MARSHALL ISLANDS FILE TRACKING DOCUMENT

Record Number: 380

File Name (TITLE): Fallout Studies by Oceanographic Methods

Document Number (ID): WT-1316 (EX)

DATE: 2/1961

Previous Location (FROM): CIC

AUTHOR: None

Addditional Information:

OrMIbox: 21

CyMIbox:

WT-1316 (EX)
EXTRACTED VERSION

11643

OPERATION REDWING

Project 2.62a
Fallout Studies by Oceanographic Methods

Pacific Proving Grounds
May - July, 1956

Defense Atomic Support Agency
Sandia Base, Albuquerque, New Mexico

February 6, 1961

NOTICE

This is an extract of **WT-1316, Operation REDWING, Project 2.62a**, which remains classified **Secret/ Restricted Data** as of this date.

Extract version prepared for:
Director
DEFENSE NUCLEAR AGENCY
Washington, D.C. 20305
1 February 1980

FOREWORD

This report presents the final results of one of the projects participating in the military-effect programs of Operation Redwing. Overall information about this and the other military-effect projects can be obtained from WT-1344, the "Summary Report of the Commander, Task Unit 3." This technical summary includes: (1) tables listing each detonation with its yield, type, environment, meteorological conditions, etc.; (2) maps showing shot locations; (3) discussions of results by programs; (4) summaries of objectives, procedures, results, etc., for all projects; and (5) a listing of project reports for the military-effect programs.

ABSTRACT

The first of five areas of study was the oceanography of the water within a 300-mile radius of Bikini Atoll prior to and during the operation. The objectives were to measure oceanographic parameters affecting the fallout pattern and to determine the radioactive background within the ocean. The results of this study have been presented as a separate report, WT-1349. A partial abstract is presented in Chapter 1 of this report.

The second study (Chapter 2) involved the determination of fallout by the use of oceanographic methods. In addition to the collection of samples for this and other projects, it was the objective of this survey to measure the intensity and extent of fallout, to convert this to equivalent land values, and to relate the in situ fallout distribution to the oceanographic parameters.

The results of the oceanographic fallout surveys show that: (1) Shot Cherokee (an air burst) produced no measurable fallout; (2) Shot Flathead (a water burst) produced fallout that mixed downward into the ocean water at a rate of 3.5 m/hr and attained an average penetration depth amounting to 75 percent of thermocline depth; (3) Shot Navajo (a water burst) produced fallout with a mixing rate of 2.3 m/hr and attained an average penetration depth of 75 percent of thermocline depth, and although Navajo had a total yield of [redacted] it produced an area of less than 150 mi^2 of hazardous dose rates; (4) Shot Tewa (a combination water-and-land burst) exhibited a mixing rate similar to Flathead (3.8 m/hr) and an average penetration depth similar to Flathead and Navajo (75 percent of thermocline depth); this 5-Mt, [redacted] produced hazardous dose rates over an area exceeding 2,000 mi^2; (5) Shot Zuni (a land burst) fallout mixed downward at 11 m/hr and reached an average penetration depth of 107 percent of thermocline depth; (6) dose rate in fallout resulting from nuclear detonations is directly proportional to the fraction of fission yield; and (7) the cube-root scaling laws are valid for fallout dose rates from nuclear detonations over the range from 0.4 to 5.0 Mt.

The third study (Chapter 3) concerned oceanographic and fallout measurements in the lagoon circulation for various wind conditions and, from this, predict the movement of radioactive water from a knowledge of the winds. The results of the lagoon oceanographic studies have been presented in WT-1349. The measurements show that the movement of radioactivity with the lagoon water corresponds to the observed current movements. These same measurements have been used in WT-1349 to develop a method of predicting the distribution of radioactivity within the lagoon from a knowledge of current directions and velocities.

The fourth interrelated field of work (Chapter 4) involved the installation and maintenance of anchored instrument stations in the deep ocean water. The results of this effort have such military and scientific implications that the complete procedure for installing these stations is included as an appendix.

The last study (Chapter 5) was a radiochemical examination of fallout in the marine biosphere. The results show the distribution of fallout material in the water, the air above the water, the sediments, and marine life. These studies were carried out in the lagoon as well as in the open ocean. Marine organisms selectively absorb such nonfission products as Mn^{54}, Co^{58}, Co^{60}, and Zn^{65}. Oceanic contamination was detected from the Eniwetok Proving Grounds to a latitude of 11 degrees south after the completion of the test series.

PREFACE

Project 2.62 received excellent cooperation and support from JTF SEVEN. Particularly the following should be mentioned: the command and staff of TG 7.3, for close and understanding cooperation in the operation of the USS Silverstein, USS McGinty, USS Sioux and M/V Horizon; Captain Payne, Captain Pennington, Captain Walkup, Captain Hopkins, and the officers and men of the vessels, for prolonged efforts and continuing interest in carrying out the work of this project; Chief Waller and the crew of the LCU 1136, for continuous help in obtaining data on the lagoon survey; the command and staff of TG 7.1 and TU 7.1.3, for support, aid and advice. The efforts of the Program 2 staff to make the operation a success cannot be overrated. Commander Campbell, Major Chiment, Major Killion, and Dr. Van Lint were thoroughly dedicated to each project and to its integration into the program. In addition, the close cooperation and support between the projects participating in the Program 2 Central Control greatly enhanced the value of the work. In particular, Projects 2.63, Dr. Triffet and Mr. Schuert; Project 2.10, Mr. Armstrong; and Project 2.64, Messrs. Graveson and Cassidy, contributed greatly to this report.

Not least should be mentioned the valuable aid of Drs. Pritchard, Paquette, and Horning and Messrs. Horrer, Faughn, Brennen, and Moulton in their assistance throughout the project and in the preparation of this report.

In addition, the "home guard" deserves high recognition; the support of Mrs. Lorayne D. Buck, Mrs. Patricia Bridger, Mrs. Jeane Oxarart, Miss Barbara Edwards and Mrs. Suzan Volkmann has been invaluable.

Finally, a sincere expression of gratitude is given to Dr. Theodore R. Folsom, for his willing and invaluable participation in the preparatory phases of the operation and his guidance in preparing this report.

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Chapter 1
INTRODUCTION

1.1 OBJECTIVES

The objectives of this project were to: (1) understand the oceanography of the fallout area, so as to allow better analysis of the fallout area; (2) determine by oceanographic methods the intensity and extent of fallout and convert this to land-equivalent values; (3) study the circulation water within Bikini Lagoon and predict the movement of the radioactive material suspended in the lagoon; (4) install and maintain anchored instrument stations in deep ocean water; and (5) perform radiochemical analyses on as wide a scope as possible with equipment on hand.

In achieving these objectives, it was hoped that enough information concerning the study and measurement of fallout at sea would be gained to permit a reduction in the number and types of measurements required to describe the fallout phenomena under various conditions of detonation. It was also anticipated that the early determination of the initial fallout distribution would be valuable to other agencies making long-range studies of the radioactive water mass.

1.2 BACKGROUND

The existence of fission-product problems — control, disposal, and fallout — were recognized virtually simultaneously with the discovery of fission. Various plans to safeguard test personnel and adjacent citizenry have been a part of all test programs since Operation Trinity. For shots in the 20-kt range, fallout was scarcely more than an added overkill on targets already heavily damaged by thermal and blast effects. An early exception was Shot Baker, Operation Crossroads, in which a highly contaminating test against refractory targets gave evidence of the added offensive value of fallout materials. The high-airburst geometry of many tests, including the Japanese attacks, precluded much attention to fallout.

It had long been apparent, however, that fallout-radiation intensities increase with some fractional power of the total yield for weapons having the same percentage of fission yield. Any fallout model is complicated by the natural conditions of atmospheric circulation; and at the time of Shot Mike, Operation Ivy, exploration of mathematical and analogue models was more popular than extensive field studies, and only a cursory fallout study was included in the weapon-effect program of that shot. Though extremely contaminating, Shot Mike was carried out without conspicuous evidence of the fallout potentialities, with the negligible exception of the experience of the Scripps Institution of Oceanography (SIO) reaearch vessel, the M/V Horizon (Reference 1).

Operation Castle included a more thorough investigation, consisting of manned and shielded vessels and free-floating telemetering collectors. Shot 1 illuminated the severity of the fallout problem. Following a hastily-mounted survey for Shots 5 and 6 of Operation Castle (Reference 2) and other experiences (Reference 3), the work, reported herein, was envisaged for Operation Redwing. The specific historical background of the methodology is reported in the appropriate individual chapters.

A particularly valuable innovation in Operation Redwing was the organization of the Program
2 Control Center, from which all survey elements of the fallout program were directed and

where discrepancies of findings were resolved. This center ensued from the difficulties encountered in resolving discrepancies of results between the various surveys of Operation Castle months after the operation had taken place.

1.3 THEORY

A large number of orgainzations have devoted much effort toward the erection of models of the fallout processes (Reference 4). A discussion of these is outside the scope of this report. Briefly, the models consist of certain partly rational, partly empirical assumptions of cloud and stem dimensions and distribution of particle size and activity therein and the projection of this distribution on the earth's surface by the precipitation of these particles through the existing wind pattern.

It is apparent that the accumulation of fallout particles on the earth's surface is an integrative process and that information pertinent to the original spatial distribution of the particles is lost to integrated measurements on this plane. Additional information can be obtained by exploring the time sequence of the integrative process, i.e., the use of time-versus-dose-rate recorders and incremental collectors. Such added information restricts the freedom of the model by additional terms, but not to the extent of permitting a unique determination of the original spatial distribution.

The surface expression of the fallout is a highly empirical finding, and veracity of similitude to other detonations in other environments cannot be assumed. Thus, the findings must be used as a spot check upon a model, erected on this and other evidence, that is sufficiently comprehensive and versatile to accomodate the introduction of very-different materials and processes. Failing this, the findings become merely "The Distribution of Radioactivity Following Shot Digger on Pokofuaku Island of Bikini Atoll, 06:31, 21 May 1956".

As an attack on the fallout problem, the surface data are merely supporting evidence for more-highly embracing cogitation, except as they apply directly to the overall disposal problem of which fallout is only a part.

Another order of empiricism is introduced by the existence of "clean weapons." Heretofore, with high-fission weapons, the environmental influences on total activity have been negligible, and the factors influencing the fallout process have been only the gross physical and chemical nature of the environment. In the case of the clean weapons, however, the total activity may be greatly influenced by microchemical constituents of the environment and the processes to which they are subjected. In partial confirmation of this is the predominance of Zn^{65} in the organisms of the Pacific following Operation Castle (Reference 5).

1.4 REPORT ORGANIZATION

The overall task accomplished by Project 2.62 is actually the sum of several smaller tasks. Each of the smaller tasks possesses a degree of completeness within itself. As a result, the report is organized so that each of the chapters, from Numbers 2 through 5, is a complete report covering a specific task. Chapters 1 and 6 apply to the overall project.

Chapter 4, the report concerning deep-moored stations, is particularly detailed, because it is felt that this method of collecting data is especially applicable to test series of this type, as well as to other scientific and military problems. The complete procedure for installing these stations is presented in Appendix B.

1.5 OCEANOGRAPHIC AND BACKGROUND RADIOACTIVITY SURVEY

Of the objectives listed in Section 1.1, the first, and part of the second, have been answered in the Project 2.62b report (Reference 6).

Chapter 2
OCEANOGRAPHIC FALLOUT SURVEY

2.1 OBJECTIVES

The objectives were to: (1) Obtain information on the distribution of radioactivity horizontally and vertically in the ocean, which together with results of other projects would result in an understanding of fallout at sea and permit a reconstruction of fallout over an equivalent land surface; (2) collect samples of radioactive water and other data for this and other agencies and projects; (3) relate the penetration of fallout into the sea to known parameters such that future surveys could be carried out with reduced effort; and (4) utilize radioactivity from bomb debris toward a better understanding of basic oceanographic processes.

2.2 BACKGROUND

In discussions following Shot 1 of Operation Castle, it was conjectured that mixing of the fine bomb debris might not proceed rapidly into and below the thermocline but would tend to be retained in the mixed surface layer. This conjecture implied the possibility that detectable levels of radioactivity would persist in the surface layers of the sea for a sufficient time following the detonation to permit surveys by surface craft. The conjecture was confirmed when ships reported detectable levels of activity accumulated in their evaporators during passage of adjacent sea areas.

In the intershot period following Shot 1 of Operation Castle, members of the Scripps staff in the EPG constructed several experimental Geiger counters for use in shallow water and performed cursory examinations of water activity in Bikini Lagoon.

The background then existed for an attempt to survey radioactive fallout, utilizing the ocean surface as a collector and surface vessels as instrument platforms.

In this connection, a special study was initiated just prior to Shot 5 to obtain an estimate of the fallout contours by water sampling and by the use of oceanographic survey techniques in the open ocean. The results of the survey following Shot 5 and of the water-sampling program following Shots 5 and 6 have been published (Reference 2).

During Operation Wigwam, the same type of survey was again carried on by SIO (Reference 3). The notable difference from Castle was that no fallout was anticipated, and the task was one of outlining the radioactive water mass and of following the transport of this water by the ocean currents. For this survey, new and improved underwater Geiger counters were utilized.

The results of the latter phases of the Wigwam survey (Reference 3) indicate that the survey techniques successfully located radioactivity in the water that was only 10 to 20 gamma counts/min higher than the natural background count of oceanic water.

2.3 THEORY

The use of the ocean as a collecting surface has one singular simplicity: there is no doubt as to the efficiency of its collection, since each unit surface area retains whatever falls on it.

Beyond this, the oceanographic survey approach is subject to the complexities of the fluid medium, and dispersive processes begin immediately following the arrival of fallout.

Except in very high latitudes, there exists in the ocean a surface layer of relatively warm water that varies in thickness, depending upon its geographic location. This thickness may range from less than 30 to more than 150 meters. The temperature of the water in this layer is uniform from the sea surface to the bottom of the layer, or thermocline, beyond which the temperature decreases rapidly with increasing depth. This layer owes its existence to the stirring action of wind and waves and is often referred to as the "mixed layer."

When a substance of soluble or colloidal nature or one having about the same density as water falls on the ocean surface, it becomes distributed into the mixed layer rapidly, often within a few hours. Upon reaching the thermocline, however, it virtually ceases to penetrate downward, because of the sharp increase in density, and thence stability, at this boundary.

It is this phenomenon that permits the success of the survey, because most of the radioactive fallout is retained in the upper layer and subjected to uniform mixing long enough for the survey vessels to measure surface values of dose rate throughout the fallout area. Since the depth of mixing of fallout is known and because the dose rate is uniform to this depth, one can mathematically squeeze all of this activity into a layer only 1 meter thick, and thence onto the surface of a hypothetical plane.

2.3.1 Dose Rate. The measurements of radioactivity in water made by the survey vessels are of two types:

1. The underwater Geiger counter (henceforth this instrument will be referred to as a probe) is towed just below the surface of the water by the survey vessel and a continuous trace of its output versus time is recorded. This is later reduced to dose-rate values and plotted against the geographic location that corresponds to the recorded time. This yields a general pattern of dose-rate values over the entire area traversed by the survey vessel.
2. During the survey, the vessel stops at selected locations and measures the depth to which the radioactive fallout has mixed into the water. This is accomplished by lowering the probe, by use of a hydrographic winch, until the output signal from the probe indicates that it is surrounded by clean water.

The final dose-rate values desired are those that would have been measured at a height of 3 feet had the same fallout occurred on flat ground, instead of on the ocean. The derivation of the factor necessary to make this transition from the dose rate in water to dose rate at 3 feet is presented in Appendix A. In the treatment of the data, two other correction factors must be utilized before the information is ready for final presentation.

2.3.2 Decay Coefficient. The radioactive-decay constant used for fission products is generally accepted as being $t^{-1.2}$; this decay value was used in Reference 2. For measurements taken under ordinary circumstances, this value is a sufficiently close approximation. However, the measurements taken from the survey vessels are far from ordinary. The fission products that fall on the ocean surface are subjected to fractionation, both in air and in water. This alone may give rise to a shift in the decay exponent. Furthermore, the measurements are being made under water, and the energy spectrum as seen by the instrument is subject to degradation by the scattering in water. The instrument itself does not have uniform response to incident gamma radiation of varying energy from a distributed source. As a result of these considerations and because the energy spectrum of the fission products changes rapidly during the first few days following their formation, it was felt a direct measurement by the probe of the decay of radioactive fallout would be valuable for Operation Redwing. This measurement was carried out following each of the shots, and the method used is presented in the section on instrumentation.

2.3.3 Current Drift. The survey vessels cannot accomplish their tasks rapidly enough to prevent the ocean currents from distorting the fallout pattern considerably. Before a meaningful picture can be presented, all measurements must be corrected for this distortion. This must be done so that radiation values will be plotted where the material fell out, rather than where they were measured. The method of obtaining this factor is presented in the section on results and discussion.

2.4 OPERATIONS

2.4.1 Survey Vessel. Three ships were utilized in making the Project 2.62 fallout survey after each shot. Two of these were destroyer escorts, the USS McGinty (DE 365) and the USS Silverstein (DE 534). These two ships were outfitted with the following equipment: (1) detector probes for measuring the dose rate at the water surface, plus the allied equipment necessary for measuring the dose rate at depths to and below the thermocline; (2) mast-head instruments (Nav-rad), for scanning the sea surface for radiation from atop the bridge; (3) drogues with which to mark water masses of particular interest for measurement of subsequent current drift; and (4) water-sampling equipment for the taking of surface samples.

The third ship was the research vessel M/V Horizon of SIO. The ship was outfitted similarly to the two destroyer escorts and had the following additional equipment: (1) decay tank for measuring the decay of radioactivity as recorded by the thick-walled probe; (2) radiochemical laboratory for a systematic study of the extent of radioactive contamination of the marine environment; (3) water-sampling equipment for the collection of samples from any desired depth; and (4) oceanographic equipment for making allied measurements and for collecting marine organisms and bottom samples.

In addition to these three vessels, the two Project 2.63 YAG's were used in the overall fallout survey. For joint Project 2.62 and 2.63 purposes, these two ships were outfitted with probes and allied equipment necessary to measure radioactivity at the water surface and at depths.

2.4.2 Control Center. In order to coordinate the movements of the survey vessels, a control center was set up on the USS Estes (AGC-12) under the direction of the Program 2 staff. This control center was operated during the entire time that each survey was in progress. Representatives from the participating projects were present during this time and had at their disposal the radio equipment necessary to communicate, advise, and direct all survey units.

It was the function of these representatives and of the Program 2 staff to: (1) coordinate the movements of the survey units so that any discrepancies in measured values could be resolved immediately; (2) ensure that all the areas of the fallout pattern were surveyed in sufficient detail to yield a complete picture; and (3) direct the various survey units to rendezvous points for intercalibration checks.

2.4.3 Procedures. During the hours of darkness preceding and at the detonation time of each event, ships remained at sea on stations assigned by CTG 7.3. After the shot, the survey ships remained on station and in communication with the control center. During this period of waiting after the shot, the control center sent estimated positions of the boundaries and axis of the expected fallout pattern. These messages, as well as all others pertaining to the survey, were sent by radio in a code agreed upon by the participating projects.

Based upon information being received from the YAG's and other projects, the control center determined when it was radiologically safe for the Project 2.62 ships to commence their survey. The three ships were informed of this decision and were also sent a recommended course for starting the survey.

From this time on, to the end of the survey, the procedure for the destroyer escorts was as follows: (1) the ship proceeded on recommended course until the boundary of fallout radiation was contacted; (2) she passed through this boundary into the area of contaminated water and made a station consisting of a bathythermograph (BT) measurement to determine the thermocline depth, measurements to determine the depth to which the radioactivity had penetrated, collection of surface-water sample for subsequent analysis by Project 2.62 and other projects, and launching of a drogue[1] to mark this region of contaminated water; (3) the ship then proceeded back through the boundary into clean water on a course approximately 45 degrees to the edge of

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[1] This method of tagging water was not used extensively after Shot Cherokee, because the drogues drifted into the area of deep-moored skiffs and were suspected of parting the pennant connecting the skiff with deep float.

the contaminated water; and (4) as soon as the ship was well into clean water, it was swung 90 degrees and proceeded into the fallout area again and made another station; thus, she followed the edge of fallout in a zig-zag fashion.

This basic procedure for the destroyer escorts was subject to whatever modifications the control center and the chief scientist aboard each ship deemed necessary.

From the time the M/V Horizon received permission to commence the survey, her procedure was slightly different from that of the destroyer escorts and is outlined as follows:

The Horizon too, proceeded into the fallout area on recommended course and speed, but with the purpose of meeting the YAG 39 and taking over the penetration measurements being made in the vicinity of a marker drogue that was previously launched by the YAG.

Either prior to or just after relieving the YAG 39, the Horizon made a station in contaminated water and filled the decay tank.

The measurements made in the vicinity of the drogue were by: (1) periodic stations consisting of BT measurements, radioactivity penetration measurements, and collection of surface water samples and (2) one station, consisting of those measurements listed above, with the addition of a Nansen bottle cast for collection of depth samples for Project 2.63, a similar cast for Project 2.64 water samples, a special bottle cast for collection of samples for AFOAT-1 element, and a zooplankton net tow for collection of biological samples.

The measurements and collections made in the vicinity of this drogue were particularly valuable because the drogue was "tied" (by a parachute) to the spot of water in which it was launched. This resulted in a study of the time variations, rather than of geographical changes in the measured values. Maintaining position on the drogue also gave an excellent measure of the current drift of this one mass of water. Therefore, the measurements were made around the drogue for as long a period as possible.

Upon departure from the drogue station, the M/V Horizon made measurements and collections in areas designated by the control center. These, in general, were areas where deep water samples were required or where insufficient measurements had been made by the destroyer escorts.

All three survey ships were required to return to Bikini prior to the morning of D+5. This was for the purpose of delivering the water samples to the flyaway aircraft. For every shot except Tewa this gave sufficient time for a complete survey.

2.5 INSTRUMENTATION

The block diagram shown in Figure 2.1 of the Project 2.62 installation on the YAG's is also applicable to the two destroyer escorts and the M/V Horizon. The notable difference is that while the winch was remotely controlled on the YAG's, such was not the case on the other three survey vessels.

2.5.1 Underwater Detector Probe. The sensing instrument itself was the probe and is shown schematically in Figure 2.2. The schematic shows the components clearly enough, but a few design points should be mentioned. The instrument was basically composed of four separate packs that could be replaced in the tube:

1. The towing end contained the pressure-sensing element, which was a bourdon-actuated potentiometer across which 2.68 volts were imposed from mercury cells. The output from the gage was a minimum at zero pressure and a maximum when full pressure was applied. Since all ships were not required to take measurements to the same depth, full-scale deflection for the gages on each ship corresponded to the following depths: M/V Horizon, 800 meters; YAG 39, 400 meters; YAG 40 and two destroyer escorts, 200 meters. The pressure-sensing elements were checked periodically for calibration. This was accomplished, on deck, by connecting the copper tube vent to a hydraulic pump and measuring the current output at the recorder panel as the pressure was increased.
2. The second section contained the high-voltage pack for the Geiger tubes. This was composed of fifteen 45-volt hearing-aid batteries and was plugged into the towing end.

3. The third section contained the battery packs for the pulse amplifier. The filament batteries were two 1.3-volt RM-42 mercury cells in parallel, and the plate voltage was supplied by forty-two 1.3-volt RM-1 mercury cells. This plate voltage was also additive to the high voltage pack, giving a total of 730 volts across the G-M tubes.

4. The radiation-sensing element was built into the switching (or terminal) end of the probe. Since the anticipated variations in dose rate were large, four combinations of G-M tubes were used to cover four different ranges of dose rate levels. The most systematic way of describing these combinations is to consider the vessels which utilized each type. The M/V Horizon and the two destroyer escorts were equipped with two interchangeable sensing heads for each probe. In order to change ranges on these heads, the instrument had to be brought on deck and the selector switch turned by hand.

For the fourth section, sensitive and medium ranges were combined into one head. The sensitive range consisted of eight Anton 315 G-M tubes wired in parallel. A pulse amplifier was used both for amplification of the signal and for range selection. Using this combination, four ranges of sensitivity were covered between 0.0005 and 25 mr/hr. Also included in this head was a single Anton BS-2 G-M tube, whose pulse was put through the amplifier. This tube covered the range from 5 to 100 mr/hr. The other head contained two Anton BS-213 G-M tubes, whose output was measured directly. This combination covered the range from 100 mr/hr to 100 r/hr.

Since the function of the YAG's was to be present under the fallout and all personnel were closeted in a shielded control room, the range selection had to be made remotely. In the medium and low sensitive head, a relay was installed. When the range required changing, the relay was tripped by a pulse from the control room. The medium sensitivity range in this head was a single Anton 315, whose output was measured directly. The range covered by this tube was from 1 to 100 mr/hr. The low-sensitivity range was the same as that used on the M/V Horizon and the two destroyer escorts. The other replaceable head was the high-sensitivity head similar to those on the Horizon and destroyer escorts, but lacking the medium-range BS-2.

All of these instruments were calibrated periodically by the use of point sources of Co^{60}. Since a drop in battery voltage would result in a calibration change, it was necessary to take calibration checks before and during each shot to guard against any shift in calibration.

2.5.2 Towing Cable. The probe was connected to the ship by use of a special, three-conductor armored cable. The conductors entered the probe first through a rubber packing gland and then through Stupakoff (glass-insulated) connectors. This ensured that, even if the packing gland leaked, no water could enter the probe through the electrical connection. The output signal traveled through the conductors and was picked up at the winch on a mercury slip-ring assembly.

2.5.3 Recorders. From the slip-ring assembly, the signal was transmitted to the recorder through a coaxial cable. Leeds and Northrup X-Y recorders were used. These were especially adapted so that a single recorder could plot radiation either against time or against depth. While the probe was being towed across the pattern, the recorder was placed on time drive and a continuous trace of surface radiation was recorded. When the ships stopped on station to make a penetration measurement, the recorder was switched to Y-axis drive and a trace of depth versus radiation was recorded.

2.5.4 Calibration of Probe. All calibrations of the towed probes were made with point sources of Co^{60}. This meant that the calibration was strictly accurate only for hard gamma radiation that struck the probe normal to the axis.

In order to relate these Co^{60} calibrations to underwater measurements of uniformly mixed fission products and subsequently to the dose rate at 3 feet above a hypothetical infinite plane, a series of special calibrations were made (Appendix A).

2.5.5 Nav-Rad Instruments. The M/V Horizon and the two destroyer escorts were equipped with special radiation detectors, which were mounted atop the pilot house of each ship. Figure 2.3 shows a schematic representation of the sensing head. Each device had two sensing elements shielded in the manner of the ship's running lights by a 2-inch lead separation. The shielding arrangement was designed in this fashion, so that the readings from the sensing heads would give a good indication of the direction of radioactive water.

Each of the two sensing elements in each head was made up of fourteen Anton 315 G-M tubes arranged in cylindrical geometry and wired in parallel. The circuit was similar to that used in the Horizon's sensitive probe. Each of the sensing elements was connected to its own microammeter, located in the wheel house. If the port meter read higher than the starboard meter, this meant that the more-highly contaminated water was on the port side of the ship. A range-selector switch was provided in the wheel house for switching through four different ranges. The total range of the instrument covered the values from 0.01 to 500 mr/hr.

2.5.6 Water Sampling. Water-surface samples were taken in polyethylene buckets. This procedure has long been used by oceanographers. The only precaution necessary is that all sampling containers be rinsed two or three times before the sample is taken. Samples were stored in polyethylene bottles.

For depth samples, the Horizon used standard Nansen bottles that had been coated inside and out with polyester resin. The Nansen bottle is a tin-dipped brass cylinder containing a valve at each end. While the bottle is being lowered, both valves are open and water flows freely through the bottle. After it is lowered to the desired sampling depth, the bottle is reversed by a messenger sent down the hydrographic wire. This reversal closes both valves at once, and the water sample is trapped in the bottle. When a cast is made, ten to fifteen bottles can be placed on the wire, so that as many different depths can be sampled at once. All depth samples for Projects 2.63 and 2.64 were taken by this method.

2.5.7 Marker Drogues. The marker drogues consisted simply of a mast with a numbered board and flag supported by an automobile inner tube with an aviator's parachute attached to the bottom. The drag of the parachute in water was so large that the drogue essentially remained tied to the spot of water in which it was launched. The drogues launched by the YAG 39 had, in addition to flag and numbered board, a light and a radar target, so that they could be followed

The use of drogues during the surveys was not as extensive as was originally planned, due to the hazard that freely floating drogues presented to the deep-moored skiff installations.

2.5.8 Decay Tank. In order to measure the effective radioactive decay, it was decided to collect a single large sample and to measure its decay using the probe. Calculations indicated that over 95 percent of the radiation measured at a point in water, containing uniformly distributed radioactive products, would be contributed by those photons emitted within a 2½-foot radius.

On this basis, a cylindrical steel tank, 5 feet high and 5 feet in diameter, was constructed. A valved opening was installed in the bottom for releasing the sample. The top contained three openings: one for manual access to the tank interior, one for the shaft of the mixing propeller, and one in the center to permit insertion and removal of the detector probe. A rack was erected on top over the center hole, so that the probe could be clamped into position with the Geiger tubes in exact center of the tank. This tank was installed on the fantail of the M/V Horizon.

Observations during Operations Castle and Wigwam had indicated that the radioactive particles in water had a tendency to plate out on metal surfaces. To avoid this, two steps were taken: (1) all of the inside surfaces of the tank were coated with polyester resin of the type used in bonding fiber glass, and (2) an attempt was made to "gel" the water sample in the tank to prevent the settling or migration of particles to any surface. By experimentation, it was found that at least in small quantities (several gallons), sea water could be so gelled by the addition of sodium silicate followed by reduction of the pH to 9.0 by the addition of hydrochloric acid.

In actual practice, involving the 700 gallons in the tank, it was found that a firm gel was not attained. However, a thick colloidal solution was formed; by use of continual mixing, it could be assumed that uniform distribution of radioactive particles was obtained.

The sample for the decay tank was collected as soon after detonation as possible. A fairly active sample was desired, so the collection was not made until the Horizon had reached a point well inside the fallout pattern. The water to be sampled was pumped into the tank by use of a small centrifugal pump from a depth of about 4 meters. The sodium silicate and acid were added as soon as practicable. The final sample, as counted, contained approximately 500 gallons of sea-water sample, 110 gallons of commercial sodium silicate, and 25 gallons of hydrochloric acid.

The probe reading was recorded as soon as the tank was filled and at ½-hour intervals until the end of the survey.

On occasion, it was impractical to add the chemicals until several hours after the sample was drawn. This made it necessary to correct the first few readings of the decay curve for the effect of dilution.

2.5.9 Penetration Recorder for Deep-Moored Stations. For measuring early depth of fallout penetration within 15 miles of ground zero, a special recorder was designed for use on the deep-moored skiffs. Figure 2.4 shows a block diagram of this penetration meter. The components, and their function in the instrument, are listed below:

1. A battery power pack provided 700, 60, 30, and 6 volts of direct current for operation of the unit.
2. A twin-drum recorder unit, driven by a geared electric motor, provided linear speed of approximately 2½ in/hr for the waxed paper recording tape.
3. A trigger device, utilizing a gas triode vacuum tube, integrated the pulses from an Anton 315 G-M tube located in a collector assembly in the air above the skiff so that when a count representing 15 mr/hr was received the balance of the recorder unit was put into operation.
4. A series of probes, placed at appropriate depths (1, 20, 40, 60, 80, and 100 meters) on an electrically conducting cable powered by the 700-volt portion of the battery pack, were used as the radiation-detecting devices, These probes were all Anton 315 G-M tubes and were enclosed in a cylindrical water-proof brass tube as a physical protective measure. After connection to the proper electrical conductor in the cable, the splice and brass-covered G-M tube were wrapped with several layers of rubber and plastic tape and then dipped in a rubber solution as further water-proofing protection.
5. A weighted pressure-sensing device completed the underwater portion of the penetration meter.
6. The counts from each of the above probes, including the pressure-sensing probe, were sequentially reported through contacts on a rotable multipoint wafer switch. This programming switch was rotated by a low-speed electric motor that made a full revolution every 12 minutes.
7. The pulse count from the G-M probe tubes was balanced by a simple vacuum-tube electronic circuit. The current required to provide a balance was fed as a servo signal to a Hayden pen-drive motor, which (by means of a rack and pinion) provided the lateral displacement to the pen, making a trace on the waxed paper of the recorder unit.
8. A spring-driven 8-day clock, preset at 2400 and prevented from running by a stop intercepting the sweep-second hand, was started by the triggering device. The stop was removed by an electrically operated solenoid. By recording the local time of recovery of the instrument, the time of arrival of radiation that triggered the metering device could be calculated from the clock reading.
9. Miscellaneous electrical switching circuits for testing all or parts of the device were included. As a part of the sequence of readings, an index of the battery voltage was also impressed on the paper record.

2.6 RESULTS AND DISCUSSION

2.6.1 Nav-Rad Device. The Nav-rad device was mounted on the survey ships to safeguard the personnel from the danger of hazardous radiation levels by detecting its approach and to assist the ships' personnel in tracking the low-level boundaries of the fallout area.

In its capacity as a safeguard, the instruments were successful. All three survey ships contacted direct fallout from Shot Zuni, and in the case of all three, the build-up of shipboard radiation was detected by the Nav-rad immediately. This gave the personnel time to take the necessary radiation safety precautions and to head the ship out of the fallout before the levels became hazardous.

In its capacity as an aid in tracking the low-level boundaries of the fallout area, the Nav-rad was singularly unsuccessful. Its failure in this respect was partly caused by the high ships' background from the Zuni fallout, but it is not implied that this is the only reason. Even though the detection elements are extremely sensitive, the height of the device above the sea surface (over 30 feet in all cases) and its shielding from the back and sides reduces its effective sensitivity to the radioactive water surrounding the ship. The probe detects a change in activity when the Nav-rad shows none. As an above-the-surface detector of water contamination, it is an excellent device, but not when compared to a sensitive probe in the water surrounded by the radioactivity.

2.6.2 Ship Surveys. The surveys following each shot involved over 1,000 miles of travel for each of the destroyer escorts. In addition, during each survey the M/V Horizon spent over 4 days inside the fallout area, taking detailed radiological and oceanographic measurements.

The ships' tracks for each shot are shown in Figures 2.5, 2.6, 2.7, 2.8, and 2.9. The tracks are based on position determined by hourly loran fixes, which have an estimated accuracy of 1 mile.

2.6.3 Reliability of Probe Measurements. At intervals during each fallout survey, the probe on each ship was removed from the water and calibrated against a Co^{60} source of known strength. This was done to ensure that probe response would be known for all measurements.

In addition to the individual shipboard calibrations, the ships were brought together inside the fallout pattern whenever possible. By this method, the probe readings were intercalibrated between ships while the probes were all in water containing the same concentration of fission products.

