difficulties 2 officers and 28 enlisted men were designated by 1 September for clearance and assignment to TU-7. The Navy (Op-36) received notice and initiated action in the latter part of August. The Air Force declined to participate in the operation.

Orders for 1st RSSU personnel were issued by the Chemical Corps Training Command in October 1953. Orders for three radiological-safety engineers were issued by the Army Chemical Center in November 1953. Orders for Naval personnel were issued by the Chief of Naval Personnel in October 1953.

CTU-7, through invitation, secured the services of three LASL health physicists as technical advisors.

Owing to staff delays in the procurement of military personnel, the unit performed its mission with a shortage of 3 control officers, 1 laboratory officer, and 1 photodosimetry technician. The last-minute deletion of the 3 control officers materially hampered the effectiveness of TU-7 in its extended decentralized system of controlled recovery operations and required the utilization of the supply and laboratory officers in secondary control functions.

2.3 DESIRABLE QUALIFICATIONS

In the procurement of personnel on a temporary-duty basis, little time is allotted to qualify individuals in a selected occupation, and therefore procurement must consider certain qualifications in the selection of individuals for assignment to the Rad-Safe Unit.

2.3.1 Control Officer

The Control Officer serves as an adviser and technical expert on all matters pertaining to the nonmedical aspect of radiological contamination. He assists project leaders in recovery plans for test equipment, performs surveys of areas subjected to radiological contamination, controls entry of personnel to contaminated areas, and assists in the control of radiological hazards. He is best qualified by excellent performance in atomic-defense schools and by experience in previous test operations.

2.3.2 Laboratory Officer

The Laboratory Officer supervises the assembly of technical information from radioanalysis of radioactive material in order to assist the commander in the establishment of the true radiological hazards. He supervises the processing of film badges and the maintenance and repair of radiation-detection instruments. The Laboratory Officer is best qualified by having civilian or military health physics experience in laboratories handling radioactive materials and by having extensive nuclear physics training.

2.3.3 Rad-Safe Monitor

The Rad-Safe Monitor performs surveys of areas subjected to radiological contamination, advises personnel of the nature and the extent of hazards to be encountered in contaminated areas, procures protective equipment and dosimetric devices for individuals entering contaminated areas, requires the proper use of protective clothing and equipment, supervises personnel-decontamination procedures, and accomplishes equipment decontamination. He is best qualified by satisfactory completion of an atomic-defense school and/or by previous experience at test operations.

2.3.4 Laboratory Technicians

Laboratory technicians are selected personnel, especially trained in nuclear analyses and radiation measurement, who perform routine operations in laboratories that are assigned these functions. The best qualifications are experience in civilian or military laboratories and commensurate educational background.

2.3.5 Photodosimetry Technicians

Photodosimetry technicians are specialized photographic laboratory technicians who are skilled in the development of dental x-ray film, operation of film-density meters, and interpretation of readings. The best qualification is laboratory or test experience in photodosimetry.

2.3.6 Radiological-instrument Repairman

The radiological-instrument repairman installs, inspects, tests, calibrates, maintains, and repairs all types of radiological-detection instruments. He is best qualified by laboratory or test experience in radiac-instrument repair and/or by training in military instrument-repair courses.

2.4 CONCLUSIONS AND RECOMMENDATIONS

2.4.1 Conclusions

1. The present system of personnel procurement for temporary duty is unsatisfactory since screening of personnel prior to selection is not practiced.
2. Slow staff action in the procurement of personnel delays security clearances, as well as the effective organization and training of unit personnel.

2.4.2 Recommendations

1. The task unit commander should interview and select personnel to be placed on temporary duty with the unit prior to the issuance of orders.
2. The task unit should request early authority to deal directly with organizations furnishing personnel.

CHAPTER 3

TRAINING AND INDOCTRINATION

3.1 PROJECT MONITOR SCHOOLS

In accordance with the expressed policy of the CTG-7.1, a series of schools was established to qualify project and Holmes and Narver (H&N) supervisory personnel as radiological-safety monitors. Three schools were conducted: one at the Nevada Proving Ground early in November 1953; one at Eninman Island, Bikini Atoll, in the middle of February 1954; and one at Parry Island, Eniwetok Atoll, in early April 1954. About 200 individuals were qualified as radiological-safety monitors as a result of these schools. Comparable training sessions were conducted by the health physics organizations of Edgerton, Germeshausen & Grier (EG&G); University of California Radiation Laboratory (UCRL), Livermore Site; and the U. S. Naval Radiological Defense Laboratory.

The first and best attended school was a three-day instruction course at the Nevada Proving Ground. The plan of instruction was practical in nature and consisted of field exercises and problems of monitoring in radiologically contaminated areas. Exercises and problems were of 2- or 4-hr duration and were handled in a "county fair" system of instruction with 12 individuals in each instructional group. The eight sessions were as follows:

1. Dosimetry: An exercise designed to familiarize the student with film badges and pocket dosimeters as radiation-dosage measuring devices and to give the student practice in charging, reading, and determining the correction factor on these dosimeters.
2. Calibration of ion-chamber type survey meter: An exercise designed to teach the student the operation, use, and calibration of an ion-chamber type survey meter.
3. Calibration of Geiger-Mueller type survey meter: An exercise designed to teach the student the operation, use, and calibration of the Geiger-Mueller type survey meter.
4. Shielding properties of common materials: An exercise to teach the effect of various absorbers of gamma radiation by determining the absorption coefficient and half thickness of different absorbing materials.
5. Organizational maintenance of instruments: An exercise designed to acquaint the student with the basic concepts of maintenance and to present some of the details of maintenance applicable to the Geiger-Mueller counter and ion-chamber type instruments.
6. Decontamination: An exercise designed to familiarize the student with some of the methods used in the decontamination of radiologically contaminated materials by having the students employ a few of these methods and make comparisons of the results.
7. Field monitoring: An exercise designed to allow students to practice monitoring of large contaminated areas and to plot isointensity lines by comparing the results of rapid and detailed surveys.
8. Problems: A session organized to introduce the student to the calculations necessary for the solution of dosage and time-of-stay problems through the use of radiation-calculator slide rules and tables.

Prior to the exercises an examination on the fundamentals of radiological safety was given to the class to determine the level of instruction to be conducted. These fundamentals included:

1. Radioactivity.
   a. Concept of radioactivity resulting from atomic detonations.
   b. Definition of the following terms: radiation, alpha particle, beta particle, gamma radiation, decay, fission, curie, roentgen, milliroentgen per hour, radiation intensity, and attenuation.
   c. Range and energy relations of fission-product radiations.
2. Biological effects.
   a. Concept of ionization.
   b. External and internal radiation hazards.
   c. Radiation dosages.
      (1) Lethal (acute and chronic).
      (2) Probable early effects of acute radiation dosage over the whole body.
      (3) Local effects, beta-ray burns.
      (4) Symptoms of radiation sickness.
3. Recognition of radiation hazards.
   a. Methods of detection of nuclear radiation by film, crystal, ionization, and heat.
   b. Survey meters.
   c. Pocket dosimeters.
   d. Photographic film badges.
4. Protection of personnel from radiation hazards.
   a. Shielding characteristics of materials.
   b. Control of radiation dosage.
   c. Clothing and equipment.
   d. Decontamination facilities.
   e. Safety indoctrination.

A prerequisite for attendance at the school was a reading knowledge of the foregoing fundamentals.

Instructors for the conduct of the initial course were provided by the Health Division, LASL; UCRL; EG&G; 1st RSSU; and JTF-7.

The second and third schools at Bikini and Eniwetok were attended by much smaller groups and received a one-day condensed version of the afore-mentioned exercises. These secondary courses were considered only as emergency supplementary instruction and left much to be desired in the qualification of monitors. Instructors for these schools were obtained from TU-7 personnel.

3.2 UNIT SPECIALIST TRAINING

The lack of continuity in operations and the loss of experienced personnel between operations necessitated the establishment of a program of training for unit specialists, i.e., laboratory technician, photodosimetry technician, and radiological-instrument repairman. Schooling for instrument repairmen was arranged through JTF-7 and AFSWP at the U. S. Naval Schools, Treasure Island, San Francisco. This technical schooling consisted of one month of instruction in the maintenance and repair of military radiac instruments. All the unit repairmen were graduates of this school.

Special arrangements were made with the Nucleonics Branch of the Signal Corps Engineering Laboratories to conduct familiarization courses with mobile field laboratories for the laboratory and photodosimetry technicians. Photodosimetry technicians attended a one-week special course and laboratory technicians attended a two-week special course at Evans Signal Laboratory early in October 1953.

3.3 TASK GROUP INDOCTRINATION

The misconceptions of radiation hazards that are retained by the average individual make a reasonable approach to radiological safety difficult. The need for an over-all indoctrination of TG-7.1 and TG-7.5 personnel became apparent early in the planning of the radiation-safety program. The objective of this indoctrination was to inform everyone of the nature of the hazard in order that operational efficiency might be maintained in the presence of radioactive materials. The first step in the indoctrination was the presentation of a series of films at the motion-picture theater. These films, shown on all screens at Bikini and Eniwetok, covered the basic physics of an atomic bomb, effects of an atomic-bomb explosion, self-preservation in an atomic-bomb attack, and the medical aspects of nuclear radiation. The viewers appreciated this informal form of instruction and retained the fundamental knowledge throughout the operation.

The second step was a series of informal discussions of the radiation-safety program between task unit personnel, representatives of H&N supervisory personnel, helicopter pilots, and H&N laundry personnel. In all cases these discussions improved relations with the various organizations.

3.4 PUBLICATIONS

An effective radiological-safety operation would be a test operation in which all participants understood the fundamentals of the program of protection from radioactivity. An initial effort to accomplish this objective was made in the summer of 1953 through the assemblage of a publication called the "Field Monitors Manual." The origin of this thought is attributed to the publication of the LASL Health Division handbook entitled "General Monitoring Handbook." Wide dissemination of the information in the manual was encouraged in order that all members of the operation might perform their appropriate duties without fear and with maximum safety.

The manual covered the concept of radioactivity, fission products, and characteristics of bomb debris. A chapter on health hazards discussed chemical and biochemical effects of direct ionization, impairment of health by radiation, and maximum permissible concentrations of fission products and alpha emitters in air and water. A third presented radiation detectors, with sections on theory, ionization chambers, and dosimetry. A fourth chapter covered general monitoring, aerial survey, water monitoring, and alpha and neutron monitoring. The final chapter, on decontamination, discussed the nature of radioactive contamination and the general principles of decontamination, i.e., removal of radioactive dust, surface washing, chemical solution, and procedures for the decontamination of fission products from surfaces of steel, wood, plastic, and skin.

Appendixes of the manual presented the radiological-safety plan and regulations, summary of responsibilities, monitor's check list, and glossary of terms.

To continue contact with the scattered project monitors, the Unit also published a series of radiological-safety bulletins covering protective techniques for laboratory workers, clearance procedures, and administrative notes for record maintenance.

This practice of dissemination of information through publication proved most essential in the widely decentralized operations of Operation Castle.

3.5 CONCLUSIONS AND RECOMMENDATIONS

3.5.1 Conclusions

1. Radiological-safety indoctrination must be carried to all levels so long as the possibility of exposure of all personnel exists. Too many fundamental decisions may be affected by improper concepts of radiation hazards.

2. Training project personnel as monitors proved more satisfactory than training separate military personnel for this purpose.

3.5.2 Recommendations

1. Indoctrination publications on radiological safety should be prepared for distribution to all participants in test operations so that they may be properly informed in the performance of this safety aspect of their individual and command responsibilities.

2. The policy of project responsibility and monitoring should be continued in operations involving large areas of contamination.

CHAPTER 4

CONTROL GROUP

4.1 FUNCTIONS

The Control Group was organized to provide for the radiological safety of all personnel entering the contaminated area. This group was established at several centers to act as operations station for all radiological-safety activities. Radiological situation data were gathered at this station, and information required by monitors was maintained in the form of memoranda or situation maps. These situation maps depicted the radiological conditions on all islands and lagoon areas. The maps delineated the areas cleared by the radiological-safety organization, as well as those areas requiring monitor escort.

Control stations maintained operations tables giving details on all missions into contaminated areas scheduled for each day, including names of monitors, destination, general type of mission, time of departure, time in contaminated area, and previous radiological exposure of the party. These stations also constituted the clearance station for all working parties prior to entry in the contaminated area.

The Control Officer accompanied the Commander of the Task Group on an initial damage and radiological survey to determine the reentry time for JTF-7 to return to the lagoon, as well as the recovery date and the time for scientific projects. The Control Officer supervised the conduct of ground and aerial surveys in order to evaluate the hazards that would be encountered by recovery parties working in the lagoon or on the islands. In several cases he posted monitors on lightly contaminated islands to advise working parties of exposures that could be expected at various places and to make sure that all workers had proper equipment. He ensured that all working parties entering moderately or heavily contaminated areas were accompanied by a trained monitor.

4.2 ORGANIZATION

The Control Group was reorganized with the changing concepts of operation. Initially, control stations were planned to operate at Parry, Eninman, and Enyu islands as soon as reentry was accomplished. Destruction and contamination required the establishment of stations at the following locations:

1. Forward ready room, USS Bairoko.
2. Rad-Safe barge alongside the USNS Ainsworth.
3. J-1 office, USS Curtiss.
4. J-1 office, USS Estes.
5. Rad-Safe Building, Parry Island.

Decentralization of TG-7.1 operations was accomplished shortly after BRAVO to accelerate recovery and reinstallation activities. This decentralization resulted in the Bairoko becoming the center for helicopter entries and exits from contaminated areas, the Ainsworth the center for small boat entries and exits from contaminated areas, the Curtiss the base for entries and exits to device barges and scientific houseboats, and the Estes the information center and entry and exit point for the Commander and his staff. The Rad-Safe Building on Parry was the control station for scientific activities at Eniwetok Atoll.

Each of the control stations was staffed by a control officer, a clerk, and a pool of monitors. These monitors acted as reserve monitors in case recovery or construction parties were unable to furnish a trained monitor.

Communications were maintained between Bikini stations by means of the administrative radio net and a special Rad-Safe net. Contact with helicopter survey and recovery parties was established through ship to plane radio circuits.

4.3 SURVEY RESULTS

Initial aerial surveys were conducted at approximately H+4 hr. This procedure was followed since experience had indicated that initial fall-out would continue through this period. Land and lagoon areas were examined from a helicopter flying at altitudes between 50 and 1000 ft.

4.3.1 BRAVO

A partial radiological-safety survey was conducted on BRAVO day. Results of this initial survey were conclusive enough to cancel all activities except those of an emergency nature for BRAVO & BRAVO + 1 DAY. Intensities ranging as high as 600 r/hr were encountered approximately 7 nautical miles east-northeast of Ground Zero (GZ) at H+4 hr. Other readings of 125 r/hr at 20 nautical miles east-southeast of GZ were encountered at H+4 hr. An analysis of this and succeeding results (Fig. 4.1) indicated that the bulk of active fall-out moved in a spreading pattern from 60 to 100 deg east of north.

Lagoon contamination, of consequence, was confined to lagoon areas containing suspended sediment. For the first few days this area was confined to the western quarter of the lagoon. This radioactive sediment washed over the western reef, out through the southwest passage, or settled to the bottom of the lagoon in a period of three days. At no time was the anchored fleet hazarded by the movement of contaminated water.

Succeeding surveys revealed a drifting of activity. The absence of rain prevented the leaching of fine particulates; consequently activity tended to decrease on the windward side of obstacles and to increase in the lee of buildings and bunkers. Surveys also indicated the presence of very low energy radiation. In many cases a thin liquid layer completely absorbed the radiation. Tents provided measurable protection, whereas intact bunkers provided complete protection. Individuals were able to work extended periods in bunkers in high-intensity areas with little exposure.

The USS Bairoko, approximately 38 miles southeast of the shot site, reported a fall-out of 20 mr/hr at 0804M, BRAVO DAY, and a maximum reading of 1000 mr/hr was reported on the flight deck at 0815M.

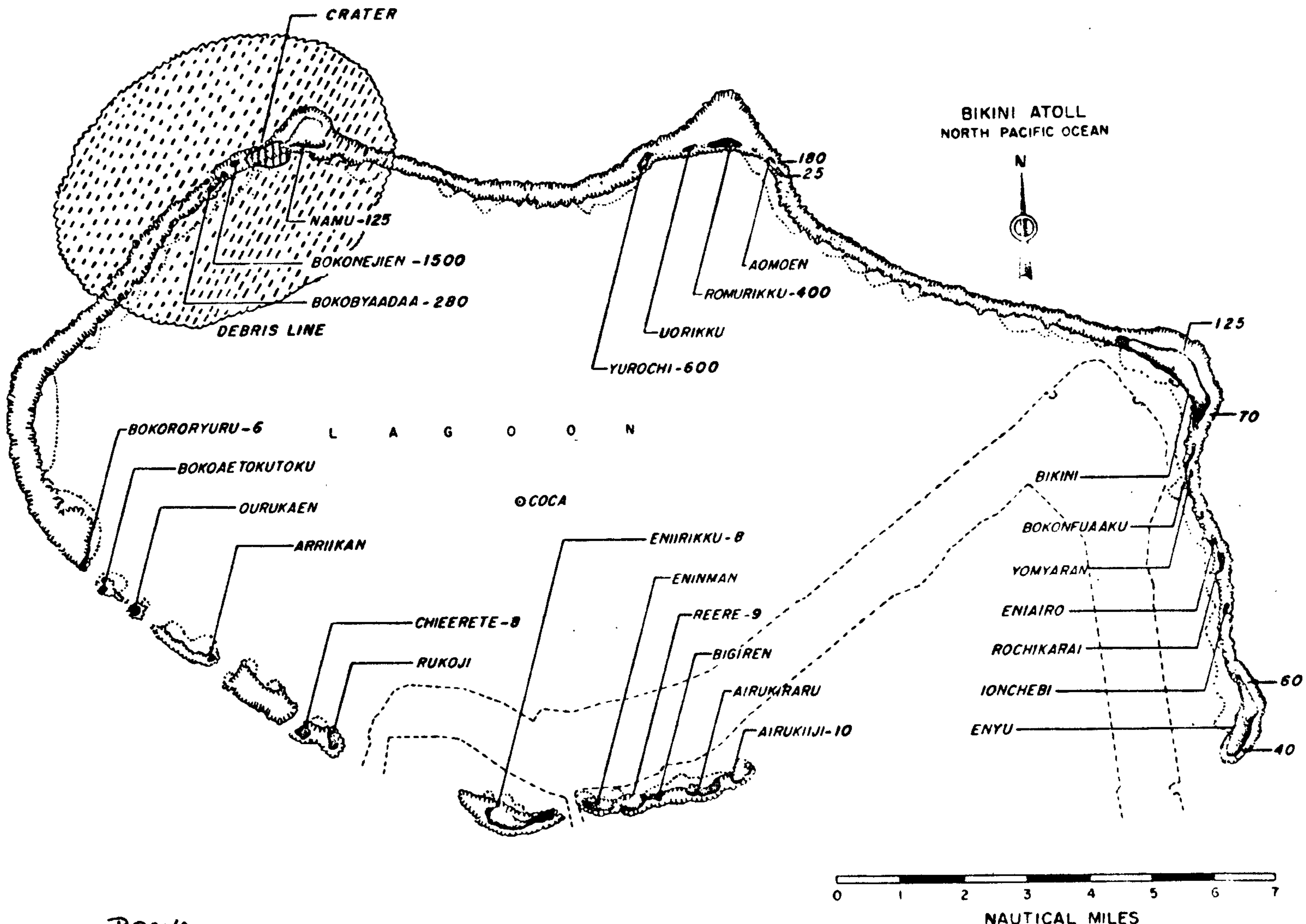
Eniwetok Atoll reported a maximum fall-out of 3 to 4 mr/hr at 1015M, BRAVO DAY

Survey parties from the USS Philip found radiation intensities to be 1.5 r/hr at Rongelap Island, Rongelap Atoll (100 nautical miles east-southeast of GZ) at 03/1045M; 3.0 r/hr at Eniaetok, Rongelap Atoll (100 nautical miles east-southeast of GZ) at 03/1245M; 0.45 r/hr at Enibuk Island, Ailingnae Atoll (75 nautical miles southeast of GZ) at 03/1545M; and 0.41 r/hr at Sifo Island, Ailingnae Atoll (70 nautical miles southeast of GZ) at 03/1715M.