As a result of these controls, the calibrations of the probes are known for all readings, and the intership comparisons show agreement within 5 percent for all shots except for a 6-hour period following Shot Navajo. During that time the probe of one of the ships showed a 70 percent disagreement with those of the other two ships. The cause of the discrepancy has not been discovered, but the readings of the errant probe have been brought into agreement for that period of time.

2.6.4 Instrument Contamination. Previous experience had shown that probes became contaminated when towed through water containing fission products. It had been found (Reference 2) that metal surfaces were notorious in this respect. In an effort to reduce the amount of contamination, the probes were wrapped with polyethylene tape.

In spite of the precaution taken in taping the probes, they occasionally became contaminated. Since it was not possible to detect this contamination in the highly radioactive water where it occurred (above 10 mr/hr), the probe was often towed for many hours before its condition was noticed and corrected by re-taping.

For the final data reduction, the contamination of the probes has been estimated for each ship during each of the fallout surveys. The estimates are based on the following: (1) the minimum probe reading recorded at the bottom of each cast — it was not always assumed that the water at the bottom of the cast was clean, however, this procedure gave a maximum for the amount of contamination; (2) comparison between the NRDL counts of the Nansen bottle samples, reduced to dose rate, and the probe readings; (3) use of inter-ship calibrations, wherever applicable; (4) reduction in the probe reading after re-taping as a direct measure of the amount of contamination; and (5) knowledge of the radiation levels traversed by the ship for information by which the contamination curves could be estimated

Figures 2.10, 2.11, 2.12, and 2.13 show the probe contamination for the fallout surveys following each shot. The unit of contamination is the in-situ probe reading as deduced from the Co^{60} point source calibration. This is used extensively throughout the report and is always denoted by "mr/hr#" (see Appendix A). The McGinty probe during the Navajo survey (Figure 2.12) was contaminated before the detonation. This was the result of a special preshot survey of radioactive water flowing westward out of Bikini Lagoon. The Silverstein probe, during all of the surveys, accumulated little contamination, because this ship was purposely directed away from water having high radiation levels. This was done in order to have at least one ship capable of determining low-level boundaries.

2.6.5 Penetration Meter. The original premise that rates of penetration could be obtained by means of Geiger tubes moored to skiffs and suspended at various levels in the sea has been proved. Mechanical and electrical difficulties prevented the accumulation of any great quantity of data; however, one penetration meter unit, triggered by the fallout 18 minutes after Shot Tewa, provided enough information to predict the usefulness of this type of instrument for other shots of a similar nature. In general, for the purposes of adding close-in penetration measurements to the Redwing series, the penetration meters were disappointing; however, even the one measurement is valuable.

The penetration meter was located at skiff station PP (see Figure 4.8) and successfully recorded on certain of the probes until 15 hours after triggering, at which time abrasion of the probe cable against the chine of the skiff caused a general electrical shorting.

The results of this record are shown in Figures 2.14 and 2.15. In Figure 2.14 dose rate is plotted on log scale and the time in minutes, in order to clearly show the rapid downward penetration of the fallout material in the water. In Figure 2.15, the dose rate is plotted on linear scale and the time in hours to show the long-term behavior. It is not certain whether the second peak exhibited by probes 1 and 2 is caused by secondary fallout or electronics malfunction.

A study of rapid rate of penetration shown in Figure 2.14 indicates the arrival, at the site, of rather large particles approximately 18 minutes after the nuclear detonation. The recorder was set to trigger at a radiation level of 15 mr/hr, and the time recorded when the instrument was recovered indicates that it started at 18 minutes after shot time; during the first cycle, none of the probes indicated any radiation. On the second cycle, which started 12 minutes after triggering, the 1-meter probe read 900 mr/hr; 1.3 minutes later, the 20-meter probe read 120 mr/hr; 1.3 minutes later (14.6 minutes after triggering), the 40-meter probe read 56 mr/hr. The 60-meter probe failed to function, but the 80-meter probe, which was read 6.5 minutes after the start of the second cycle (18.5 minutes after triggering), read 45 mr/hr. Assuming that particles would be falling past the corrected depth of the 80-meter probe at a constant rate of descent and had reached the water surface at the time the triggering device functioned, a calculation of the particle size can be made if certain assumptions are made. These assumptions are: (1) the particle has a constant fall rate of 6.05 cm/sec, (2) the particle is spherical and homogeneous with a density of 2.32 gm/cm^3, and (3) the sea water had a density of 1.02 gm/cm^3 and a viscosity of 0.0086 dyne sec/cm^2. Utilizing the formula for Stokes law as:

$$V = \frac{2ga^2(d_1 - d_2)}{9n}$$

Where: V = velocity in cm/sec
a = radius of sphere in cm
d_1 and d_2 = density of sphere and medium respectively
n = coefficient of viscosity dynes sec/cm^2
g = gravity at 981.45 cm/sec^2

the particle size can be calculated as 0.02 cm radius or 400 microns in diameter. A particle size of this diameter at this range is entirely possible, based on the NRDL fallout-prediction method.

Because of the high sensitivity of the G-M tubes used in the probes, saturation was reached before the maximum radiation could be read. This resulted in the flattened peaks, as seen in Figures 2.14 and 2.15. Since this penetration meter represents a single point, further interpretation of the results seems unnecessary; however, the amount of information obtainable from this type of radiation-recording device is considerable, and the general methods with certain modifications could be an important means of evaluating fallout from future tests.

2.6.6 Probe Penetration Depth. In reducing the measurements made during Operation Castle (Reference 2) it was assumed that the depth of mixing corresponded to that of the top of the thermocline. By making this assumption, it then became only necessary to gather together all of the bathythermograms taken during the test period and to compute the average depth of the mixed layer (top of the thermocline) to determine the depth of mixing.

In order to check the validity of the above asumption and to actually measure the penetration depth at various points throughout the fallout pattern, the probes were constructed with pressure-sensing elements. These have been described in the section covering instrumentation.

A comparison between penetration depth and depth of the mixed layer is shown in Figure 2.16. The penetration depth is defined as follows: if dose rate is plotted against depth, the penetration depth is the depth which, when multiplied times the surface dose rate reading, would yield the same area as graphic integration of the area under the curve from the surface to the depth at which the sea-water background is attained.

In Figure 2.16, the penetration depth is 93 meters. When this is multiplied by the dose rate reading of 0.041 mr/hr# at the surface, a value of 3.82 (mr/hr#)-meters is obtained. Graphic integration of the area above the curve yields 3.9 (mr/hr#) meters.

It may be seen from Figure 2.16 that some of the fallout products penetrate below the mixed layer. This is particularly true for Shot Zuni, which was fired over land. The percentage lost from the mixed layer in this fashion cannot be determined from the measurements that were made. This is a function of particle size and character that varies both with the particular shot and with direction and distance from ground zero. For purposes of calculating the 3-foot dose rate, it has been assumed that none of the fallout penetrates below the calculated penetration depth. This assumption yields values of 3-foot dose rate which can only be less than the actual case.

The penetration depths, from probe measurements, for each shot are listed in Tables 2.1 through 2.4 for each ship. Some of the stations are not listed. In those cases, either the penetration depth could not be determined from the probe record or, as in the case of Horizon Stations 13 through 17 during Shot Navajo, the ship was measuring radioactive water flowing out of Bikini Lagoon. For purposes of comparison, the depth of the mixed layer, as determined from BT measurements at each station, is listed.

The above information is plotted graphically in Figures 2.17 through 2.20, wherein penetration depth and mixed layer depth are plotted against hours since arrival of fallout. At early times, while downward mixing was still taking place, the plot of penetration depth versus time results in a sloping line. After mixing is complete, a constant penetration depth is assumed to hold for the remainder of the survey.

Table 2.5 summarizes the penetration measurements. The average penetration depth, with its probable error, is listed for each shot. The same information is shown for the depth of the mixed layer. The ratio of penetration depth to mixed-layer depth is also listed. Only in the case of the land shot, Zuni, does this ratio exceed one. The other three shots give about the same ratio, 0.75.

Part of the probable error in penetration measurements arises from the presence of internal waves, which cause fluctuations as great as 20 meters in the depth of the mixed layer at any given geographic location (Reference 6). Another cause is the variations in the depth of the mixed layer from one region of the fallout pattern to another (Reference 6). The penetration depth was plotted against mixed-layer depth and against geographic location; no direct correlation could be found. Because of this, the average penetration depth for each shot (Table 2.5) is used to determine the 3-foot dose rate after mixing is complete. Prior to completion of mixing, the penetration-depth curves shown in Figures 2.17 through 2.20 are used.

2.6.7 Rate of Penetration. The probe installations were made on Project 2.63 ships, the YAG 39 and YAG 40. Since these ships contained shielded control rooms, they were maneuvered to be in position to measure the fallout as it arrived. The probes were lowered and raised by remote control from the shielded control room, and the depth of penetration was measured from the time fallout started until the YAG 39 station was taken over by the M/V Horizon. It was desired that all the measurements during a single shot be made in the same spot of water, even though that spot would be moving with the current. To accomplish this, a drogue was launched just prior to fallout, and the ship maintained station around the drogue as it drifted with the current.

The results of the probe measurements taken aboard the YAG 39 are shown in Figures 2.17 through 2.20 for each detonation. The downward progress of the fallout clearly can be seen during the first few hours after fallout arrival. The slope of the curve changes during the downward progress of penetration. Because of this, the rate of penetration is here defined as 90 percent of final mixing depth divided by the number of hours required to reach that depth. These rates are listed for each shot in Table 2.5.

In the case of Zuni, it is clear that the high rate of penetration is due to particle fall. It is also evident that some portion of the fallout penetrates below the "depth of penetration." For Shot Navajo, the penetration rate is about the same as found during Castle (Reference 2) and undoubtedly is due to physical mixing. The penetration rates for Shots Flathead and Tewa are probably due to a combination of mixing and particle fall.

The factors affecting the rate of penetration are the same as those discussed in the penetration depth. Certainly it is evident, that in the case of particle fallout, the penetration rate will decrease as distance from ground zero increases. If the rate is due to mixing alone, it will probably remain the same throughout the fallout pattern. For purposes of calculating the final 3-foot dose rate from penetration depth, it will be assumed that penetration rates measured by the YAG 39 and shown in Figures 2.17 and through 2.20 are valid over the entire fallout area for each shot.

2.6.8 Fallout Time of Arrival. In correcting the ships' track for current drift and in determining the penetration depth for each probe reading, the time of arrival of the fallout must be taken into consideration.

During Operation Redwing, few measurements of fallout arrival time were made outside the boundaries of Bikini Atoll. Those that are available beyond the atoll limits were taken by Project 2.63 on skiff stations and aboard ship (Reference 7). But even those do not cover a large portion of the fallout area.

The only other available information is the predicted central time of arrival for each shot, which was presented in the Program 2 Preliminary Report (Reference 8) and will be contained in the overall final summary of Operation Redwing, WT-1344.

In order to obtain an estimated time of arrival, the results of the two references were combined. That is, the estimated central time of arrival was used to obtain a general pattern but was modified to fit the actual measurements of Reference 7. Concerning the actual measurements, whenever the data was presented the measured arrival time was taken as the midpoint between time of first arrival and the time of peak activity. This was done to ensure that arrival time would correspond to the time at which sufficient fallout had occurred to give a significant dose-rate reading in water.

Figures 2.21 through 2.24 show the estimated times of arrival used for final data reduction. During the fallout after Shot Zuni, the estimated central time-of-arrival pattern in Reference 8, showed the contours folding back and producing double fallout. In Figure 2.21 this has been averaged to show a single, smooth contour line for each period of time after detonation.

2.6.9 Deduced Ocean Currents. Prior to and during Operation Redwing, efforts were made to establish ocean-current patterns that could be used in correcting fallout observations for current drift. The results of these efforts have been presented in Reference 6, wherein it is shown that the current directions and velocities fluctuate over periods of a few days to a week.

In view of these short-term fluctuations, it was necessary to establish a current pattern for the time period covered by the oceanographic fallout surveys following each shot. Because of the scarcity of current measurements during the fallout surveys, it was not possible to establish a pattern from the direct measurements. Instead, the shift of sharp boundaries and hot spots, over the 4-day period of each survey, were used to deduce a current pattern. By plotting the anomalies in radiation intensities for each day of the survey, and noting the distance and direction of shift, a fairly clear picture of the currents could be deduced over the entire fallout area. Whenever possible, the results of the Project 2.64 aircraft surveys were also used in determining boundaries shifts (Reference 9).

The current patterns deduced in this manner for each of the shots are shown in Figures 2.25 through 2.28. Here the current streamlines are presented. A particle of water would follow the path of the streamline and would move with the indicated velocity.

2.6.10 Corrected Ships' Tracks. In order to determine the geographic location and shape of the original fallout pattern, the pattern obtained from the 4-day survey must be corrected current drift.

The fallout-arrival time has been estimated for each shot, and the time of each observation is known. The difference between them is the length of time that the observed water, at a given location, has been subjected to current drift. To correct for this drift, the original ships' tracks (Figures 2.6 through 2.9) were overlaid on the deduced current pattern for each shot and shifted back along the streamlines an amount corresponding to the current velocity multiplied by the time difference between fallout arrival and observation.

In essence, this is what has been done for each shot. Actually, the procedure is complicated by the fact that a shift in position results in a change in the deduced time of arrival. It is necessary to make the current correction, for each position, by trial and error so that the final location anf fallout arrival time correspond.

The corrected ships' tracks are shown in Figures 2.29 through 2.32 and represent the tracks the ships would have taken had the measurements been made at the time of fallout. These also represent the tracks that three vehicles would have made in taking the same survey had the fallout occurred on dry land.

2.6.11 Water Sampling. The method of collecting water samples has been described in the sections concerning instrumentation and operations. A summary of the sampling program for each shot is listed in Tables 2.6 through 2.9. The type of sample is listed along with time and date, position at which sample was collected, position of sample at time of fallout as deduced from the corrected ships' tracks, and probe reading of surface water at time of collection. The probe reading has been corrected for instrument contamination in each case.

The water samples were delivered to Projects 2.63 and 2.64 on the fifth day after each shot. The results of analyses are presented in the final reports of these two projects.

2.6.12 Decay Constants. The M/V Horizon's decay tank has already been described in the section covering instrumentation. The results of the measurements are shown graphically in Figure 2.33. The constant calculated is the exponent of t in the equation $A_t = A_0 t^{-k}$ where A_t is the dose rate at time t after detonation and A_0 is the dose rate H + 1.

A decay tank similar to that installed on the M/V Horizon was aboard the YAG 39. The differences between the design and operation of the tanks were: (1) the tank on the YAG was 6 feet high and 6 feet in diameter, as compared to the Horizon tank (which was 5 feet high and 5 feet in diameter); (2) the YAG tank was filled with clean water prior to the shot, and fallout was collected as it fell, instead of being pumped in with water from the sea after completion of fallout; and (3) the sample was not gelled but merely acidified and stirred.

Examination of the results of the YAG 39 tank measurements as shown in Reference 7 shows the following best-fit straight-line values for k: Zuni, k = –0.86 from H + 25 to H + 50; Flathead, k = –0.92 from H + 12 to H + 40 (beyond H + 40 the slope was less); Navajo, k = –1.40 from H + 10 to H + 150 (for the original, instrument calibration curve); the results for Shot Tewa were so irregular that no straight line could be drawn through the plotted points. These decay constants may be compared to the Horizon decay tank values as shown in Figure 2.33. Considering the difference in the method of collecting and treating the decay sample, the agreement between the two methods is good.

The late time at which fallout occurred where tank measurements could be made precluded the possibility of obtaining decay constants for correcting dose rates to H + 1. No other decay measurements at such early times are directly applicable to the probe readings.

In spite of this, an examination of time-intensity records (Reference 7) of gamma field intensities at close-in stations shows that decay constants of dose rate change little between H + 1 and H + 50 hours. Using this evidence, in the absence of actual probe decay measurements, it will be assumed the decay constants shown in Figure 2.33 are valid for correcting probe readings to H + 1 for each of the indicated shots.

2.6.13 Decay Correction Factor for Dose Rates. For the purposes of correcting all readings to a common time, the measured decay constants were used to calculate decay correction factors (Figure 2.34).

To determine the dose rate at H + 1, the radiation level at the time of observation is multiplied by factors shown on the ordinate, corresponding to the observation time. The effect of the large decay constants for Shots Navajo and Tewa is clearly shown during the latter days of the surveys, where the correction for decay becomes very large.

2.6.14 Factor for Determining Accumulated Dose. The dose rate levels at H + 1 hour do not give a realistic picture of the hazards resulting from fallout, because over most of the area, fallout has not occurred this early.

A realistic presentation of the true radiation hazard from fallout is the total dose that a person in an unshielded position would receive during the first two days following a shot. Using the measured decay constants and assuming a dose rate of 1 r/hr at H + 1, the accumulated dose was calculated for each hour from H + 1 to H + 50. These values are presented graphically in Figure 2.35, wherein the abscissa is time of fallout and the ordinate is accumulated dose in roentgens, assuming 1 r/hr at H + 1. To use this figure, the dose rate at H + 1 of a given measurement is multiplied by numerical value of the ordinate corresponding to the fallout time of arrival for that measurement.

2.6.15 Data Reduction. The large volume of data prohibits the presentation of all measurements in tabular form. A small section of the results, from one ship during one survey, will be presented here to clarify the steps involved in reducing the measurements. This will also help to explain the use of various tables and figures which have thus far been introduced.

The ensuing procedure has been used to reduce the data collected during each of the fallout surveys. The columns referred to are found in Table 2.10:

Column 1 Date of observation.

Column 2 Time of observation.

Column 3 Instrument number and sensitivity scale (switch position).

Column 4 Current readings in microamperes (probe output) which were recorded on the Leeds and Northrup recorder.

Column 5 Derived from Column 4 by conversion of the microampere reading to apparent dose rate mr/hr# by use of the Co^{60} point source calibration curves. An example of these calibrations is shown in Figure A.1 (Appendix A).

Column 6 Lists the contamination of the probe in mr/hr# at the time of each observation as shown in Figure 2.13.

Column 7 Derived by subtracting Column 5 from 6. This is the apparent dose rate mr/hr# which would have been recorded from an uncontaminated probe in the water.

Column 8 Gives the figures in Column 2 converted to time since detonation in hours. This is required for decay corrections.

Column 9 Is the probe reading from Column 7 corrected for radioactive decay to H + 1 hour. The factors used for this correction are shown in Figure 2.34.

Column 10 Lists the time of fallout arrival for each point of observation. The derivation of this column involves the use of several of the figures already presented and is derived at the same time the ship's tracks are corrected for current drift.

The geographic distribution of arrival time is shown in Figures 2.21 through 2.24. The deduced ocean currents are shown in Figures 2.25 through 2.28. For each shot, these two figures are overlaid and on top of them, the appropriate figure of the ships' original tracks, Figures 2.6 through 2.9. Any point on a ship's tracks is then moved back along the current streamline, a distance corresponding to the current velocity and the number of hours between time of observation and time of fallout arrival. If this shift results in a corrected position that does not correspond to the time of arrival that was used in determining the amount of shift, a new time of arrival is used. This trial and error is continued until the corrected position and time of arrival correspond. This process results in an arrival time, as listed in Column 10, and a corrected ship's track, shown in Figures 2.29 through 2.32, which corresponds to the path the ships would have followed had there been no ocean currents in the fallout area.

Column 11 Is the difference between Columns 8 and 10. This is the number of hours the fallout has been in the water, up to the time of measurement. It is used for correcting the ships' tracks as described above and for determining the depth of penetration at the time of measurement.

Column 12 Is the depth of penetration of fallout (mixing depth) at the time of measurement. It is derived by applying the times listed in Column 11 to the fallout penetration curves shown in Figures 2.17 through 2.20

Column 13 Is the dose rate in roentgens per hour that would be received at an elevation of 3 feet had this same fallout occurred on an infinite hypothetical plane at H + 1. This is derived by multiplying Column 9 by the depth of penetration (Column 12) and by the conversion factor of 0.01 derived in Appendix A. The values listed in this column are plotted along the corrected ships' tracks. Areas of equal intensity are then outlined, resulting iso-dose-rate contour lines at H + 1 hour.

Column 14 Results from the application of the times listed in Column 10 to the conversion factors are shown in Figure 2.35. These are used to calculate the total dose accumulated during the first two days after detonation.

Column 15 Lists the accumulated dose, in roentgens, between time of fallout and H + 50 hours. This is derived from the products of Columns 13 and 14 and is a fairly realistic presentation of the actual hazard from fallout, since it takes into consideration the fact that fallout does not occur simultaneously over the entire area. These values are also plotted on the corrected ships' tracks and presented as accumulated dose contours.

2.6.16 Fallout Surveys, General. The final presentation of the oceanographic fallout surveys is in the form of contours of H + 1 hour iso-dose-rates and accumulated total dose (time of arrival to H + 50 hours) that would be received at 3 feet above an infinite hypothetical plane. The methods used to derive these contours has just been presented. The reliability of the final contours is dependent upon the measurements and factors that were used in the data reduction. Therefore, these factors will be reviewed before the presentation of the individual survey results:

1. Probe surface measurements. These measurements have been carefully cross checked between the three survey ships and are in agreement within 5 percent. In addition, the probe contamination has been determined for all measurements and subtracted from the probe readings. The accuracy of the probe measurements is estimated to be ± 15 percent of the calibration value.

2. Radiation background of ocean water. As the operation progressed, the background of the surface water increased. A background survey prior to Shot Navajo showed that a wide expanse of ocean had retained a measurable amount of radioactivity from previous shots. This was a small increase and amounted to no more than 30 percent of the Navajo readings, even in the extreme case of boundary measurements late in the survey. In most cases, the background amounted to a very-small fraction of the actual measurement and is neglected in this report.

3. Penetration depth. The penetration depths used for data reduction of each shot represent the average of the probe measurements taken during the corresponding survey. These values are within a probable error of 10 percent or less for all surveys. The probability that these figures are representative of the entire quantity of fallout depends on the amount of fallout

that fell through the thermocline. This is a function of both direction and distance from ground zero.

4. Decay constants. The decay constants used for data reduction are straight-line averages of measured values. The measurements were not started prior to 20 hours after each shot. Examination of other types of decay records shows that decay constants of dose rate change very little between H + 1 and H + 50 hours. On this basis, the decay-tank measurements extrapolated to H + 1 hour are probably reliable.

5. Fallout time of arrival. The time of arrival was determined by combining the predicted values with actual measurement. The values are probably correct to within a few hours over most of the fallout area. A 2-hour error in fallout time yields about a 10 percent error in the final results up to the time mixing is completed. After that, such an error in time has no effect in final calculated dose rate and results in an error of a few percents in the total dose.

6. Current correction. The correction used for drift due to ocean currents was deduced from the day-to-day shift in boundaries and hot spots in the fallout pattern of each shot. Judging from the crossings of ships' tracks and the general coherence of the pattern as a whole, the current corrections used are truly representative of the actual ocean currents.

7. Conversion from in-situ to 3-foot dose rate. The factor that was used to convert the probe reading in the water to the dose rate at an elevation of 3 feet is derived in Appendix A. The lack of knowledge of the energy spectra limits its accuracy. If the assumption of energy spectra during the fallout surveys is valid, this factor has an estimated accuracy of ± 15 percent.

2.6.17 Cherokee Surveys. The measurements taken following Shot Cherokee were not reduced. Only one small spot of water, 2 miles wide and of unknown length, was detectably above the oceanic background. The survey ships ranged as far as 300 miles from ground zero, but were unable to detect any other measurable fallout. The ships' tracks are shown in Figure 2.5.

2.6.18 Zuni Surveys. The first shot of the series that produced a measurable amount of fallout was Zuni. All three survey ships became contaminated by direct fallout during the early stage of the survey. This made low-level ship-board calibration checks impossible, but the calibrations at levels of above 30 mr/hr were sufficient to give confidence to the measurements. The shot was detonated on land at Site Tare on 28 May 1956 at 0556 M. The total yield was 3.38 Mt, Much of the fallout was associated with solid particles large enough to penetrate below the thermocline. This is evident from the penetration measurements taken by the Project 2.62 YAG's.

The portion of fallout that penetrated below the thermocline is unknown and is indeterminable from these measurements. Rather than attempting to estimate the percentage, these results assume no penetration beyond the depth of mixing. Using this assumption, the iso-dose-rate contours of fallout from Shot Zuni at H + 1 hour are shown in Figure 2.36. These are the dose rates that would be received at a height of 3 feet had the fallout occurred on dry land instead of in the ocean. The areas, in square miles, enclosed within the contour lines of Figure 2.36 are listed in Table 2.11, in which the total and fission yield is presented for comparison between the different shots.

The total dose that would be accumulated between time of fallout and H + 50 hours is shown in Figure 2.37 for Shot Zuni, and the areas enclosed by these contours are presented in Table 2.11.

2.6.19 Flathead Surveys. Shot Flathead was fired over water from a barge off Site Dog at 0626 M on 12 June 1956. Very little of the fallout should have been associated with solid particles large enough to penetrate below the thermocline. The H + 1 hour iso-dose-rate contours are presented in Figure 2.38 and the accumulated total dose to H + 50 hours is shown in Figure 2.39. The area within the contours of both these figures is listed in Table 2.11.

2.6.20 Navajo Surveys. Shot Navajo was also a water shot and was fired on a barge moored off Site Dog at 0556 on 11 July 1956.

[redacted] it was feared that the residual oceanic background from previous shots might be sufficient to cause large errors in results of the fallout surveys. To evaluate this, a special survey was made to determine the oceanic radioactivity background in the anticipated Navajo fallout area. This was accomplished between the first and the eighth of July, being completed just 3 days before Navajo. The results are shown in Figure 2.40 in "apparent" mr/hr# as of shot time for Navajo.

To compute the values in terms of Navajo H-hour, all readings were corrected for decay, assuming that the background activity resulted from the Dakota device and using a decay constant of 1.2. No current correction has been applied for either the 7 days during which the survey took place or for the 3 days between the end of the survey and Navajo shot time.

To give some meaning to the contour values shown in Figure 2.40, it may be stated that a value of .01 mr/hr#, if measured at H + 50 hours during the Navajo survey, would appear as 1.4 r/hr at H + 1 hour after all correction factors had been applied.

The background shown in Figure 2.40 was not subtracted from the Navajo survey for the following reasons: (1) no current pattern could be deduced by which the current corrections could be applied, although it seems likely from the Navajo pattern, that the "warm" area northeast of Bikini would be carried out of the Navajo fallout area and the "hot" region being fed by Bikini Lagoon would probably remain; (2) the area being fed by the lagoon was the first surveyed during Navajo, so the background has no effect on the H + 1 contours; (3) the largest error that could result from the background is about 30 percent of the H + 1 contour in the northwest region of the Navajo area. Aside from this one region, it is doubtful if the background error is as much as 10 percent.

The H + 1 hour, 3-foot iso-dose-rate contours for Navajo are shown in Figure 2.41. The cross-hatched area at the westernmost part of the fallout region is thought to result from Shot Apache, which was fired at Eniwetok two days previously. It had already been pointed out that the area north of latitude 12 degrees 30 minutes north and lying between longitude 163 degrees and 164 degrees, 20 minutes east may be in error as much as 30 percent, owing to the residual oceanic radioactivity background.

In determining the areas listed in Table 2.11, the effect of Apache has been taken into consideration, as shown by the dotted lines enclosing the 3-r/hr and 5-r/hr areas.

The same considerations apply to the 2-day accumulated total dose, shown in Figure 2.42, and to the areas for accumulated dose, which are listed in Table 2.11.

2.6.21 Tewa Fallout Surveys. Shot Tewa was detonated at 0546 M on 21 July 1956. The total yield was 5 Mt [redacted] Although it was detonated from a barge, Tewa has been considered a land shot, because of the shallowness of the water and the yield of the device. The survey results are therefore subject to somewhat the same considerations as Zuni. That this is not entirely so, may be seen in the relatively slow penetration rate for Tewa (Table 2.5).

The 3-foot iso-dose-rate contours for H + 1 hour are shown in Figure 2.43. The geographic extent of the fallout from this detonation was so large that the survey ships were unable to locate the western boundary of the 10-r/hr contour in the time allotted for the survey. This is reflected in Table 2.11, which can only indicate the area enclosed by the 10-r/hr contour line as greater than 29,000 mi^2.

The two-day accumulated total dose for Tewa is shown contoured in Figure 2.44. The area within these contours is listed in Table 2.11.

2.6.22 Comparison of Shots. Table 2.11 summarizes the extent of fallout resulting from each nuclear detonation and may be used to compare the results derived from the surveys.

To make this comparison, the total yield of each device is normalized to a 5-Mt shot having a fission yield of 100 percent. To correct to 100-percent fission, the dose rates are divided by the fission fraction. To normalize to the 5-Mt detonation, dose rates are assumed to increase with the cube-root scaling law and the areas, following the same law, are increased by the square of the cube root.

Figure 2.45 presents the results, after normalizing the Redwing surveys. The H + 1 hour dose rate in roentgens per hour is shown plotted against the area in square miles, enclosed by the contour of that dose rate. For comparison, the predicted contour areas for a 5-Mt detonation have also been indicated (Reference 8).

From this presentation, several things become apparent.

The area of the highest radiation level for Zuni (1,180 r/hr after normalizing) is considerably less than for Shots Navajo and Tewa. This is further evidence of the loss of fallout material below the assumed mixing depth in the region close to ground zero, where high radiation levels are to be expected. The dropoff of area at the lower dose rates for Zuni results from the fact that these are only minimum areas, since the survey contour lines could not be completed.

The straight-line plot for Tewa indicates that although this was considered a land shot, the thin film of water approximately 20 feet beneath the barge must have had a modifying effect on the type and size of particles in the close-in region. No attempt was made to estimate the contour areas below 10 r/hr for Tewa.

The good agreement of Navajo with Tewa indicates that the errors introduced by the oceanic background were indeed negligible. This agreement also lends credence to the assumption that dose rate increases in direct proportion to the fractional fission yield.

TABLE 2.1 PENETRATION MEASUREMENTS, SHOT ZUNI

Station	Time	Date	Time Since Detonation	Time Since Fallout Arrival	Penetration Depth	Thermocline Depth
			hr	hr	m	m
H-Z-3	2330	May 28	17.7	11.6	68.5	80.0
H-Z-4	0800	May 29	26.0	13.8	87.5	85.0
H-Z-5	1500	May 29	33.0	19.0	96.0	70.0
H-Z-6	1900	May 29	37.0	24.0	73.5	67.0
H-Z-7	2330	May 29	41.6	29.2	83.0	73.0
H-Z-8	1100	May 30	55.0	40.0	70.0	75.0
H-Z-9	1600	May 30	59.4	45.0	90.0	70.0
H-Z-10	2300	May 30	67.0	51.5	103.5	80.0
H-Z-11	0230	May 31	68.5	54.7	65.0	73.0
H-Z-12	0630	May 31	72.5	58.9	101.0	90.0
H-Z-13	1020	May 31	76.3	63.4	105.0	70.0
H-Z-14	1410	May 31	80.3	66.4	93.0	75.0
H-Z-15	1900	May 31	85.0	72.1	87.0	70.0
M-Z-2	1650	May 28	10.9	9.4	63.0	74.0
M-Z-3	1955	May 28	13.9	4.3	62.0	73.0
M-Z-4	0005	May 29	18.0	—	—	—
M-Z-5	1300	May 29	31.0	16.0	77.5	72.0
M-Z-7	0100	May 31	67.0	51.6	76.0	73.0
M-Z-8	0300	May 31	69.0	56.0	73.0	75.0
M-Z-10	0830	May 31	74.5	68.6	77.0	80.0
M-Z-11	1100	May 31	77.0	71.9	68.0	75.0
M-Z-12	1320	May 31	79.3	76.5	82.0	87.0
S-Z-8	0015	Jun 1	90.2	74.8	53.0	—
S-Z-9	0130	Jun 1	91.7	77.8	68.0	—
S-Z-10	0230	Jun 1	92.7	82.0	53.0	—

TABLE 2.2 PENETRATION MEASUREMENTS, SHOT FLATHEAD

Station	Time	Date	Time Since Detonation	Time Since Fallout Arrival	Penetration Depth	Thermocline Depth
			hr	hr	m	m
H-F-1	2350	Jun 12	17.4	16.6	22.5	88.5
H-F-2	0830	Jun 13	26.0	18.8	55.7	80.0
H-F-3	2200	Jun 13	39.5	30.7	64.0	80.0
H-F-4	0415	Jun 14	46.3	38.9	88.0	97.0
H-F-5	1815	Jun 14	49.9	42.8	70.0	100.0
H-F-6	1530	Jun 14	57.0	49.2	54.0	95.0
H-F-7	0015	Jun 15	65.9	58.3	40.0	75.0
H-F-8	0445	Jun 15	70.3	59.7	55.0	100.0
M-F-1	1730	Jun 12	11.0	9.0	27.0	112.0
M-F-2	1215	Jun 13	29.8	18.0	73.7	86.0
M-F-3	1655	Jun 13	34.5	20.0	67.0	78.0
M-F-4	0100	Jun 14	42.4	19.8	86.0	85.0
M-F-5	0650	Jun 14	48.3	27.2	58.0	62.5
M-F-6	1030	Jun 14	52.0	32.5	43.0	57.0
M-F-7	1830	Jun 14	60.0	36.8	68.5	80.0
S-F-1	2210	Jun 12	15.7	16.7	48.0	—
S-F-2	0130	Jun 13	19.0	16.3	65.0	—
S-F-3	1355	Jun 13	31.7	27.4	69.0	85.0
S-F-4	1650	Jun 13	34.7	31.2	80.0	—
S-F-5	1900	Jun 13	36.4	33.6	54.0	—
S-F-6	0622	Jun 14	47.8	45.7	46.5	82.0

TABLE 2.3 PENETRATION MEASUREMENTS, SHOT NAVAJO

Station	Time	Date	Time Since Detonation	Time Since Fallout Arrival	Penetration Depth	Thermocline Depth
			hr	hr	m	m
H-N-2	1905	Jul 11	13.1	12.1	58.0	70.0
H-N-3	2100	Jul 11	15.1	12.8	25.0	67.0
H-N-4	0030	Jul 12	18.6	15.0	28.5	76.0
H-N-5	0315	Jul 12	21.2	17.3	42.5	75.0
H-N-6	0747	Jul 12	25.7	20.9	38.0	72.0
H-N-7	1300	Jul 12	31.0	26.7	52.5	71.0
H-N-8	1620	Jul 12	34.3	30.2	51.0	81.0
H-N-10	0735	Jul 13	49.5	47.6	72.0	65.0
H-N-11	1032	Jul 13	52.7	50.8	67.0	72.5
H-N-12	1330	Jul 13	55.6	—	—	—
H-N-18	0446	Jul 15	94.8	87.0	77.5*	75.0
M-N-1	2000	Jul 11	14.0	11.4	25.5	70.0
M-N-2	2145	Jul 11	15.7	11.8	22.5	69.0
M-N-3	0018	Jul 12	18.3	13.6	27.5	79.0
M-N-4	1830	Jul 12	36.5	20.0	55.0	67.0
M-N-5	0049	Jul 13	42.9	19.8	73.0	65.0
S-N-1	1845	Jul 11	12.8	7.6	38.5	60.0
S-N-2	1216	Jul 12	30.3	22.3	40.0	72.0
S-N-3	1615	Jul 12	34.3	29.3	39.5	72.0
S-N-4	0105	Jul 13	43.2	30.7	57.5	95.0
S-N-5	1408	Jul 13	56.3	40.7	—	60.0
S-N-6	1840	Jul 13	60.8	57.6	49.0	90.0
S-N-8	1035	Jul 14	76.7	58.4	—	75.0
S-N-9	1905	Jul 14	85.2	64.7	—	86.0
S-N-10	0045	Jul 15	90.7	71.6	—	70.0
S-N-11	0438	Jul 15	94.5	86.0	—	84.0
S-N-12	0855	Jul 15	99.0	91.0	46.0	75.0
S-N-13	1025	Jul 15	100.5	92.0	41.0	70.0

* Data questionable.