Survey parties from the USS Renshaw reported 0.1 r/hr at Utirik Island, Utirik Atoll (275 nautical miles east-southeast of GZ) at 04/1000M.

Intensities of 0.1 r/hr were reported from Rongerik Island, Rongerik Atoll (140 nautical miles east-southeast of GZ) at 17/1200M by survey parties of TG-7.4.

Task force parties reported intensities of 0.003 r/hr at Likiep Island, Likiep Atoll (270 nautical miles southeast of GZ) at 06/0800M; 0.003 r/hr at Jemo Island (270 nautical miles southeast of GZ) at 06/1100M; 0.005 r/hr at Ailuk Island, Ailuk Atoll (300 nautical miles east-



BRAVO

Fig. 4.1— Irradiation intensities in roentgens per hour extrapolated to H + 4 hr. Location, on reef 2950 ft; bearing, 250 deg true from southwest tip of Namu. Yield, 15 Mt. Time fired, 01/0645M March 1954.

southeast of GZ) at 06/1600M; 0.005 r/hr at Mejit Island (350 nautical miles east-southeast of GZ) at 07/1300M; 0.003 r/hr at Ormed Island, Wotje Atoll (320 nautical miles southeast of GZ) at 05/1600M; 0.001 r/hr at Erikub Island, Erikub Atoll (320 nautical miles southeast of GZ) at 05/1715M; 0.002 r/hr at Kaven Island, Maloelap Atoll (365 nautical miles southeast of GZ) at 06/1130M; 0.001 r/hr at Wotho Island, Wotho Atoll (100 nautical miles south-southeast of GZ) at 06/1615M; 0.0004 r/hr at Uliga Island, Majuro Atoll (440 nautical miles southeast of GZ) at 07/1200M; and 0.160 r/hr at Bikar Island, Bikar Atoll (290 nautical miles east-northeast of GZ) at 09/1200M.

4.3.2 ROMEO

Results of the initial ROMEO radiological-safety survey indicated no extensive recontamination except within the Bokobyaadaa–Namu chain. Slight recontamination occurred within the remainder of the Atoll. Intensities of 1000 to 2000 r/hr could have been encountered in the crater area (Fig. 4.2).

A secondary fall-out occurred the night of ROMEO +1 day in the southern islands of the Atoll and aboard the ships anchored off Eninman. This fall-out is shown in Figs. 4.3, 4.4, and 4.8 in the late radiation peaks of the interval. Intensities leveled off between 0700 and 0800 on ROMEO +2 days with residual topside levels on the Ainsworth at 8 mr/hr, the Estes at 12 mr/hr, and the Bairoko at 30 mr/hr, whereas intensities on the adjacent islands were increased by 100 mr/hr.

The western quarter of the lagoon was recontaminated by radioactive sediment with radiation levels comparable to those of BRAVO. The flushing of lagoon waters through the southwest passages materially increased background radiation levels in the vicinity of Ourukaen, Bokoaetokutoku, and Bokororyuru.

The USS Epperson, at a position 18 miles north-northwest of Enyu anchorage, reported a fall-out of 100 mr/hr at 27/2030M March 1954.

Eniwetok Atoll experienced a light fall-out of radioactive material on ROMEO +1 day. This fall-out peaked at about 9 mr/hr at approximately 30/1200M (Fig. 4.9). No significant fall-out was reported from areas outside the Pacific Proving Grounds.

4.3.3 KOON

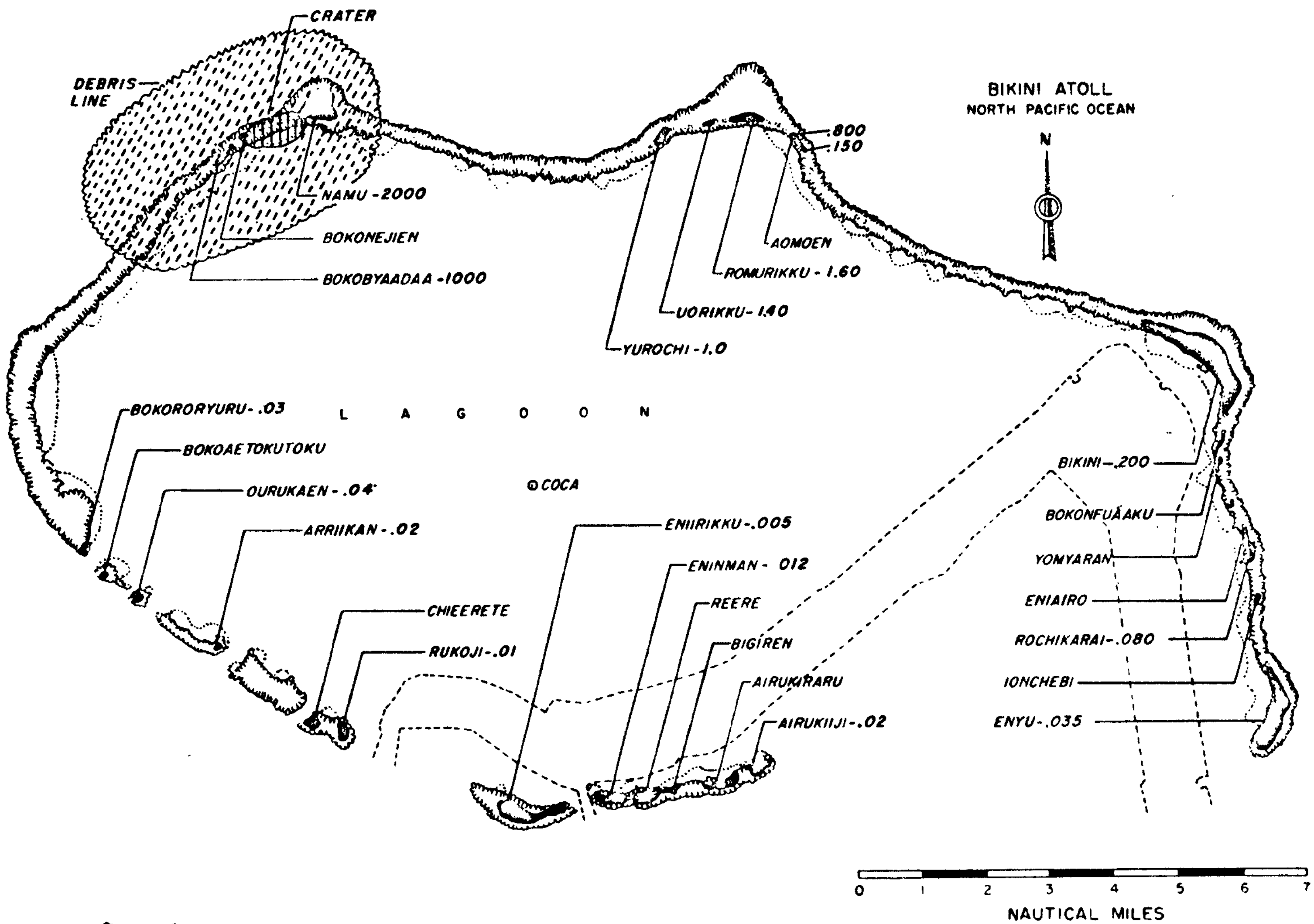
The initial radiological-safety survey was able to determine that Bokobyaadaa, Namu, Eniirikku, and Bikini islands and the Yurochi–Aomoen chain of islands were materially contaminated by the KOON detonation (Fig. 4.10). The lagoon survey indicated contaminated waters spreading north from the crater. Consequently all the lagoon northwest of a line between Airukiiji and Bikini was considered contaminated to an extent that would require radiological-safety control within the first few days.

KOON crater was materially different in size and surrounding intensities from that of BRAVO and ROMEO. With the exception of size and water in the crater, there was much similarity to the crater of the Jangle surface burst. Small sand dunes surrounding the crater were extremely radioactive. These dunes were later washed away by wave action from UNION and the revised

Rain squalls shortly after detonation were instrumental in the removal of contamination from equipment and islands. No significant fall-out was reported by land areas outside the Pacific Proving Grounds.

4.3.4 UNION

The initial survey of the Atoll indicated that recontamination was limited to the Yurochi–Aomoen and the Bikini–Enyu sequence of islands (Fig. 4.11). Waters of the north central portion of the lagoon were materially contaminated in a rough circular pattern about 3 miles in diameter. Readings of 4.2 r/hr were obtained at an altitude of approximately 500 ft above GZ. This contamination settled with time, and therefore a layer of maximum contamination could be found at a 60-ft depth 30 hr after detonation. Surface contamination moved to the west and southwest, flushing over the western reef and through the southwest passages.



ROMEO

Fig. 4.2— adiation intensities in roentgens per hour extrapolated to H + 4 hr. Location, barge in crater of Yield, 11 Mt
Time fired, 27/0630M March 1954.

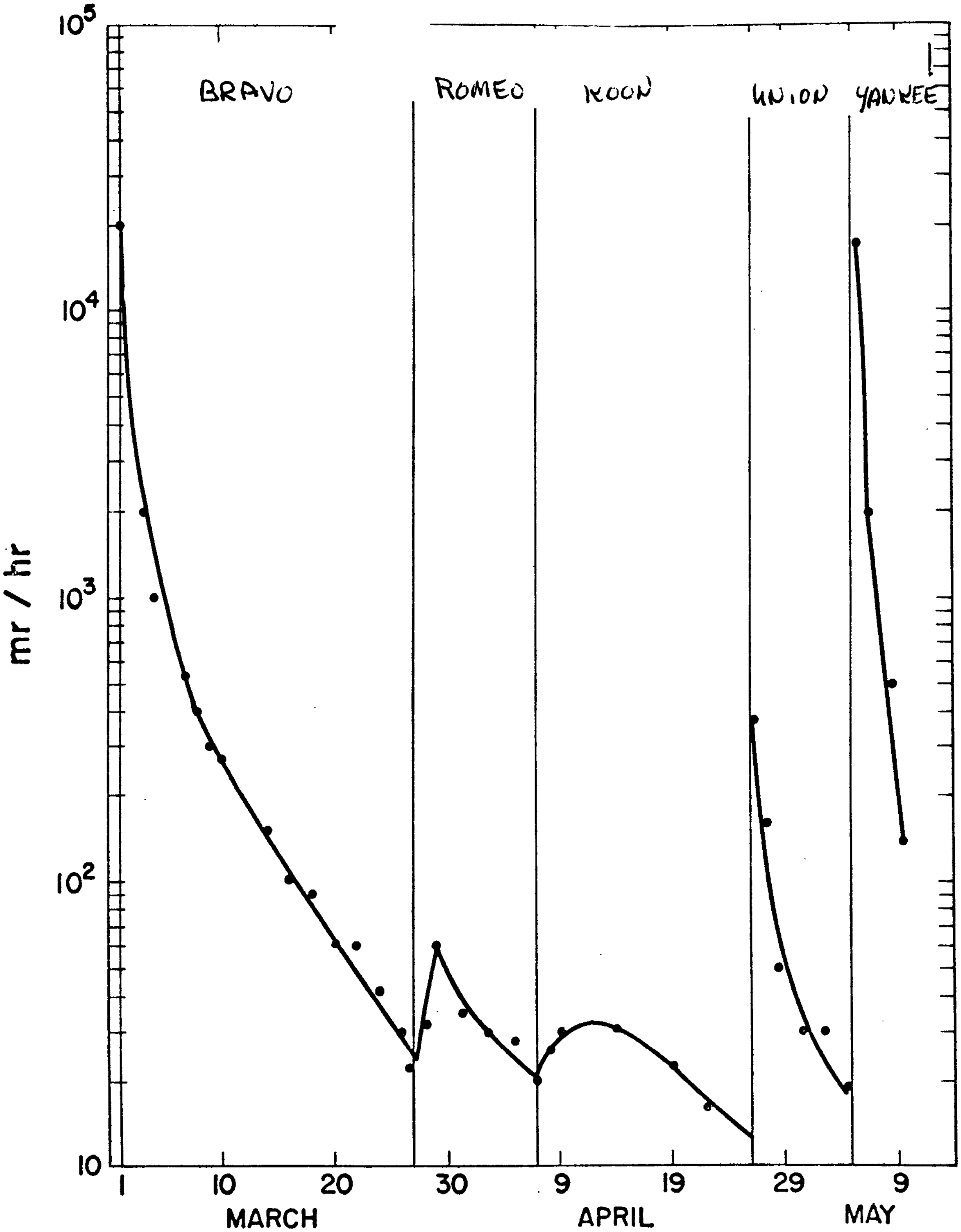


Fig. 4.3 — Fall-out record, Enyu.