TABLE 2.4 PENETRATION MEASUREMENTS, SHOT TEWA

Station	Time	Date	Time Since Detonation	Time Since Fallout Arrival	Penetration Depth	Thermocline Depth
			hr	hr	m	m
H-T-1	2331	Jul 21	17.7	14.4	17.5	70.0
H-T-2	0300	Jul 22	21.1	16.6	48.5	78.0
H-T-3	0815	Jul 22	26.5	21.7	49.0	75.0
H-T-4	1200	Jul 22	30.2	25.8	56.0	70.0
H-T-5	2030	Jul 22	38.7	32.4	31.0	90.0
H-T-5A	2324	Jul 22	41.7	34.8	73.0	90.0
H-T-6	0347	Jul 23	46.0	39.6	40.0	71.0
H-T-7	0820	Jul 23	50.6	39.8	46.0	67.0
H-T-8	1603	Jul 23	58.4	54.5	67.0*	67.0
H-T-10	0540	Jul 24	71.9	69.9	75.5	75.5
H-T-11	1125	Jul 24	77.6	75.3	46.0	75.0
H-T-12	1500	Jul 24	81.2	75.8	40.5	72.0
H-T-13	2030	Jul 24	85.7	84.4	50.0	62.0
H-T-14B	0500	Jul 25	95.3	92.0	57.0	60.0
H-T-15	1205	Jul 25	102.3	99.5	63.5	50.0
M-T-1	1930	Jul 21	13.7	12.7	36.0	95.0
M-T-2	0015	Jul 22	18.5	16.4	42.0	60.0
M-T-3	0647	Jul 22	24.0	20.7	63.0	73.0
M-T-4	1500	Jul 22	33.3	23.5	57.0	87.0
M-T-5	1952	Jul 22	38.1	30.4	63.5	87.0
M-T-6	0005	Jul 23	42.3	38.9	40.5	57.0
M-T-7	0325	Jul 23	45.6	42.1	40.5	85.0
M-T-8	0916	Jul 23	51.5	41.4	73.5	75.0
M-T-9	2027	Jul 23	62.7	41.9	54.0	55.0
M-T-10	0308	Jul 24	69.3	56.9	48.0	67.0
M-T-12	1920	Jul 24	85.5	68.5	70.0	67.5
M-T-14	0844	Jul 25	99.0	74.7	57.5	50.0
S-T-1	1803	Jul 21	12.2	10.3	17.5	70.0
S-T-2	2336	Jul 21	17.7	8.3	47.0	75.0
S-T-4	0930	Jul 22	27.7	6.2	23.5	52.0
S-T-5	1630	Jul 22	34.7	8.9	22.5	52.0
S-T-8	1235	Jul 23	54.8	43.8	43.0	50.0
S-T-9	1710	Jul 23	59.3	55.2	81.5	74.0
S-T-10	2300	Jul 23	65.3	60.7	50.0	86.0
S-T-11	0910	Jul 24	75.5	73.1	69.5	86.0

* Data questionable.

TABLE 2.5 SUMMARY OF PENETRATION MEASUREMENTS

Shot	Penetration Depth	Probable Error	Mixed Layer Depth	Probable Error	Rate of Penetration	Penetration Depth Mixed Layer Ratio
	m	m	m	m	m/hr	
Zuni	80.0	± 9.6	75.0	±4.0	11.0	1.07
Flathead	63.0	± 8.4	82.5	±8.4	3.5	0.765
Navajo	53.5	± 9.5	73.5	±6.1	2.3	0.735
Tewa	53.5	±10.1	70.0	±8.4	3.8	0.765

TABLE 2.6 SUMMARY OF WATER SAMPLING PROGRAM, SHOT ZUNI

Ship Station	Time	Date	Time Since Detonation	Sampling Position		Corrected Position		Type Sample	mr/hr# (in situ)
				Latitude, N	Longitude, E	Latitude, N	Longitude, E		
			hr						
H-Z-1	1340	May 28	7.3	11-47.2	165-39	11-47	165-42	*	—
H-Z-3	2330	May 28	17.7	12-19	165-17	12-17	165-18.5	*	7.63
H-Z-4	0800	May 29	26.3	13-00	165-12	12-57.7	165-14.2	*	0.295
H-Z-5	1430	May 29	32.5	13-00	165-12	12-57.7	164-14.2	†	0.138
H-Z-6	1900	May 29	37.0	13-04	165-12.5	13-00.5	165-15	*	0.160
H-Z-7	2345	May 29	41.8	13-04.7	165-12.5	13-00	165-16.2	*	0.090
H-Z-8	1200	May 30	54.0	13-06	165-04.5	12-57.8	165-12.5	*	0.070
H-Z-9	1640	May 30	58.7	13-06.4	165-02	12-57	165-09.8	*	0.058
								†	
H-Z-10	2000	May 30	64.0	13-08.5	164-59	12-56.5	165-09	*	0.045
H-Z-11	0200	May 31	68.0	13-09	164-58.5	12-56	165-08.2	*	0.047
H-Z-12	0615	May 31	72.2	13-11.5	164-55	12-55.5	165-01	*	0.038
H-Z-13	1000	May 31	76.0	13-11.5	164-55	12-55.5	165-01	*	0.036
H-Z-14	1415	May 31	80.2	13-12.5	164-53	12-55	164-59	*	0.031
H-Z-15	1830	May 31	84.5	13-13	164-52	12-54	164-57.5	*	0.031
M-Z-1	1300	May 28	7.0	11-29	165-09.1	11-27	165-09.2	*	—
M-Z-2	1650	May 28	10.9	11-45.1	165-08.9	11-43.5	165-11	*	1.88
M-Z-3	1946	May 28	13.8	12-10	165-27.8	12-10	165-30	*	8.45
M-Z-4	2400	May 28	18.0	12-13.8	165-53	12-14.2	165-55.8	*	0.405
M-Z-4	1300	May 29	31.0	12-46.1	166-01.3	12-49.5	166-05.8	*	0.415
M-Z-6	0720	May 30	49.3	13-37	163-40.2	13-29	163-41	*	—
M-Z-7	0100	May 31	67.0	12-52.7	165-45.2	12-55.8	165-57.5	*	—
M-Z-8	0300	May 31	69.0	12-39	165-48.5	12-41.8	166-06	*	0.185
M-Z-10	0840	May 31	74.7	12-35	165-13.7	12-28	165-30.3	*	1.23
M-Z-11	1105	May 31	77.1	12-32.8	164-41.5	12-20	164-56	*	0.35
M-Z-12	1313	May 31	79.2	12-20	164-59.3	12-10	165-06	*	1.31
M-Z-13	1430	May 31	80.2	12-10.3	164-50.8	12-00	165-14	*	—
M-Z-14	2045	May 31	86.8	12-39.7	163-38	12-24.5	163-45	*	0.065
S-Z-1	1250	May 28	6.9	11-40.3	165-35.2	11-40.3	165-36.5	*	—
S-Z-2	1720	May 28	11.3	11-59	165-04	11-57	165-06.5	*	4.28
S-Z-3	2220	May 28	16.5	12-54	164-29	12-13.8	164-32.5	*	2.68
S-Z-5	1445	May 30	56.9	13-46	164-32.5	13-36	164-29.2	*	0.014
S-Z-6	1915	May 30	61.3	13-47	163-47	13-39	163-50	*	0.01
S-Z-8	0015	Jun 1	90.2	12-44	165-59	12-53	166-10	*	0.28
S-Z-9	0130	Jun 1	91.7	12-33.8	165-57	12-39	166-15.2	*	0.14

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* Surface samples for Projects 1.63 and 1.64

† Depth samples for Projects 1.63 and 1.64.

TABLE 2.7 SUMMARY OF WATER SAMPLING PROGRAM, SHOT FLATHEAD

Ship Station	Time	Date	Time Since Detonation hr	Sampling Position Latitude, N	Sampling Position Longitude, E	Corrected Position Latitude, N	Corrected Position Longitude, E	Type Sample	mr/hr# (in situ)
H-F-1	2400	Jun 12	17.5	11-33.5	165-10.5	11-34	165-11	*	—
H-F-2	0830	Jun 13	26.0	12-07	165-29	12-12	165-30	* † ‡	0.08
H-F-3	2300	Jun 13	40.5	12-10.5	165-31	12-17	165-33	*	0.137
H-F-4	0430	Jun 14	46.1	12-07	165-51	12-08.5	164-58	*	0.534
H-F-5	0800	Jun 14	49.6	12-07	164-52.3	12-09.5	164-58.5	* † ‡	0.196
H-F-6	1515	Jun 14	56.8	12-07	164-48.6	12-08	164-56	*	0.168
H-F-7	2400	Jun 14	65.6	12-06	163-52	11-52	163-57	*	0.033
H-F-8	0430	Jun 15	70.0	12-29	164-00	12-15	163-56	*	—
H-F-9	0930	Jun 15	75.0	12-22.5	164-34	12-17	164-39	* † ‡	0.018
H-F-10	1430	Jun 15	80.0	12-24	164-32	12-17	164-39	*	0.017
H-F-11	1000	Jun 16	99.6	12-36.5	165-23	12-44	165-30.5	*	0.100
H-F-12	1200	Jun 16	101.6	12-14	164-27.2	12-34.1	165-33	*	0.046
M-F-1	1730	Jun 12	11.0	11-30.5	164-53.8	11-30.8	164-54.5	*	0.28
M-F-2	1215	Jun 13	29.8	12-30	165-14.2	12-34	165-15.2	*	0.41
M-F-3	1653	Jun 13	34.5	12-44	165-31.2	12-47	165-31.8	* ‡	0.40
M-F-4	0100	Jun 14	42.5	13-10.3	166-09.1	13-10.3	166-14	*	0.085
M-F-5	0630	Jun 14	48.0	13-20.5	165-36.9	13-20	165-43	*	0.100
M-F-6	1030	Jun 14	52.0	13-17	165-05.3	13-15	165-13.5	*	0.116
M-F-7	1830	Jun 14	60.0	13-30.5	164-04	13-27	164-12	*	0.100
S-F-1	2210	Jun 12	15.7	11-25.5	165-11.8	11-28.5	165-12	*	0.64
S-F-2	0130	Jun 13	19.0	11-53	165-15	11-54	165-16	*	2.45
S-F-3	1400	Jun 13	31.7	11-52	165-09	11-53	165-15.2	*	1.05
S-F-4	1655	Jun 13	34.7	11-48	165-10	11-53	165-15.2	* ‡	1.22
S-F-5	1930	Jun 13	37.1	11-52.2	164-57.8	11-53	165-04.5	*	0.82
S-F-6	0622	Jun 14	47.8	11-45.4	165-03.8	11-51	165-15	*	0.54
S-F-7	1943	Jun 14	61.3	12-42	164-28	12-40.2	164-18	*	0.023

* Surface samples for Projects 2.63 and 2.64.

† Depth samples for Projects 2.63 and 2.64.

‡ Special samples for AFOAT-1.

TABLE 2.8 SUMMARY OF WATER SAMPLING PROGRAM, SHOT NAVAJO

Ship Station	Time	Date	Time Since Detonation	Sampling Position		Corrected Position		Type Sample	mr/hr# (in situ)
				Latitude, N	Longitude, E	Latitude, N	Longitude, E		
			hr						
H-N-1	1345	Jul 11	7.9	11-21.3	165-19	11-21.5	165-20	*	—
H-N-2	1905	Jul 11	13.1	11-34.5	165-09	11-34.5	165-09	*	—
H-N-3	2130	Jul 11	15.6	11-47.2	165-07.3	11-47.5	165-09.5	*	7.56
H-N-4	0030	Jul 12	18.6	11-57	165-17.5	11-56.5	165-19	*	2.025
H-N-5	0305	Jul 12	21.1	11-58.5	165-13	11-58.5	165-13	*	1.71
H-N-6	0800	Jul 12	26.0	11-58.3	165-12.3	11-58.3	165-12.3	*	1.075
H-N-7	1330	Jul 12	31.5	11-59	165-08	11-59	165-08	*	0.65
H-N-8	1700	Jul 12	35.0	11-59.5	165-09	11-59.5	165-09	*	0.486
								†	
								‡	
H-N-9	0000	Jul 13	42.0	11-44.8	165-16.2	11-47.5	165-19.2	*	—
H-N-10	0810	Jul 13	50.2	11-50	165-14.4	11-50.7	165-20	*	0.436
H-N-11	1035	Jul 13	52.7	11-46.5	165-14	11-46	165-19.8	*	—
H-N-12	1330	Jul 13	55.6	11-43.2	165-17.2	11-43.8	165-22	*	—
H-N-13	2110	Jul 13	63.2	11-34	165-11	11-34	165-11	*	—
H-N-14	0410	Jul 14	70.2	11-29	164-45.3	11-33.5	164-48.2	*	0.38
H-N-15	0710	Jul 14	73.2	11-39	165-03.8	11-42.5	165-08	*	0.37
H-N-16	1430	Jul 14	80.6	12-07	164-56.5	12-05.2	164-55	*	0.031
								†	
								‡	
H-N-17	0000	Jul 15	90.0	11-46.2	165-15.6	11-49	165-23	*	—
								†	
								‡	
H-N-18	0415	Jul 15	94.3	12-00.8	165-29.5	12-01	165-43.5	*	0.033
M-N-1	2000	Jul 11	14.0	11-38.0	164-53.4	11-40	164-54	*	4.0
M-N-2	2120	Jul 11	15.3	11-38.0	164-43.6	11-40	164-44	*	4.55
M-N-3	0015	Jul 12	18.3	11-37.5	164-37.5	11-40	164-37	*	2.9
M-N-4	1830	Jul 12	36.6	12-03	163-18.2	12-10	163-14	*	—
M-N-5	0050	Jul 13	42.9	12-44.3	162-40	12-48	162-44	*	0.21
M N 6	0900	Jul 14	75.0	12-23.1	164-41.4	12-22.7	164-48	*	Lost
								‡	probe
S-N-1	1845	Jul 11	12.8	11-52	165-41	11-52.5	165-41.5	*	0.32
S-N-2	1300	Jul 12	31.0	12-09	165-12.5	12-08	165-12.5	*	0.403
								‡	
S-N-3	1615	Jul 12	34.3	11-52.0	164-50.5	11-52	164-49.5	*	0.89
S-N-4	0105	Jul 13	43.2	11-58	163-54	12-05	163-57	*	0.113
S-N-5	1408	Jul 13	56.3	12-36	164-54	12-34	165-00.5	*	—
S-N-6	1840	Jul 13	60.8	11-41	164-53.2	11-45	164-56.5	*	0.72
S-N-7	2250	Jul 13	65.0	11-25	164-26.5	11-34	164-27.2	*	0.20
S-N-8	1035	Jul 14	76.7	12-09	163-50	12-22	163-55	*	0.038
S-N-9	1905	Jul 14	85.2	12-10.5	163-09.7	12-30	163-14	*	0.015

* Surface samples for Projects 2.63 and 2.64.

† Depth samples for Projects 2.63 and 2.64.

‡ Special samples for AFOAT-1.

TABLE 2.9 SUMMARY OF WATER SAMPLING PROGRAM, SHOT TEWA

Ship Station	Time	Date	Time Since Detonation hr	Sampling Position		Corrected Position		Type Sample	mr/hr# (in situ)
				Latitude, N	Longitude, E	Latitude, N	Longitude, E		
H-T-1	0010	Jul 22	18.4	11-53.6	165-26.2	11-54	165-30.5	*	—
H-T-2	0330	Jul 22	21.6	12-05	165-16	12-05	165-19	*	25.97
H-T-3	0900	Jul 22	27.2	12-06.9	165-13.2	12-04	165-18	*	27.93
H-T-4	1245	Jul 22	31.0	12-06.6	165-12	12-04.5	165-16	*	21.42
H-T-5	2200	Jul 22	40.2	12-11	165-10.5	12-06.5	165-12	*	18.91
								†	
								‡	
H-T-6	0400	Jul 23	46.2	12-13.2	165-08.7	12-06.5	165-10	*	14.41
H-T-7	0830	Jul 23	50.7	12-30.5	164-57.1	12-21.5	164-54	*	3.51
								†	
								‡	
H-T-8	1615	Jul 23	58.5	11-53.2	165-15	11-54	165-30	*	1.81
								†	
								‡	
H-T-10	0549	Jul 24	71.9	12-00.8	164-52	11-48	165-06	*	0.73
H-T-11	1130	Jul 24	77.7	11-58.2	164-57	11-50	165-15	*	0.79
H-T-12	1500	Jul 24	81.2	12-10.3	165-11.2	12-03.5	165-23	*	10.94
H-T-13	2030	Jul 24	85.7	11-45	164-28	11-40	164-45	*	2.82
H-T-14	0500	Jul 25	95.3	11-59	164-20.5	11-46.8	164-36	*	0.66
H-T-15	1200	Jul 25	102.2	12-05.3	164-36.2	11-50	165-00	*	1.49
M-T-1	1930	Jul 21	13.7	11-31.5	165-06.2	11-28.5	165-08	*	1.15
M-T-2	0015	Jul 22	18.5	11-35.7	164-40	11-34	164-42.2	*	15.42
M-T-3	0650	Jul 22	24.0	11-36	164-07.2	11-39.5	164-10	*	6.2
M-T-4	1500	Jul 22	33.3	11-43.7	163-05.6	11-43.5	163-02	*	0.34
M-T-5	2000	Jul 22	39.2	11-51.4	163-43.6	11-48	163-40	*	1.1
M-T-6	0010	Jul 23	42.4	11-57	164-32.8	11-49.5	164-40	*	6.7
M-T-7	0330	Jul 23	45.7	12-02.5	165-13.8	12-00	165-21.5	*	13.0
M-T-8	0900	Jul 23	51.2	12-24.2	165-24	12-22.5	165-13.8	*	0.18
M-T-9	2005	Jul 23	62.3	13-08.7	164-51.2	13-08.7	164-51.2	*	0.30
M-T-10	0300	Jul 24	69.2	12-40.5	164-53.9	12-26.5	164-44	*	2.45
M-T-12	1846	Jul 24	85.0	12-00.8	164-05	12-43	164-13	*	0.188
								‡	
M-T-13	0245	Jul 25	93.0	12-31.2	163-49.5	12-26	163-54	*	0.144
M-T-14	0850	Jul 25	99.1	13-35.8	163-30	13-30	163-42	*	0.126
M-T-15	1428	Jul 25	104.7	13-50	162-41	13-50	163-05	*	0.03
M-T-16	1900	Jul 25	109.2	13-09.9	162-25	13-10	162-40	*	0.054
S-T-1	1815	Jul 21	12.5	11-47.0	165-33.2	11-46.2	165-35.5	*	—
S-T-2	2332	Jul 21	17.8	12-19.5	165-38.5	12-22	165-37	*	0.055
S-T-3	0655	Jul 22	25.1	12-57	166-07	12-58	166-08	*	—
S-T-5	1630	Jul 22	34.7	13-39	165-47	13-28.5	165-48.5	*	0.038
S-T-6	2330	Jul 22	41.7	13-48.8	164-46.9	13-48	164-51	*	0.029
S-T-7	1000	Jul 23	52.3	12-49.5	164-42	12-41	164-35	*	0.57
S-T-8	1230	Jul 23	54.7	12-34	164-42.7	12-19.5	164-42	*	1.61
S-T-9	1710	Jul 23	59.3	12-06	164-31	11-53	164-42	*	0.94
S-T-10	2300	Jul 23	65.3	11-32	164-00	11-38	164-09	*	1.10
S-T-11	0900	Jul 24	75.3	11-58.2	164-54.5	11-50.2	165-12	*	0.41
S-T-13	0800	Jul 25	98.3	11-41.2	163-10.8	11-41.4	163-02	*	0.153
S-T-14	1515	Jul 25	105.5	12-52	162-55	12-54	163-09.8	*	0.080
S-T-15	0115	Jul 26	115.5	12-19	162-44	12-19	162-44	*	0.064
S-T-16	0540	Jul 26	119.9	11-37	162-34.5	11-37	162-34.5	*	0.060

* Surface samples for Projects 2.63 and 2.64.

† Depth samples for Projects 2.63 and 2.64.

‡ Special samples for AFOAT-1.

TABLE 2.10 EXAMPLE OF DATA REDUCTION

Record from USS McGinty, Shot Tewa.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Date	Time	Instrument and Scale	Recorder Reading	In situ Dose Rate	Contamination	Col 5 Minus Col 6	Time Since Shot	H+1	Time of Arrival	Col 8 Minus Col 10	Mixing Depth	Dose Rate at H+1	Conversion Factor	Total Dose
			μa	mr/hr#	mr/hr#	mr/hr#	hr	mr/hr#	hr	hr	m	r/hr		r
Jul 22	1300	E-1	2.4	0.39	0.10	0.29	31.2	29.1	8.0	23.2	53	15.4	0.66	10.1
Jul 22	1400	E-1	4.0	0.68	0.10	0.58	32.2	61.0	8.8	23.4	53	32.4	0.61	19.8
Jul 22	1500	E-1	2.5	0.40	0.10	0.30	33.2	31.9	9.7	23.5	53	16.9	0.56	9.4
Station 4														
Jul 22	1517	E-2	21.4	0.45	0.10	0.35	33.5	38.6	9.7	23.8	53	20.5	0.56	11.4
Jul 22	1600	E-2	20.8	0.44	0.10	0.34	34.2	38.6	9.7	24.5	53	20.5	0.56	11.4
Jul 22	1635	E-2	21.5	0.46	0.10	0.36	34.8	42.0	10.0	24.8	53	22.3	0.55	12.3
Probe retaped resulting in drop in radiation of 0.10, mr/hr#														
Jul 22	1640	E-2	15.5	0.36	0	0.36	34.9	39.5	10.0	24.8	53	20.9	0.55	11.6
Jul 22	1700	E-2	15.0	0.32	0	0.32	35.2	37.8	10.0	25.2	53	20.0	0.55	11.0
Jul 22	1730	E-2	18.4	0.39	0	0.39	35.7	47.0	9.5	26.2	53	24.9	0.57	14.2
Jul 22	1800	E-2	19.2	0.41	0	0.41	36.2	50.3	9.3	26.9	53	26.8	0.58	15.6
Jul 22	1838	E-2	29.0	0.62	0	0.62	36.9	77.8	8.6	28.3	53	41.2	0.63	25.9
Jul 22	1900	E-2	24.4	0.51	0	0.51	37.2	64.7	8.4	28.8	53	34.4	0.64	22.0
Jul 22	1912	E-2	23.2	0.49	0	0.49	37.4	62.7	8.4	29.0	53	33.3	0.64	21.4
Jul 22	1917	E-2	35.7	0.76	0	0.76	37.5	98.0	8.3	29.2	53	51.9	0.64	33.3
Jul 22	1930	E-2	24.8	0.52	0	0.52	37.7	67.4	8.2	29.5	53	35.8	0.64	22.9
Jul 22	1945	E-2	28.2	0.60	0	0.60	38.0	78.3	7.8	30.2	53	41.6	0.67	27.9
Jul 22	1952	E-2	48.5	1.05	0	1.05	38.1	138.	7.7	30.4	53	73.3	0.67	49.0
Station 5														
Jul 22	2019	E-1	6.1	1.02	0	1.02	38.5	136.	7.5	31.0	53	72.2	0.68	49.0
Jul 22	2045	E-1	5.0	0.84	0	0.84	39.0	114	7.3	31.7	53	60.3	0.70	42.2

TABLE 2.11 SUMMARY OF AREAL EXTENT OF FALLOUT

	Zuni	Flathead	Navajo	Tewa
Total Yield, Mt	3.38			4.6
H + 1 Hour Dose Rate (r/hr)	Area (mi^2) Within Contour Lines			
1,000	—	—	25	450
500	—	—	55	1,050
300	—	—	80	1,550
100	750	—	310	3,500
50	1,720	—	950	5,850
30	4,000	90	1,350	11,500
10	7,600	2,100	3,300	> 29,000
5	10,800*	7,600	8,250*	—
3	> 16,500	10,800	11,600*	—
1	> 28,000	> 20,000	—	—
Two-day Accumulated Dose, Roentgens				
1,000	—	—	20	520
500	—	—	30	1,050
300	—	—	45	1,500
100	1,450	75	350	3,000
50	2,750	425	770	3,900
30	4,300	800	1,300	5,450
10	7,900	2,700	2,150	13,600
5	11,400*	5,400	3,100	> 22,000
3	> 15,700	9,500	4,650*	—
1	> 26,000	> 18,000	11,700*	—

* Contour lines that have been closed by estimation.

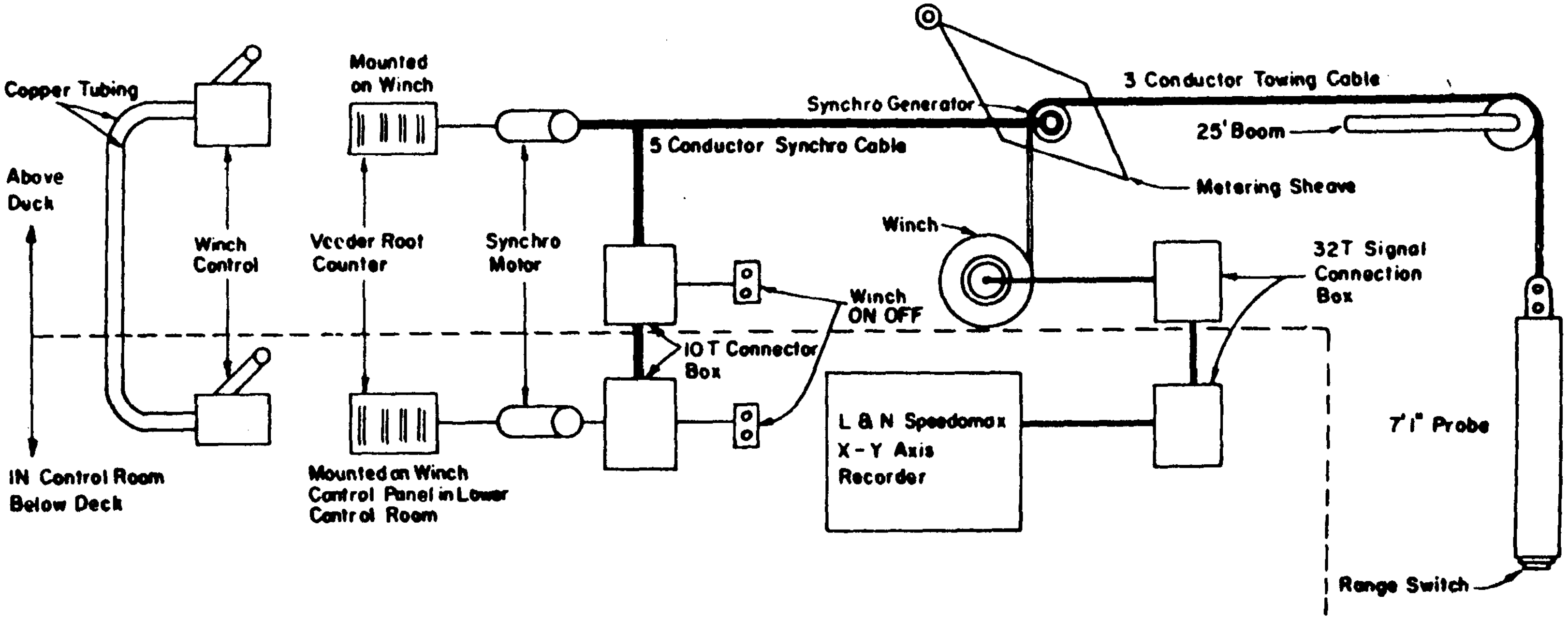

Figure 2.1 Block diagram of Project 2.62 installation on YAG's.

A	Cable attachment device
B	Special three-conductor steel armored cable
C	Vent to pressure sensing element
D	1.3-Volt mercury cells for pressure sensing element
E	Pressure-sensing element (Bourns Gage)
F	1/4" Shelby tubing, 3" outside diameter
G	High voltage battery pack, 680 volts DC
H	Low voltage battery pack, 60 volts DC
J	Vacuum-tube pulse amplifier
K	One Geiger-Mueller tube BS-2 Anton
L	Eight Geiger-Mueller tubes, E315 Anton
M	Removable waterproof sealing cap
N	Sensitivity selector switch

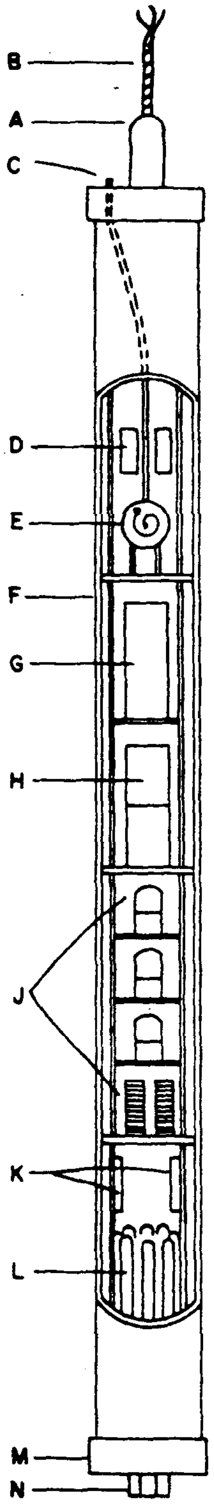

Figure 2.2 Schematic diagram of underwater radiation detectors.

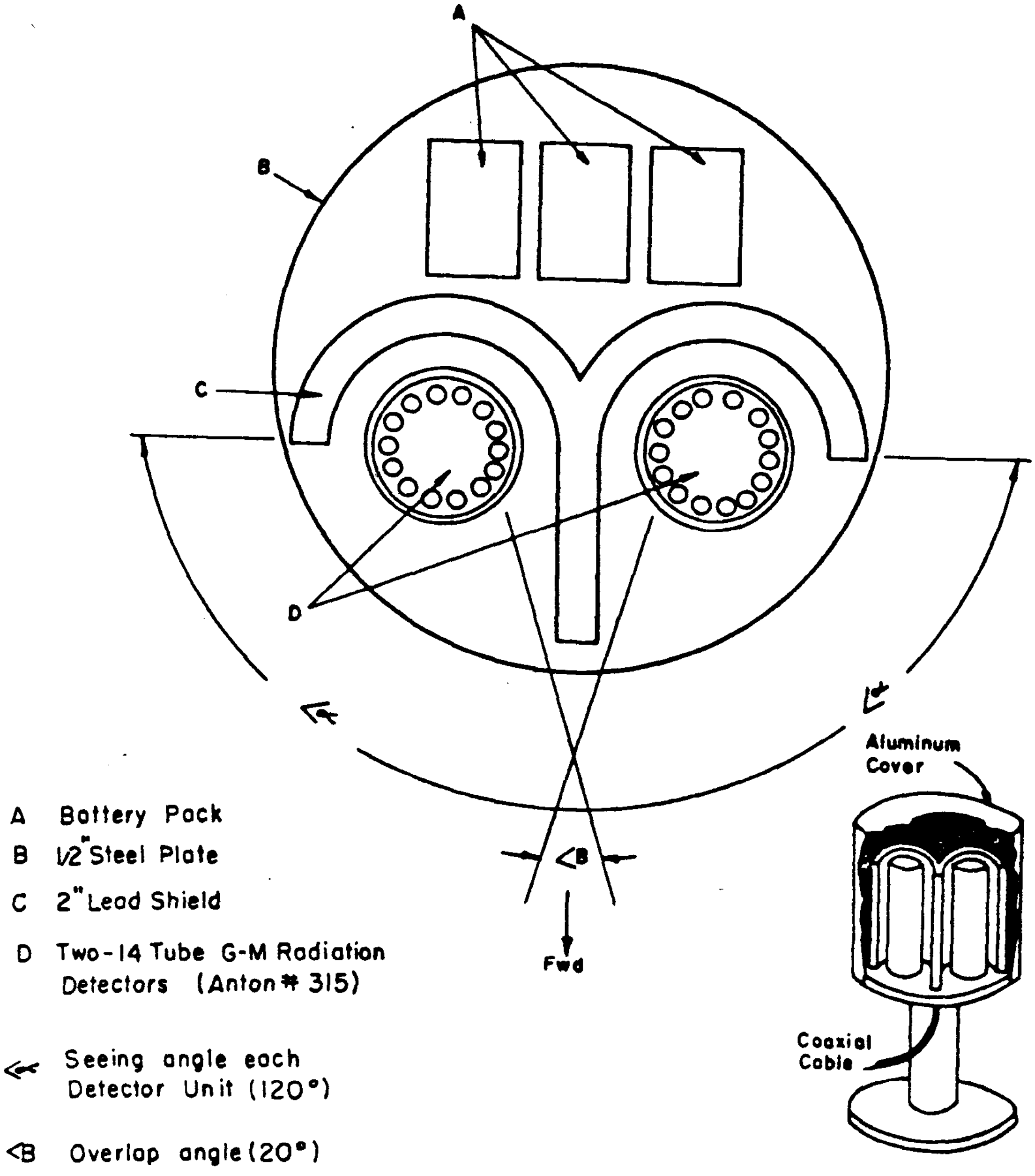

Figure 2.3 Schematic diagram of Nav-Rad unit.