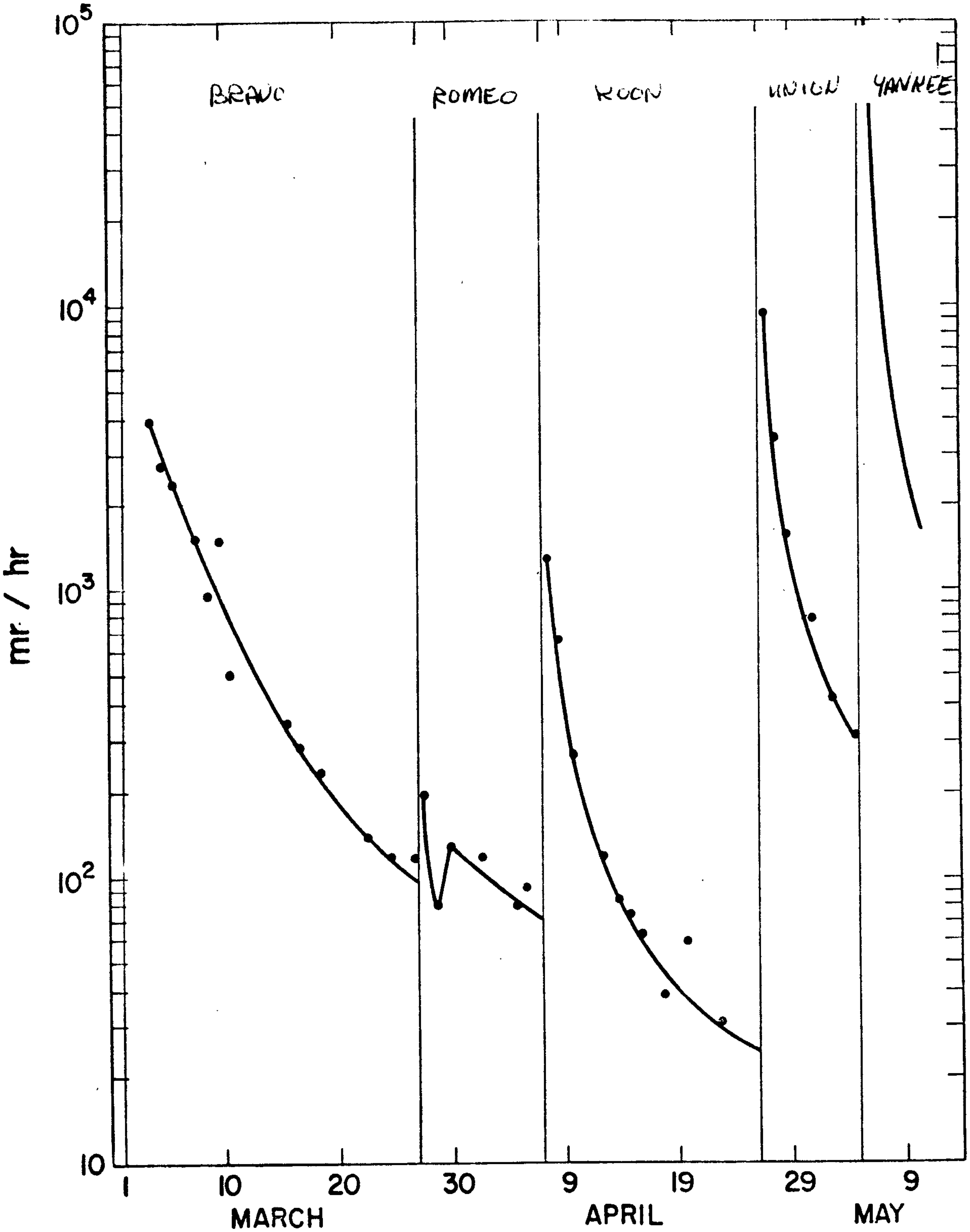


Fig. 4.4—**Fall-out record, Bikini.**

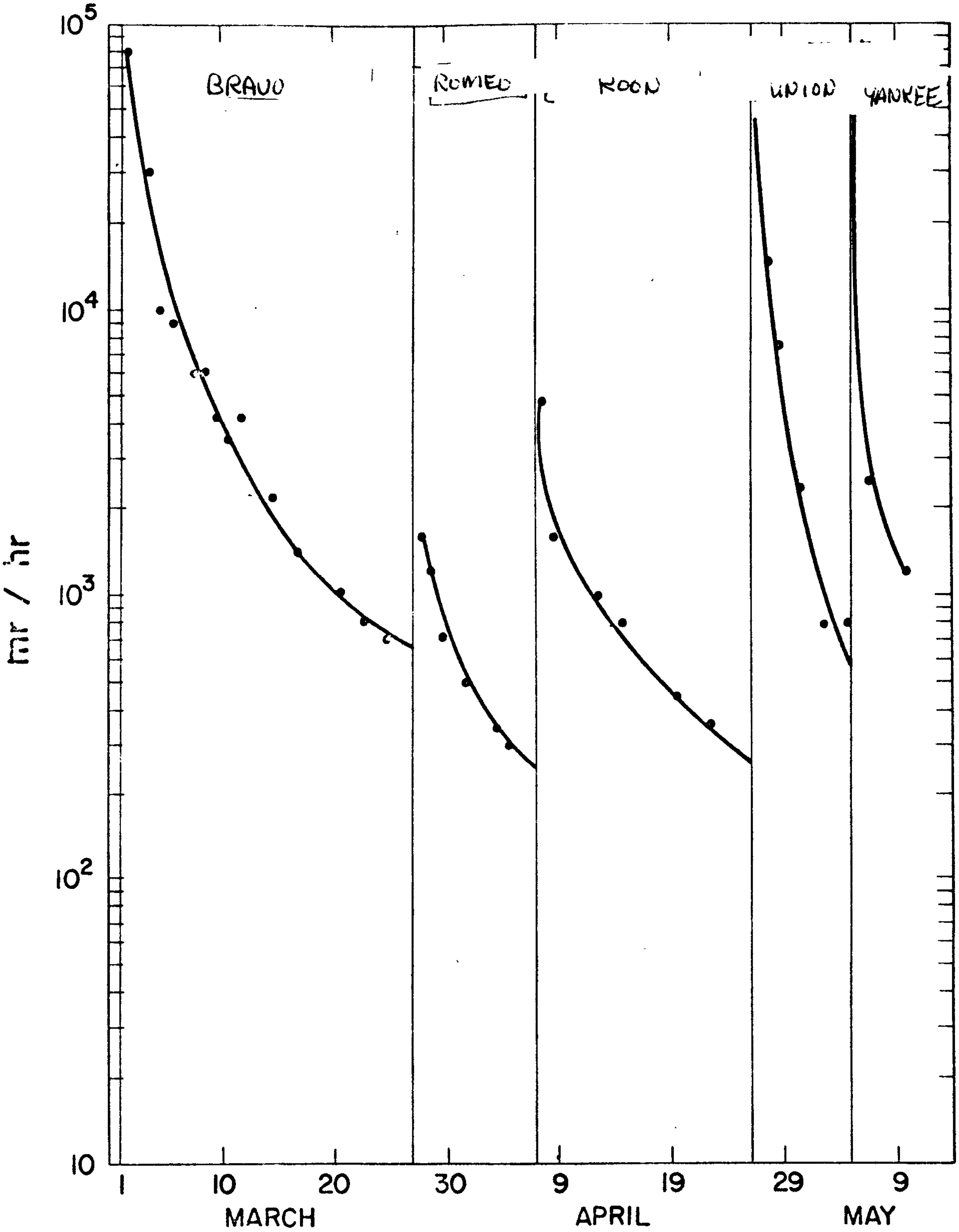


Fig. 4.5—Fall-out record, Romurikku.

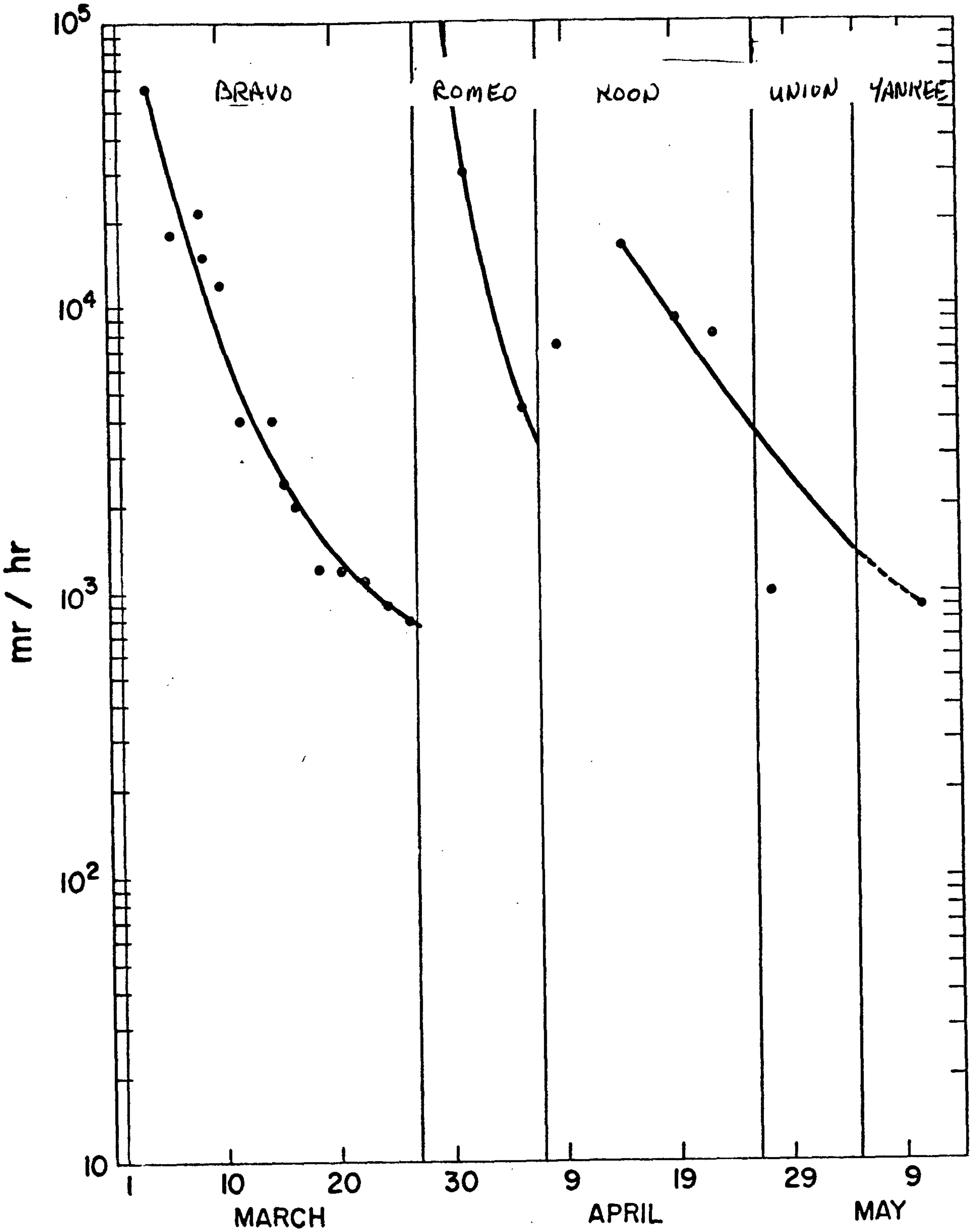


Fig. 4.6—Fall-out record, Bokobyaadaa.

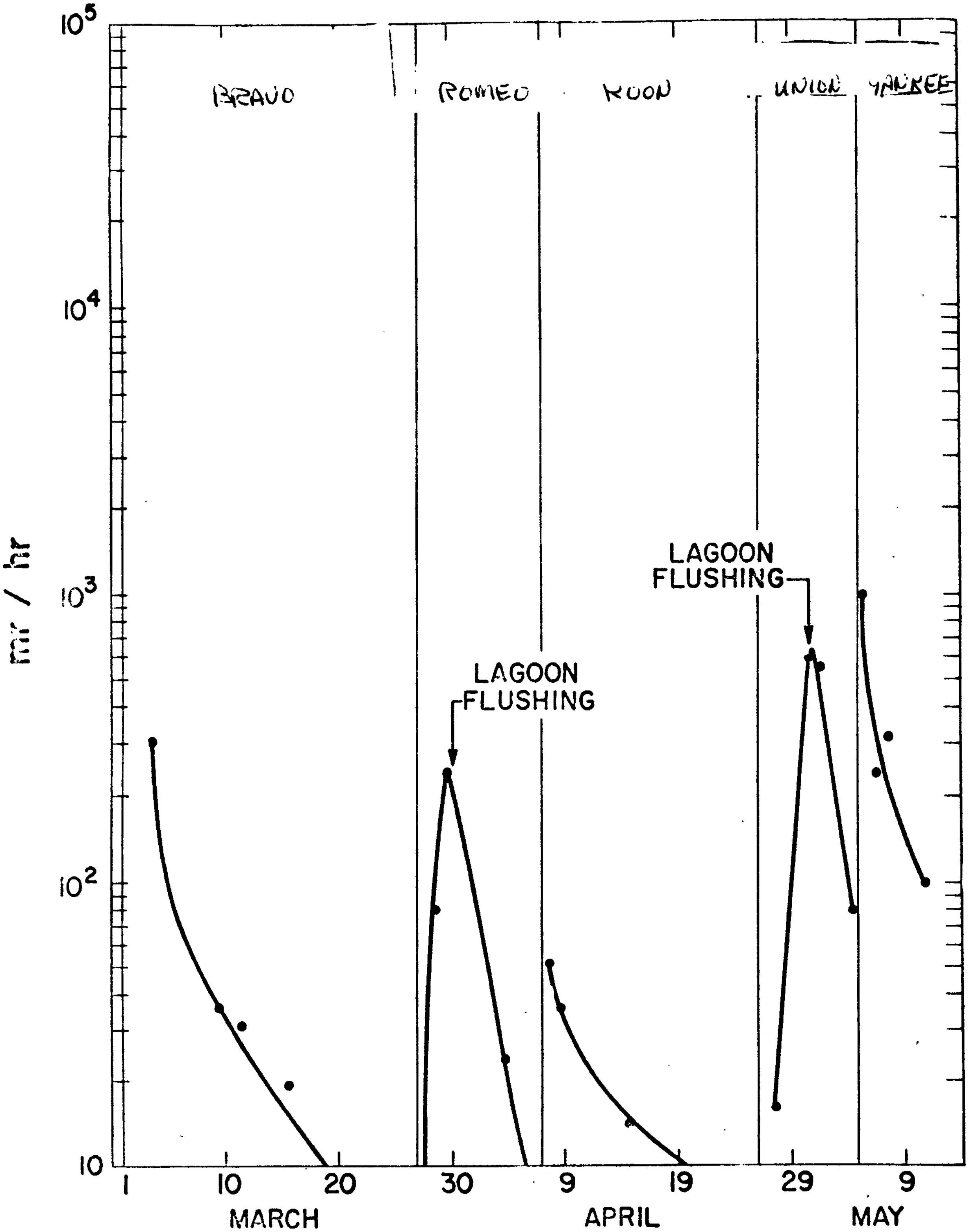


Fig. 4.7—Fall-out record, Arriikan.

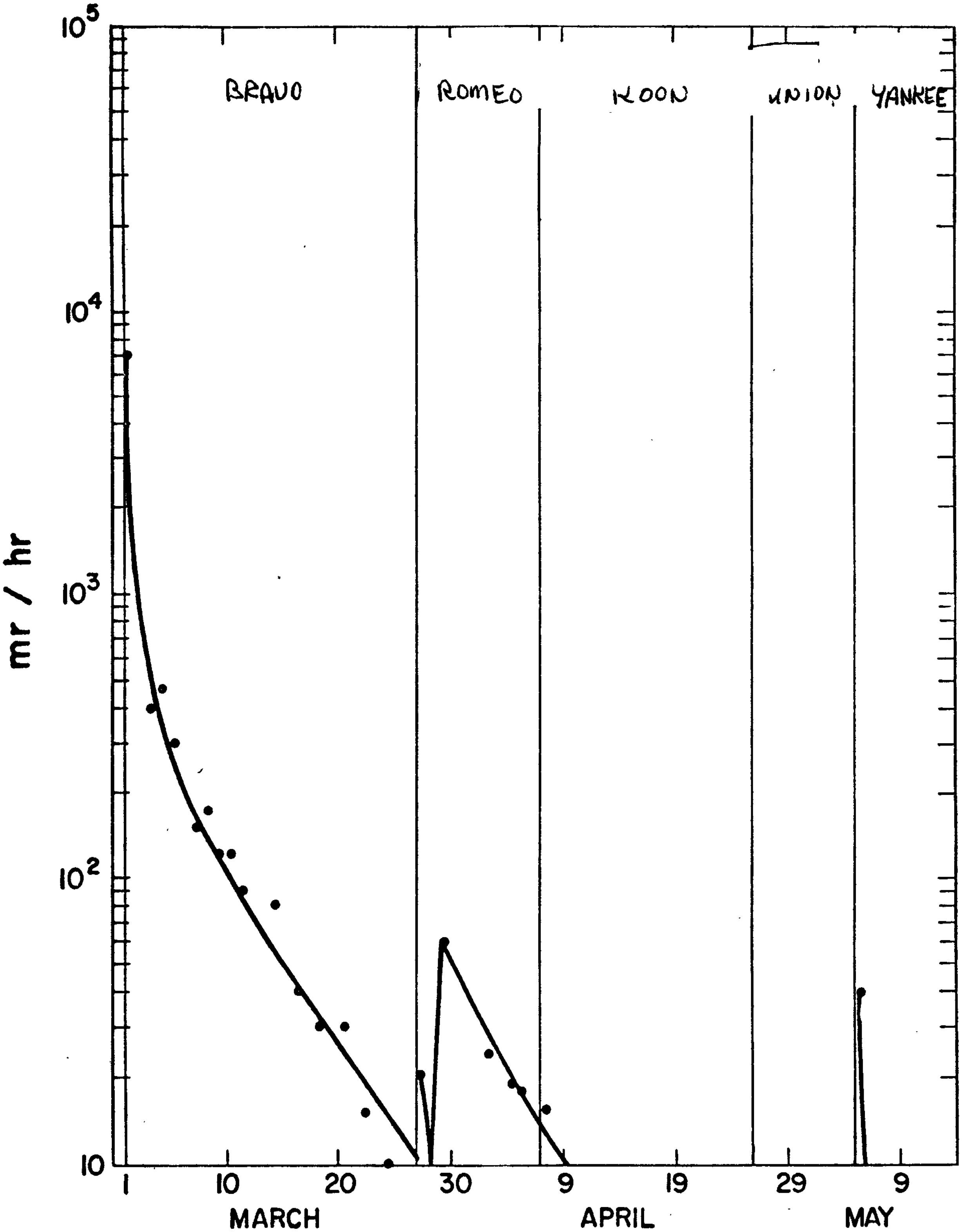
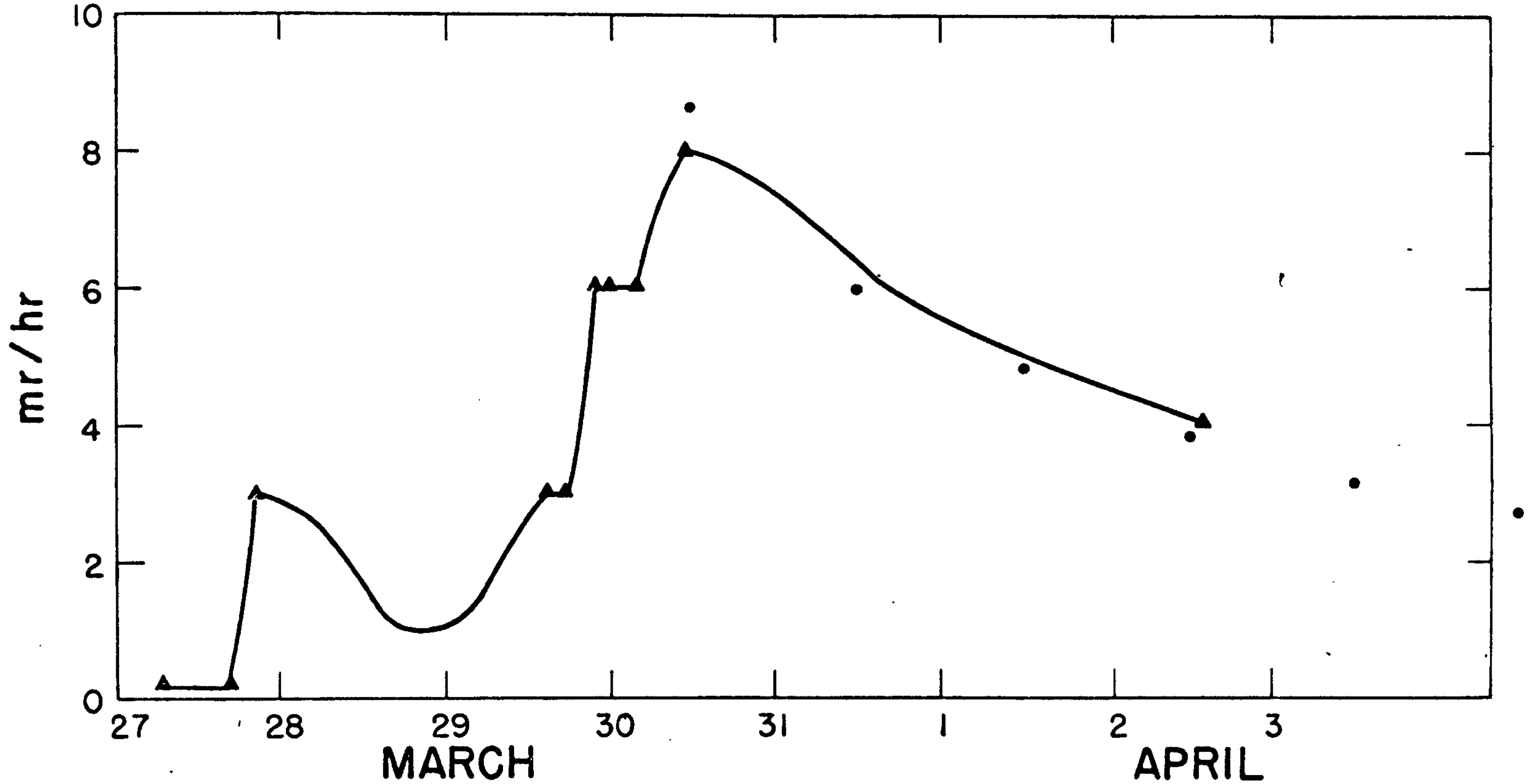
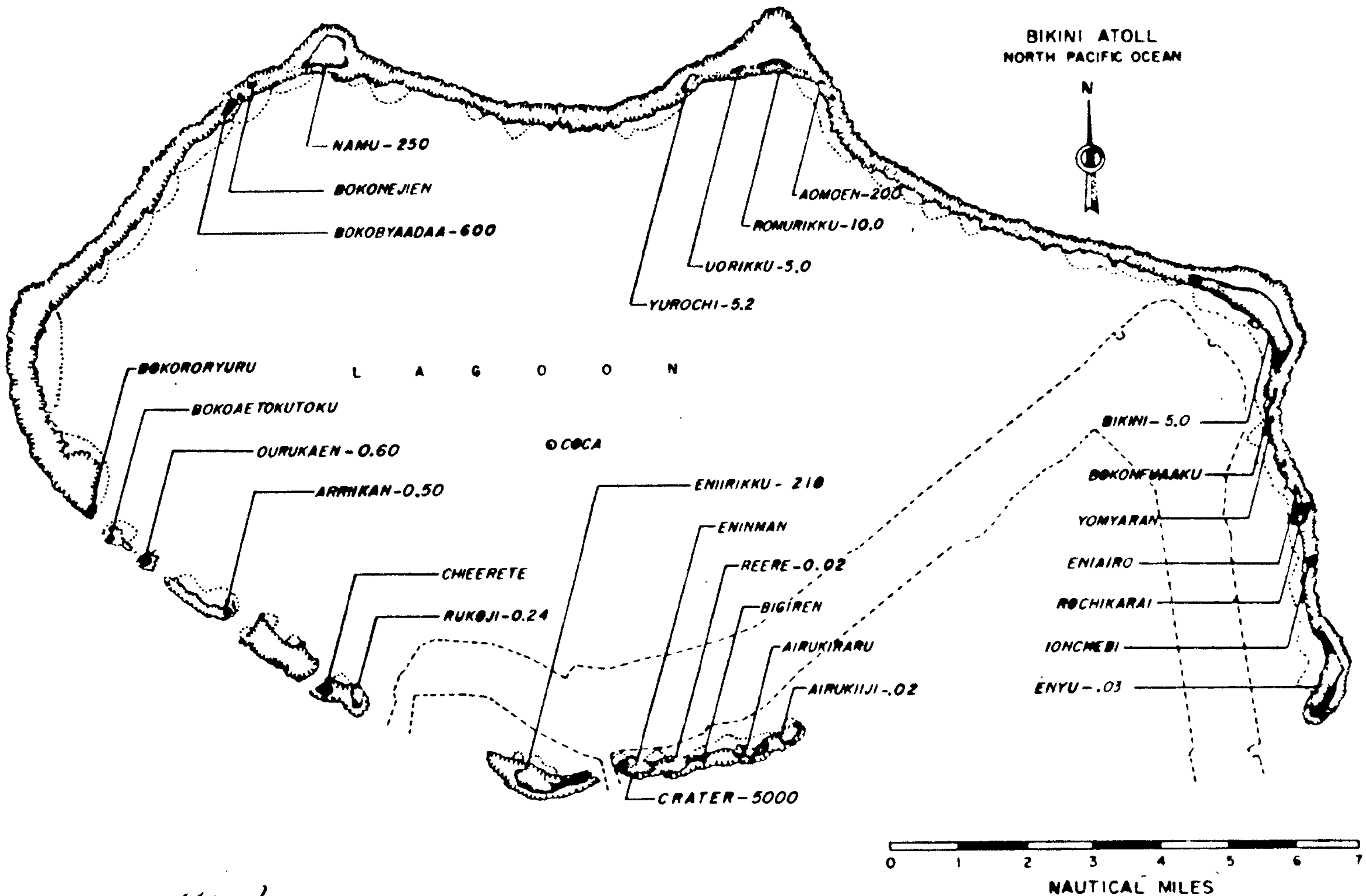