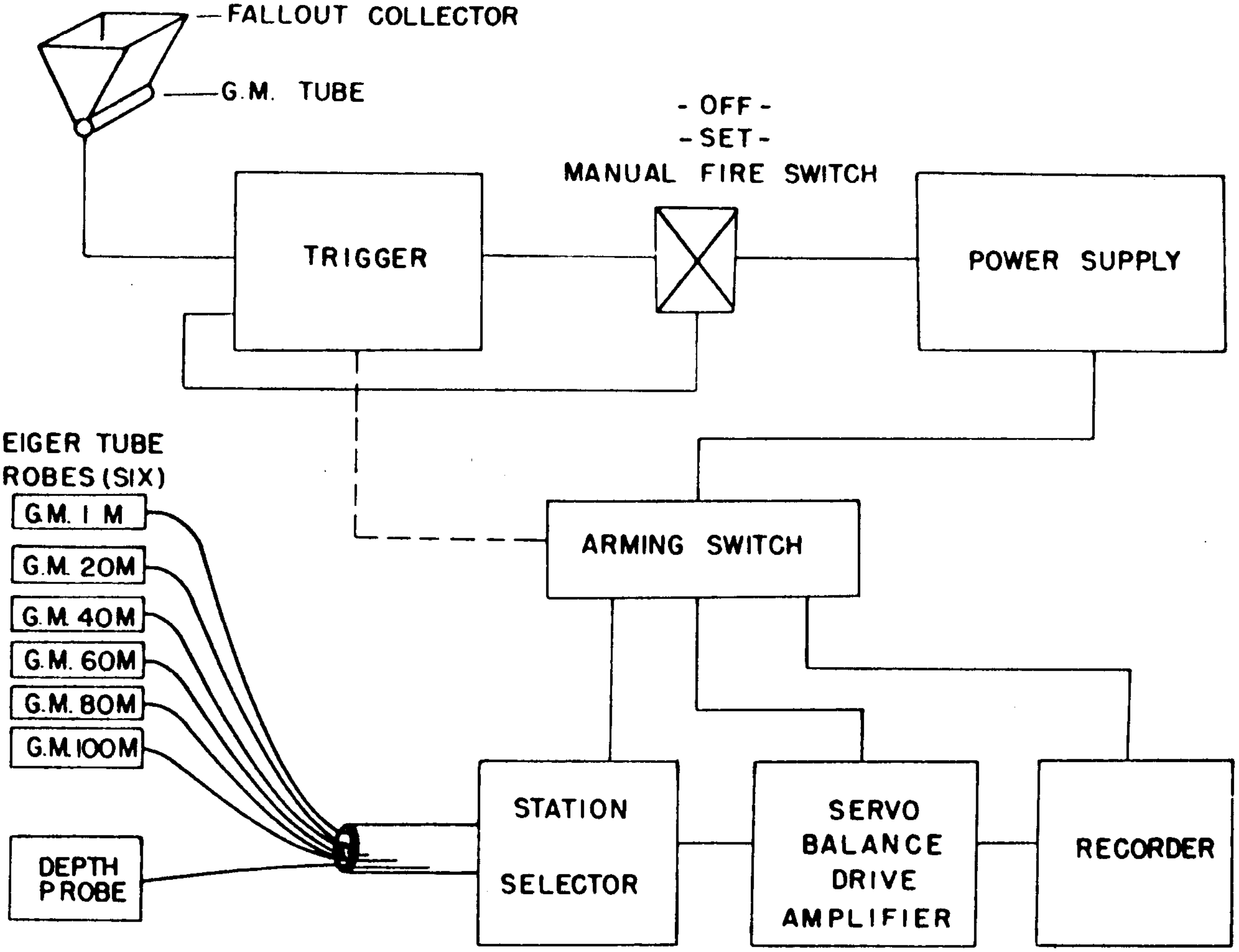

Figure 2.4 Block diagram of penetration meter.

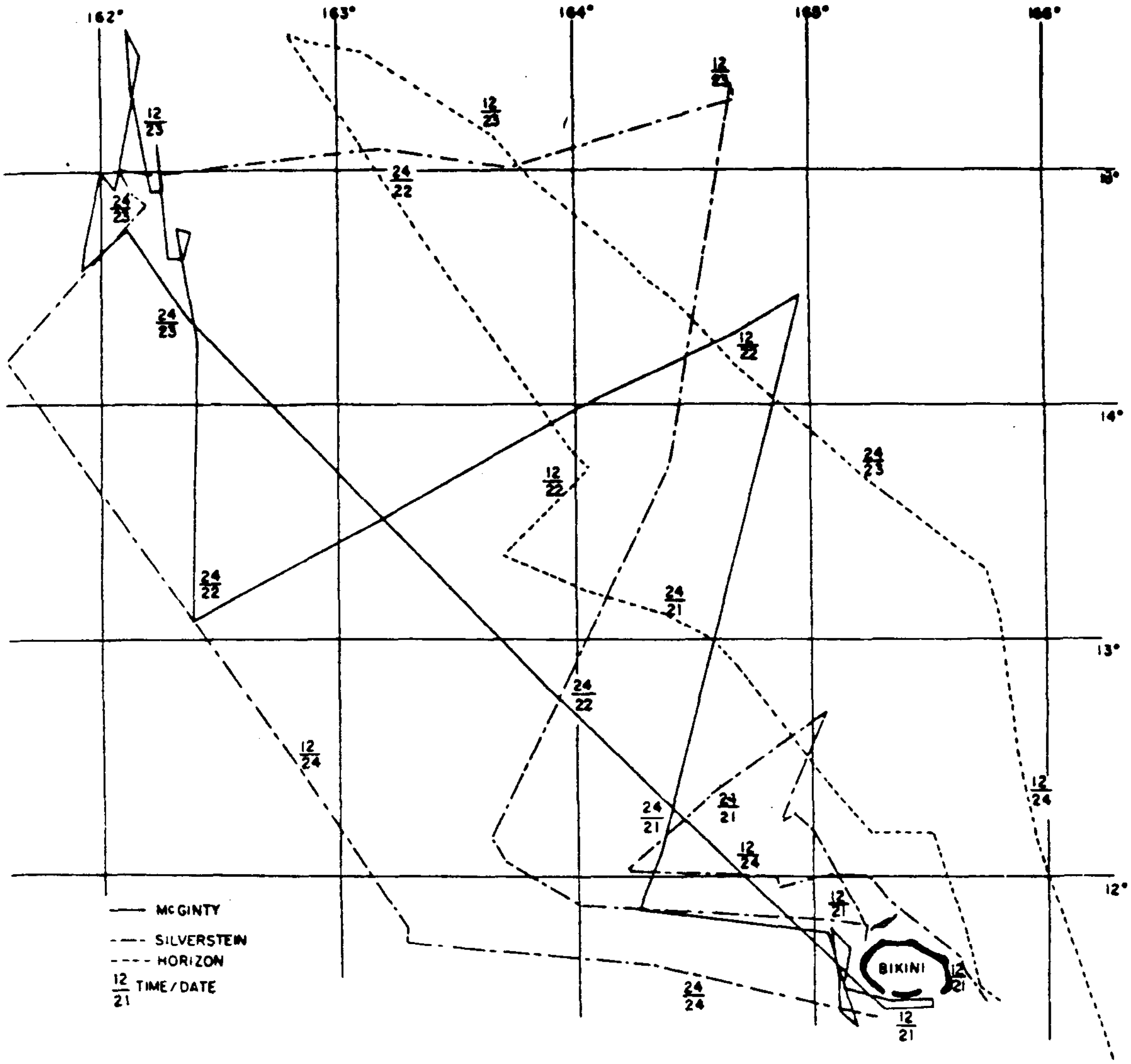

Figure 2.5 Tracks of survey ships for Shot Cherokee.

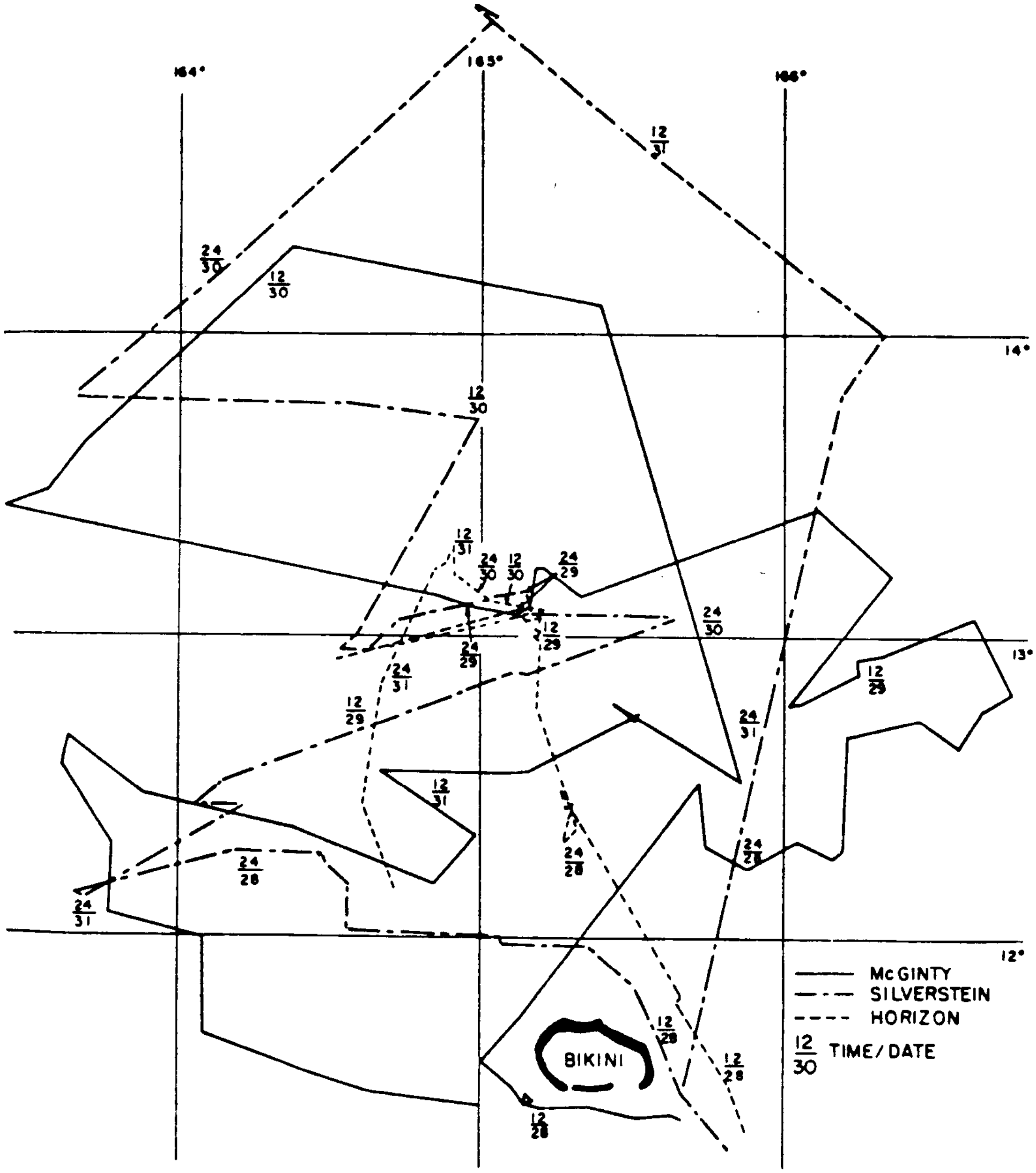

Figure 2.6 Tracks of survey ships for Shot Zuni.

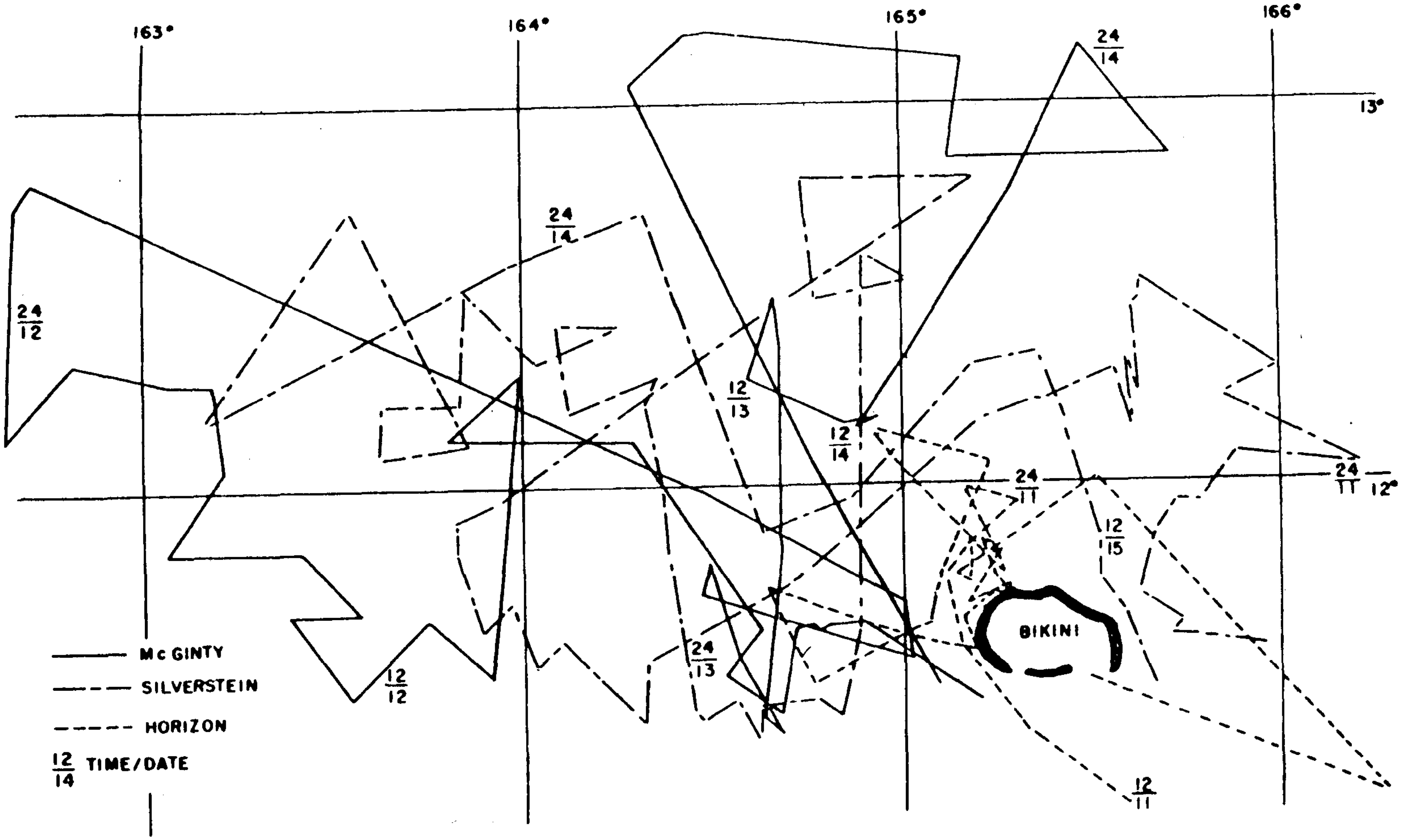

Figure 2.8 Tracks of survey ships for Shot Navajo.

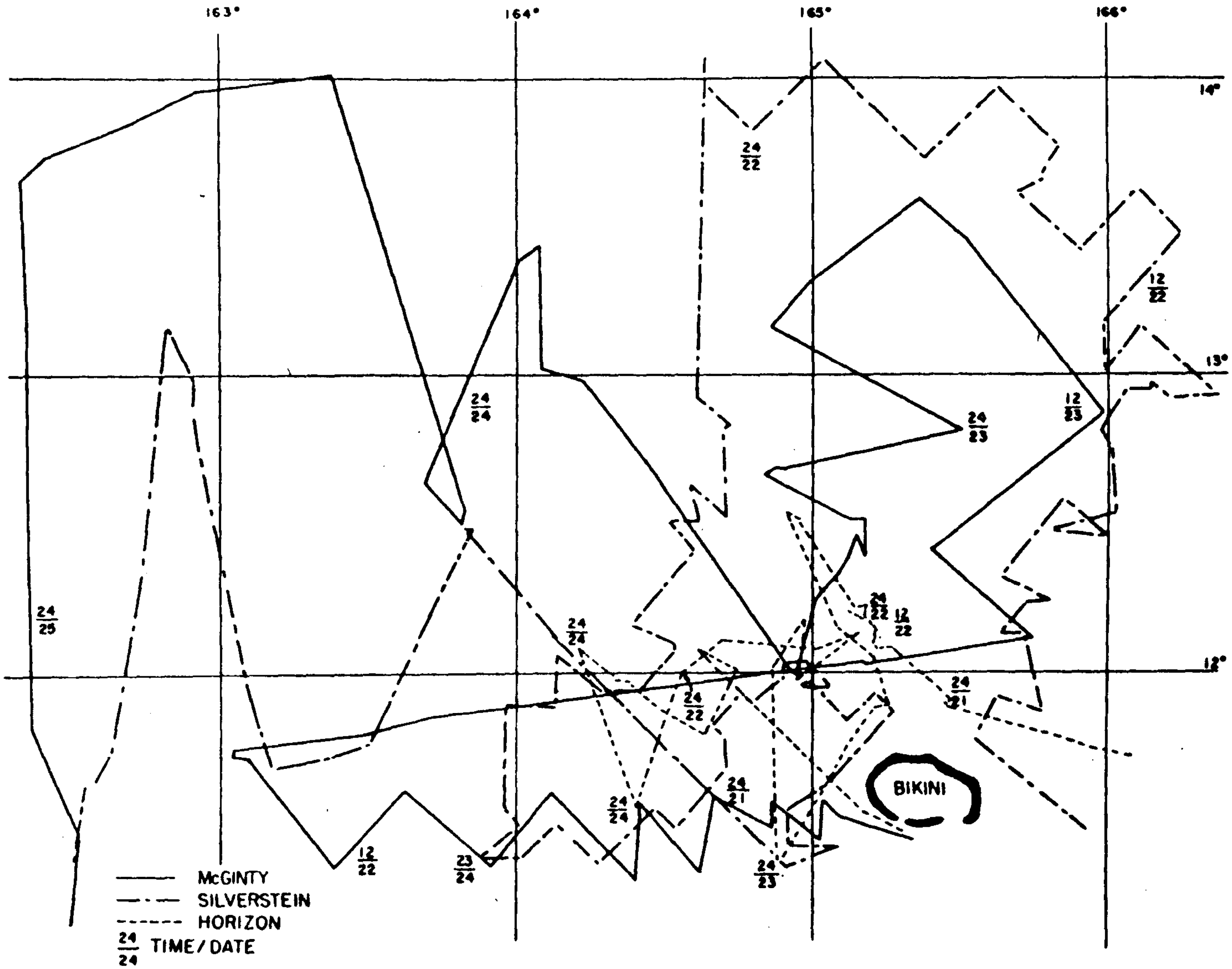

Figure 2.9 Tracks of survey ships for Shot Tewa.

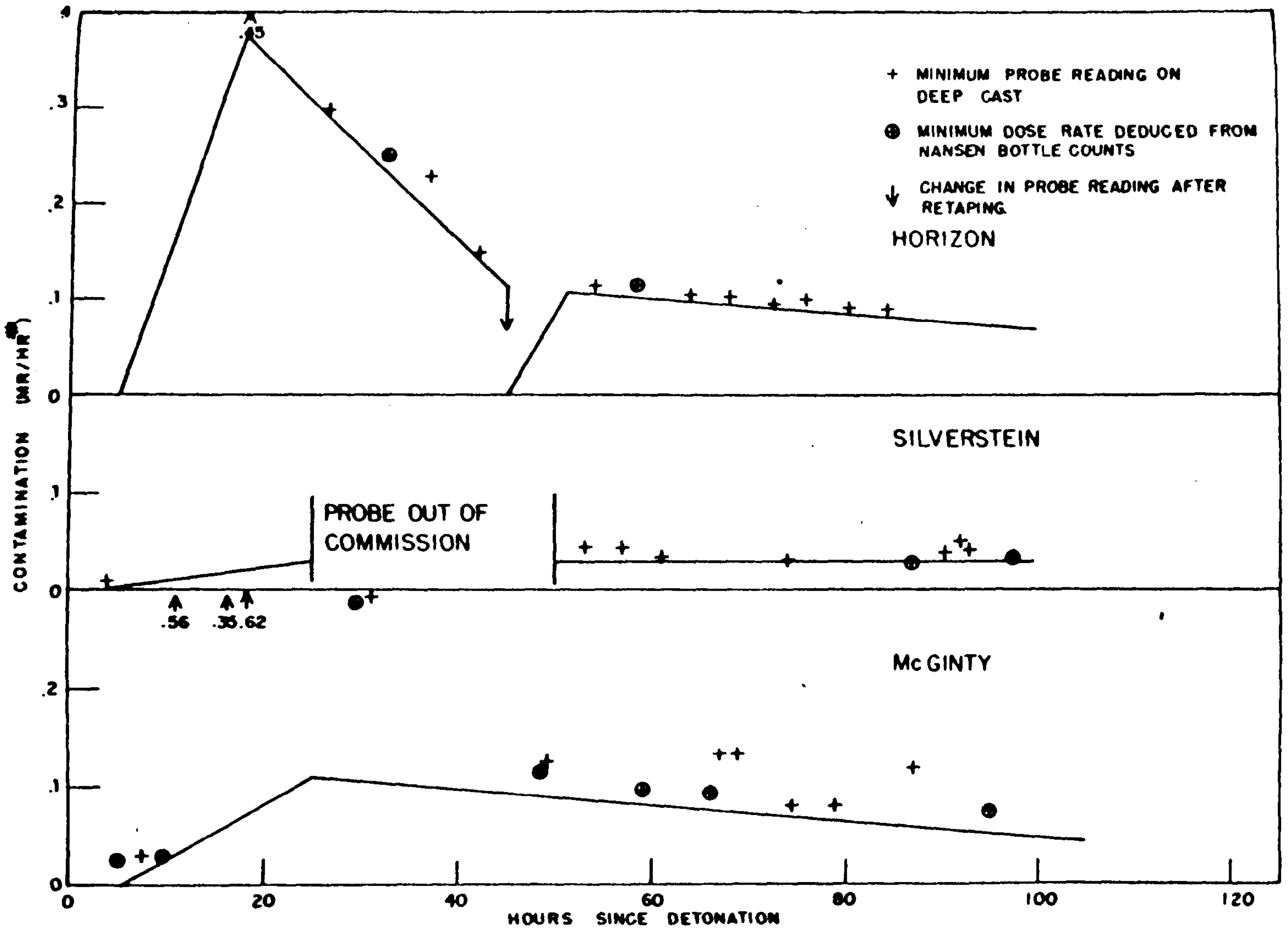

Figure 2.10 Probe contamination for Shot Zuni surveys.

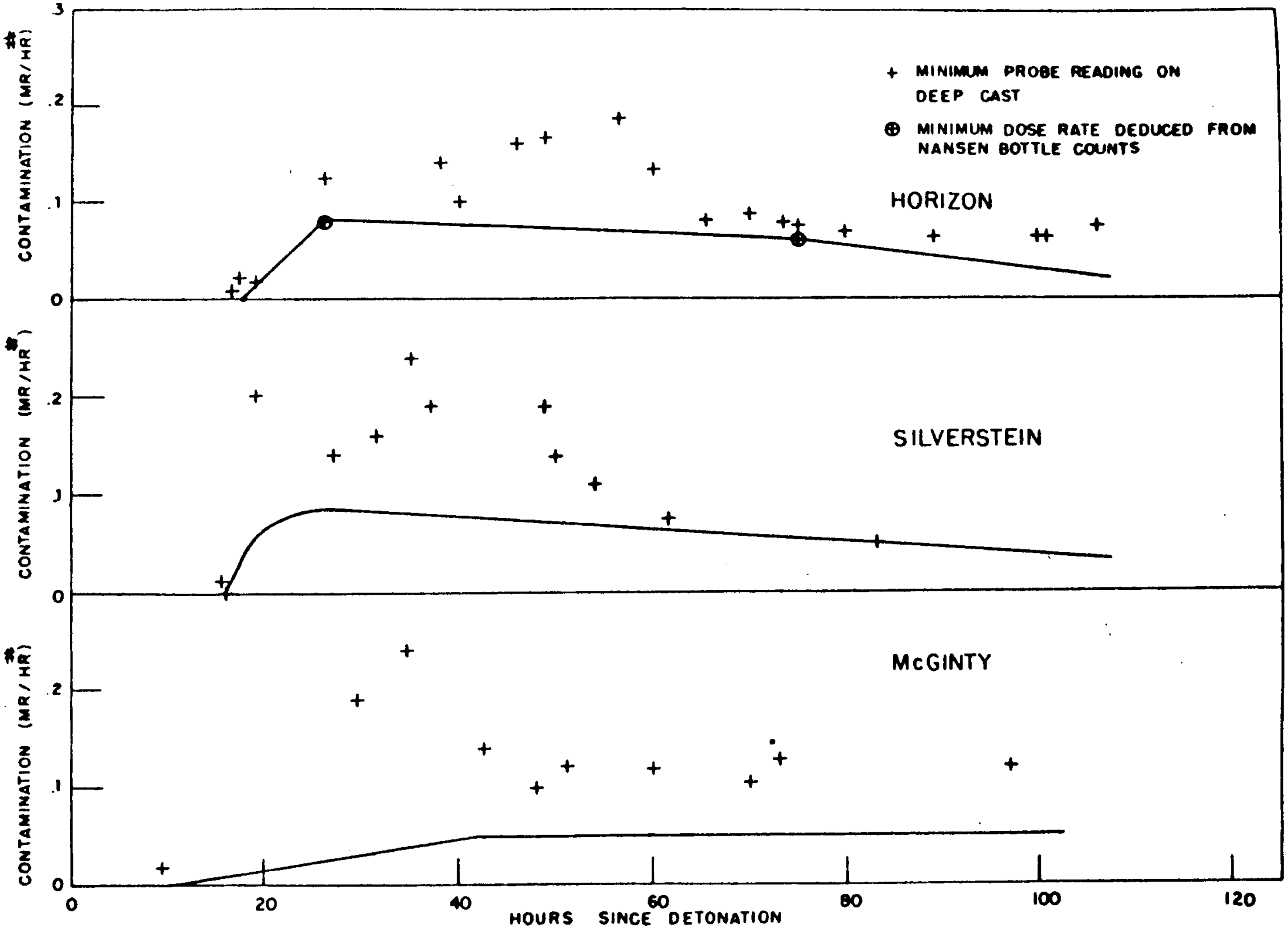

Figure 2.11 Probe contamination for Shot Flathead surveys.

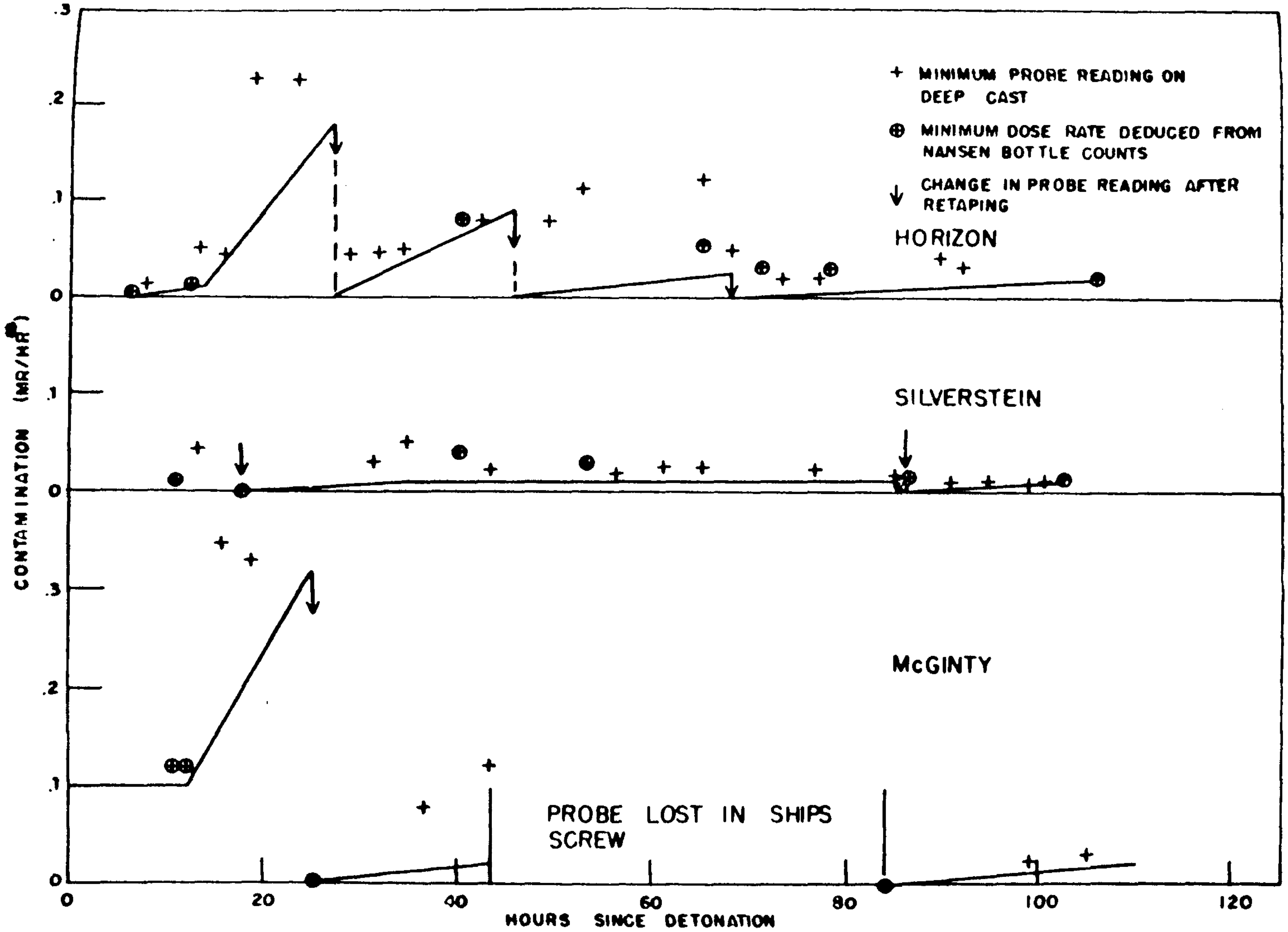

Figure 2.12 Probe contamination for Shot Navajo surveys.

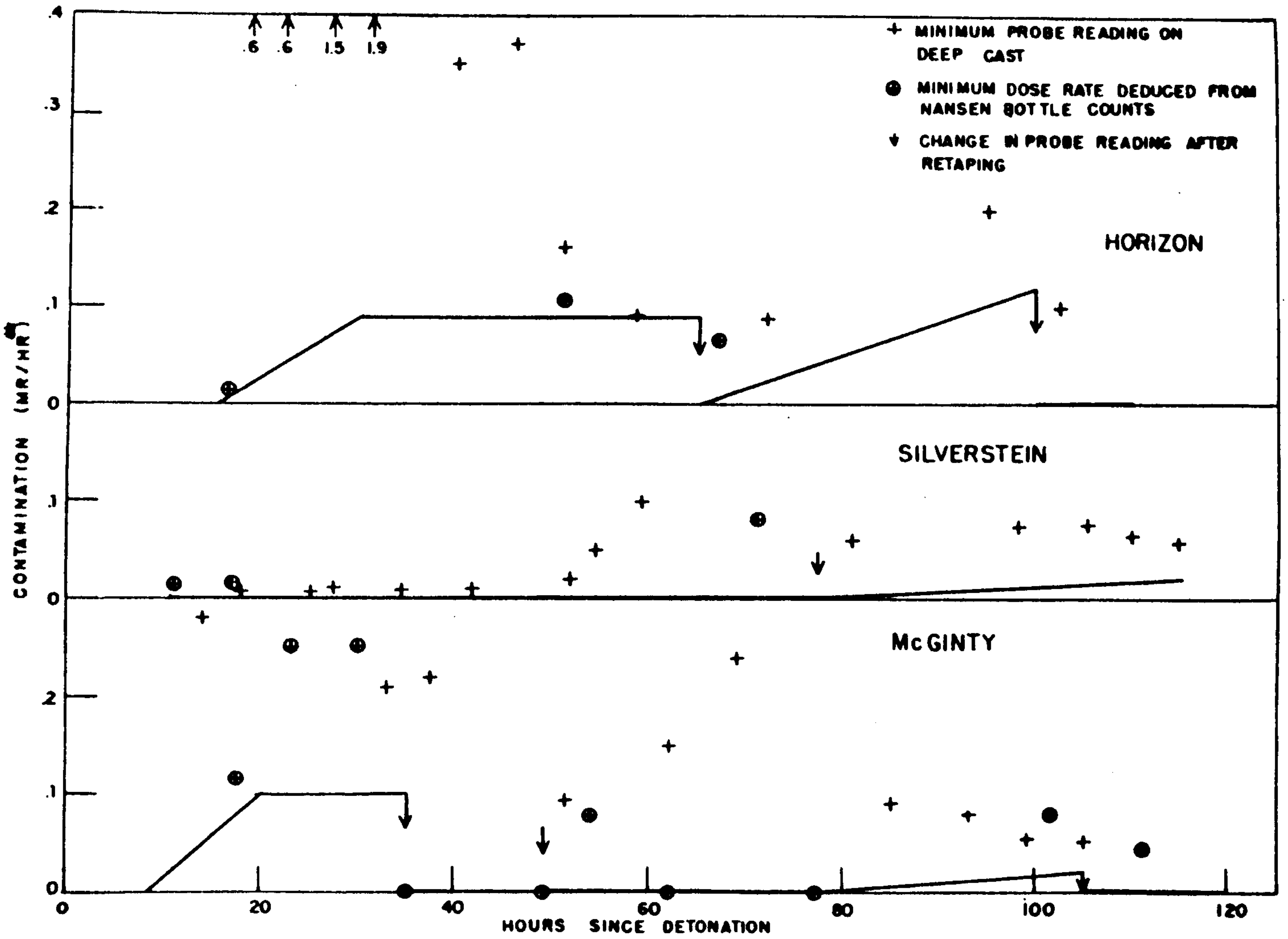

Figure 2.13 Probe contamination for Shot Tewa surveys.

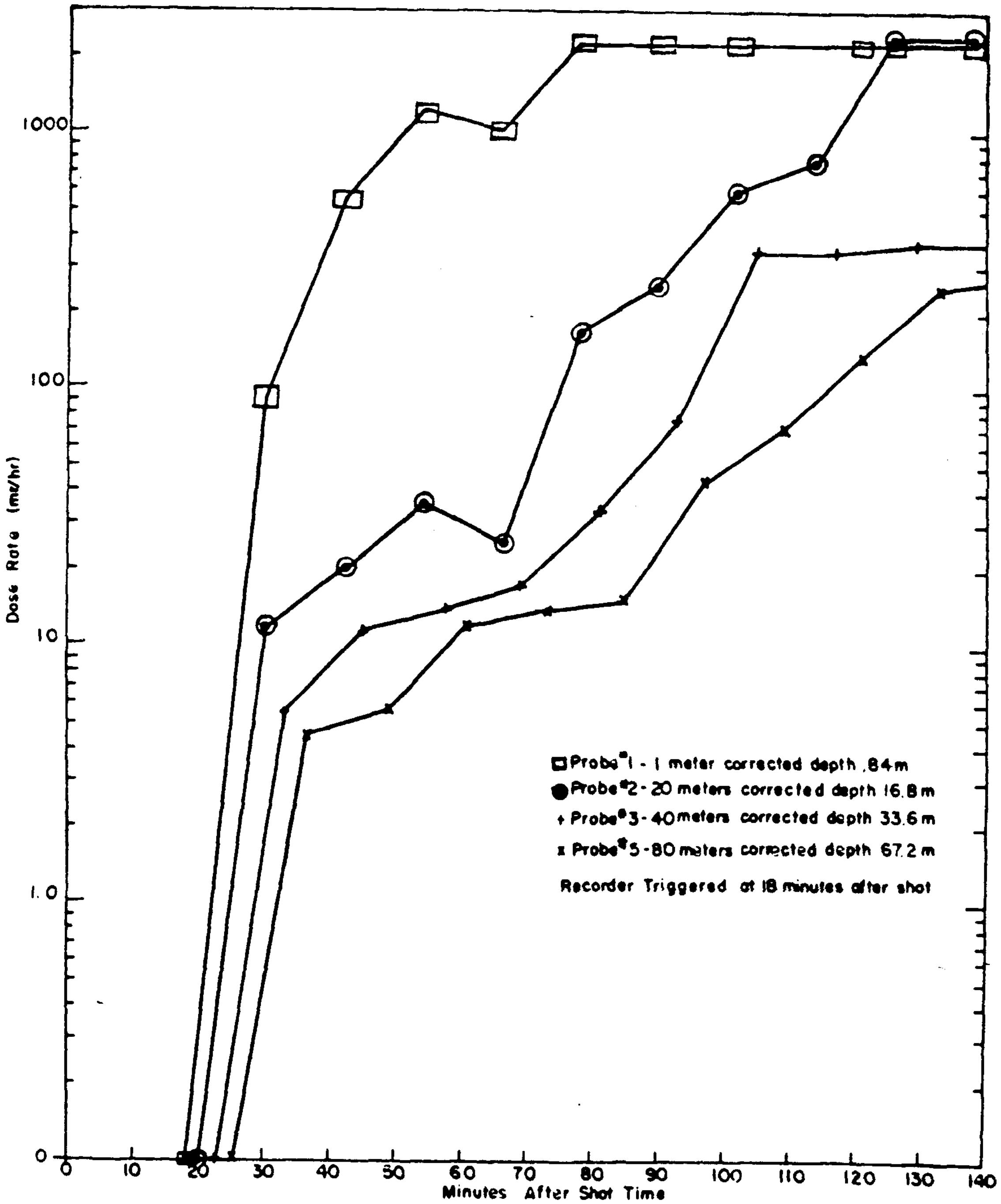

Figure 2.14 Shot Tewa penetration meter readings, log scale, time in minutes.

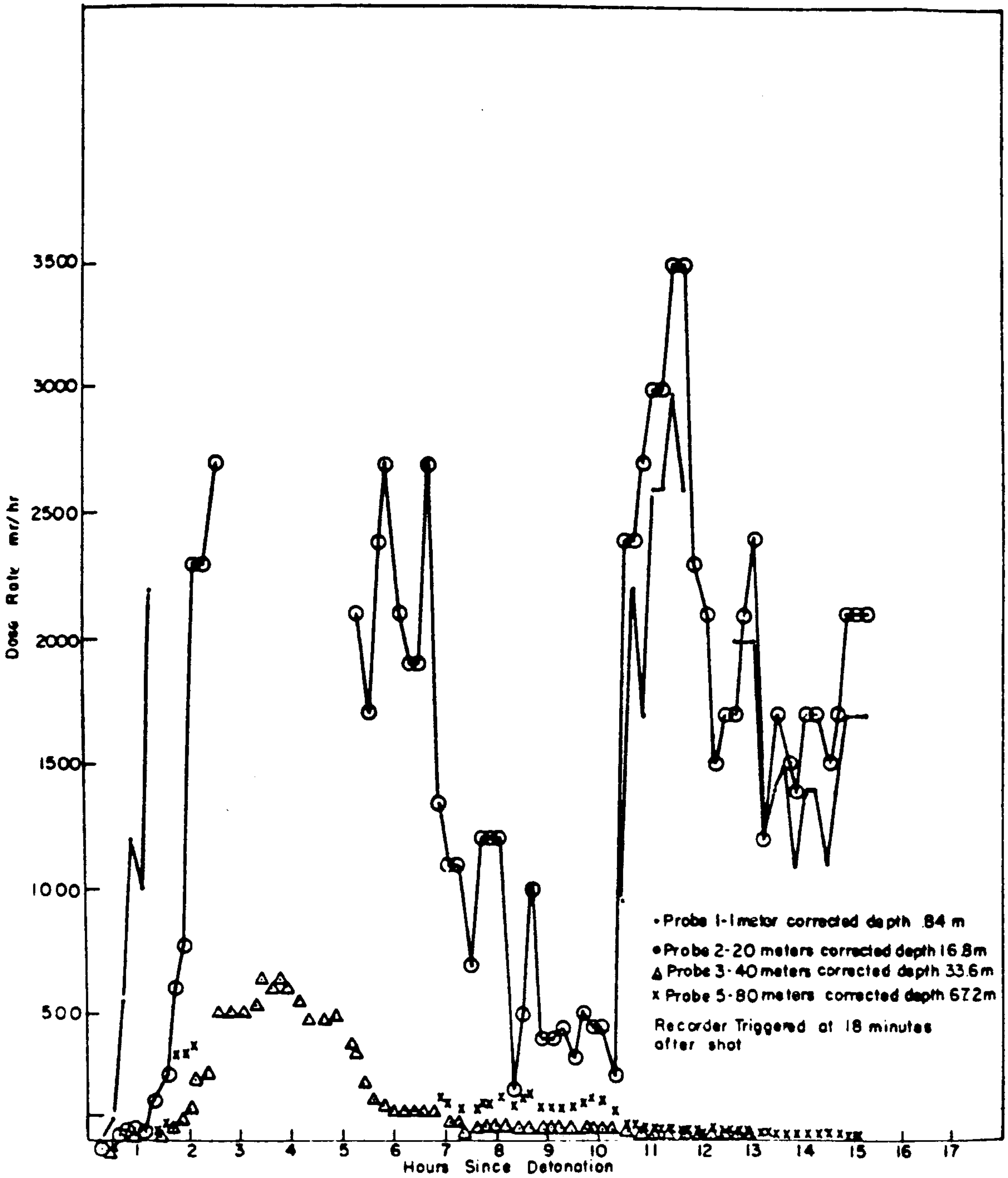

Figure 2.15 Shot Tewa penetration meter readings, linear scale, time in hours.

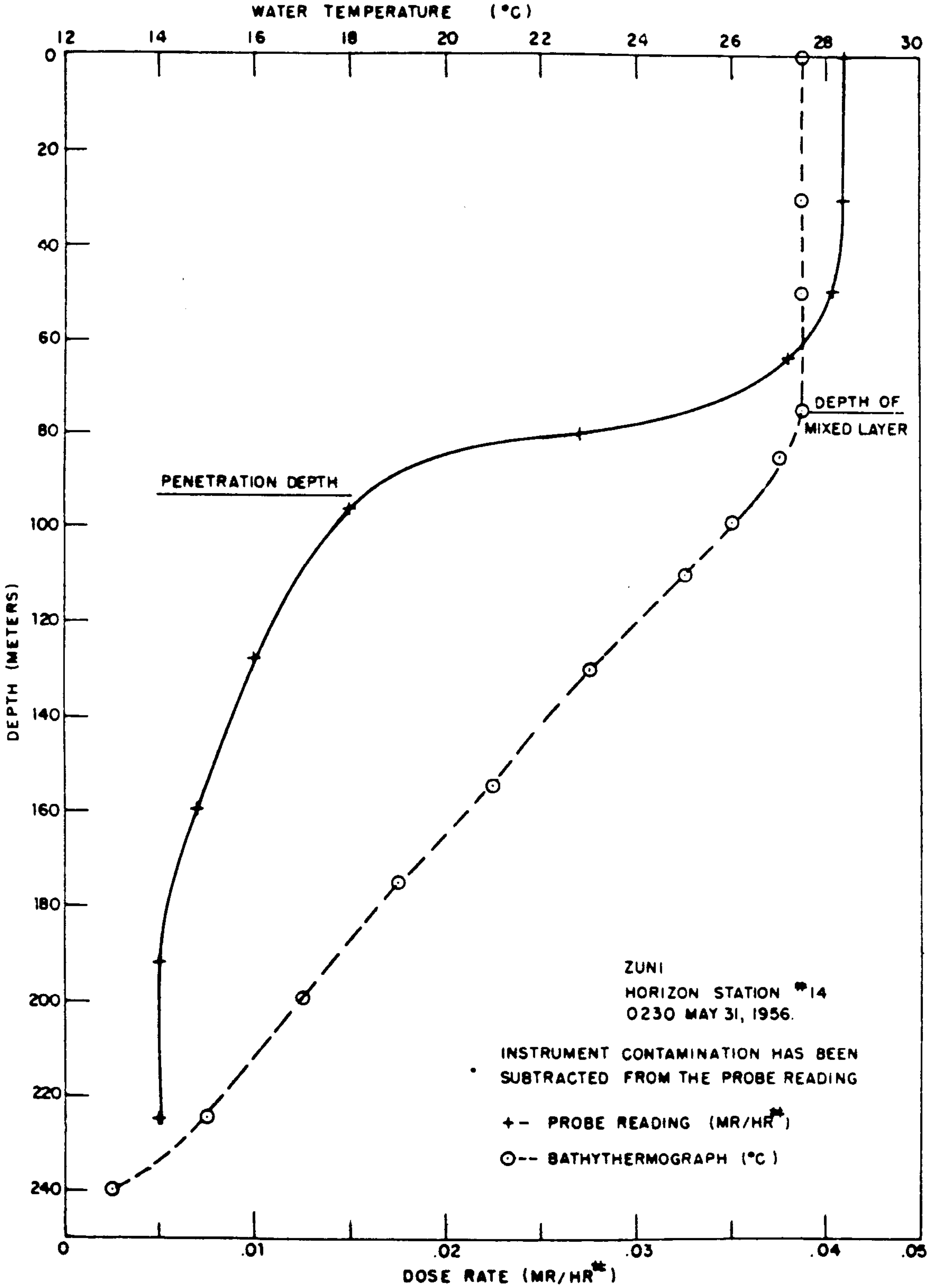

Figure 2.16 Comparison of dose rate and temperature versus depth, Shot Zuni.

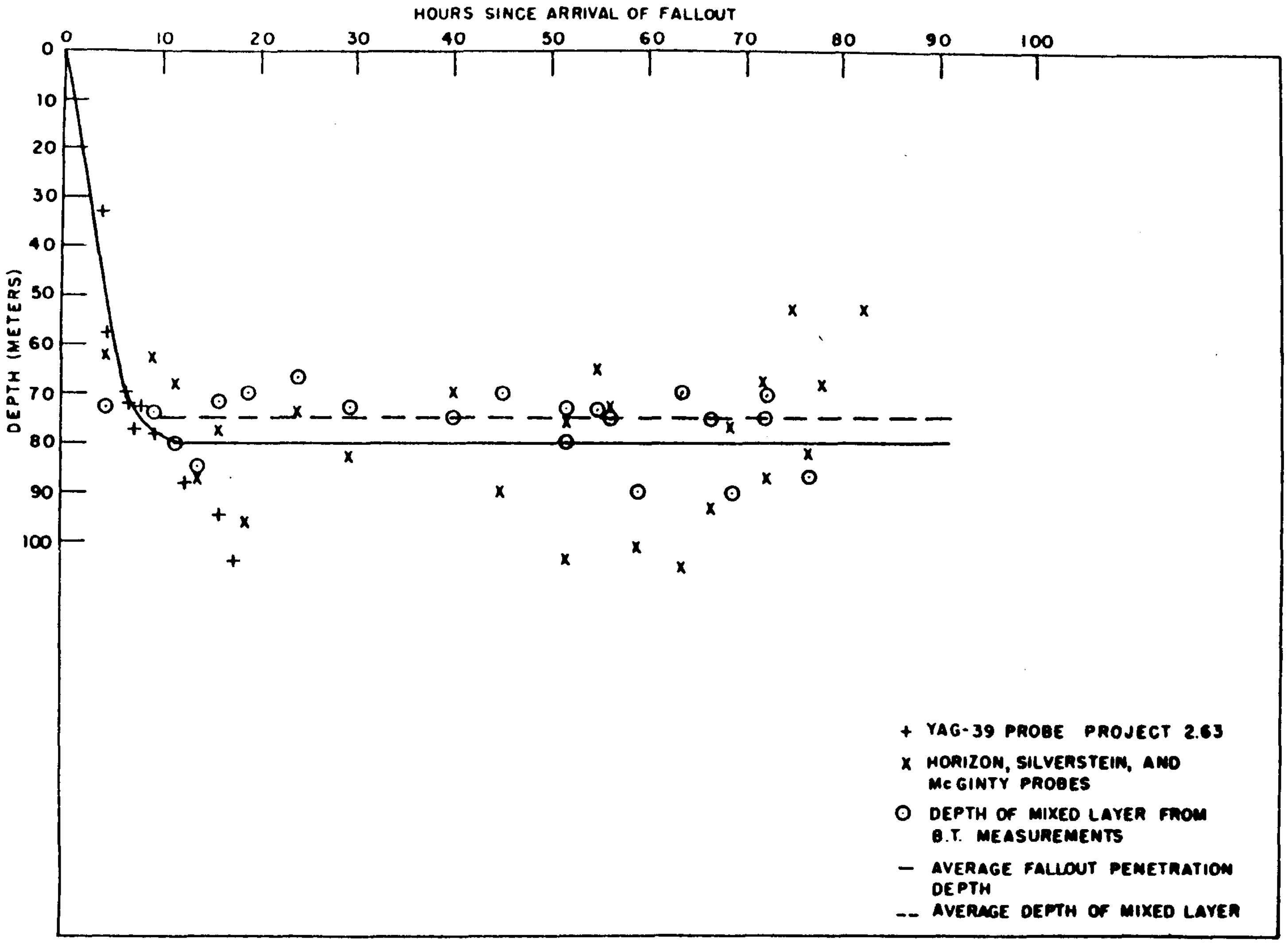

Figure 2.17 Probe measurements of fallout penetration depth, Shot Zuni.

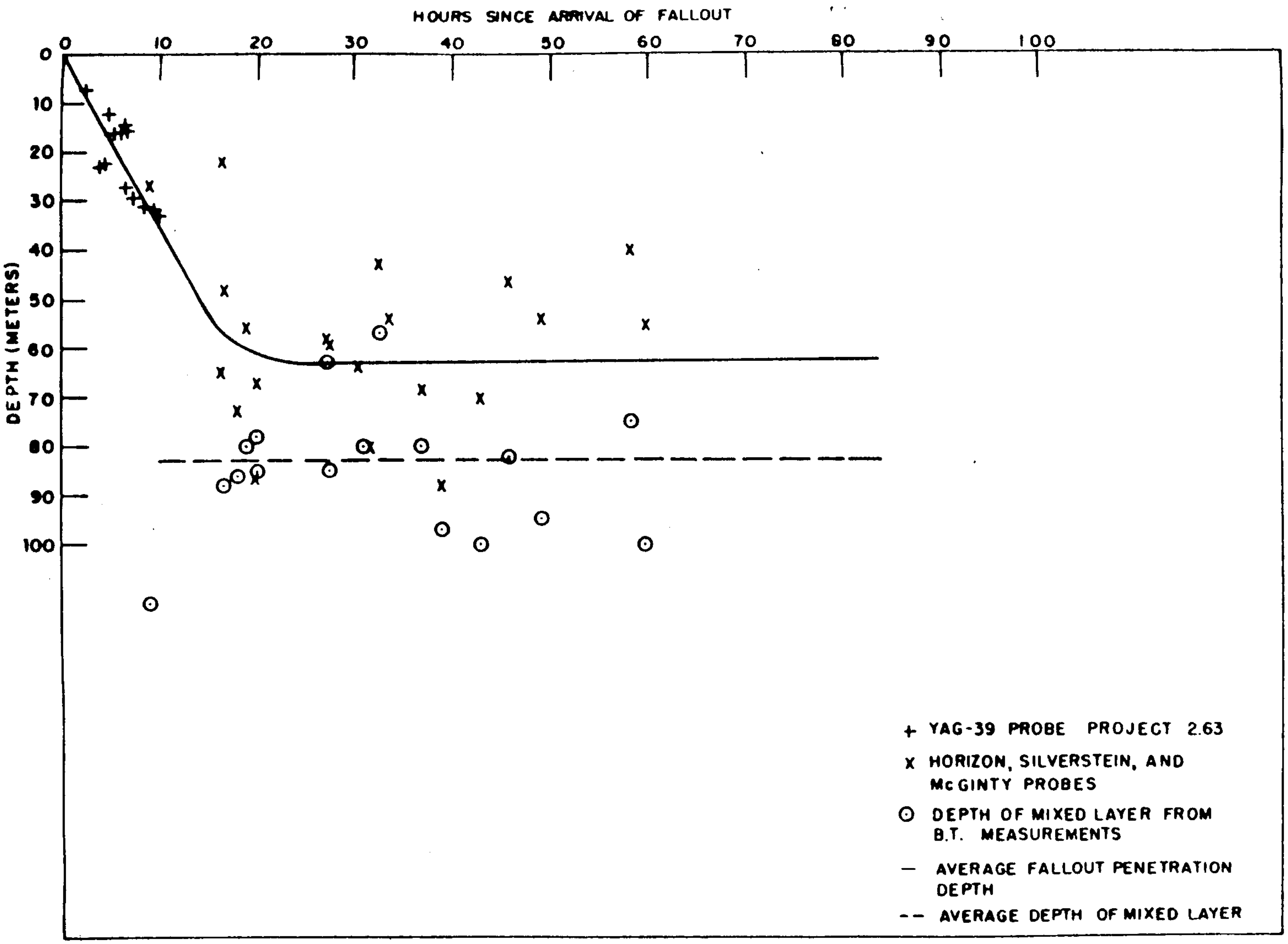

Figure 2.18 Probe measurements of fallout penetration depth, Shot Flathead.

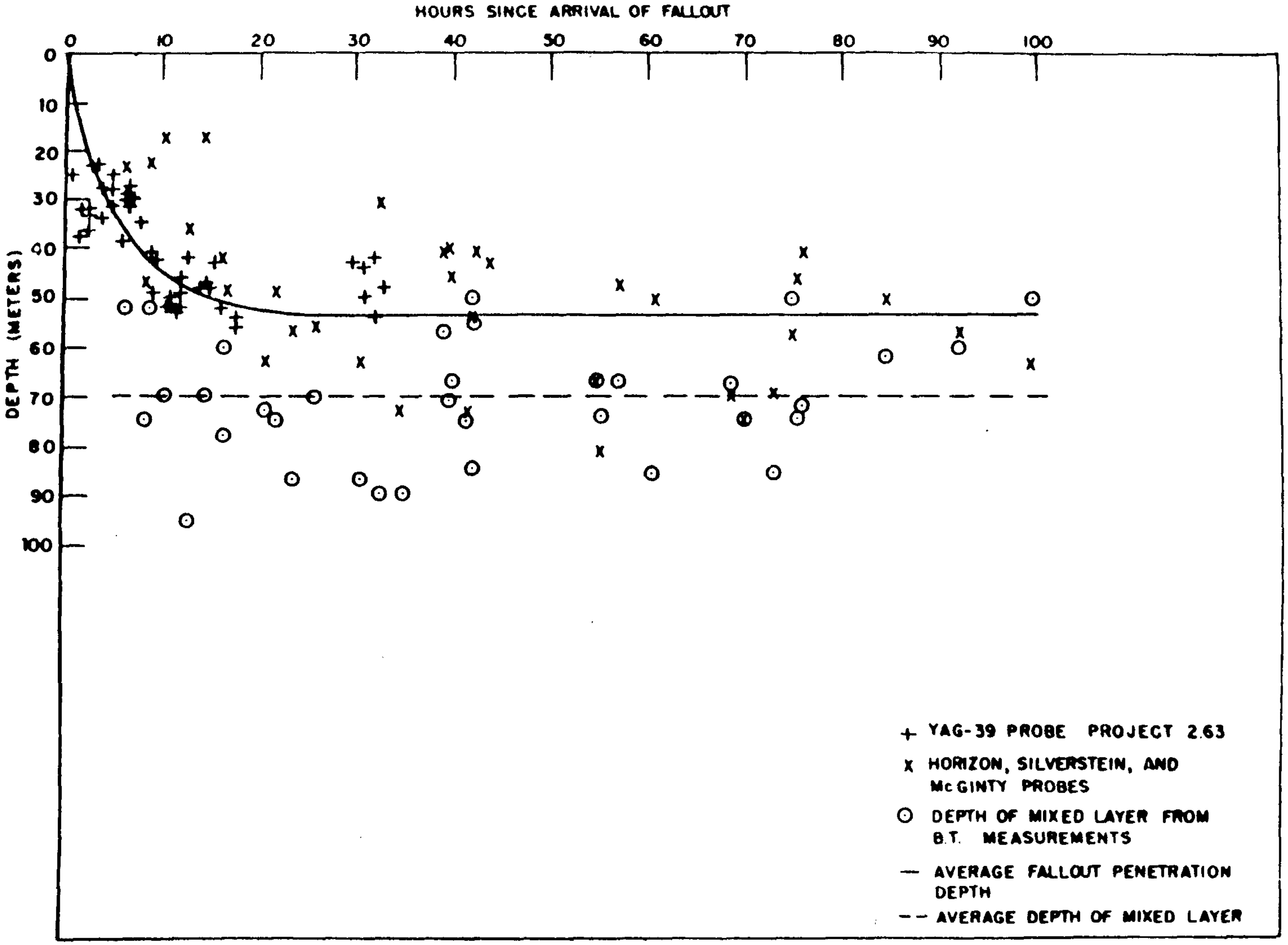

Figure 2.20 Probe measurements of fallout penetration depth, Shot Tewa.

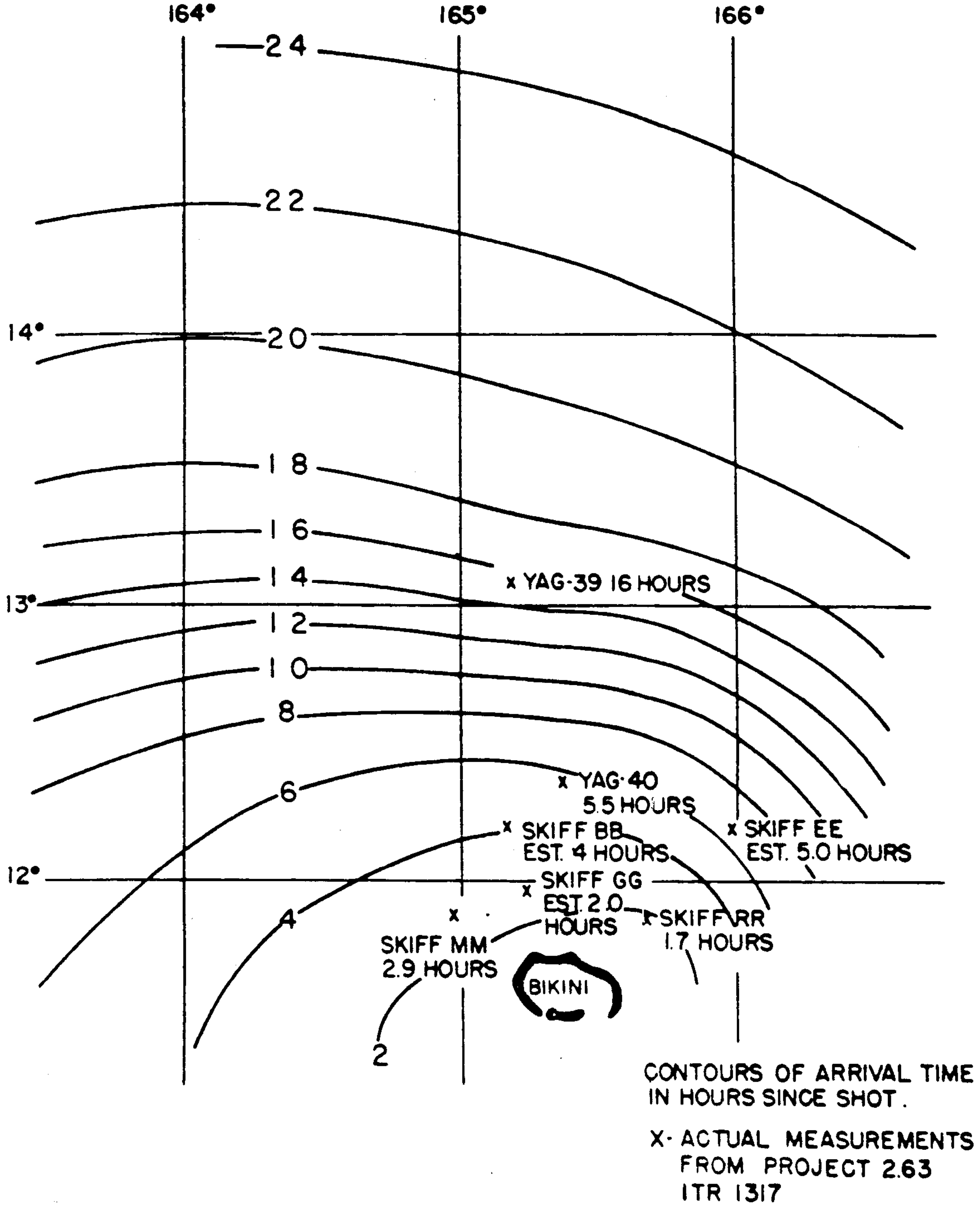

Figure 2.21 Estimated fallout time of arrival for Shot Zuni.

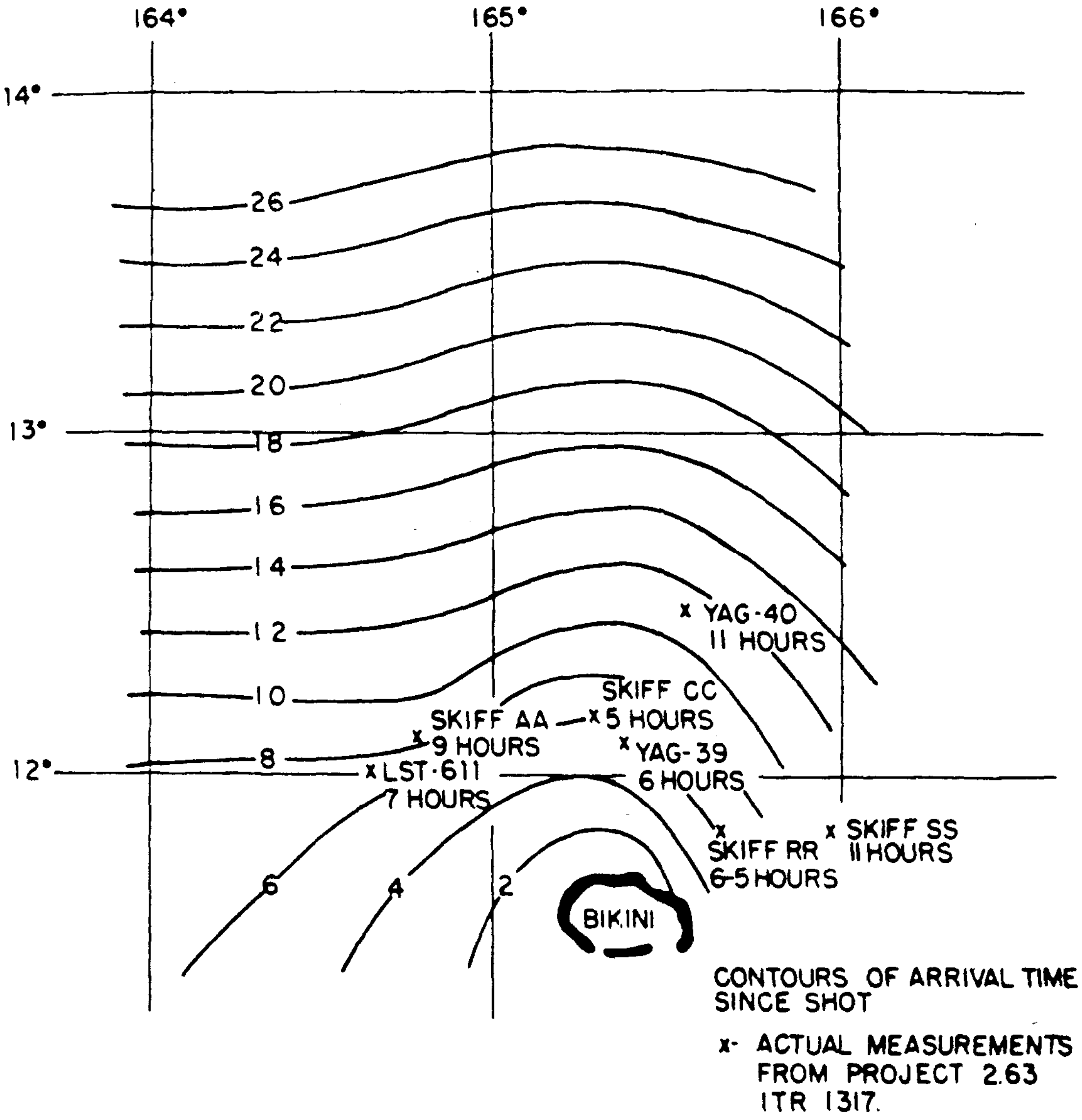

Figure 2.22 Estimated fallout time of arrival for Shot Flathead.

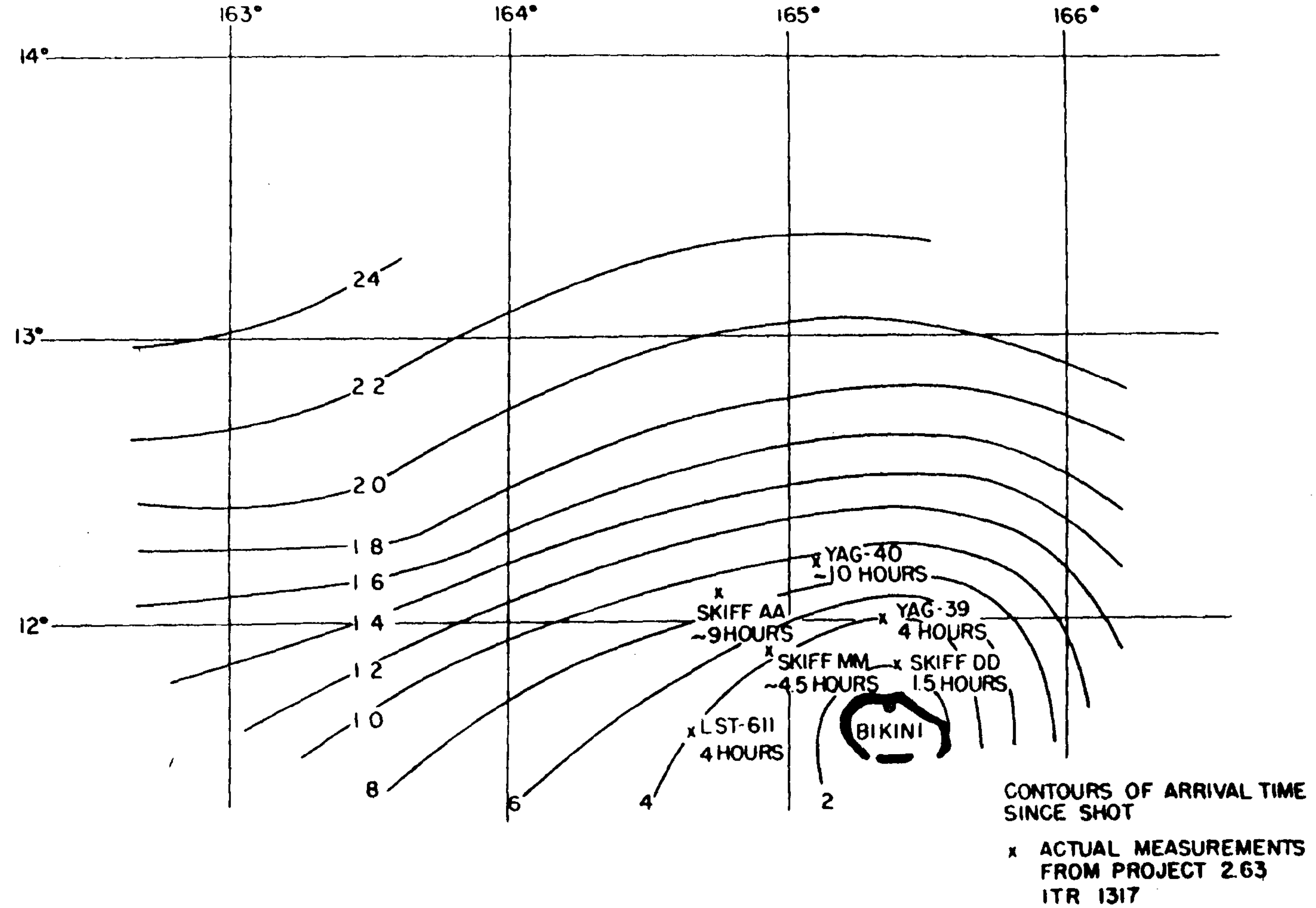

Figure 2.23 Estimated fallout time of arrival for Shot Navajo.