Fig. 4.8—Fall-out record, Airukiiji.



ROMEO
Fig. 4.9 [redacted] radiation fall-out, Parry Island.

35



KOON

Fig. 4.10— radiation intensities in roentgens per hour extrapolated to H + 4 hr. Location, west Eninman (ground). Yield, 0.1 to 0.15 Mt Time fired, 07/0620M April 1954.

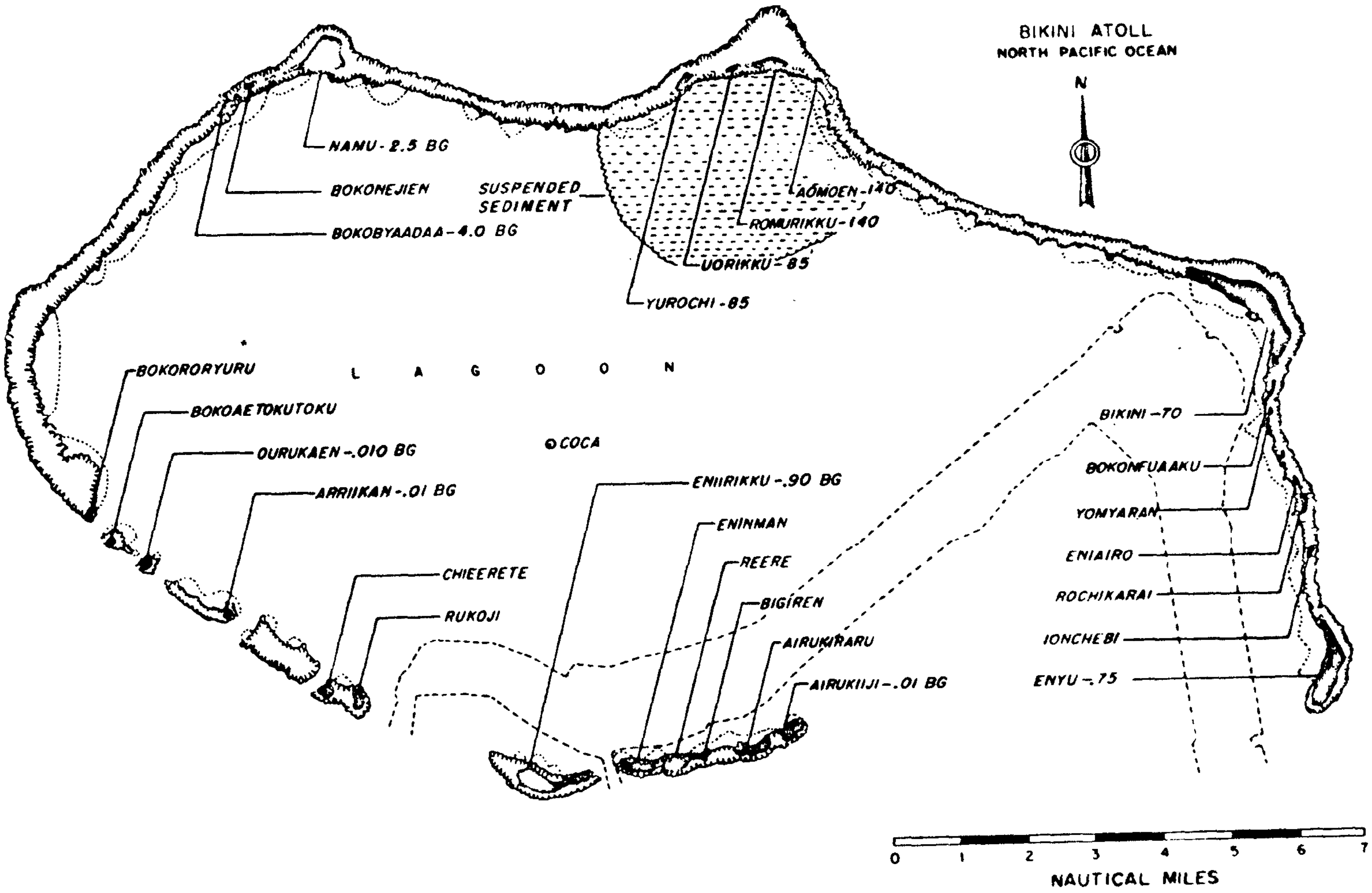


Fig. 4.11—UNION radiation intensities in roentgens per hour extrapolated to H + 4 hr, plus background levels (bg) for some islands. Location, intersection of arcs with radii of 6900 ft from Yurochi and 3 nautical miles from Aomoen (barge). Yield, 7 Mt, Time fired, 26/0610M April 1954.

No secondary fall-out was encountered within Bikini Atoll as a result of this detonation.

Intensities in the Ourukaen–Bokoaetokutoku–Bokororyuru area tended to rise with increased flushing of contamination through the adjacent passages.

No significant fall-out was observed on land areas outside the Pacific Proving Grounds.

4.3.5 YANKEE

The survey on this date was conclusive enough to limit reentry and recovery to Enyu and Airukiiji. Recontamination was extensive throughout the islands and lagoon (Fig. 4.12). Lagoon waters were heavily contaminated with radioactive sediment and gave readings in excess of 1 r/hr at a 100-ft altitude in the vicinity of zero point on YANKEE + 1 day. Enyu anchorage water contamination in this area approximated 500 mr/hr at 05/1047M, 22 mr/hr at 05/1700M, and 7 mr/hr at 06/0700M.

On shot day barges and boats in this vicinity were contaminated by fall-out with intensities between 0.6 and 10 r/hr. Floating objects revealed readings of 1 to 3 r/hr, whereas submerged equipment, i.e., buoys and anchors, revealed significant readings for the first time. It is estimated that the major portion of the floor of the lagoon was thoroughly contaminated by this time.

Suspended sediment covered a circular area about 5 miles in diameter and moved to the southwest or settled at the bottom for a period of four days. Tidal areas in the vicinity of the southwest passages were retaining significant activity at this time.

Rainstorms shortly after YANKEE day were instrumental in reducing radiation intensities by a factor of 3 or 4. Radioactive material was being rapidly leached before chemical combination occurred.

No significant fall-out was noted outside the Pacific Proving Grounds.

4.3.6 NECTAR

This detonation in the Mike crater at Eniwetok caused limited contamination of the northern islands (Fig. 4.13). An aerial survey indicated that radioactive contamination extended north of a line from Bogallua to Piiraai. Lagoon water was moderately contaminated in the vicinity of the Bogallua–Teiteiripucchi chain but was cleared within two days.

Background radiation levels on Parry Island started to increase at 1830M on NECTAR day. Fall-out peaked at a radiation level of 1.9 mr/hr at 2100M.

Heavy rains in the forenoon of NECTAR day delayed recoveries and materially increased the rates of dissolution of intensity.

No significant fall-out was reported on land areas outside the Pacific Proving Grounds.

4.4 CONTROL RESULTS

As a result of deliberations over a number of years by the National Committee on Radiation Protection, certain principles have evolved which bear upon the general determination of what is a permissible exposure of persons to radioactive materials. One of the considerations is the degree to which radiation exposure may be integrated over a period of time without regard to the rate at which such exposure has been acquired. The permissible limit for gamma exposure, in general, presupposes a uniform rate, or at least one that is capable of being averaged over a brief span of time. At the present time the geneticists tend to regard the genetic effects of gamma radiation as related to total exposure, but there is beginning to be some question relative to the possible rate dependence of genetic effects. In general, somatic injury shows very marked rate dependence, and consequently the National Committee on Radiation Protection has felt that there should be a definite reduction in total exposure when most of the exposure is acquired at a high rate.

In such activities as the conduct of nuclear weapons tests, it is obvious that a uniform exposure rate cannot be the basis for the operation. A special case has therefore been made in terms of the integration of the occupational permissible exposure rate over a reasonable period

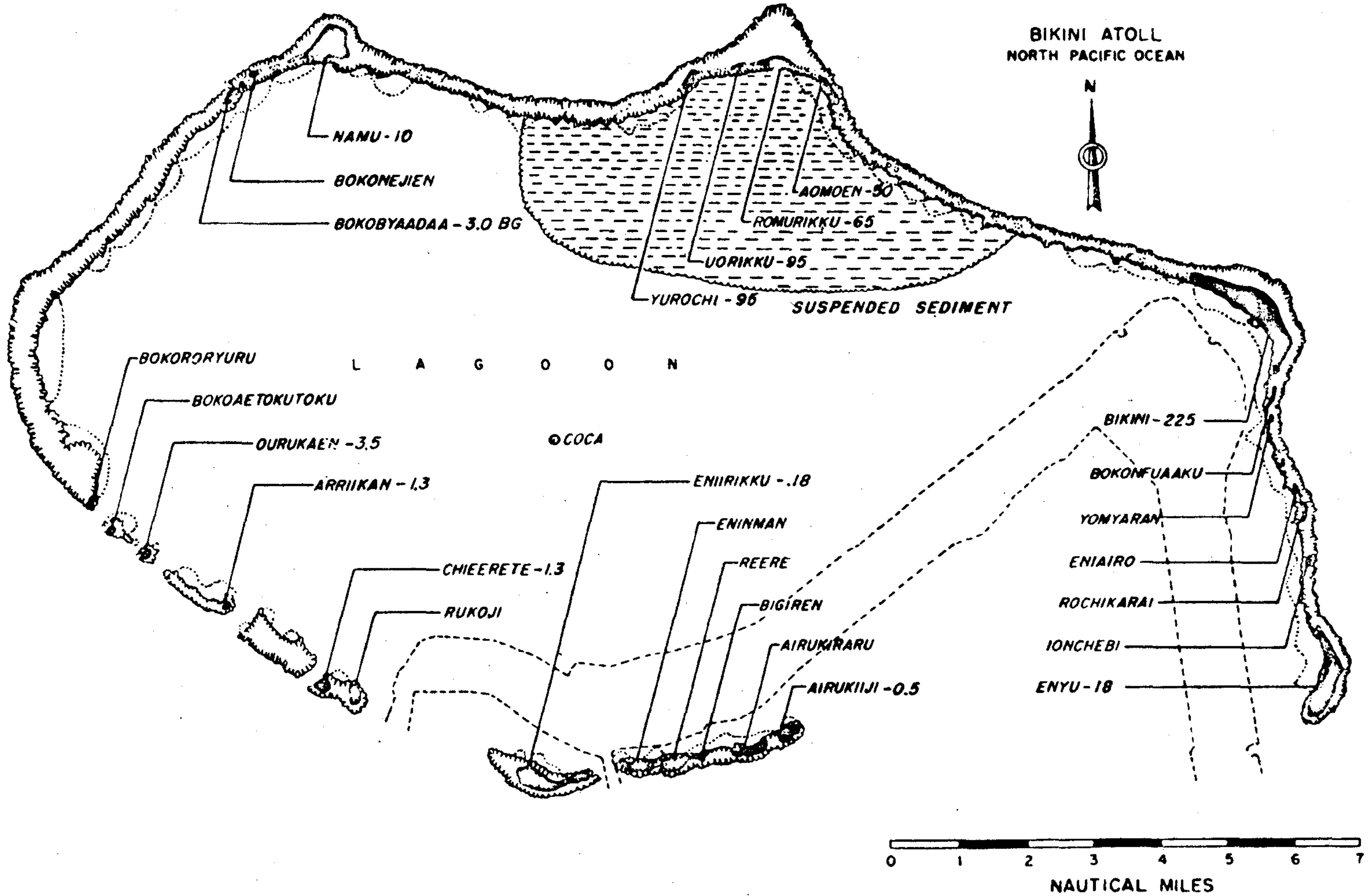
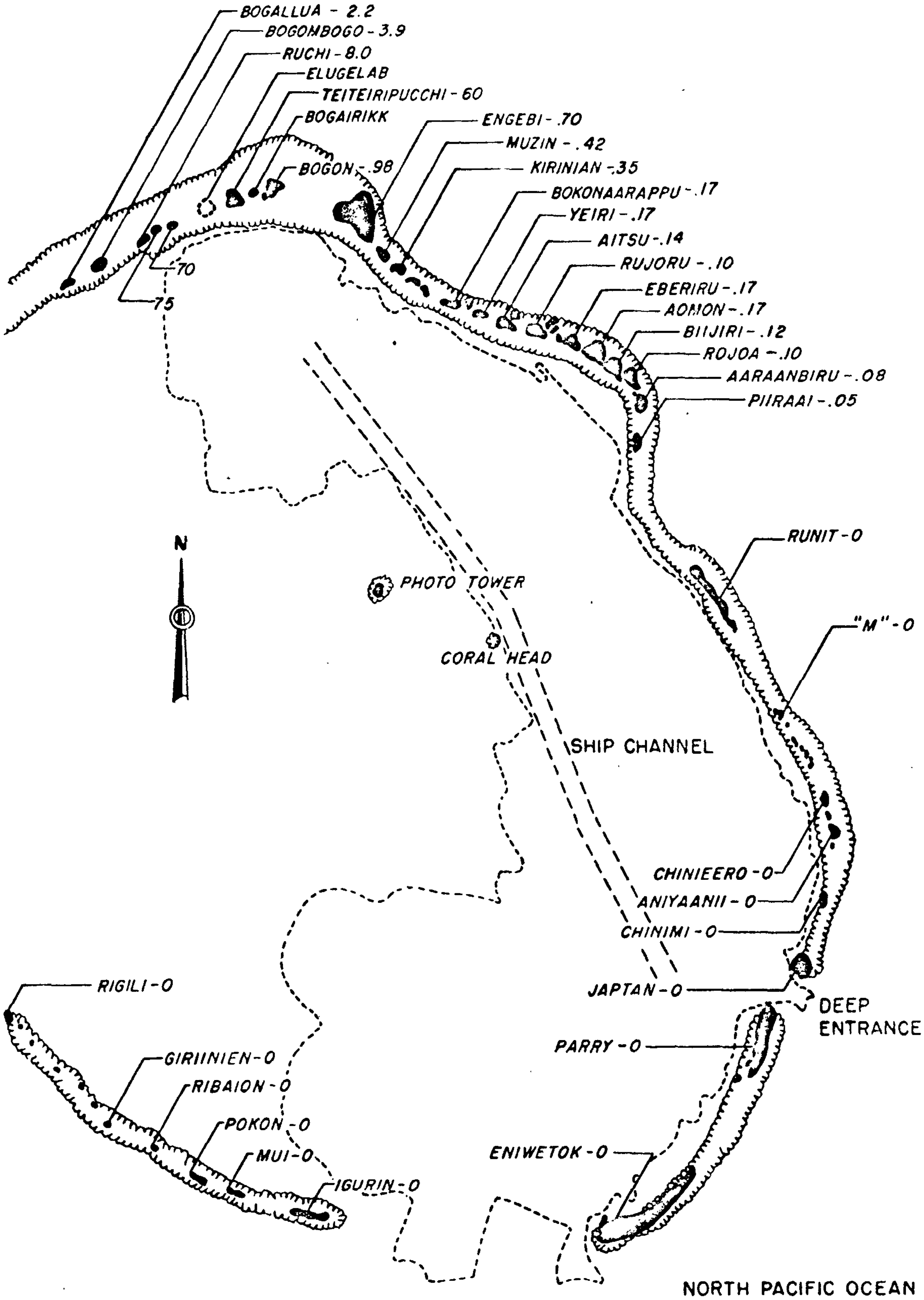


Fig. 4.12— YANKEE radiation intensities in roentgens per hour extrapolated to H + 4 hr, plus background (bg) for Bokobyaadaa. Location, UNION anchorage (barge). Yield, 14 Mt Time fired, 05/0610M May 1954.