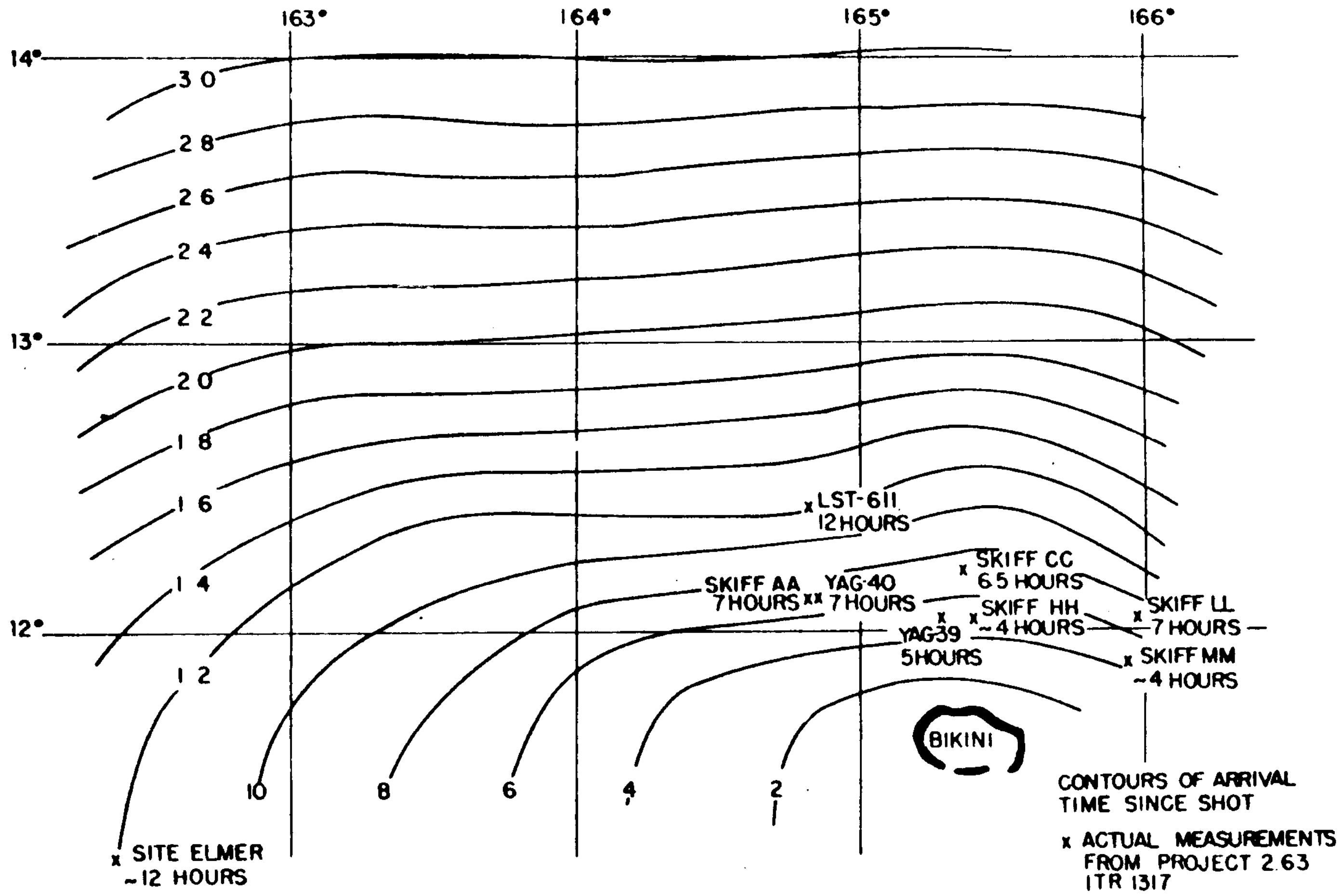

Figure 2.24 Estimated fallout time of arrival for Shot Tewa.

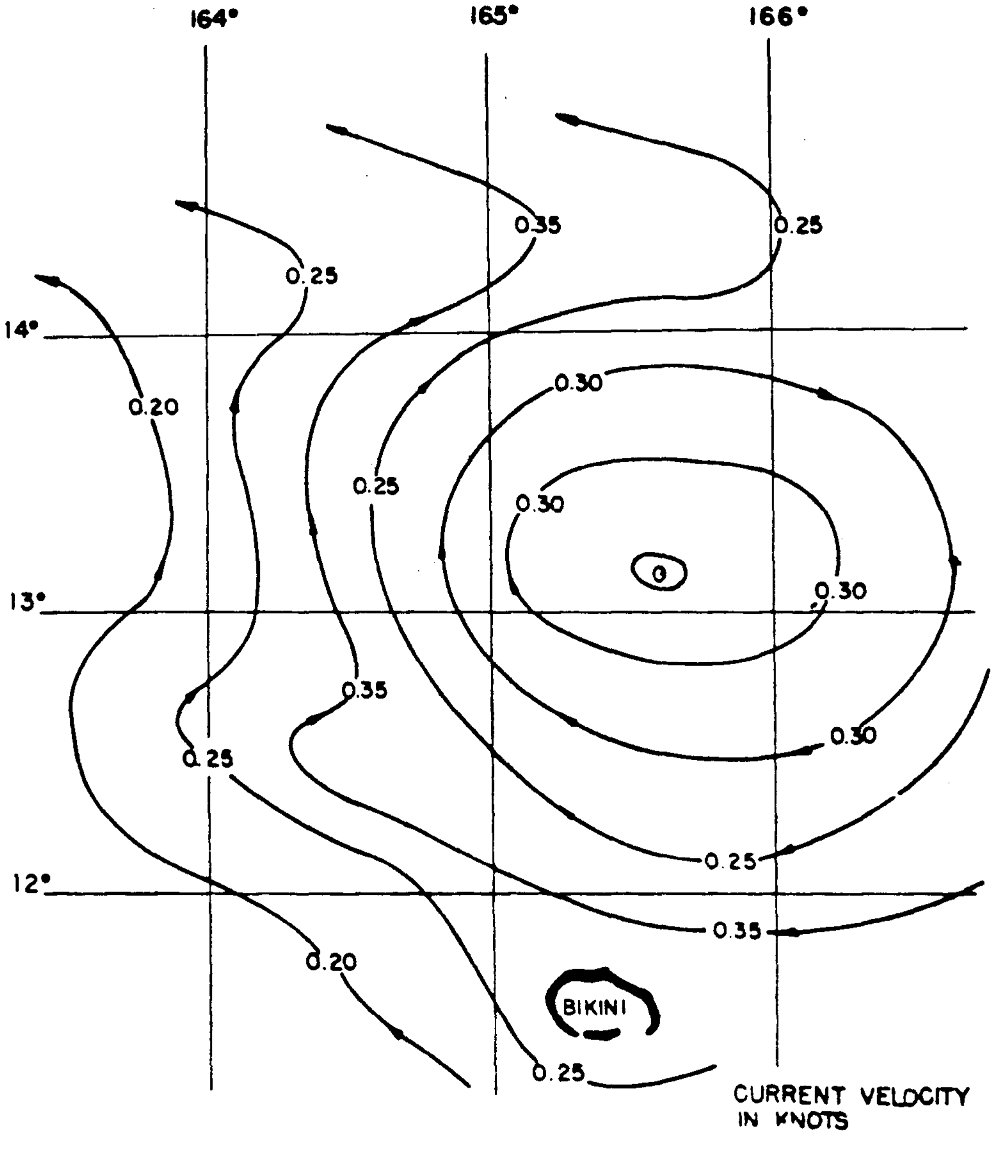

Figure 2.25 Deduced streamlines of ocean currents, Shot Zuni.

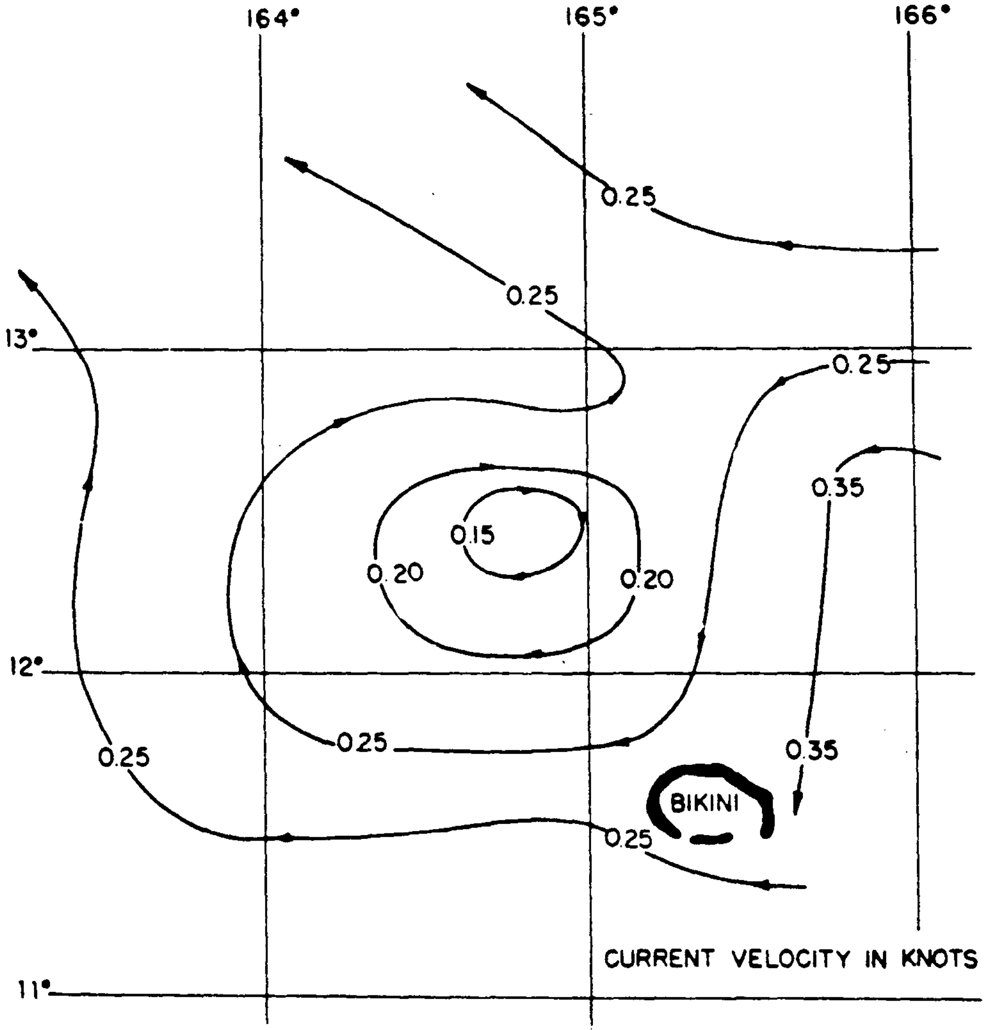

Figure 2.26 Deduced streamlines of ocean currents, Shot Flathead.

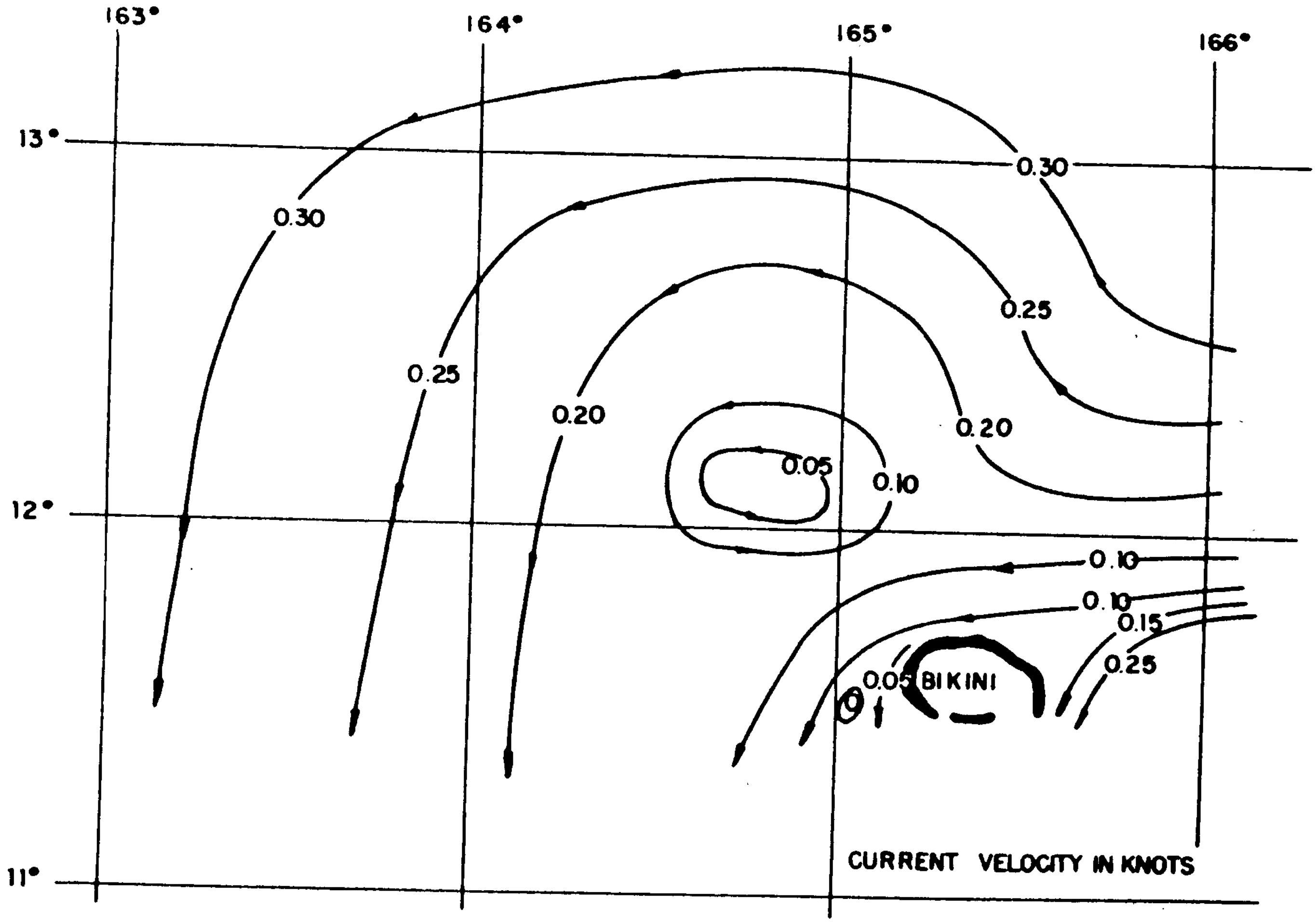

Figure 2.27 Deduced streamlines of ocean currents, Shot Navajo.

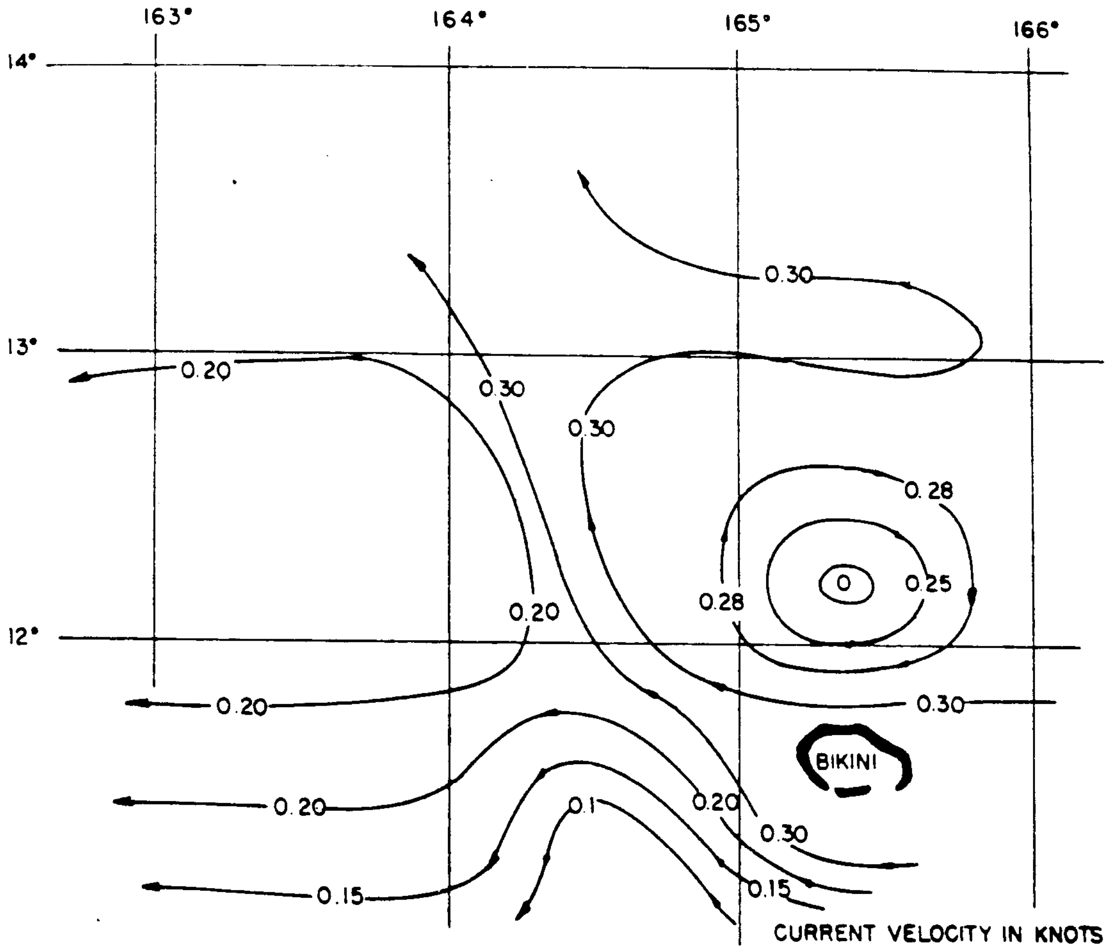

Figure 2.28 Deduced streamlines of ocean currents, Shot Tewa.

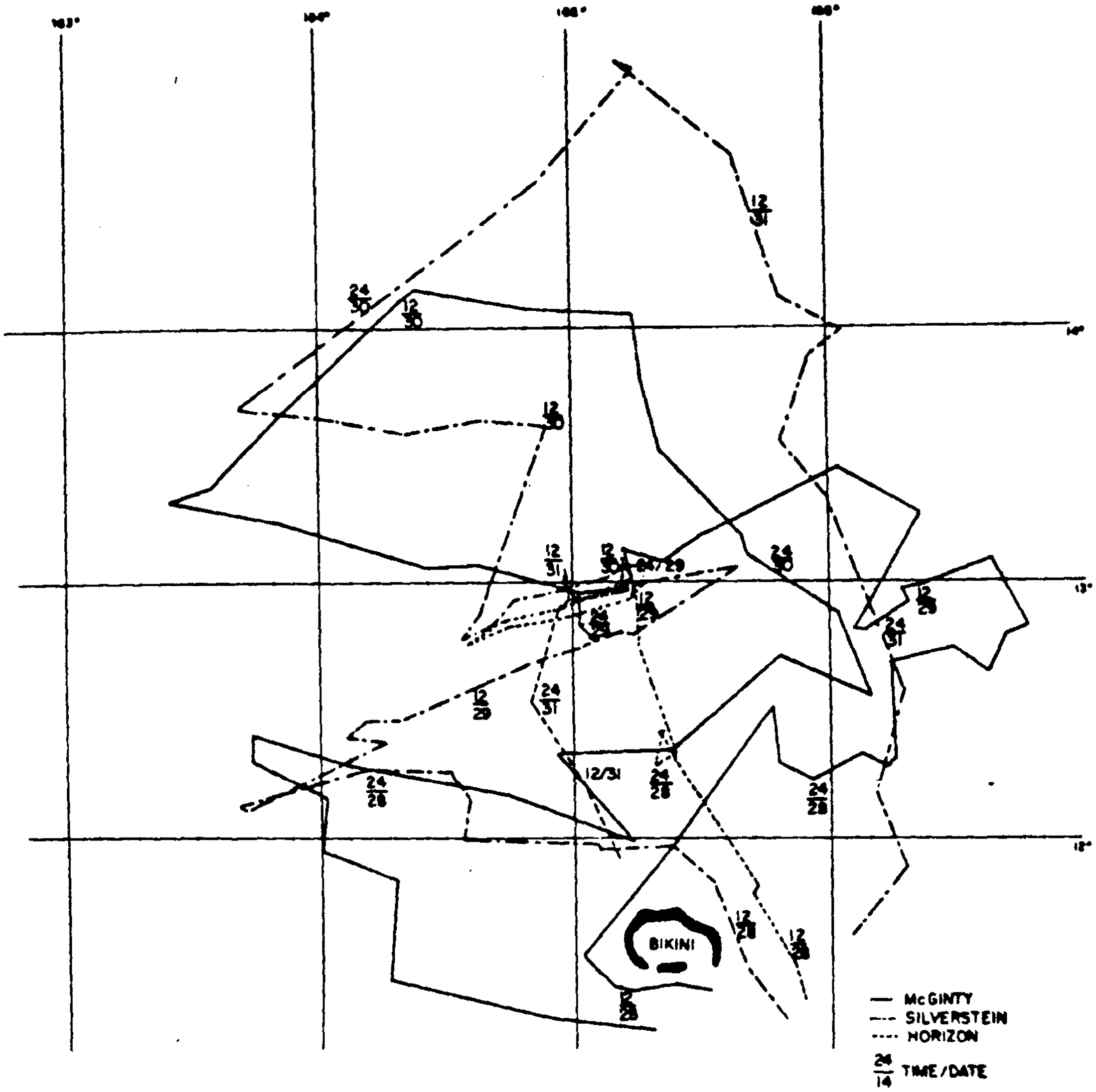

Figure 2.29 Corrected tracks of survey ships, Shot Zuni.

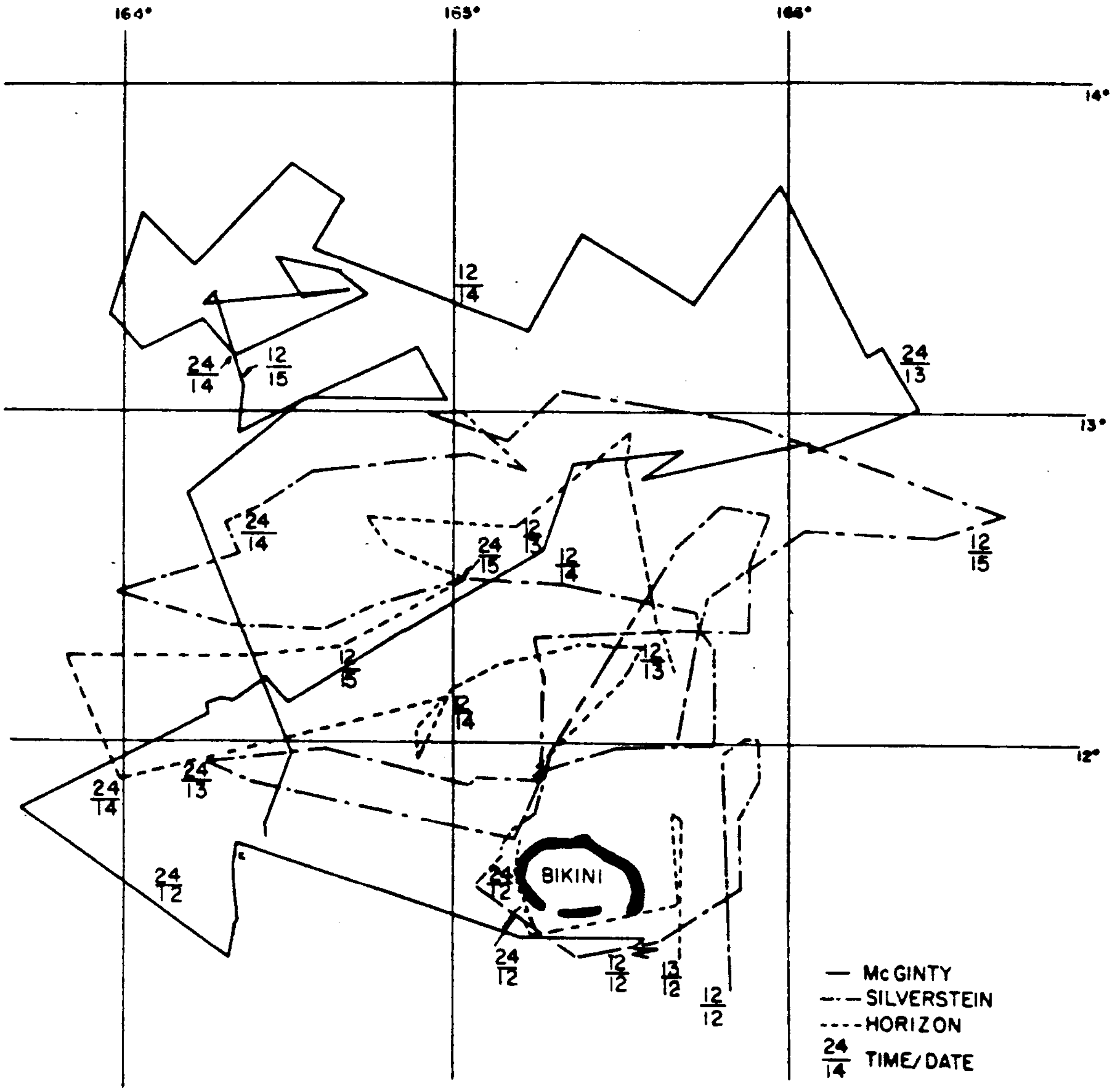

Figure 2.30 Corrected tracks of survey ships, Shot Flathead.

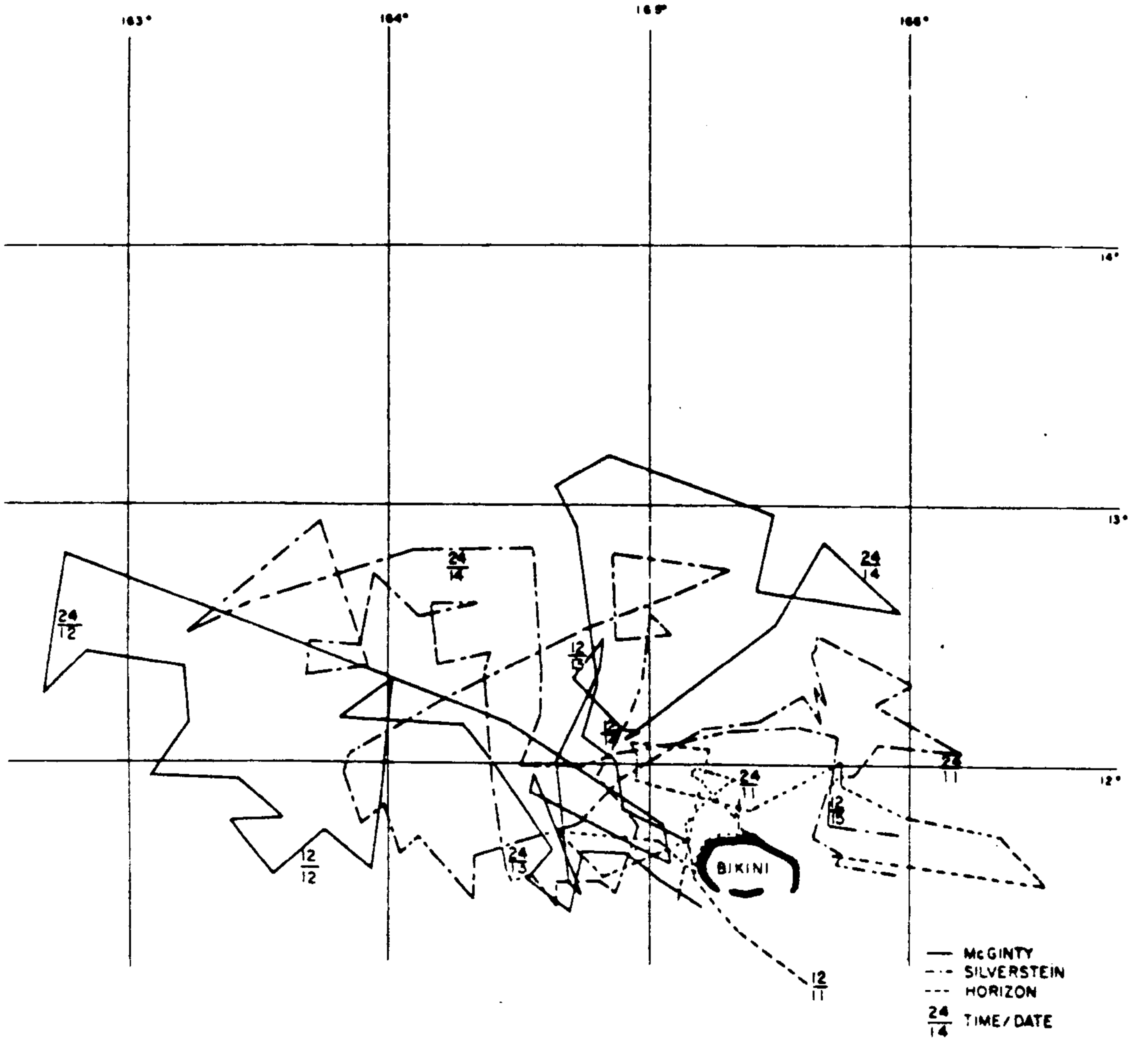

Figure 2.31 Corrected tracks of survey ships, Shot Navajo.

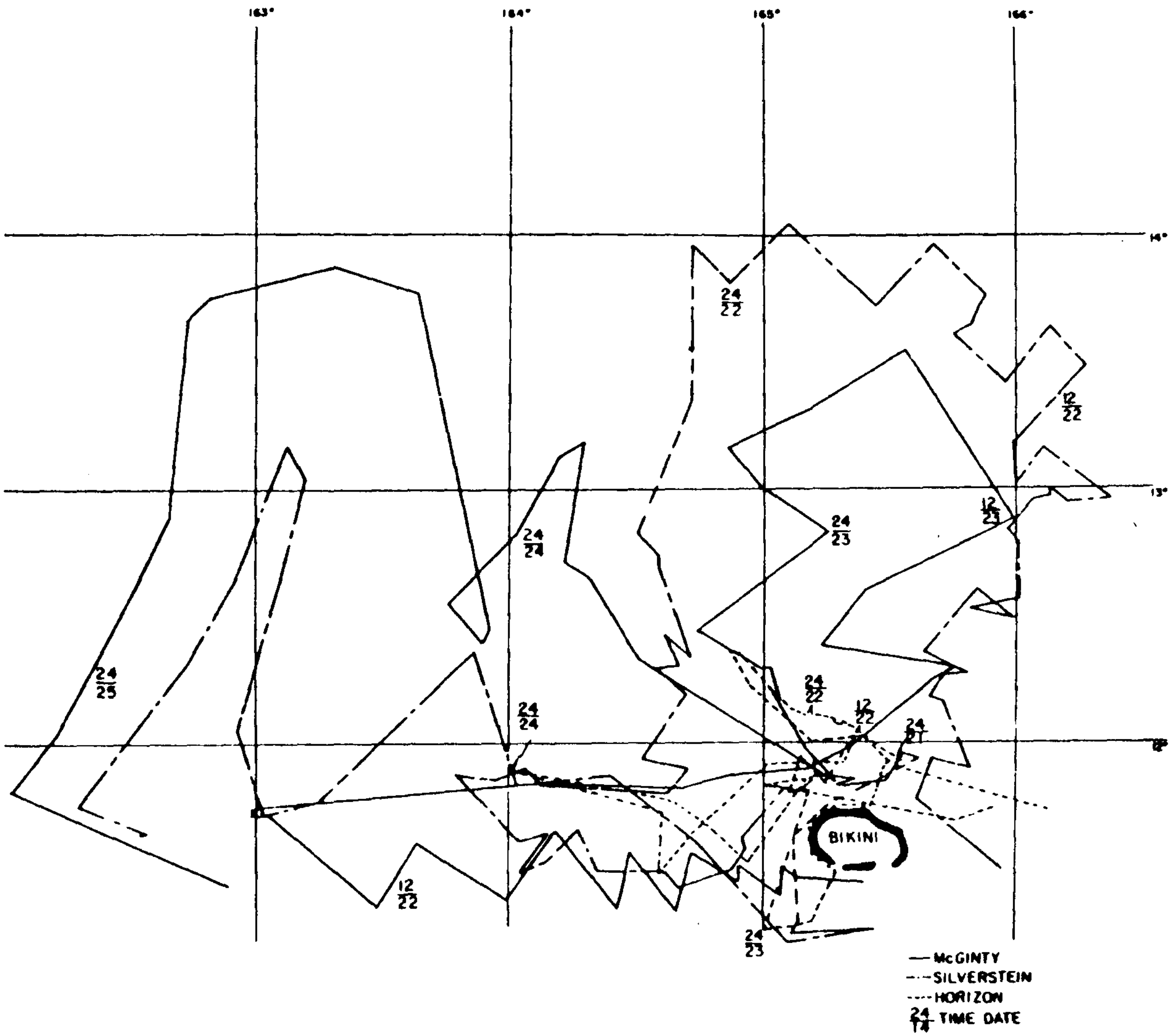

Figure 2.32 Corrected tracks of survey ships, Shot Tewa.

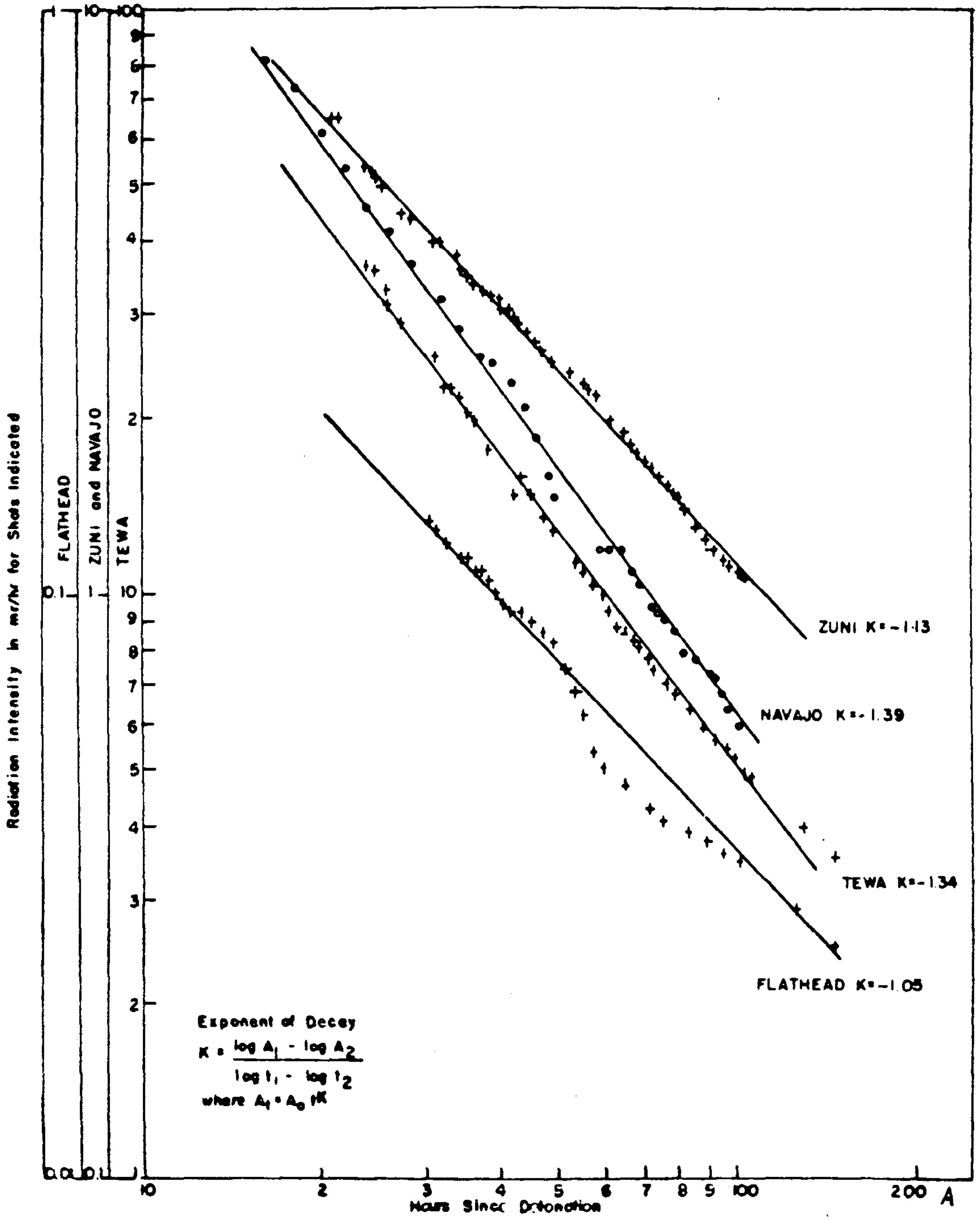

Figure 2.33 Exponent of decay as measured in decay tank of M/V Horizon.

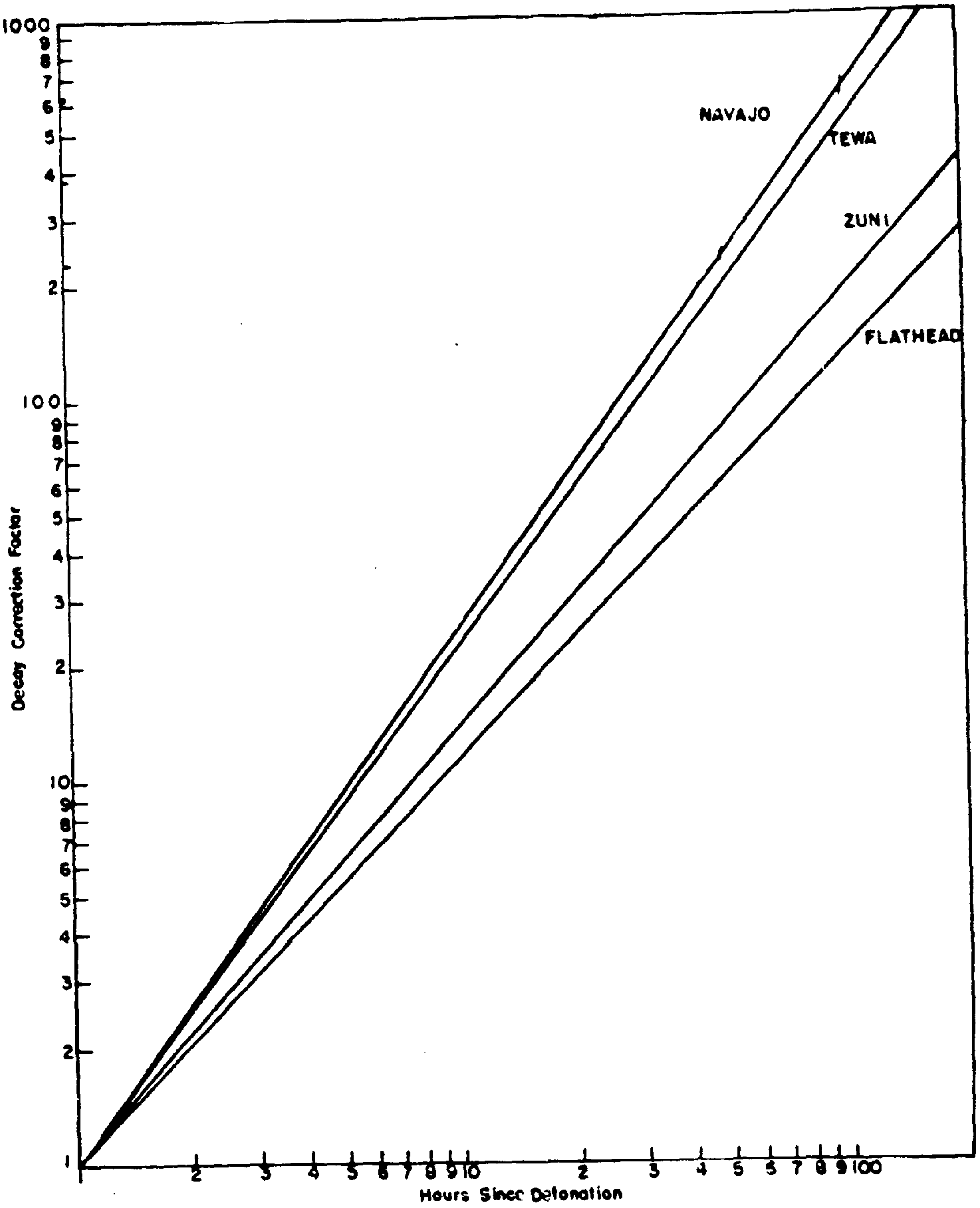

Figure 2.34 Decay correction factor for correcting dose rate values from time of measurement to H+1 hour.

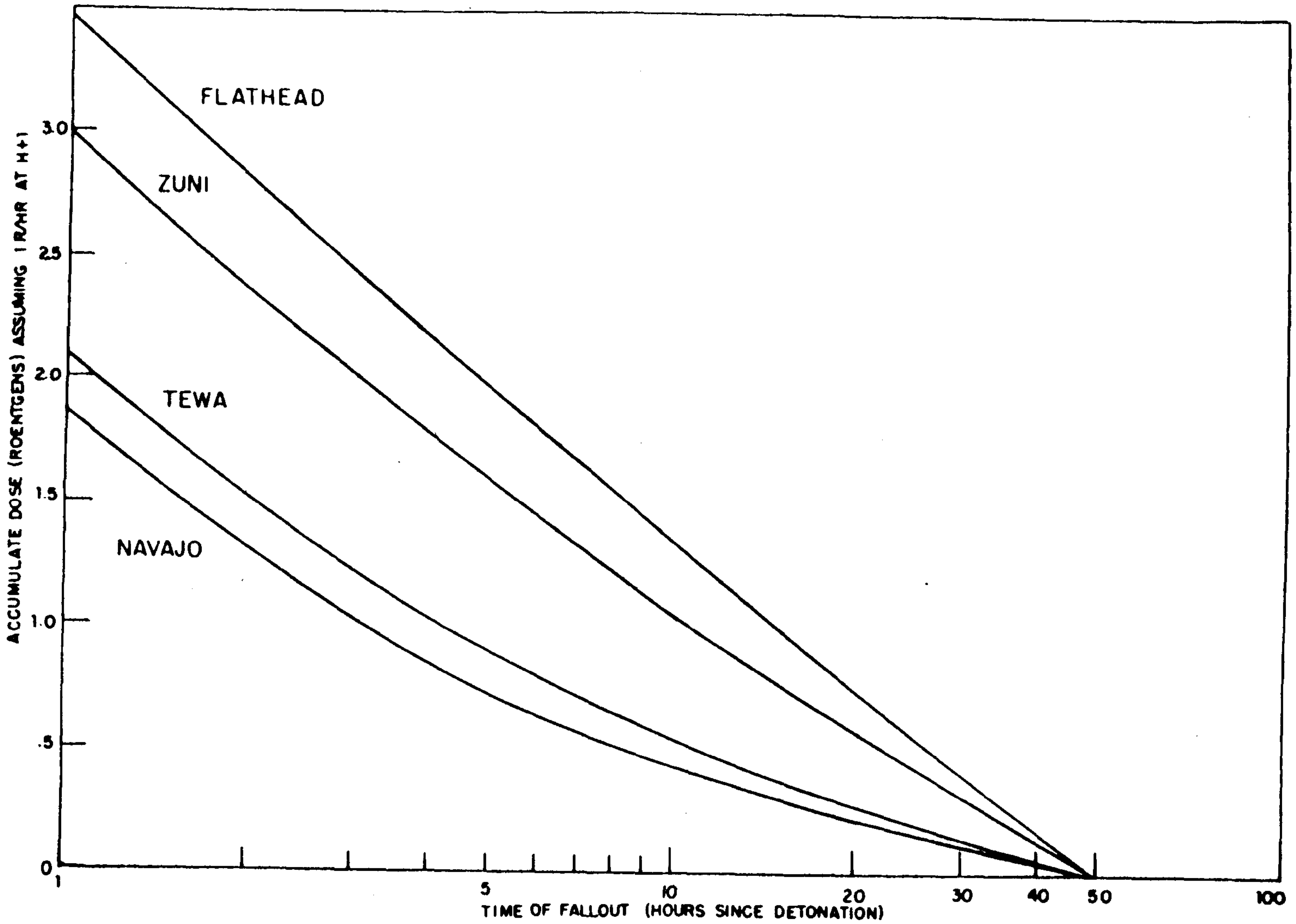

Figure 2.35 Factor for determining accumulated dose (time of arrival to H+50) from dose rate at H+1.

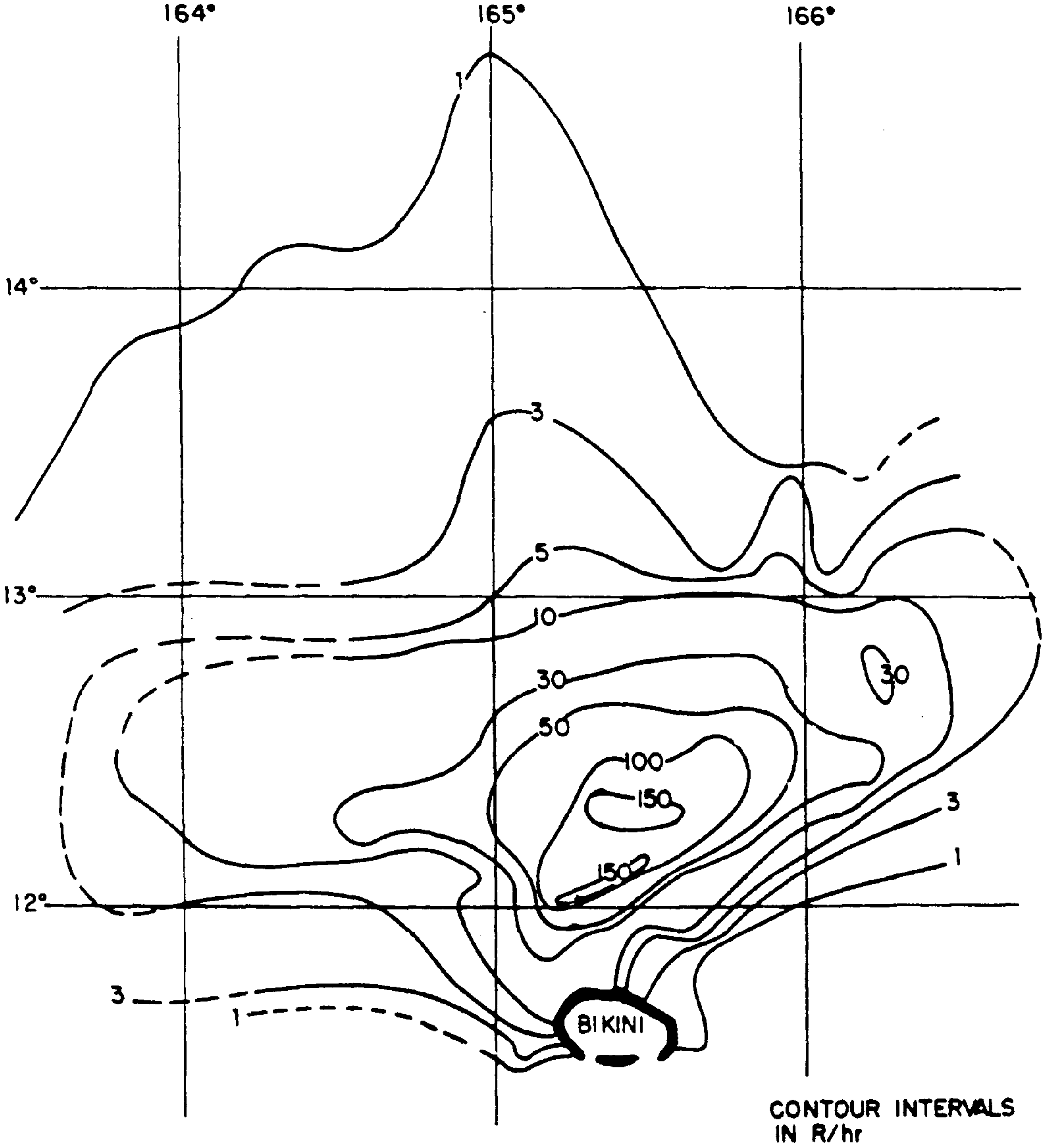

Figure 2.36 H+1 isodose rate contours for Shot Zuni.

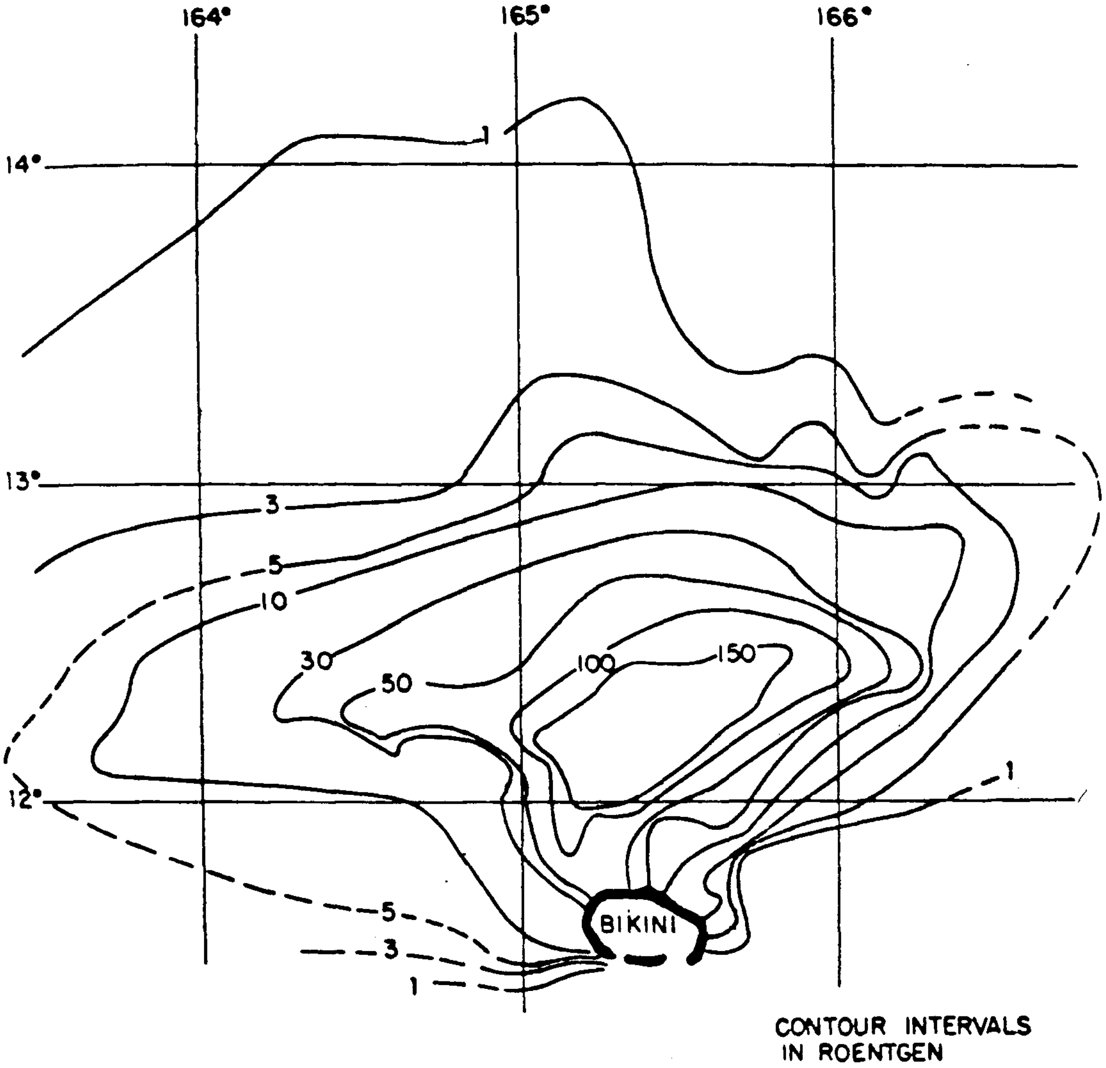

Figure 2.37 Accumulated dose (time of arrival to H+50), Shot Zuni.

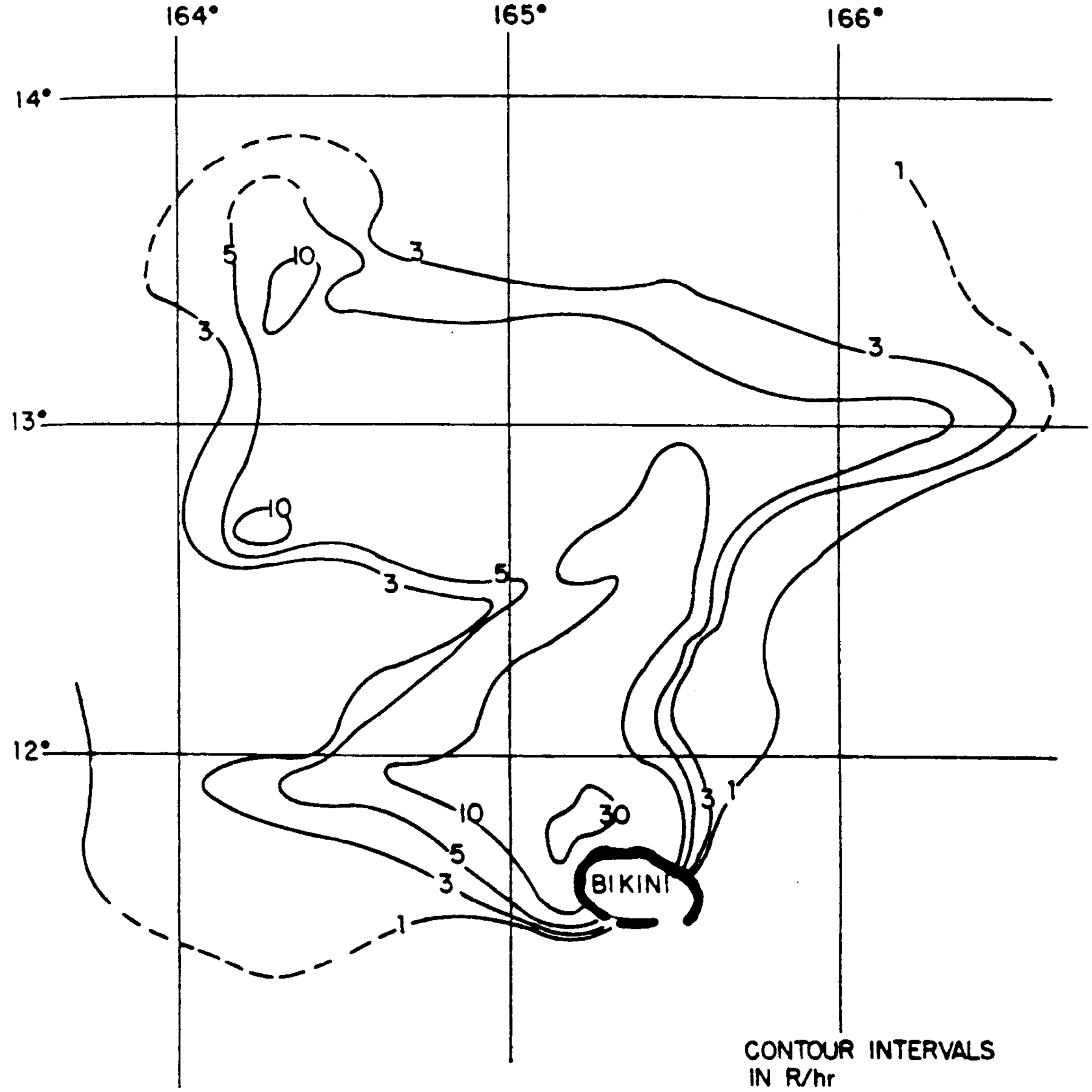

Figure 2.38 H+1 isodose rate contours for Shot Flathead.

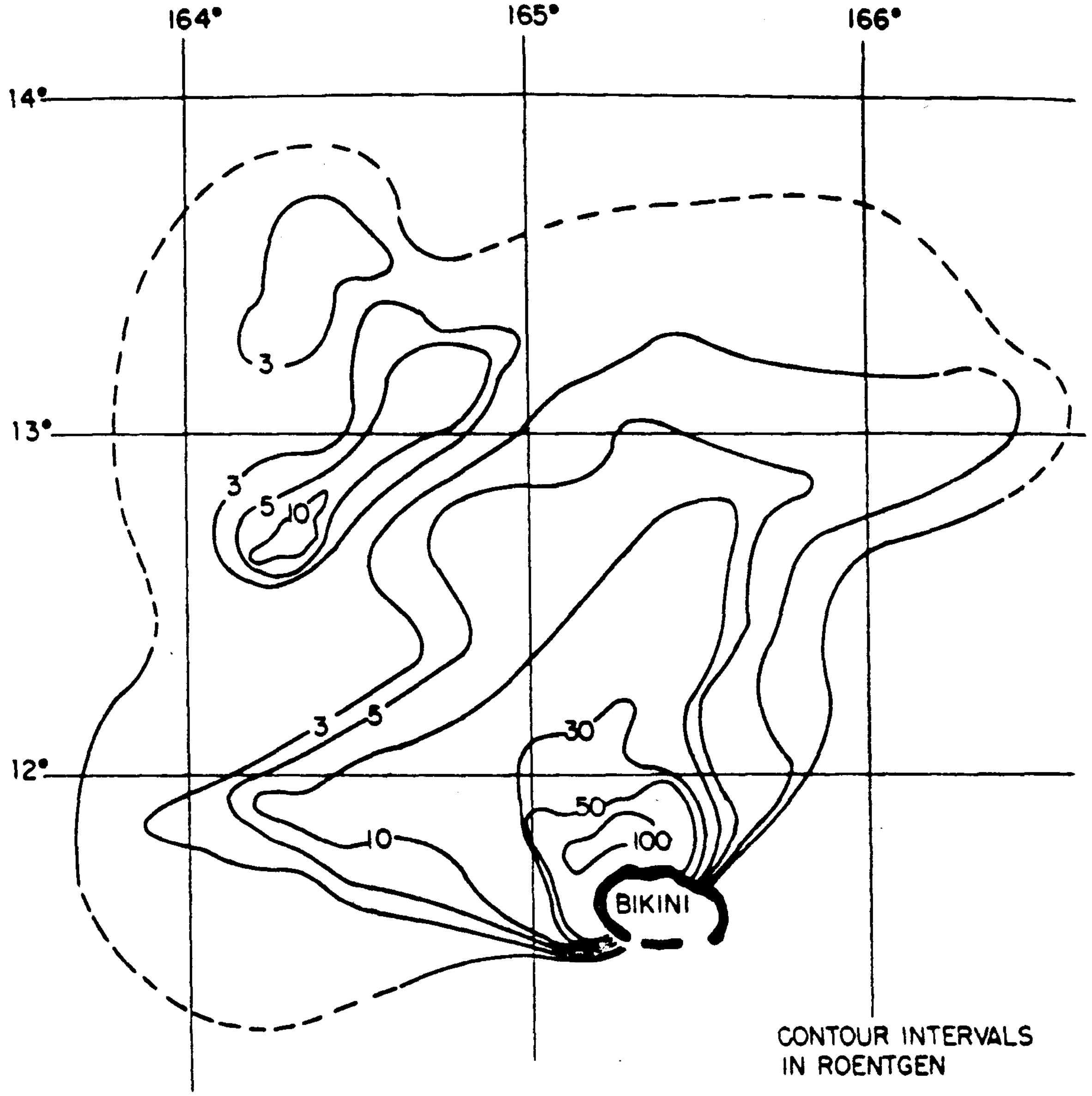

Figure 2.39 Accumulated dose (time of arrival to H+50), Shot Flathead.

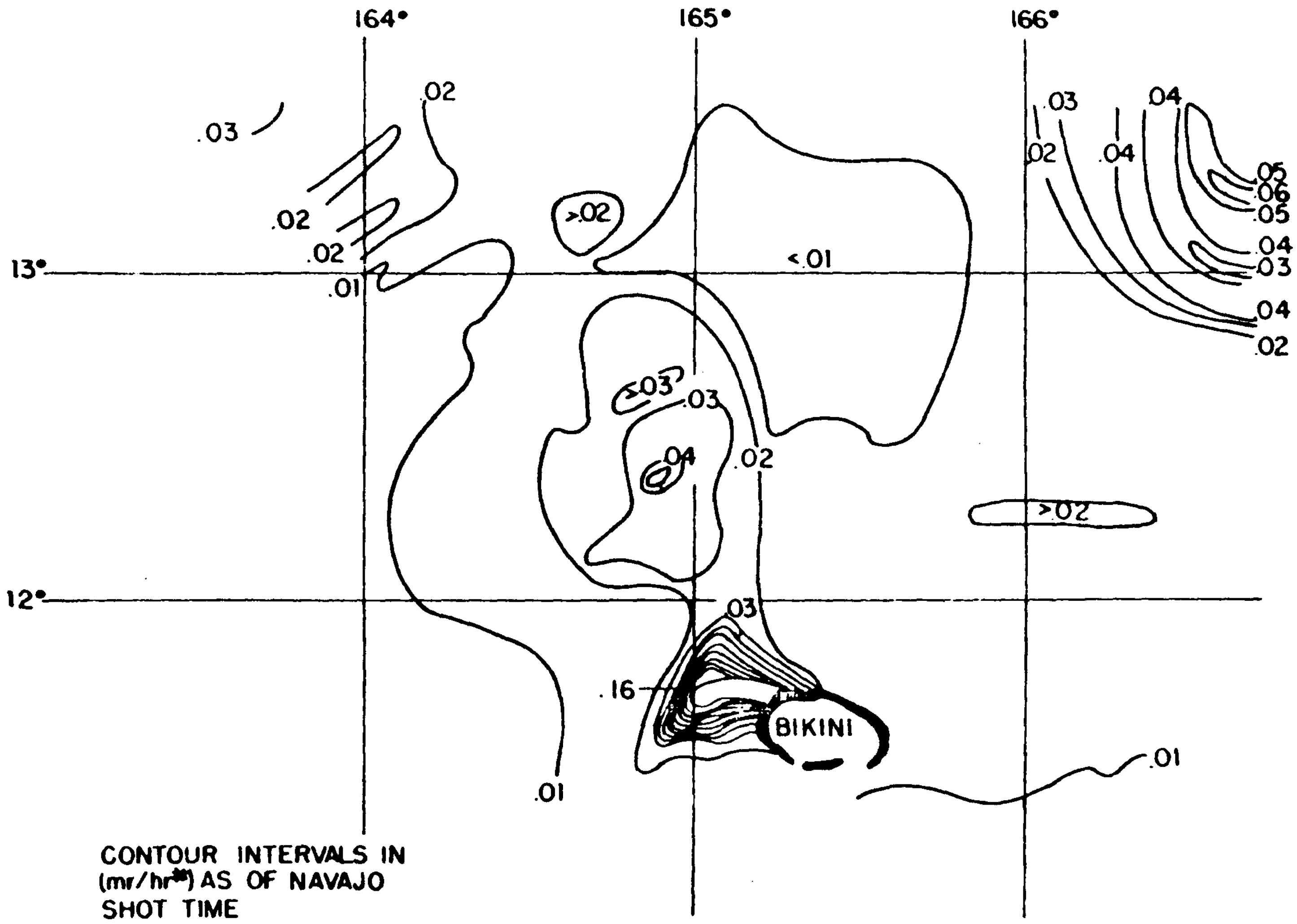

Figure 2.40 Oceanic radioactivity background at Navajo shot time.

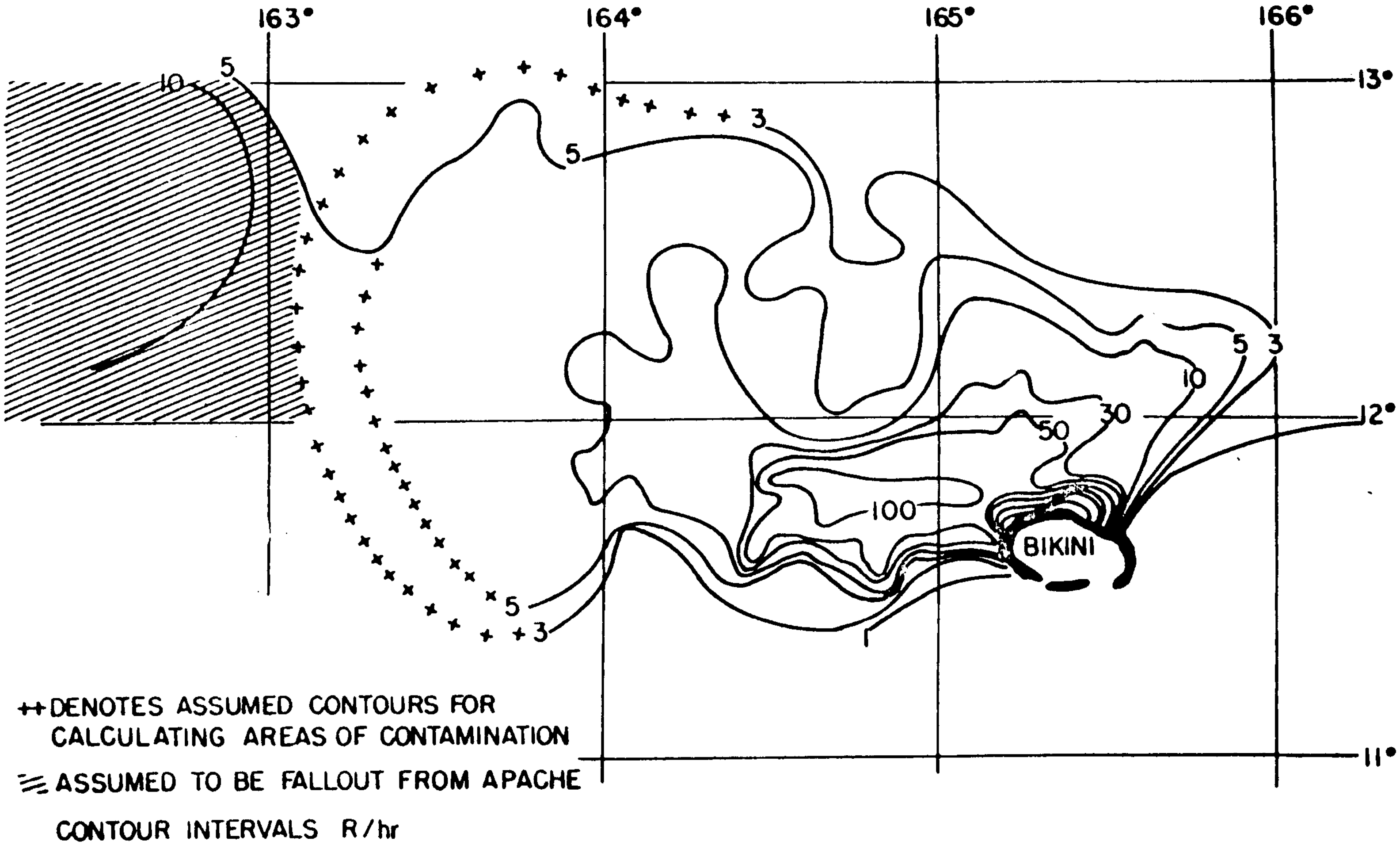

Figure 2.41 H+1 isodose rate contours for Shot Navajo.

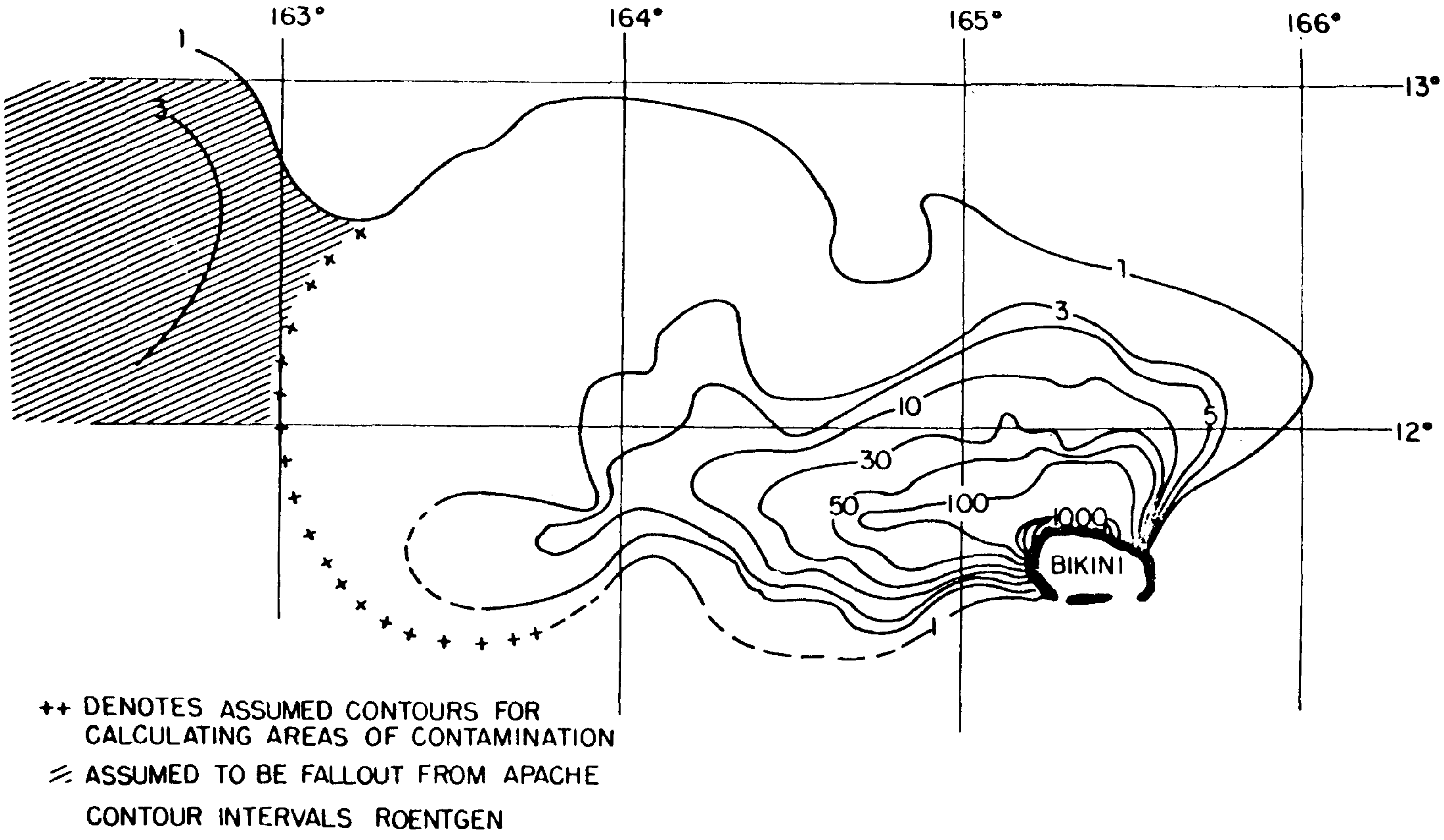

Figure 2.42 Accumulated dose (time of arrival to H+50), Shot Navajo.