NECTAR

Fig. 4.13— radiation intensities in roentgens per hour extrapolated to H + 4 hr. Location, Elugelab crater (barge). Yield, 1.7 Mt Time fired, 14/0620M May 1954.

of time, which most recently has been taken to be one quarter of a year, or 13 weeks. By such reasoning the permissible limit for test operations has been set at 3.9 r of gamma exposure in 13 weeks.

Although it may be stated with considerable certainty that no significant injury is going to result to any individual participating in test operations at the levels mentioned and although it is true that the same thing would probably apply if the limits were set two or three times as high, it nevertheless is true that there is no threshold to significant injury in this field, and the legal position of the Atomic Energy Commission is jeopardized if there is deliberate departure from what may be considered a reasonable interpretation of the accepted permissible limit.

Provision is made in Task Force operation plans to allow the permissible limits to be exceeded when the Commander finds that the requirements for the successful completion of the operation require a departure from standards of safety that are accepted in normal operation. Such a decision is thus one of command responsibility, and the figure given is in the nature of an upper limit for such a departure and does not constitute a restatement of what is to be considered safe and acceptable practice.

Unfortunately this is a philosophy that the military services find difficult to accept in view of the normal hazards of a test operation at the Pacific Proving Grounds. The military project requirements to work in contaminated areas and with contaminated equipment soon led to block requests for an authorized exposure of 7.9 r per operation. The grant of waiver of the maximum permissible exposure early in the test series created a loss of confidence in the established limit of 3.9 r and was soon reflected in the actions of the nonmilitary task groups. When it became apparent that a waiver of the maximum permissible exposure could be obtained upon application, the practices of conservation of exposure and wide utilization of recovery and contractor personnel became nonexistent. In many cases waivers were requested after overexposure, and in many cases approved waivers were never utilized. Although 10.8 per cent of TG-7.1 exceeded the maximum permissible exposure, only 33 per cent of the overexposures were covered by waivers. Twenty-two per cent of the waivers granted were not utilized. Although 14.2 per cent of TG-7.5 exceeded the maximum permissible exposure, less than 3 per cent of the overexposures were covered by waivers.

CTG-7.1 soon realized the deteriorating situation and expressed the policy that any individual exceeding 6.0 r would be relieved of duty and returned to the United States. This policy was of great assistance to the Control Group in the minimization of personnel exposures. Those exposures in excess of 6.0 r were accrued accidentally by individuals stationed at Rongerik Atoll at the time of the BRAVO fall-out or by members of Project 6.4, Proof Testing of Atomic Warfare Counter Measures, a project directing two liberty ships through the radioactive fall-out.

Three military members of Project 6.6, Effects on the Ionosphere, were associated with the Air Weather Service Detachment at Rongerik at the time of the BRAVO fall-out. Film badges that were left in tents revealed readings of 95 r total dose, but an investigation indicated that the actual exposure was more nearly 40 r. These exposures were unanticipated and could only have been avoided if evacuation capability had been present.

Several members of Project 6.4 received exposures of between 6 and 12 r as a result of continued activity aboard the contaminated drone ships. This hazard was anticipated and accepted as an occupational hazard by members of the project in view of the military importance of the information to be gathered.

Differences in control philosophy provided seeds of contention in relations of the Rad-Safe Unit and TG-7.1 and TG-7.5. The scientific personnel considered unit and project leaders as being responsible for the radiological safety of personnel, whereas contractor personnel considered the Rad-Safe Unit as being responsible for the radiological safety of personnel and felt that the unit was providing more support to the scientific programs than to the salvage and construction programs. This second consideration is not feasible under large-scale operations since the Control Officer is not in a position to supervise civilian employees. His control of exposures can only be a reflection of the acceptance of the radiological-safety philosophy by supervisory personnel during their organization and performance of work assignments.

Daily knowledge of activities throughout the Atoll when personnel were traveling by small boat and helicopter from a number of housing areas and the maintenance of daily current exposure records at five control stations on two atolls with limited transportation and communication facilities proved to be the most difficult control problems. In many instances records were from 24 to 48 hr behind the activities of the individual. When the records were made current, the individual was listed as an overexposure, and the Control Officer was criticized for not informing the individual of his current exposure at time of entry. This time delay was caused by the practice of issuing film badges at Eniwetok and developing the film at Bikini and by a lack of night transportation in the lagoon.

The practice of entry control by film-badge exposures left much to be desired, but it was the only method available in the absence of reliable self-reading dosimetric devices. The practice of daily issuance and development of film badges may have penalized many individuals because of inherent inaccuracies of the film badge in the presence of low-energy radiation and low dosages.

4.5 CONCLUSIONS AND RECOMMENDATIONS

4.5.1 Conclusions

1. The practice of controlling entry into extensive contaminated areas by means of current exposure records obtained from film-badge development is inadequate.
2. Radiological-safety control groups of TG-7.1 and TG-7.5 should be separate entities.
3. The system of waivers of the maximum permissible exposure is inappropriate to the situation.
4. The policy of project responsibility for safety practices is the only realistic means by which an adequate control of radiation exposures can be obtained.

4.5.2 Recommendations

1. A study should be initiated to determine an adequate integrating dose meter that will effectively operate under Pacific Proving Grounds conditions. This meter should contain a current indication of the radiation exposure of the individual and should be readable both by the individual and the Control Officer.
2. TG-7.5 should establish a separate radiological-safety organization to provide a continuity of service in the test and interim periods.
3. The maximum permissible exposure should be based on a calender quarter and not on an arbitrary 13-week period. The system of waivers should be abandoned, and all individuals exceeding the maximum permissible exposure should be listed as overexposures since a thorough preliminary planning of the safety aspects of recovery and construction will minimize the requirements of waivers. Every effort should be made to avoid the establishment of limits other than the specified 3.9 r per quarter.

CHAPTER 5

LABORATORY GROUP

5.1 FUNCTIONS

The Laboratory Group was organized to provide technical assistance to the operations of the Control and Decontamination groups, as well as service to the several radiological-safety organizations of JTF-7. In this capacity this group was responsible for the maintenance and repair of the various types of radiological-safety instrumentation in use throughout JTF-7. It also processed and interpreted the photographic film badges of the Task Force. One section collected, interpreted, and disseminated data on the nuclear nature of the radioactive contaminants.

5.2 ELECTRONIC SECTION

The Electronic Section consisted of one officer and three instrument repairmen. They serviced and maintained the densitometers, voltage regulators, scalers, count rate meters, and scintillation counters of the laboratory, as well as the following portable survey meters: AN/PDR-39, AN/PDR-T1B, AN/PDR-18, MX-5, 2610, and AN/PDR-27A of the Control Group.

The AN/PDR-39 was considered the basic survey instrument for all monitors and met the stringent requirements of the Pacific Proving Grounds, although humidity leaks developed after frequent use on small boat missions in the Bikini lagoon. At times data were lost because the meter had become inoperative on the higher scale. Shop rotation, inspection, and drying remedied this primary difficulty. Other failures were noted in the electrical meter movements and lucite screw mounts.

The MX-5 was considered the basic personnel-monitoring instrument and performed satisfactorily when used for this function in low-level background radiation. The high background radiation level at Bikini caused a high loss rate of Geiger-Mueller tubes. Instruction in the proper use of the instrument reduced this loss rate.

Trouble was experienced by individuals when attempting to correlate 1- to 5-mr readings on the two instruments since neither instrument was calibrated in this range.

The major problem in instrument maintenance was the procurement of adequate numbers of appropriate batteries.

It was necessary to shift the personnel of this section from one shop to another to meet the work load. In the interest of economy and efficiency, the repair personnel often would be sent to the instrument rather than having the faulty instruments returned to the shop for repair. Thus the instruments that suffered only minor faults were repaired and returned to service immediately, whereas those in need of more extensive repair were returned to the shop. The number of repair personnel proved adequate, and at no time was there an abnormal backlog of equipment in need of repair.

5.3 PHOTODOSIMETRY AND RECORDS SECTION

This section consisted of one officer, six photodosimetry technicians, and five clerks. The Section operated two facilities, one at the Rad-Safe Center on Parry and one in a Signal Corps laboratory trailer on the hangar deck of the USS Bairoko. Two shifts of technicians and clerks functioned throughout the 24-hr day aboard the Bairoko while one shift handled the program at Parry.

5.3.1 Film Packet

The presently accepted film badge for test operations resulted from the recommendations of a conference of interested individuals at the AEC Division of Biology and Medicine on 18 August 1952.

The conference recognized that the film dosimeter to be devised must be a compromise between known factors of film response and poorly known factors of energy spectrum and biological response. The exact spectrum of energy to which personnel are exposed when in a field of bomb debris is unknown; in fact, the spectrum probably varies considerably with time and place. There is good evidence that the spectrum contains a large amount of degraded gamma energy in the region below about 0.1 Mev. The biological effects of radiation in this energy region are difficult to assess. The amount of beta-ray energy associated with these fall-out fields and its biological effect are likewise difficult to assess.

It was agreed that the blood-forming organs would be considered as the critical tissue. Degraded gamma energies of less than 0.05 Mev might be neglected. Beta radiation would be ignored in ordinary fall-out fields, except where there is direct contact with contamination. Ordinary shoes and clothing may be considered as adequate protection against beta rays from contaminated ground.

As a result of this meeting and further discussions with the National Bureau of Standards, the AEC Division of Biology and Medicine recommended adoption of the procedures used for personnel dosimetry at the proving grounds.

The accepted film badge consists of:

1. Film pack: For convenience and reliability two films, Du Pont 502 and 606, were recommended. Du Pont 502 has a reasonably accurate range up to about 3.0 r, with a measurable range up to about 10 r. Du Pont 606 has a range between approximately 10 to 300 r. This particular combination of films has the disadvantage of being unable to evaluate accurately exposures in the region of 10 r, although both films may be used to assist the evaluation.

2. Metal shield: Not only does the spectrum to be measured have a peak in the region of about 0.1 Mev but also the film response is high in this region, a combination which can lead to sizable errors in the photodosimetry of personnel exposed to fall-out radiation. To suppress the high response of the film to radiation in the region of about 0.1 Mev, a metal shield is ordinarily used. The Radiation Physics Laboratory of the National Bureau of Standards collected data that indicated 0.72 mm of lead would give the approximate sensitivity response desired. Until more complete information on the fall-out spectrum is available, the observed dose may be considered reasonably accurate (see Appendix A).

Except for minor changes, procedures of photodosimetry were followed according to the operating procedures outlined in Appendix B.

5.3.2 Dosimeters

Considerable difficulty was encountered in the use of pocket dosimeters during the Bikini phase. Three types were used, namely, the Victoreen, 0 to 5 r; the Cambridge, 0 to 1 r; and the Keleket, 0 to 200 mr. These instruments were issued to monitors during missions only.

Because of their sensitivity to low-energy radiation, the dosimeters consistently gave readings higher than the measured integrated dose from film badges. In general, these readings were higher by approximately a factor of 2. This phenomena had also been encountered during Operation Ivy. Although the true exposure could be approximated by dividing the dosimeter reading by two, other characteristics proved this practice to be unsatisfactory.

Specifications for the purchase of the dosimeters provided for the moistureproofing of the instruments. In spite of this precaution, however, many of the instruments tended to leak electrical charges in high humidity conditions that existed aboard ship, barge, and small boat. This condition was aggravated by the presence of salt spray and extensive radioactive contamination throughout the Bikini area. Dosimeters were cleansed with alcohol as much as practicable, calibrated, and placed back in operation as soon as possible. It soon became apparent that the reading mechanism and ion chamber needed to be separated in order to prevent contamination of the chamber.

Approximately 33 per cent of the dosimeters became inoperative before the end of the operation, and 30 per cent were lost due to the fluid nature of the operations in the Bikini area. Much improvement must be made in the present pocket dosimeters in order for an effective dosimetry program to be handled under conditions similar to Operation Castle.

5.3.3 Records

Roughly 40 per cent of the unit activities became centered in the maintenance of JTF-7 records of radiological exposures. This consisted of over 10,174 individual exposure records. The accuracy of the records was a reflection of the accuracy of the individual personnel sections, individual cooperation in designating proper home stations, and cooperation in returning film badges for development and record.

Duplicate sets of exposure records for TG-7.1 and TG-7.5 were maintained at Bikini and Eniwetok Rad-Safe centers during the operation. As a rule these records were about 36 hr out of phase. TG-7.2 and TG-7.4 maintained operational control files within their respective headquarters. TG-7.3 also maintained operational control records aboard each ship.

JTF-7 radiological-safety regulations directed the Rad-Safe Officer to maintain standard type film-badge records of all Task Force personnel. It was required that records indicate the full name, rank or rate, serial or service number, organization, home station or laboratory, date of exposure, approximate duration of exposure in hours and minutes for Army personnel, and remarks such as limitations on assignment because of overexposure. Upon completion of the operation, disposition of the records was as follows:

1. A consolidated list of exposures, together with exposed film badges and control film badges, were forwarded to the Chief, AFSWP.
2. A consolidated list of personnel exposures was forwarded to the Director, Division of Biology and Medicine, AEC.
3. Individual records of Navy and Air Force personnel were forwarded to their unit of permanent assignment for inclusion in the health record of the individual.
4. Individual records of Army military and civilian personnel were forwarded in accordance with SR-40-1025-66, dated 21 April 1953, for inclusion in the individual's field military 201 file or the civilian 201 file.
5. Individual records of AEC administered and controlled personnel were provided to each laboratory or agency having administrative jurisdiction over such personnel.

Final completion of records was delayed six weeks due to receipt of film badges one month after the end of the operation from several ships of the Navy task group. The development and recording of these badges after the dissolution of TU-7 required special arrangements with the Health Division of LASL.

Difficulties were encountered in notifying Air Force units of exposures because some of these units were disbanded shortly after the completion of the operation.

An analysis of exposures revealed that the Air Force task group had the highest percentage of personnel exceeding 3.9 r (see text table on the next page).

5.4 RADIATION ANALYSIS SECTION

5.4.1 Introduction

1. Mission: The mission of the Radiation Analysis Section of the Laboratory Group of TU-7 was to perform radiological assays of liquids, solids, and airborne particulate matter in

Task Group	Analysis of exposures, %					Total exposed
	0 to 2 r	2 to 4 r	4 to 6 r	6 to 12 r	Over 12 r	
7.1	68	21.7	8.4	2.1	0.3	1,300
7.2	94.8	3.9	1.3	0	0	551
7.3	80.3	14.5	3.4	1.7	0.1	6,153
7.4	83.2	8.8	4.6	2.1	1.7	759
7.5	73.2	12.3	13.1	1.0	0.1	1,421
Hq. JTF-7	100	0	0	0	0	90
						Total 10,174

order to provide the Task Force Rad-Safe Officer with the necessary information to accurately evaluate any radiological hazard. In particular, samples analyzed by the Section included the following:

a. Lagoon samples to prevent undue radiological contamination to surface vessels anchored within the lagoon.
b. Drinking-water samples from the evaporators of ships anchored in contaminated lagoon water.
c. Drinking-water and food samples as dictated by the occurrence of fall-out on inhabited islands.
d. Air samples collected in fall-out areas by vacuum type air filters and cascade-impactor slides.
e. Solid soil samples containing fall-out particulate matter for the determination of the decay rate and apparent energies of the various types of radiations.
f. Urine samples analyzed for tritium content were obtained from personnel who may have been exposed as a result of working with tritium gas. STET
g. Other special samples as required by TG-7.1.

2. Organization and equipment: The Section included an officer supervisor and four navy hospital technicians who had been given a brief training period at LASL prior to joining TU-7. This organization proved to be adequate to handle any of the assignments.

A mobile radiological field laboratory, completely equipped for carrying out chemical as well as radiological analysis of samples, was stationed on board the USS Bairoko and was utilized throughout the operation for carrying out most of the laboratory work. An alpha scintillation counter, two counting rate meters, and four Geiger-Mueller type detectors and Berkeley scaler combinations comprised the major components of the laboratory. An adequate supply of spare parts enabled the instrument repair section of the Laboratory Group to keep the instruments in good working order.

3. Work load: The majority of the samples analyzed by the Section were water samples consisting of samples taken from the lagoon and drinking-water samples from the ships anchored in contaminated water. Fig. 5.1 shows graphically the number of such samples analyzed by weekly periods from 1 March to 10 May 1954. Peak periods occurred the week following BRAVO and ROMEO events. In addition to these samples, air samples, soil samples, decay rates, etc., were run. A total of 706 samples were analyzed during Operation Castle from the period 1 March to 14 May 1954.

4. Occurrence of fall-out on USS Bairoko: The operation of the Section was rendered more difficult, particularly following BRAVO by the occurrence of fall-out on the USS Bairoko. On this occasion the background became so high that precise counting became impossible. Primary fall-out commenced at 0755, 1 March, 1 hr and 24 min after BRAVO and continued off and on throughout the day. Fall-out again occurred at 2230 on 28 March, 41 hr following ROMEO This was a secondary fall-out, however, as was that

which commenced about 1015, 5 May following YANKEE and did not materially interfere with the work carried on by the Section.

5.4.2 Discussion

1. Lagoon and drinking-water samples: After the BRAVO event it became evident that recovery programs and preparations for future detonations at Bikini Atoll could only be accomplished by personnel working from ships anchored in the lagoon. Each detonation resulted in the lagoon water being contaminated; the magnitude and persistence of the contamination depended on the yield and location of the shot with respect to the anchorage sites.

A program was initiated by the TG-7.3 Rad-Safe Officer to pick up daily samples, both from the surface and 90 ft below the surface, at various points in the lagoon. The samples were turned over to the Radiation Analysis Section, where the specific beta activity in microcuries per milliliter was determined. The purpose of the program was to protect the ships from the accumulation of hazardous amounts of radiation when anchored. The maximum concentration encountered in the lagoon anchorages was 8.4×10^{-3} µc/ml. The average activity varied from 1×10^{-4} µc/ml to 3×10^{-4} µc/ml.

Also of interest was the drinking water on the ships since it was derived from the distillation of the lagoon water in the ships' evaporators. The possibility of carrying radioactive particulate matter into the fresh-water output existed, especially on board ships used primarily as hotel accommodations. Accordingly a program was set up by which ships turned in samples of drinking water and intake water from the lagoon on at least a daily basis. These samples were also analyzed for beta activity in microcuries per milliliter. No drinking water on board the ships was found to contain any appreciable radioactive material. In view of the fact that the activity found in the lagoon water was associated with the sediment left after evaporating the water, it was not surprising that the drinking-water samples derived from the condensation of water vapor from a distillation process contained no activity.

As the operation progressed it became evident that excessively contaminated water could be observed visually as a result of the sediment being deposited in the water and could be evaluated adequately using only a PDR-39 survey type meter operated from a helicopter hovering over the surface of the water. As a result of using this technique, following the KOON event the number of lagoon samples to be analyzed was reduced considerably and more time could be devoted to more pertinent problems (see Fig. 5.1).

In addition to the drinking-water samples from the ships, drinking-water samples were analyzed from Rongelap, Kwajalein, and Uterik islands. The initial samples from Rongelap were collected at the time the natives were evacuated from the island on 5 March and followed to the end of the operation for decay characteristics. The specific activity of these samples indicated that the water was contaminated from 2 to 25 times above the AEC operational tolerance of 5×10^{-3} µc/ml. A representative decay curve for one of these samples is shown in Fig. 5.2. No appreciable activity was found in the samples from Kwajalein Naval Station. Samples taken on the survey trip to Rongelap and Uterik islands indicated an average specific activity of 1.4×10^{-3} µc/ml and 2.1×10^{-4} µc/ml, respectively. Two samples from Rongelap contained no activity and are not included in the above values.

2. Air sampling: Portable air samplers, capable of drawing 0.65 cu ft of air per minute through a 6-in. filter paper, were used on the initial survey flights following each event and during those periods when fall-out occurred on board ship. With the instrument on for 15-min intervals during the fall-out period, a continual check could be made as to whether fall-out was still occurring and at least a qualitative estimate could be made of the order of magnitude of the concentration of the radioactive contamination in microcuries per cubic foot of air. Using such a large-sized filter paper necessitates folding the paper twice in order to place it on the bottom of a large lead pig. Only gross counts per minute were obtained in counting. After these initial data were taken, however, a small portion of the filter paper was mounted on a brass planchet and followed for a period of time in order to obtain the decay characteristics of the sample. The decay curve for two such samples, collected after UNION and YANKEE are shown in Fig. 5.3. The air samples collected on 1 March, when the USS Bairoko received a

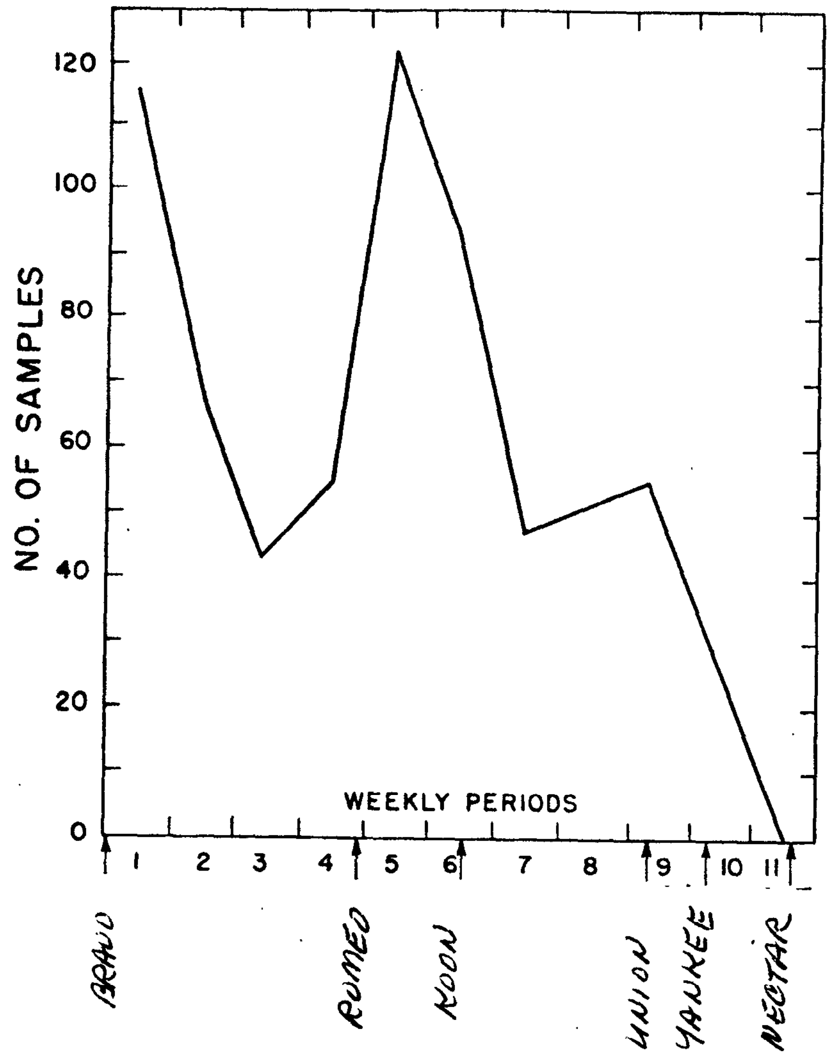


Fig. 5.1—Water samples analyzed during Operation Castle.

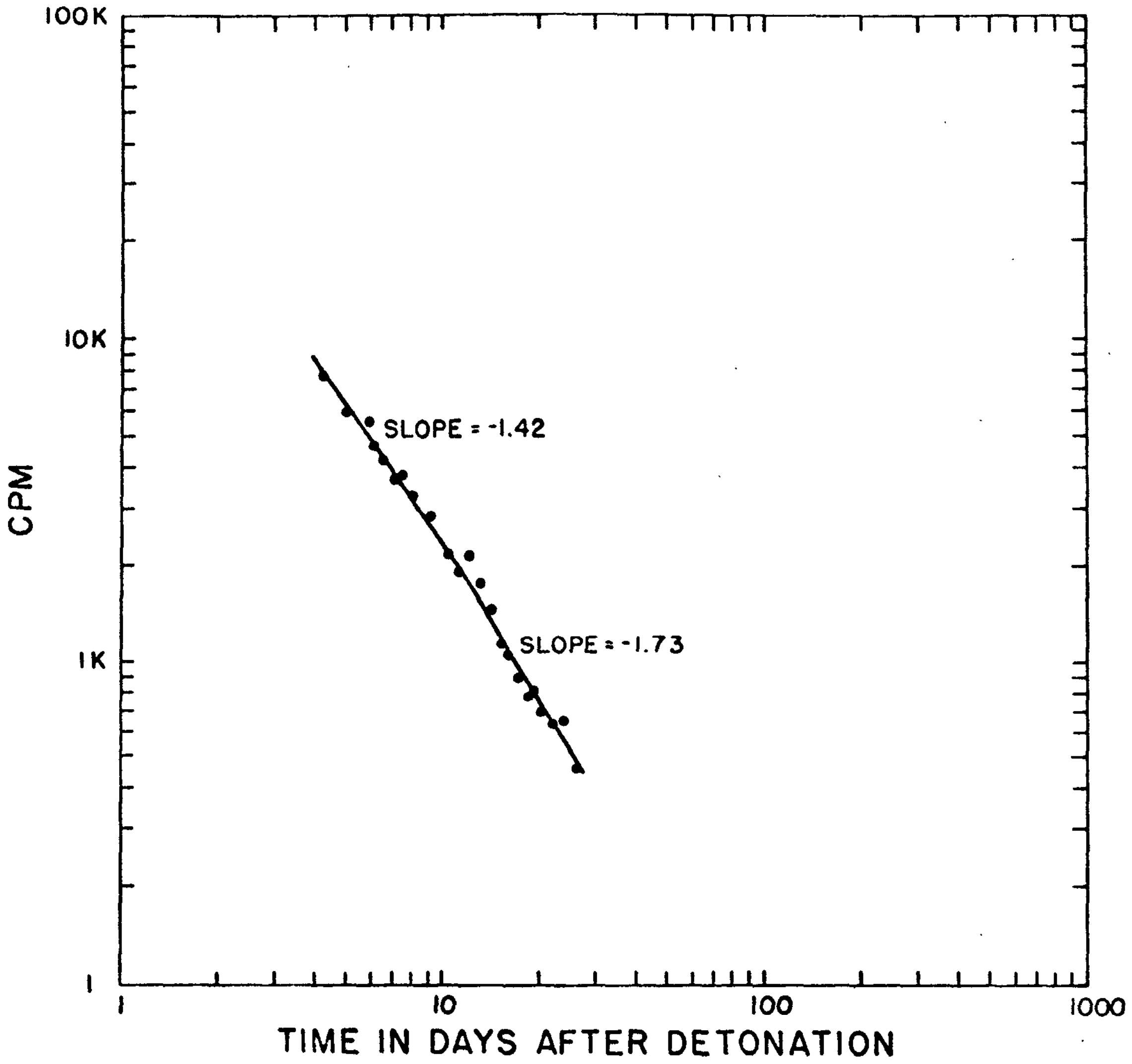


Fig. 5.2—Decay rate of Rongelap water sample collected 5 March 1954.

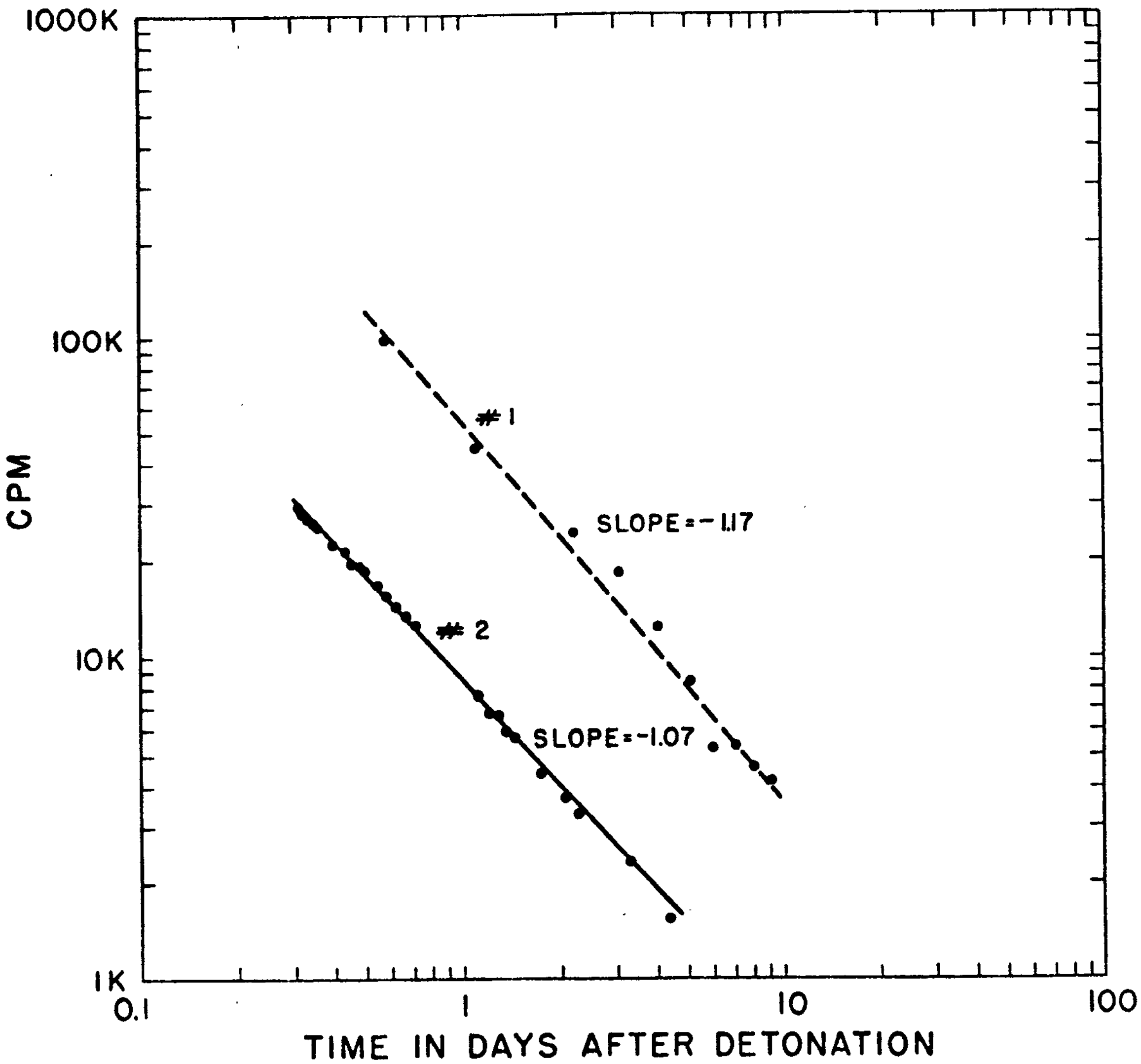


Fig. 5.3—Decay rate of air samples. Curve 1, UNION air sample collected 26 April 1954. Curve 2, YANKEE air sample collected 5 May 1954.

substantial fall-out from BRAVO indicated activities ranging from 455 to 2740 counts/min per cubic foot of air.

In addition to the portable air samplers, a cascade impactor was installed in the radiac repair shop on board the USS Bairoko near the ventilation outlet. Additional impactors were also located on Parry and Eniwetok islands to be utilized if fall-out should occur on these islands. The purpose of the impactor was to determine the percentage of the total activity associated with particles 5 μ in diameter or less in order to evaluate the inhalation hazard to personnel subjected to the fall-out. The only cascade-impactor data obtained were collected during the fall-out that occurred on the USS Bairoko. An average of 65 per cent of the activity collected by the cascade impactor was found to be associated with particles less than 5 μ in diameter.

3. Decay and energy measurements: As mentioned previously, the mission of the Radiation Analysis Section included the determination of the characteristic radioactive properties encountered in the various samples collected throughout Operation Castle. Beta- and gamma-energy measurements, however, were difficult to obtain by absorption methods because of the very low energy of the gamma present in the samples collected. Low-energy gamma photons being absorbed on aluminum filters gave rise to misleading beta-absorption curves and yet could not be readily detected using lead absorbers because of the combination of low-counting efficiency for gamma with a Geiger-Mueller tube and the high attenuation in the smallest lead filter. Beta-energy measurements using absorption methods actually should more properly be referred to as the combination of beta plus low-energy gamma.

In order to obtain a gamma-absorption curve of significance, it was necessary to use a sample having a very high specific activity in order to compensate for the low counting efficiency. Such a curve is illustrated in Fig. 5.4. It is noteworthy that the low-energy component is less than 50 kev and the high-energy component is 0.6 Mev. Other samples for which the gamma energy was determined fell within this range of values.

Beta energies (beta plus low-energy gamma) varied from 0.2 to 2.2 Mev, depending on the sample being studied.

Log-log plots of counts per minute vs time after detonation were utilized to obtain decay-rate data, and many different types of samples were studied throughout Castle. Rather than to present all the data, the most interesting samples for each detonation have been selected, and the decay curves representing these samples are included in Figs. 5.3, 5.5, and 5.6. A tabulation of the slopes of the other decay curves is included in Table 5.1. It is interesting to note that the drinking-water samples from Rongelap indicated an average slope of -1.37 from BRAVO + 4.2 to 10 days and -1.78 until last counted. This deviation from the 1.2 law, especially during the early period, obviously has important implications with respect to the total amount of radiation received by the Rongelap natives, assuming that this law held from the beginning of their exposure.

As shown in Table 5.1, the lagoon samples studied after ROMEO indicated a slope of -1.35. This same slope was obtained irrespective of whether the sample was taken on the surface, below the surface, or even four days after the detonation.

5. Miscellaneous samples and problems: During the course of the operation the Section was called upon to study samples of food, soil, and water brought back from the resurvey of Rongelap and Uterik islands. The food samples consisted of coconuts, papaya, pandanus, arrowroot, and breadfruit, all of which are important constituents of the native diet, in addition to sea food. All the material from Rongelap, the more heavily contaminated island, showed considerable surface activity; however, no internal activity was detected. This finding was

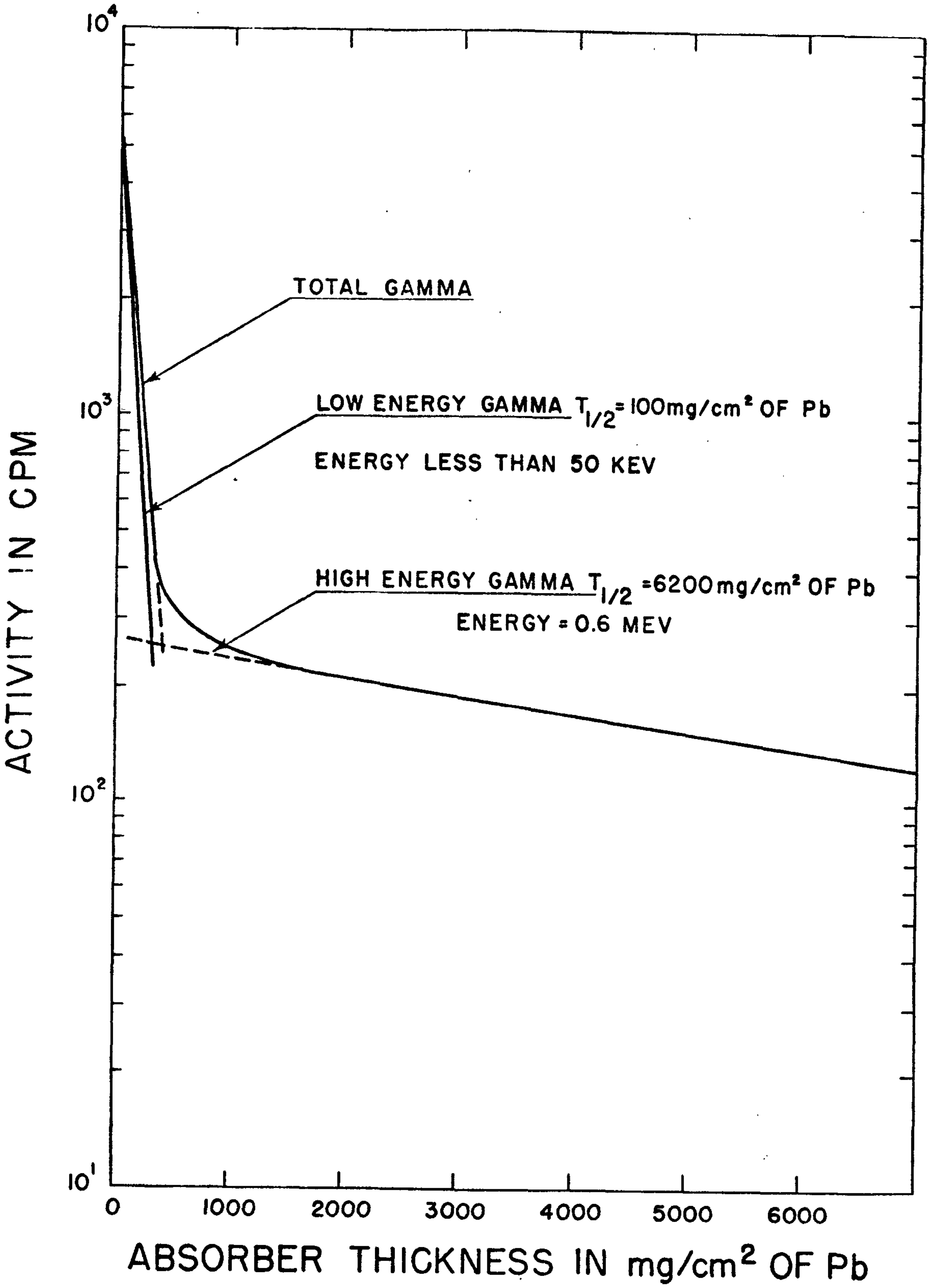


Fig. 5.4—Gamma-absorption curve.

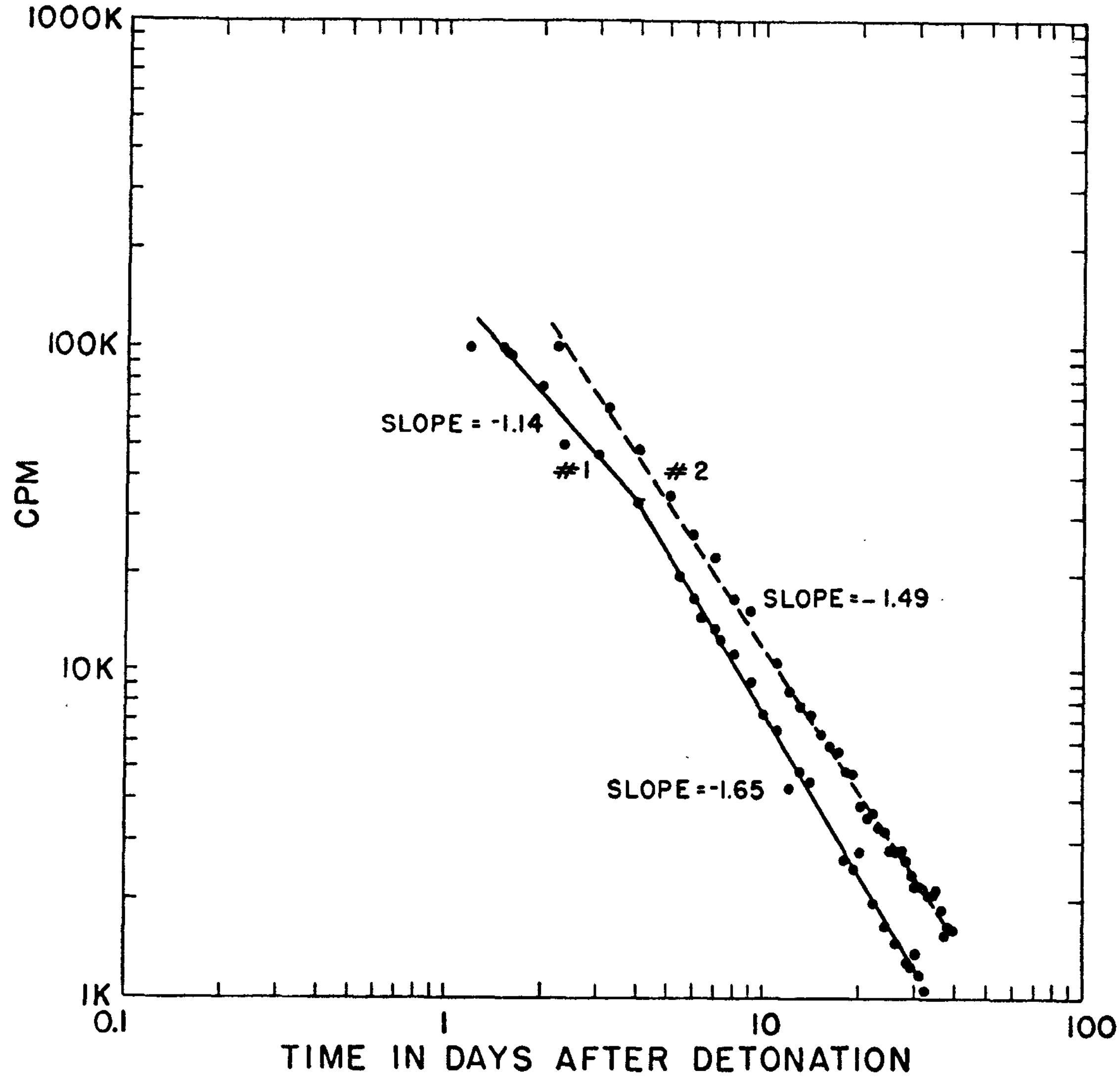


Fig. 5.5—Decay rate of fall-out samples. Curve 1, BRAVO fall-out sample collected 1 March 1954 on USS Bairoko flight deck. Curve 2, ROMEO fall-out sample collected 29 March 1954 on USS Bairoko flight deck.

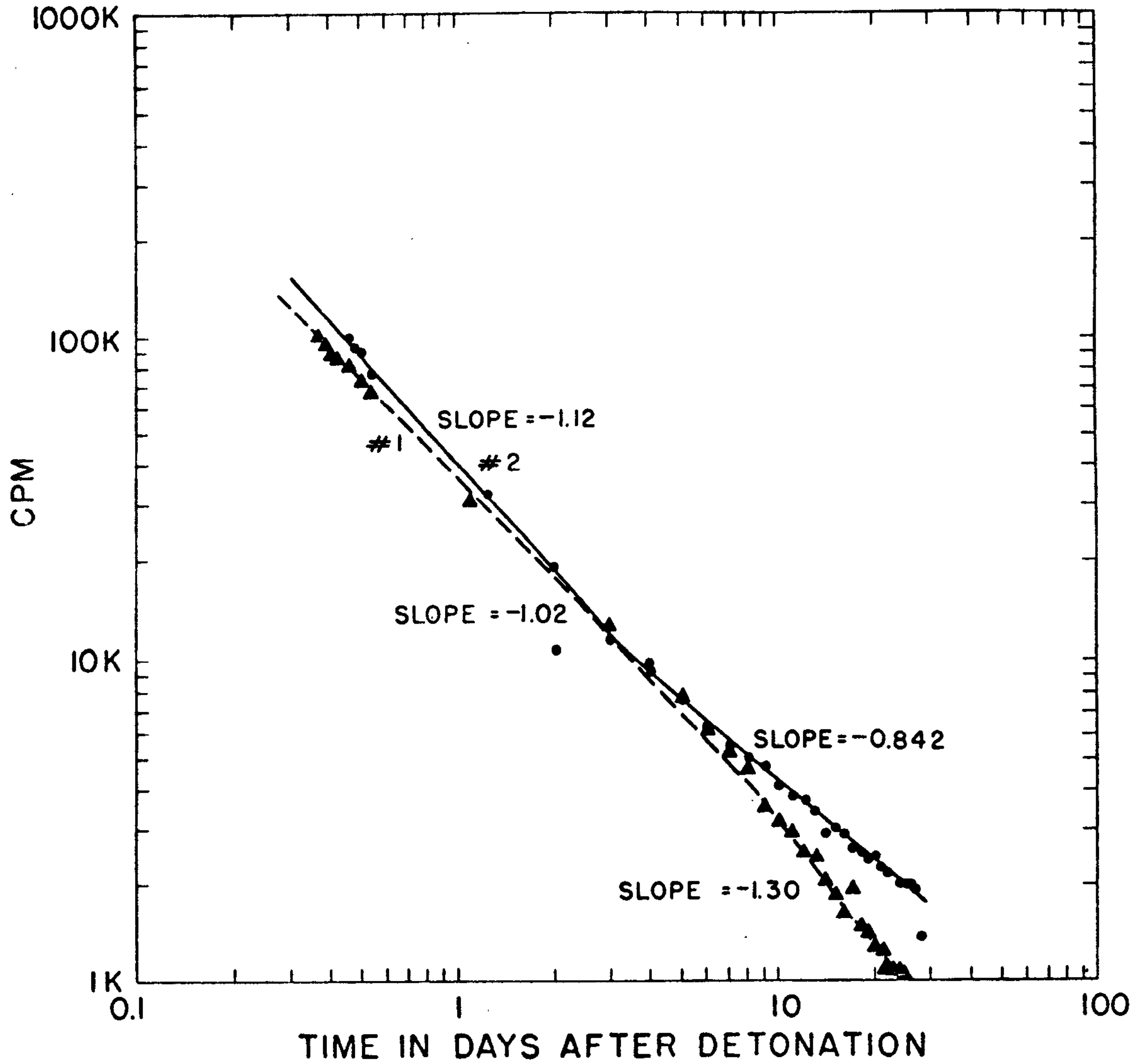


Fig. 5.6—Decay rate of lagoon and soil samples. Curve 1, KOON lagoon sample collected 1220 on 7 April 1954. Curve 2, KOON soil sample collected from Bikini at 1430 on 7 April 1954.

Table 5.1 — SAMPLE SLOPE DECAY CURVES

Event	Sample description	Slope	Remarks
BRAVO	Fall-out sample collected on USS Bairoko (Fig. 5.5)	−1.14 −1.65	H + 1.6 to H + 4 days H + 4 days
"	Solid portion of crater collected 1110, 4 March 1954, 90 ft below surface	−1.96 −1.33	H + 5.4 to H + 18 days H + 18 days
"	Rongelap drinking-water sample No. 1, collected 5 March 1954	−1.46 −1.71	H + 4.2 to H + 9 days H + 9 to H + 33 days
"	Rongelap drinking-water sample No. 2, collected 5 March 1954 (Fig. 5.2)	−1.42 −1.73	H + 4.2 to H + 10 days H + 10 days
"	Rongelap drinking-water sample No. 3, collected 5 March 1954	−1.20 −1.78	H + 4.2 to H + 10 days H + 10 days
"	Rongelap drinking-water sample No. 4, collected 5 March 1954	−1.39 −1.90 −1.41	H + 4.3 to H + 10 days H + 10 to H + 21 days H + 21 days
"	Rongelap drinking-water sample No. 5, collected 5 March 1954	−1.41 −1.86	H + 4.5 to H + 10 days H + 10 days
"	Rongelap drinking-water sample No. 6, collected 5 March 1954	−1.36 −1.86	H + 4.2 to H + 12 days H + 12 days
ROMEO	Lagoon sample collected 0900, 28 March 1954, 90 ft below surface	−1.32	
"	Surface lagoon sample collected 0900, 28 March 1954	−1.39	
"	Surface lagoon sample collected 1300, 28 March 1954	−1.34	
"	Crater sample collected 1557, 28 March 1954, 90 ft below surface	−1.34	
"	Lagoon sample taken from crater, 90 ft below surface, 1300, 2 April 1954	−1.36	
"	Fall-out sample collected 29 March 1954 on USS Bairoko (Fig. 5.5)	−1.49	
"	Water used to leach soil sample collected 1400, 2 April 1954; water in contact with sand 30 min	−4.23	H + 5.4 to H + 7.2 days
"	Water used to leach soil sample collected 1400, 2 April 1954; water in contact with sand 1 hr	−5.26 −1.74 −2.22	H + 6 to H + 7 days H + 7 to H + 12 days H + 12 to H + 36 days
KOON	Lagoon sample collected 1220, 7 April 1954 (Fig. 5.6)	−1.02 −1.30	H + 3.8 to H + 18 days H + 18 days
	Soil sample collected 1430 from Bikini, 7 April 1954 (Fig. 5.6)	−1.12 −0.842	H + 0.46 to H + 3 days H + 3 days
UNION	Air sample collected 26 April 1954 (Fig. 5.3)	−1.17	
YANKEE	Air sample collected 5 May 1954 (Fig. 5.3)	−1.07	
NECTAR	None		

consistent with the observation that almost the entire activity on the surface of Rongelap was found on the first inch of soil. Some simple leaching experiments were conducted with samples of the soil from Rongelap and Uterik, but no conclusive results were obtained.

An intensive study was made concerning the half life of material obtained from a semi-trailer that had been exposed to BRAVO and ROMEO contamination. This rate of decay information was desired so that levels of contamination could be approximated upon arrival in the United States. The sample indicated a half life of approximately 28 days. Task group personnel interested in complying with the Interstate Commerce shipping regulations found this information helpful.

5.5 CONCLUSIONS AND RECOMMENDATIONS

5.5.1 Conclusions

1. Present military and civilian instruments are still humidity sensitive during amphibious operations.
2. Du Pont film packet 559 with modifications will be adequate.
3. Present commercial pocket dosimeters are inadequate for use at the Pacific Proving Grounds.
4. Present methods of exposure recording need to be studied and improved.
5. Lagoon contamination can be followed adequately by visual observation of the sediment appearing in the lagoon and by utilization of a standard type survey meter.
6. The evaporation system of the ships for obtaining fresh water provides adequate means for removing radioactive particulate material, at least for the concentrations encountered in Operation Castle.

5.5.2 Recommendations

1. Consideration should be given to the improvement of the air seal on the compartment housing the high-megohm resistors and the electrometer tubes in the PDR-39. The high humidity at the Pacific Proving Grounds affects these components and causes the instrument to become inoperative.
2. Study should be initiated in an effort to obtain increased low-range sensitivity, complete waterproofing, and improved emulsion stability for the Du Pont 559 film packet.
3. Study should be initiated in an effort to obtain reduced electrode leakage, stability under rough handling, and easy decontamination of a pocket dosimeter suitable for use at the Pacific Proving Grounds.
4. Study should be initiated to simplify the record method and to improve the reliability of records maintained at the Pacific Proving Grounds.

CHAPTER 6

DECONTAMINATION GROUP

6.1 ORGANIZATION

The Decontamination Group was organized to provide for the protection of personnel against the effects of radiological contamination and to establish effective means of contamination control. In the accomplishment of this mission it became necessary to establish the following:

1. Personnel decontamination stations at the Parry Island Rad-Safe Center, aboard the USS Bairoko and USS Curtiss, and aboard a barge alongside the USNS Ainsworth.
2. Equipment decontamination areas at Parry Island.
3. Entry and exit check points at Parry Island, aboard the USS Bairoko and USS Curtiss and aboard a barge alongside the USNS Ainsworth.

6.2 METHODS

6.2.1 Personnel Decontamination

These stations included, in some form, a clean change room, a contaminated change area, a shower area, and a monitoring point. At the Parry Rad-Safe Center the clean change room, showers, and monitor check point were all located within the building, whereas a contaminated change area was located in a squad tent adjacent to the shower area. All persons who were found to be contaminated in excess of the background radiation readings upon return from contaminated areas were required to soap and shower until residual contamination had been removed. The Bairoko decontamination station consisted of salt-water showers and contaminated-clothing storage containers on the catwalk adjacent to the flight deck with the change room located in a cabin just off the catwalk. The Curtiss decontamination station utilized the CPO shower facilities at the aft end of the ship for a change and shower area. The Rad-Safe barge alongside the Ainsworth, which handled the greatest volume of personnel, was equipped with a control tent, clean change tent, clothing issue area, and outside salt-water showers. All persons returning to the Ainsworth were monitored before being permitted to enter the ship. All contamination was retained aboard the barge.

6.2.2 Equipment Decontamination

The main base for equipment decontamination was established at the Parry Island contaminated storage area. No center for decontamination was established at Bikini because of the high background levels present on the islands and aboard ship. All equipment with excessive readings was washed with a high-powered spray from a fire truck or Navy tug. After the shipment of this equipment to Eniwetok, a more thorough decontamination was accomplished in the equipment decontamination area through the use of vacuum cleaning, detergent and water scrubbing, steaming, chemical solutions, and removal of surfaces (sanding, chipping, etc.).

Porous materials, such as wooden boats, canvas truck tarpaulins, rope, and rubber, were simply stored until the radioactivity decayed to an acceptable level.

Maximum permissible contamination levels were stated as advisory limits for the control of contamination under average conditions and listed 2 mr/hr as satisfactory for the interior surfaces of aircraft, vehicles, and small boats. Seven milliroentgens per hour was considered applicable for the exterior surfaces of the same transportation, and 20 mr/hr was considered applicable for distant exterior surfaces such as tail surfaces, bumpers, and keels of the aforementioned craft.

All readings were made with side-window type Geiger counter instruments containing counter tubes with walls not substantially in excess of 30 mg/cm^2 and with the beta shield open. When possible, the surface of the probe was held from 1 to 6 in. from the surface that was under observation.

A check point was established at the boat landing on Parry Island. When landing craft with vehicular or other mobile equipment discharged their loads, check-point personnel monitored the equipment. If the reading was below the permissible contamination limit, the equipment was moved on to its destination. If the reading was above the contamination limit, the equipment was moved to the decontamination area for storage or decontamination.

Other check points were established aboard the Bairoko and at the airstrip on Parry Island. Aircraft departing on missions into highly contaminated areas had their interiors lined with paper. When required, paper liners were removed and interiors were cleaned by brushes and industrial type vacuum cleaners.

6.3 RESULTS

The extent of contamination from Operation Castle detonations caused a quick revision of maximum permissible contamination levels. From the outset, background levels aboard ship and on the islands of Bikini exceeded the permissible contamination levels. Emergency personnel and equipment levels were established at 15 mr/hr.

Because the ships were so quickly contaminated, before washdown systems became operational, BRAVO created the largest mass decontamination practice in history. All major ships and the small boats anchored in the lagoon required decontamination. Decontamination procedures were initiated aboard ship shortly after cessation of fall-out. These procedures were generally water methods in which a vigorous washdown by means of fire hose was used on the top surfaces. In general, this action removed about 80 per cent of the contamination except in the case of the wooden flight deck of the Bairoko.

Small boats (LCM and LCT) that were left at the Enyu anchorage at the time of the BRAVO and the revised ROMEO detonations became heavily contaminated and were decontaminated by strong hose washing of water and a mixture of boiler compound and lye. These caustics were used to remove paint and iron rust and were an excellent supplement to strong hose washing. Heavy water flushing and repainting were requirements following decontamination. In dry dock, steam was utilized to remove grease and oil from bearing surfaces. As was to be expected, the most difficult items to be decontaminated were canvas covers, tarpaulins, rope, and fabric bumpers. In most cases these items were simply removed and allowed to decay. Versene scrubbing was attempted on the large canvas "bathtub" on the flight deck of the Bairoko with little success. This treatment tended to solubilize the radioactive particles, causing a spread and increase of intensity.

Other than decontamination of marine equipment, i.e., ships, boats, buoys, anchors, etc., little decontamination was attempted at Bikini. Construction and technical equipment was washed and isolated at the time of shipment to Eniwetok. The standard practice was to isolate items such as trailers, trucks, bulldozers, and cranes within a 10 mr/hr zone and then to clean the transport vessel after the removal of the equipment at Eniwetok.

At Eniwetok the decontamination area soon became filled with an assortment of items that varied from personal luggage to heavy cranes. At one time more than 1200 items were awaiting decontamination. A standard practice of flushing, scrubbing, steaming, and storing was applied to the majority of metal items. Wooden, plastic, rubber, and fabric materials were stored until decay reached the acceptable release value of 10 mr/hr. An added decontamination feature of this outside contaminated storage was a daily rain shower typical of this area.

The release of vehicles and equipment reading less than 10 mr/hr still provided problems when these items were moved into the technical areas or shipped to the United States. Sensitive counting equipment immediately detected low-level contamination when contaminated items were moved into technical areas. This consequent increase in background jeopardized low-level decay measurements, and therefore items were moved from this sensitive area. Decontamination of items to lower levels would have been difficult and impractical.

Since everything and everyone in the northern Marshall Islands had become more or less radiologically contaminated, the continental shipping tolerances of the Interstate Commerce Commission and the Post Office Department became a problem. It is not amiss to say that all packages, persons, and letters returning from the Marshall Islands were contaminated in excess of background radiation. Although not a health hazard, this could have resulted in bad publicity if certain agencies had detected and publicized this nuisance. It was for this reason that the sale of shipping containers from the Pacific Proving Grounds to the general public was restricted.

Interstate Commerce Commission regulations state that all shipments of radioactive isotopes in commercial carriers must be packaged so that no significant alpha or beta radiation is emitted from the exterior of the package and the gamma radiation at any surface of the package must be less than the equivalent of 10 mr of radium gamma radiation filtered through ½ in. of lead for 24 hr. This meant, in many cases, a waiting period in excess of four months between the release from contaminated storage and the acceptable shipment of items by common carrier in the United States.

Because, in many cases, using agencies were unwilling to wait this period of decay, courier service was utilized since this service is free of all Interstate Commerce Commission regulations, provided that a common carrier is not used.

Personnel decontamination progressed satisfactorily throughout the Task Group, although there were many objections to slightly contaminated salt-water showers. Since the majority of personnel were advised to take daily hygienic showers aboard ship, only one instance of beta burns occurred in the Task Force. These burns were found on the abdominal belt line of several members of the Bairoko air operations department. These men had been on the flight deck during the period of BRAVO fall-out, and they did not shower for about 12 hr after exposure. The use of protective clothing would have prevented the small circular patches that appeared on the abdomens of these men. All burns were minor in nature.

Other than aboard the Ainsworth, the arrangement of change room and shower facilities aboard ship did not minimize the spread of contamination. Contaminated individuals, in many cases, had to walk through the ships in order to reach the contaminated change room or showers. The barge facilities adjacent to the Ainsworth provided the most ideal system for the control of contamination aboard ship.

6.4 CONCLUSIONS AND RECOMMENDATIONS

6.4.1 Conclusions

1. Present methods of field decontamination are adequate.
2. Present maximum permissible contamination limits should be reevaluated from the overseas test standpoint.
3. Change room and shower facilities for personnel decontamination aboard ship should be redesigned.

6.4.2 Recommendations

1. Studies should be initiated to determine health hazards from handling, inhalation, and ingestion of low-level fission-product contamination.
2. Personnel decontamination facilities should be investigated and constructed prior to operations in order to maximize contamination control aboard ship.

CHAPTER 7

SUPPLY

7.1 PROCUREMENT AND SHIPMENT

Equipment procurement differed from that of Operation Ivy in that items were obtained on a permanent issue basis rather than on temporary loan. A table of equipment was conceived and expanded during the interim period so that requisitions could be initiated to military and AEC supply agencies.

It was understood that the expenses of TU-7 were jointly sponsored by the AEC and the Department of Defense (DOD), with the latter considered responsible for providing standard military items of equipment. When nonstandard items of equipment were utilized by the task force, in general, i.e., density goggles and film badges, it was the custom to obtain these items from a fund established by JTF-7.

A request was made through the Budget and Fiscal Officer for the establishment of a fund of $8500 to cover the purchase of 2500 4.5 density goggles, 500 dust respirators, and 20,000 film badges; $4500 to provide for the modification of a mobile photodosimetry trailer; and $2000 to provide for the transportation charges of the Unit.

Requisitions of military items were processed through JTF-7 and issued on memorandum receipt to J-4 by TG-7.2. Nonmilitary items were shipped to J-4 by the Supply and Property Division, LASL, for further issuance to TU-7. Nonstock items were purchased by the Supply and Property Division and charged to Test Division funds.

All agencies were extremely cooperative in providing equipment for the overseas operation and contributed immeasurably to the accomplishment of the mission of the Unit.

TU-7 equipment was shipped by water three months prior to Operation Castle and arrived without material loss or damage. Ninety per cent of the equipment was on hand one month prior to the operation. An oversight by staff agencies caused a temporary shortage of critical batteries just prior to the operation.

Two field laboratory trailers were loaded and off-loaded from the USS Bairoko at the San Diego Naval Air Station prior to and after Operation Castle. Transportainers were utilized to transport and store protective clothing throughout the operation. These cubical storage areas were required to provide versatility throughout Castle.

7.2 LAUNDRY

Contaminated clothing was laundered principally at Parry Island, although small amounts were initially laundered at Tare. The ship's laundry aboard the USNS Ainsworth laundered all Rad-Safe towels at Bikini Atoll. The contaminated clothing was shipped in plastic and cloth bags to the Parry Island Rad-Safe Center, where it was turned over to the H&N laundry.

Facilities specifically set aside for the laundering of contaminated clothing were:

1. One 42- by 54-in. American Cascade washing machine.
2. One 30-in. American solid curb extractor.
3. Two-hundred linear feet of clothesline space for air-drying clothing.

These facilities were sufficient to handle 1000 pounds, dry basis, of laundry for a 9-hr working day, provided that rain did not interfere with the air-drying operation. During the first eight weeks of March and April an average of 839 towels, 1348 coveralls, and 776 pairs of booties per week was established.

Laundering procedures consisted of a 5-min cold-water soak, three consecutive washings of 10 min each with hot suds, and four water rinses of 5 min each. A souring or neutralizing compound was added to the last water rinse. "Synsuds" or "Orvis," synthetic detergents, were used for nongreasy clothing. In general, about 5 lb of chemicals was consumed per 100 lb of clothing washed.

Contaminated clothing was monitored before and after laundry for effectiveness of decontamination. After a radiological-safety indoctrination, laundry personnel were badged and provided with protective clothing.

7.3 UTILIZATION OF EQUIPMENT

The supplemented table of equipment met the requirements of TU-7 with few exceptions. The number of dosimeters was considered inadequate, and one more decontamination apparatus could have been utilized by the Unit if Castle had gone as scheduled.

The use of AEC coveralls and the practice of marking shoes reduced the loss rate on these items. A large loss of canvas booties, gloves, 4.5 density goggles, and dosimeters occurred throughout Castle. Booties and gloves were discarded if they were heavily contaminated rather than recovered and laundered. This practice materially reduced the spread of contamination in transportation vehicles and housing areas. The density goggles were issued to various task group representatives for further distribution to personnel of the task group.

The large demands on storage space by TU-7 and Project 6.4 required additional space in J-4 warehouses and additional transportainers. Instrument storage area, control space, and decontamination facilities proved to be adequate. Office space for the Unit would have been adequate if it had not been shared with project personnel. Photodosimetry facilities proved adequate for development but inadequate for recording purposes.

The majority of equipment was left at the Pacific Proving Grounds under the supervision of the AEC resident engineer. This practice was adopted to avoid unnecessary shipment of equipment to and from the Pacific Proving Grounds. With the exception of protective clothing little procurement needs to be initiated for forthcoming operations. An inventory should be made at least six months prior to an operation.

7.4 CONCLUSIONS AND RECOMMENDATIONS

7.4.1 Conclusions

1. The radiological-safety facilities are adequate only for the requirements of the Unit.
2. Types and amount of equipment utilized were adequate to the need.
3. Fluid situations require the utilization of a number of transportainers.

7.4.2 Recommendations

None

APPENDIX A

FILM-BADGE-ACCURACY DATA

A.1 ACCURACY OF DU PONT FILM PACKET 559 AS A PERSONNEL DOSIMETER

To assist in devising this dosimeter, the Radiological Equipment Section of the U. S. National Bureau of Standards carried out a determination of the accuracy to be expected in interpreting dose from photographic densities of Du Pont 502 films exposed to Co^{60} gamma radiation. Twenty-five readings were made on each film with the following results:

Exposure, mr	Density spread over area of film sample	Inaccuracy in dose reading due to density spread: Absolute, mr	Inaccuracy in dose reading due to density spread: Percentage
None	0.01	20	
30	0.02	30	±50
50	0.02	30	±30
100	0.02 to 0.03	27 to 40	±14 to 20
300	0.02 to 0.03	25 to 37	±4 to 6
500	0.03 to 0.04	43 to 50	±4 to 5

The corresponding percentages of inaccuracy in dose readings from exposures at an effective x-ray energy of 0.07 Mev were about 3 to 5 per cent better for the 30 and 50 mr exposures and the same for all higher energies.

A.2 RELATIVE SENSITIVITY OF FILMS BEHIND LEAD FILTERS*

	Du Pont 502		Du Pont 606	
Mev	Sensitivity	Inaccuracy, %	Sensitivity	Inaccuracy, %
0.04	Negligible		Negligible	
0.07	1.22	18 high	1.23	19 high
0.12	0.99	1 low	0.89	12 low
0.17	1.02	2 high	0.98	2 low
0.21	0.94	6 low	1.07(?)	6 high
1.25	1.00	Accurate	1.00	Accurate

Sensitivity is normalized to the value at 1.25 Mev. Response is assumed to be flat above 1.25 Mev.

* 0.72 mm of lead.

A.3 VARIATIONS OF RESPONSE DUE TO LEAD-FILTER THICKNESS

The Radiological Equipment Section has also found that in the low-energy region the variation in response due to variations in lead thickness is quite considerable but not prohibitive. There is practically no variation of response with lead thickness for energies above 1 Mev. Unfortunately vendors are unable to meet 10 per cent tolerances.

Effective radiation energy	Exposure needed to obtain unit density behind various lead thicknesses, r					
	0.65 mm		0.72 mm		0.79 mm	
	D-502	D-606	D-502	D-606	D-502	D-606
0.07	0.80	32.0	0.98	39.0	1.18*	45.5*
0.12	1.08	45.0	1.28	54.0	1.57	62.2*
0.17	1.11	43.7	1.22	49.0	1.33*	54.4*
0.21	1.22	44.3	1.31	45.0	1.40	45.7*
1.25	1.23	47.0	1.23	47.0	1.23	47.0

A.4 VARIATIONS BETWEEN 559 PACKETS AND PROJECT EXPERIMENTAL BADGES

Discussions on variances between the test badge and experimental project badges led to a controlled comparison utilizing 364 μc of Co^{60} for a time period of 100 min and 45 sec at a distance of 40 cm. Calculated dosage was 5103 mr.

Film type: Du Pont 502-606; emulsion 559-107

Film badge	Average densitometer reading	Actual dosage	Variation from calculation, %
36	2.50	5819	13.9
37	2.49	5765	12.9
38	2.49	5765	12.9
39	2.47	5615	10.03
30	2.55	6215	21.8
29	2.52	6085	19.2
28	2.46	5515	8.06
27	2.49	5765	12.9
26	2.52	.6085	19.2
25	2.51	5915	15.9
24	2.55	6215	21.8
23	2.50	5815	13.9
22	2.49	5765	12.9
21	2.49	5765	12.9
20	2.46	5515	8.06
Control	0.26	85	
Average			14.42

* Extrapolated.

Film type: 502-510

Film badge	Uncorrected dosage	Correction factor	Actual dosage	Variation from calculation, %
83	6400	0.44	2816	44.8
84	6600	0.53	3498	31.4
85	6500	0.44	2860	43.4
86	6500	0.44	2860	43.4
87	6800	0.53	3604	29.4
88	6600	0.44	2904	43.1
89	6600	0.44	2904	43.1
90	6800	0.44	2992	41.3
91	6600	0.53	3498	31.4
92	6500	0.44	2860	43.4
93	6500	0.44	2860	43.4
94	6500	0.53	3445	32.4
95	6200	0.44	2728	46.4
96	6400	0.44	2816	44.8
97	6400	0.44	2816	44.8
98	6500	0.44	2860	43.4
Average				40.6

APPENDIX B

FILM-BADGE CALIBRATION AND DEVELOPMENT

B.1 GENERAL

B.1.1 Radiation Standards

The primary radiation standard for calibration of film badges used at the Pacific Proving Grounds was radium. This standard offers the closest approximation to the energy spectrum of fission products available. Where Co^{60} sources were utilized, correction was applied, where necessary, to producé results consistent with radium. The stronger Co^{60} source available was utilized mainly because of the shorter exposure time required.

B.1.2 Range of Calibration

The low-range film was calibrated from 40 mr to 10 r and the high-range film from 10 to 60 r. This curve was extended to 200 r on the initial calibration. Additional extensions were obtained only if needed.

B.1.3 Frequency

A new calibration curve was obtained whenever developing solutions were changed and between all shots. In addition, changes in developing procedure, poor temperature control, changes in emulsion, or excessive correction factors required recalibration.

B.2 CALIBRATION PROCEDURE

B.2.1 Range Construction

A variable distance-constant time calibration range was constructed, utilizing a 4- by 8-ft plywood sheet. Exposure and distance relationships are as follows for the 2.64-curie Co^{60} source:

1-hr exposure		6-min exposure	
Distance, cm	Dose, mr	Distance, cm	Dose, mr
24	60,000	65.3	800
29.4	40,000	75.5	600
33.7	30,000	92.9	400
41.4	20,000	106	300

1-hr exposure		6-min exposure	
Distance, cm	Dose, mr	Distance, cm	Dose, mr
58.1	10,000	131	200
65.3	8,000	185	100
75.5	6,000	207	80
92.9	4,000	240	60
131	2,000	294	40
185	1,000		
207	800		

Circles were drawn with radii equal to the distances given above, and slotted pegs were set into holes drilled on the circumference of the circle. The distance between adjacent pegs was such that the slots gripped the edges of a film badge when inserted between them with the long axis vertical. The pegs were placed on a spiral in order to minimize scatter.

The calibration curve was extended by placing film badges at the proper station and exposing them for 10 hr instead of 1 hr, as noted in the table above.

B.3 STANDARD FILM BADGES

"Standards" were film badges exposed to a known amount of radiation and then developed with the unknown film. A comparison with the calibration curve detected variations in the development procedure.

Standards used were exposed as a group to 500 mr prior to the first shot and then stored with unissued film. A standard was included with each batch of film developed.

B.4 FILM-BADGE PROCESSING

All film-badge processing laboratories that were operated at the Pacific Proving Grounds were air conditioned to reduce emulsion breakdown caused by excessive heat and/or moisture.

Film badges were stored in a refrigerator at a temperature of 40°F. A drying agent in open pans was placed inside to reduce the air humidity.

Film-badge standards and controls were allowed to come to room temperature before development.

Development was usually done at night after all film badges of recovery parties were collected. Exposures so obtained were filed nightly so that accumulated doses were up to date for the operation for the following morning.

B.5 PROCEDURE

B.5.1 Equipment

Film badges were processed in three stainless-steel tanks containing 5 gal each of developing solution, stop solution, and fixer. The temperature of the solutions was maintained at 68°F by being immersed in a water bath that was thermostatically controlled.

After development, film badges were washed in running water of the same temperature.

Drying was accomplished by passing heated dry air over the badges.

All development was done under safelights of the Wratten 6B type.

B.5.2 Film-badge Development

Film badges were carried into the darkroom in wooden carrying boxes. There the lightproof covering was removed, and the film components were loaded into LASL type racks, the high-range film followed by the low range.

The racks were placed in the developing solution and agitated for 4.25 min. They were removed and allowed to drain for 15 secs. They were then placed in the stop solution for 20 sec and then fixed for 10 min. As a final operation the film was washed for 30 min to remove all traces of the three developing solutions.

Following the washing the film was dried for 30 min at a temperature of 100°F while still in the racks.

B.5.3 Density Determination

The densitometer and the attached voltage regulator were allowed to warm up for 30 min to eliminate drift.

The densitometer was then zeroed, and the calibration wedge was used to fix one point on the scale. The film-badge readings were taken from the area that was under the lead strip, and the density was recorded on the laboratory processing sheet. The density was converted to dose from a table prepared from the calibration curve.

To allow for changes in background, the densities of the controls were converted to dose, and the average was subtracted from the dose of the personnel film badges. This adjusted dose is recorded on the laboratory processing sheet. (The density of the controls cannot be subtracted from the density of the exposed film badges because the slope of the calibration curves is not constant.)

B.5.4 Standard Film Error Adjustment

If the standard film dose, after adjustment for control variations, was still in error by an amount greater than 10 per cent, all film-badge doses were multiplied by the ratio of the correct standard dose to the dose obtained.

B.5.5 Filing and Records Transfer

Each night, as soon as the processing was completed, the issue sheets were separated, and the duplicate was immediately sent to the other atoll.

The laboratory processing sheets were made in duplicate, and the duplicate was immediately forwarded to the other atoll.

B.5.6 Film-badge Storage

After being processed, the personnel film badges were placed in small envelopes and stored in oblong white boxes in numerical order.

APPENDIX C

ASSIGNMENT OF PERSONNEL

The following is a list of the divisions of JTF-7, with the number of assigned personnel:

Command Section		
John D. Servis, Major, USA, Commander		
Technical advisers		5
LASL	4	
US Public Health Service	1	
Control Group		
Control officer		1
Assistant control officers		5
USA	2	
USN	3	
Laboratory Group		
Laboratory officer		1
Analysis officers		2
Instrument repair supervisor		1
Laboratory supervisor		1
Instrument repairmen		2
Laboratory technicians		3
Dosimetry shift supervisors		3
Dosimetry technicians		5
Clerk-typists		6
Decontamination Group		
Decontamination supervisor		1
Assistant decontamination supervisor		1
Decontamination specialists		6
Supply and Administration Section		
Supply officer		1
Supply sergeants		2
Administrative assistants		2
Supply NCO		1
Supply assistants		2
Project Monitors		
Program 1		37
Project 1.1	1	
Project 1.2a	18	

Project 1.2b	7	
Project 1.4	5	
Project 1.6	2	
Project 1.8	4	
Program 2		35
Project 2.1	7	
Project 2.2	2	
Project 2.3	6	
Project 2.5a	8	
Project 2.5b	7	
Project 2.6a	5	
Program 3		4
Project 3.1	2	
Project 3.2	1	
Project 3.3	1	
Program 6		22
Project 6.4	19	
Project 6.5	2	
Project 6.6	1	
Program 7		2
Project 7.1	2	
Program 11		3
Project 11.3	3	
Program 12		3
Project 12.3	3	
Program 13		14
Project 13.1	14	
Program 14		5
Project 14.1	5	
Program 15		1
Project 15.1	1	
Program 16		4
Program 18		6
Program 21		3
Program 22		18
TU-2		1
TU-7.1		1
TU-13		3
J-1		2
J-3		4
J-4		1
Support		4

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