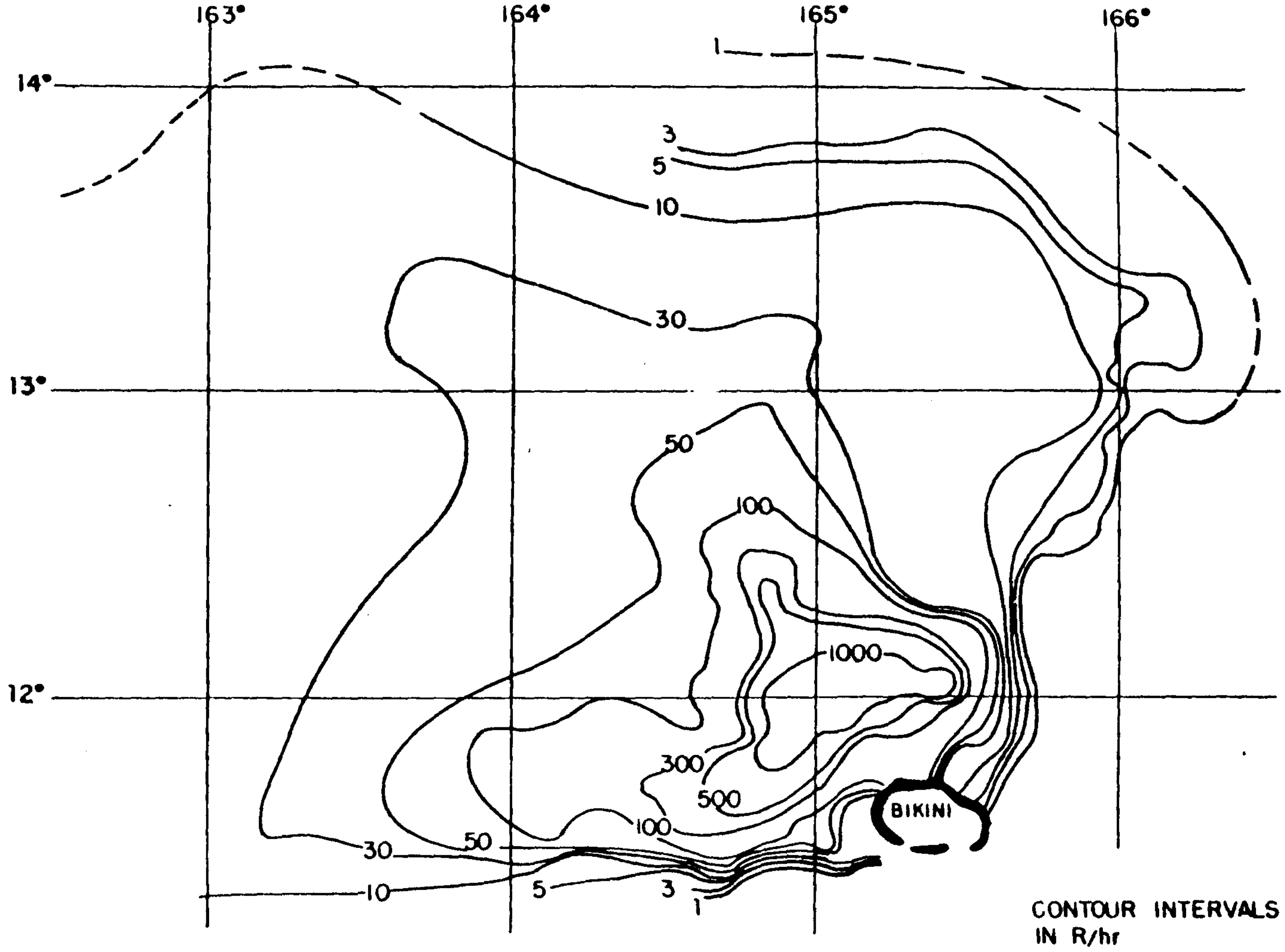

Figure 2.43 H+1 isodose rate contours for Shot Tewa.

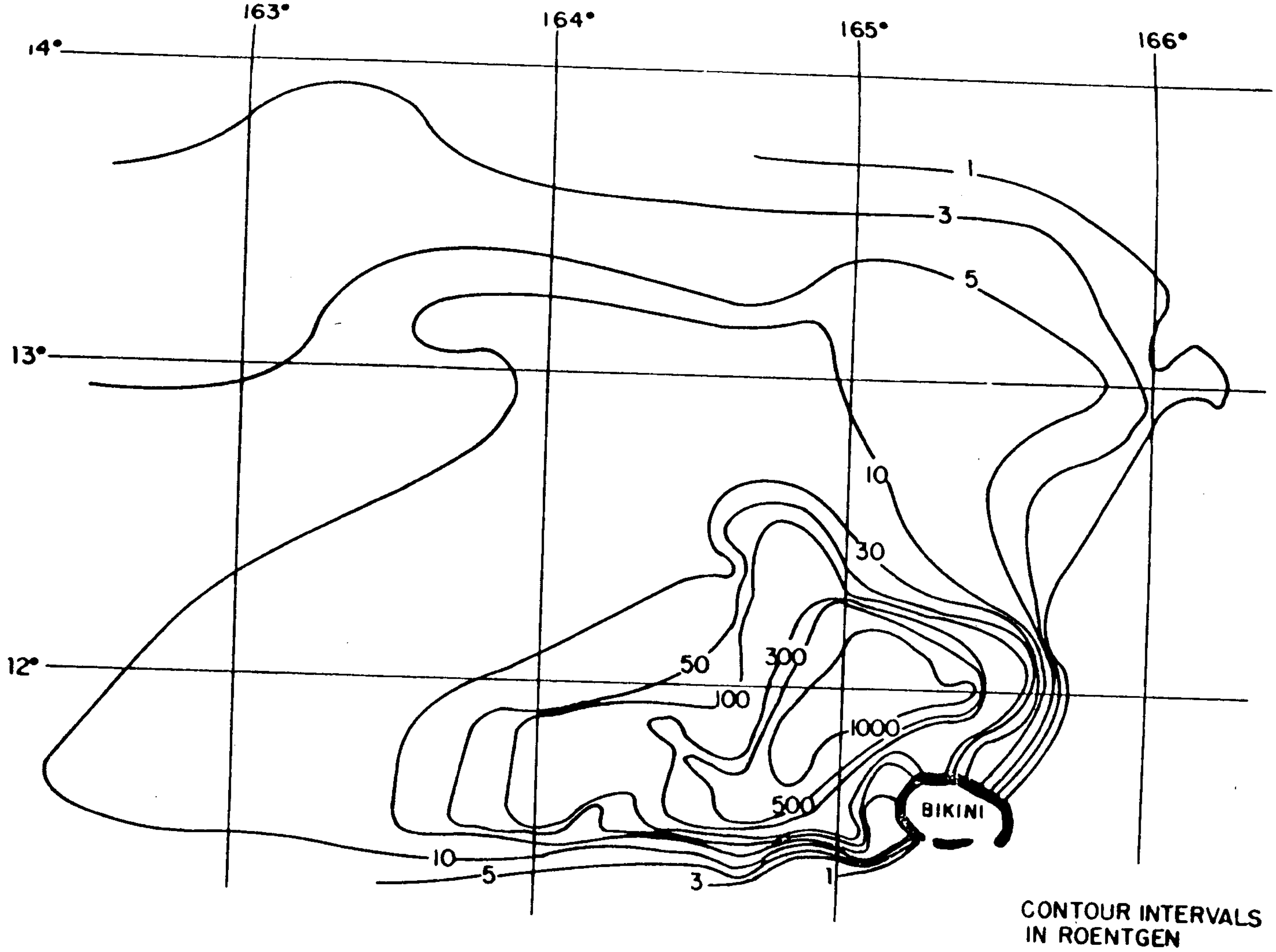

Figure 2.44 Accumulated dose (time of arrival to H+50), Shot Tewa.

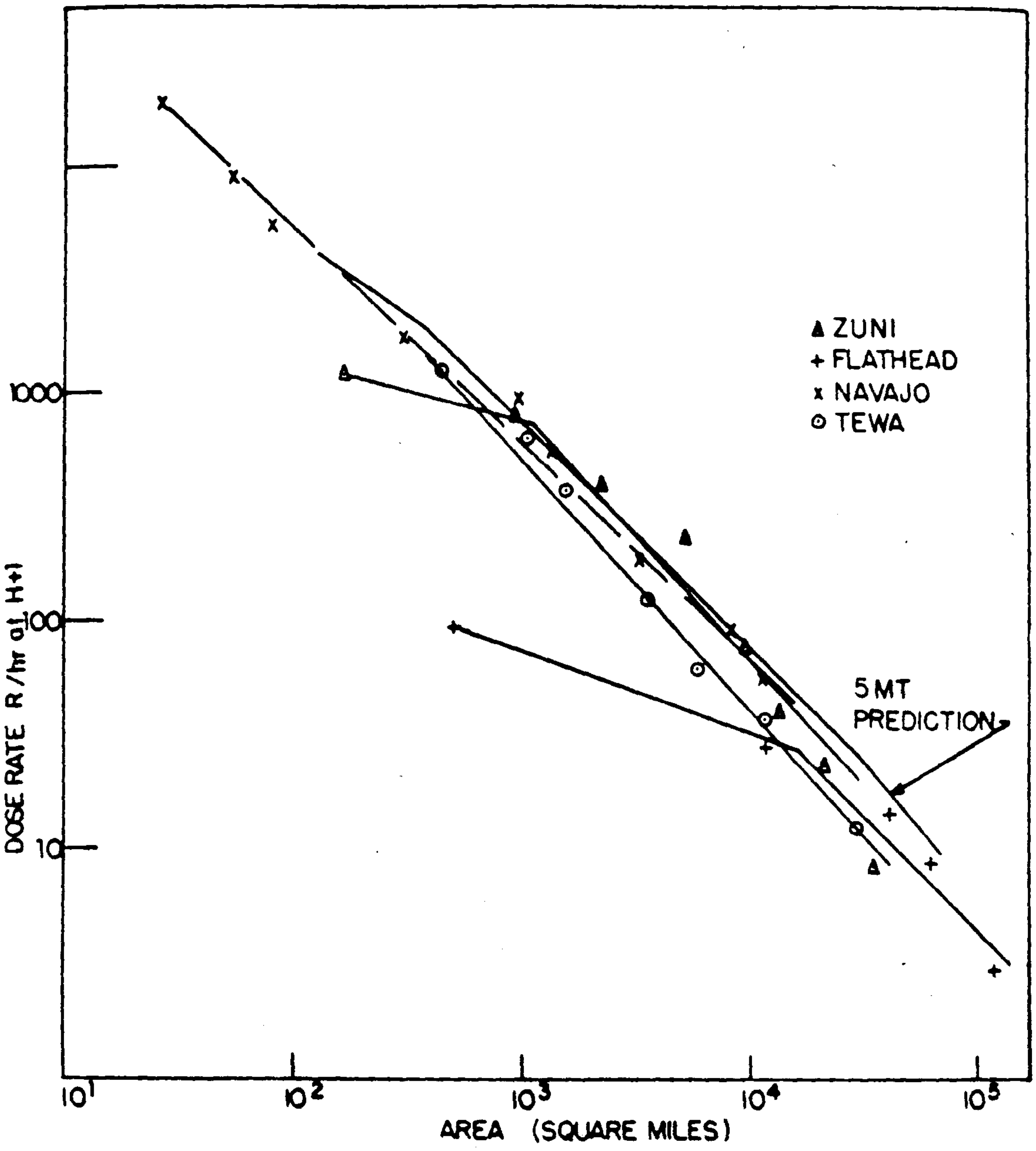

Figure 2.45 Areas of dose rate contours for Redwing shots normalized to 5 Mt 100 percent fission.

Chapter 3
LAGOON RADIOACTIVITY SURVEY

3.1 OBJECTIVES

The Bikini Lagoon radioactivity survey was a continuation of the lagoon current survey. It was to determine the pattern of fallout and the movement of radioactive water in all sections of the lagoon. Also, the fallout pattern in the lagoon was to be tied in with the oceanographic fallout survey when possible.

3.2 BACKGROUND

During Operation Castle, radioactive water welled up around the ships at anchor in Bikini Lagoon. The lagoon survey was to keep track of the movement of radioactivity to prevent this from happening again. Previous studies indicated that radiation might be used to study the movement of water throughout the lagoon. The findings on the use of radioactivity for current direction and velocity measurements was discussed in Reference 6.

3.3 THEORY

The lagoon would tend to hold radiation within its system of circulation. Clean water would be entering over the windward reefs continuously to dilute the radiation, but the influx of clean water would be small in comparison to the total volume of contaminated water in the lagoon. The general circulation of the lagoon would tend to concentrate the radiation in the lower layers. The upper layer would lose its radioactive water rather quickly across the leeward reefs, whereas the radiation in the lower layers would be held there and upwelled at the windward end of the lagoon. In addition, due to mixing, part of the radioactivity in the lower levels would be brought into the upper layers.

3.4 OPERATIONS

The procedure for gathering this information was new to the personnel on the LCU. As a result, changes in technique were made as the survey progressed. At first the probe was only in the water when a vertical cast was made. There was, at this early time, no arrangement for towing the probe just under the surface, as was being done in the ocean survey. Later, a method for towing the probe was developed, and it was towed at the surface. Vertical casts were also made at various intervals along the track of the vessel.

At first, the operation was concentrated near the site of the detonation, rather than over the entire fallout pattern on the first few days. Later, the procedure was changed to cover as much of the fallout boundaries as possible during the first day, leaving the most radioactive water until the following day or later, as seemed practical at the time. This seemed most advisable, since the contamination of the LCU reached a point where several hours had to be spent in decontamination. This time could have better been spent in gathering more data on shot day.

The final method for collecting the data was to tow the probe just under the surface of the water. At various times the vessel was stopped and vertical casts taken. To avoid internal contamination of the instrument, the low-level head was not taken out of the probe and replaced by the high-level head when the radioactivity became too high (150 mr/hr). Instead, the readings of radiation were taken on a hand instrument in the instrument trailer at the time the probe was in highly radioactive water. The ship was only allowed to the edge of the highly radioactive water, then turned out away from this water. By the use of this method, the ship remained fairly free of contamination. Vertical casts were made just outside the highly radioactive water along its edge.

Water samples were taken at various intervals for later determination of the radioactivity. These were taken at the surface and at various depths.

3.5 INSTRUMENTATION

The surveys were carried out aboard an LCU. An underwater radiation detector (probe) was used to survey the radioactivity in the lagoon. This instrument was discussed in Chapter 2. No recorder was used on the LCU. The readings were presented on a microammeter and recorded on data sheets by the scientist, as required. For surveying in contaminated water having a dose rate too high for the low-level probe, an AN/PDR-27C hand set was used on deck. This type of measurement gives qualitative results that permit a rough presentation of the fallout zones.

3.6 RESULTS AND DISCUSSION

3.6.1 Shot Cherokee. No radioactive water was found on shot day, and no further measurements of radioactivity were made for this detonation.

3.6.2 Shot Zuni. The fallout pattern for shot day is sketchy. The probe became inoperative after the first four stations. The stations that were occupied during the next few days indicated that the fallout immediately following the detonation covered the entire lagoon, except for a small zone roughly between Sites Nan and Oboe.

On Zuni plus 1 day, the most radioactive water (25 to 100 mr/hr[1]) was found from the shot site westward in a narrow band to the eastern edge of Site Victor (Figure 3.1). By Zuni plus 2 days, the radioactivity of the water at the shot site was 31 mr/hr at the surface and 54 mr/hr at 25 meters. The radioactive body of water off Site Uncle and Rukoji Pass was less than 4 mr/hr at the surface. At the shot site, the persistence of the radioactivity is, in part, due to fine radioactive particles washing from the sides of the crater.

At the time of the shot, the ebb tide had just begun. This would indicate that a great amount of highly radioactive water near surface zero was expelled from the lagoon as the tide ebbed.

The highly radioactive water was quickly lost from the lagoon by the proximity surface zero to several passes, the influence by the tide, the westward moving lagoon current and westward moving ocean current. The lagoon currents from the surface to the bottom flow westward along the southern edge of Bikini Atoll. These currents carried the highly radioactive water from the shot site westward to Rukoji Pass, between Site Tare and Site Uncle, where a large amount was lost at ebb tide. The westward-moving ocean current on the south side of Bikini Atoll carried all the radioactive water from the lagoon beyond the mouth of the passes so that it could not enter on the flood tide. On a flood tide, D+1 values of 1.2 mr/hr at the surface, and 0.22 mr/hr at 20 meters and below were measured in the pass between Sites Uncle and Tare. Measurements taken 1,000 yards to seaward of the pass were 0.24 mr/hr from the surface to 39 meters.

The currents in the lower layers near the edge of the lagoon have low velocities and move in the same direction as the upper layer. The maximum depth in the pass between Sites Uncle and Tare is 19 fathoms, but at one location in the pass there is 20 fathoms. These two passes allowed a large amount of the radioactive water in the lower depths to get to the open ocean. The last observation taken near the shot site (1,600 yards, bearing 000 degrees) on D+5 indicate that below the depth of the sill in the passes, the radioactivity of the water was relatively high compared to the water above this depth. The surface was 0.49 mr/hr, at 37 meters the reading was

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[1] In this chapter, all dose rates are presented as "apparent" mr/hr as defined in Appendix A.

1.8 mr/hr and at 45 meters it was 15.0 mr/hr. The radioactivity of the water in the deepest layer is lost by decay and by the mixing of this layer with the less radioactive water above.

During the Project 2.64 aircraft fallout survey, an area of radioactivity was found in the ocean near Site William. This in all probability came from the radioactive water draining through the passes. The ocean currents transported the contaminated water westward. An attempt was made to obtain permission for the LCU to explore the radioactive water mass outside the lagoon. This request was denied, because regulations prohibited operation of LCU's in the open ocean. Hence, the activity in this mass will remain unknown.

3.6.3 Shot Flathead. The fallout pattern included two thirds of the lagoon. Only the southeastern third was free of contamination (Figure 3.2). The fallout was graded from light contamination along its southern edge to heavy contamination in the northern area. A line of light-colored water, formed from the mixing of powdered coral, marked the boundary of the most-intensely radioactive water. This water registered 3 r/hr, when observed 6.5 hours after the shot; and its boundary was very sharp in both color change and contamination. The distance between 3.0 and 0.23 r/hr water was not more than 50 yards.

The edge of discoloration in the water began off the middle of Site Fox and extended clockwise in an arc to about a mile south of the shot site, then straight towards 240 degrees, beyond which no observations were made the first day.

By Flathead plus one day, the water that measured more than 150 mr/hr was located in the northwest corner of the lagoon. The center appeared to be about 2 miles south of Site Charlie. At the shot site, the water measured 30 mr/hr at the surface, with a gradual increase to 112 mr/hr at 18 meters.

The large decrease in radioactivity at ground zero from the day of the shot to Flathead plus one can be accounted for through the processes of decay, the settling of the floured coral to the bottom, and the transport to the west end of the lagoon by currents. The transport of radioactive water from the vicinity of surface zero to the zone of high activity in the western end of the lagoon on D+1 is very possible, considering the length of time and average velocity of the current.

On D+2, a series of current-stations and probe measurements were made from the shot site towards 255 degrees. The currents on the surface were in a direction of 260 degrees. The currents in the lower layers were from a half to two thirds of the velocity of the surface currents and, generally, in a direction between 150 and 260 degrees. The probe measured a maximum of more than 150 mr/hr in the lower layers.

Due to the failure of the probe on D+3, the next observations were on D+7. By this time, a pattern was well developed. There was a trough of radioactive water along an axis of 070 degrees. The high radioactivity was located about 3 miles south of Site Charlie. It was 1.9 mr/hr on the surface and 4.5 mr/hr in the lower layer. Five miles due south of Site George, the surface was 1.0 mr/hr, and in the lower level it was 1.5 mr/hr (Figure 3.3). This figure illustrates the current in the lower layer transporting radioactive water toward the southeast and the radioactive water on the surface being moved toward the westward by the upper-layer current.

By D+11, the pattern of D+7 still held for the surface level (Figure 3.4). The cell of highest radioactive water still existed south of Site Charlie, feeding the lower levels of the lagoon as the current moved the water eastward. By this time the observed 1.0- mr/hr line had moved 2 miles east southeast. The 0.4-mr/hr contour line had been over 5 miles from Site How, whereas on D+11, it was 1.5 miles from How.

The pattern of radioactive water represents the current pattern of the lower layer. There appears to be a cellular system rotating counterclockwise in the area of highest radioactivity in the water. The current data gives evidence to its existence, and the pattern of radioactive water tends to support this idea. Coming from this cell on its east side were currents toward the East Southeast that continue feeding radioactive water into the East Southeast flow. As the water flowed in that direction, it was mixed with the upper layer by the wind, and some upwelling may have occurred before the lower layer reached the eastern edge of the lagoon. The leading edge of the lower water was continually being eroded away by nonradioactive water with which it was in contact. In addition, mixing with the nonradioactive water above reduced the activity of the lower layer.

3.6.4 Shot Dakota. The boundary of the fallout pattern was extremely sharp (Figure 3.5). No probe measurements were made in the area of more than 150 mr/hr. Deck readings just inside the boundary measured up to 700 mr/hr. The edge of fallout was marked by the light-colored water, as appeared following Shot Flathead. Some 200 feet outside the light-colored water, the radioactivity of the water measured less than 1 mr/hr along part of the boundary. In the western end of the lagoon, the fallout became graded, and the transition from clean water to the 150-mr/hr contour covered much more distance.

3.6.5 Discussion of Presented Dose-Rate Values. No attempt has been made to construct iso-dose-rate contours as they would have resulted from fallout on an infinite level plane. In the lagoon there is the complication of shallowness. By the time most measurements could be taken, the radioactivity would have reached the bottom of the lagoon. There is no way to tell what percentage of the radioactive particles would have settled on the bottom. Also, there is the problem of the upper layer currents transporting the radioactive water westward while the lower layer is being transported eastward. Near the edges of the lagoon, there is much mixing with fresh water from the ocean, which would cause the upper layer to measure less radioactivity that the lower layer.

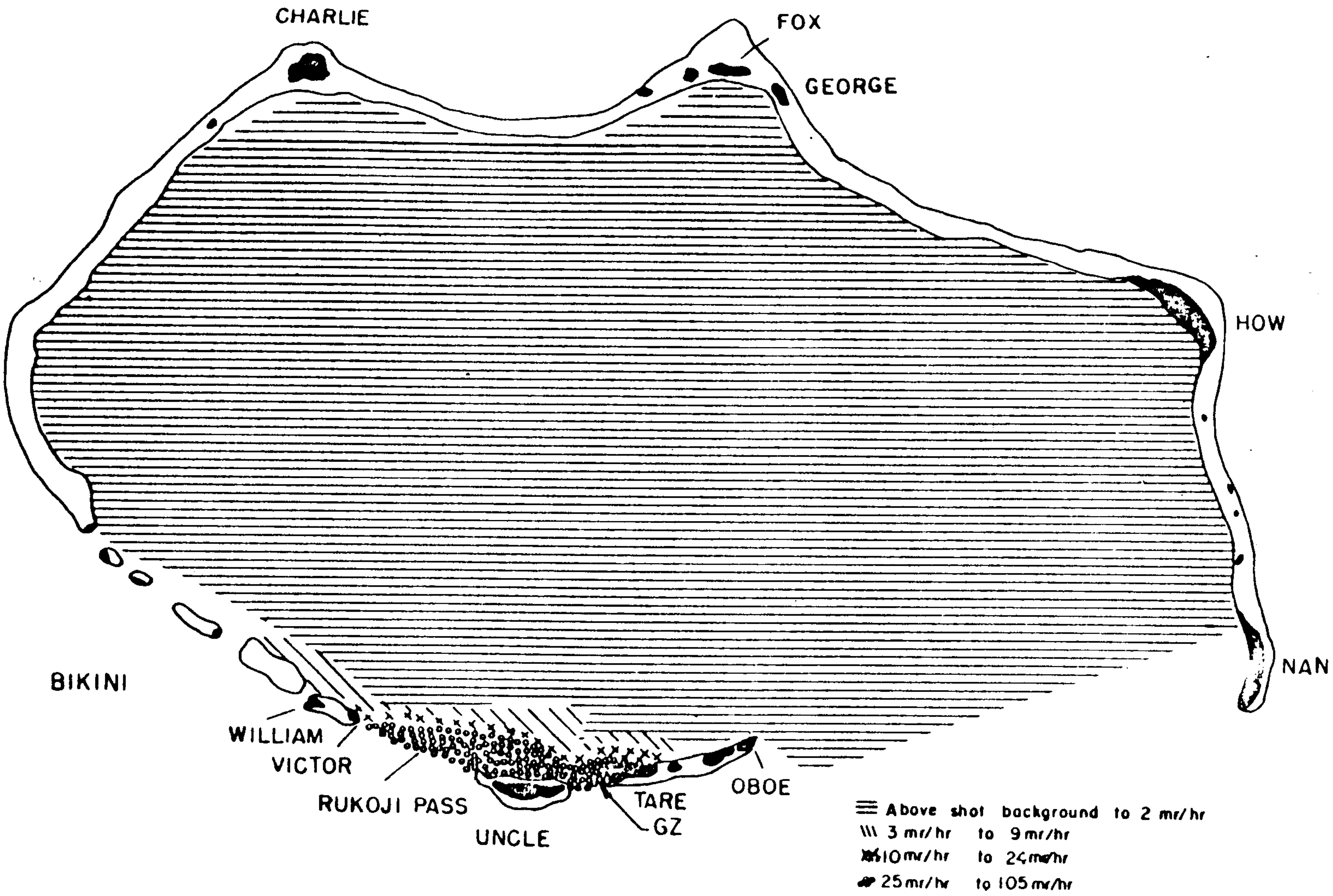


Figure 3.1 Area of contamination resulting from Shot Zuni, May 29, 1956. Summary of surface measurements made between 0600 and 1800 hours.

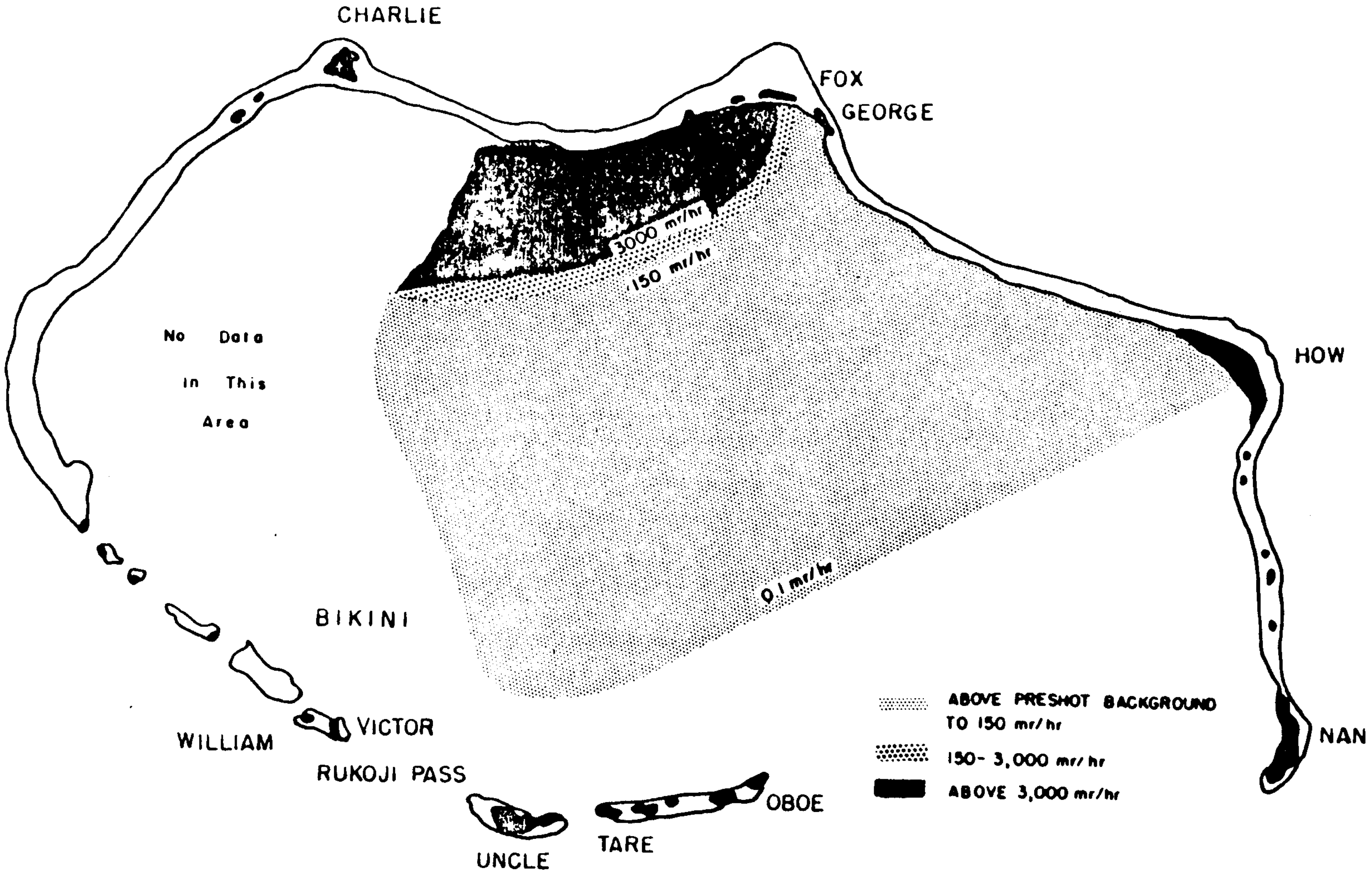


Figure 3.2 Area of contamination resulting from Shot Flathead, June 12, 1956 (D day).

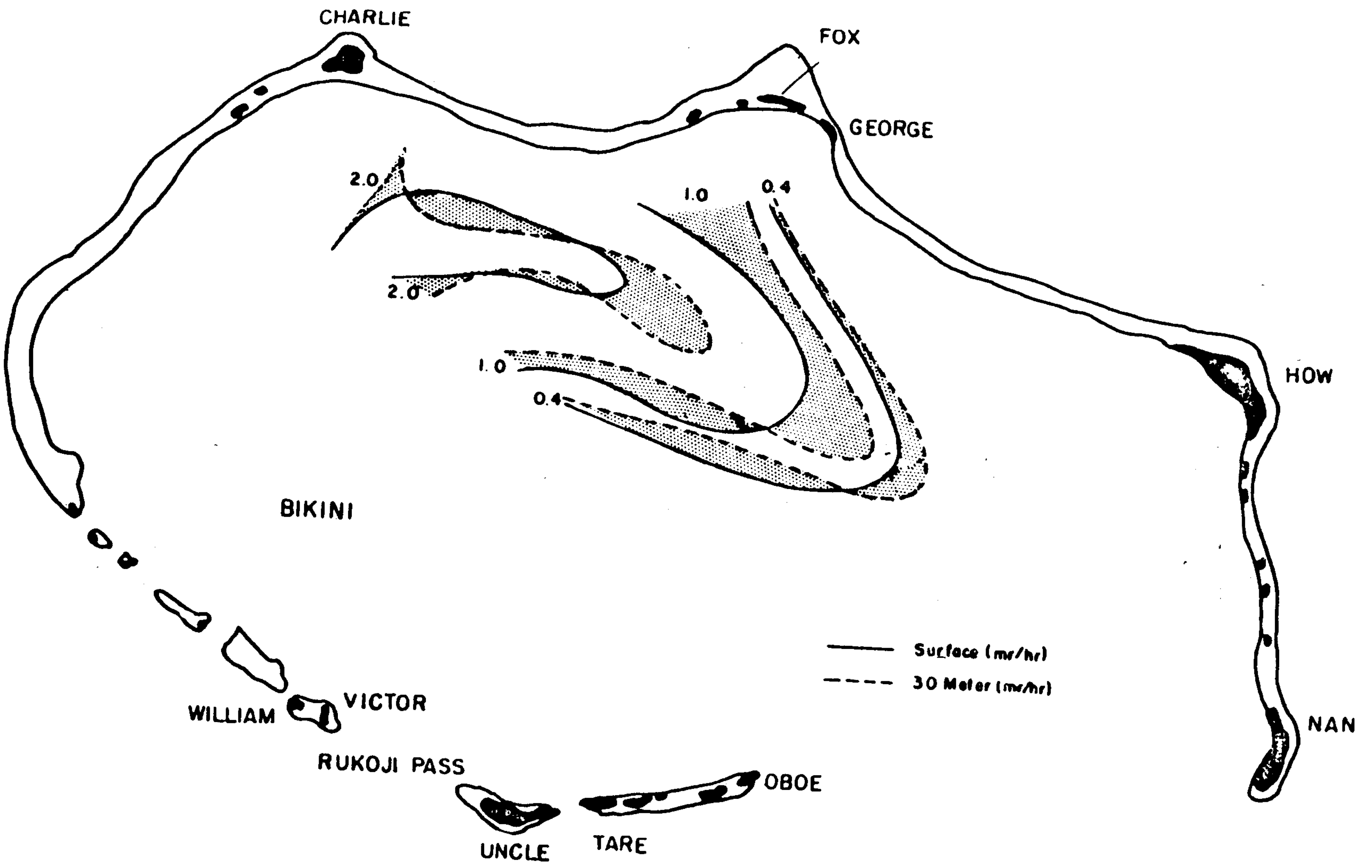


Figure 3.3 Observed surface and 30-meter dose rate contours on Shot Flathead plus 7 days.

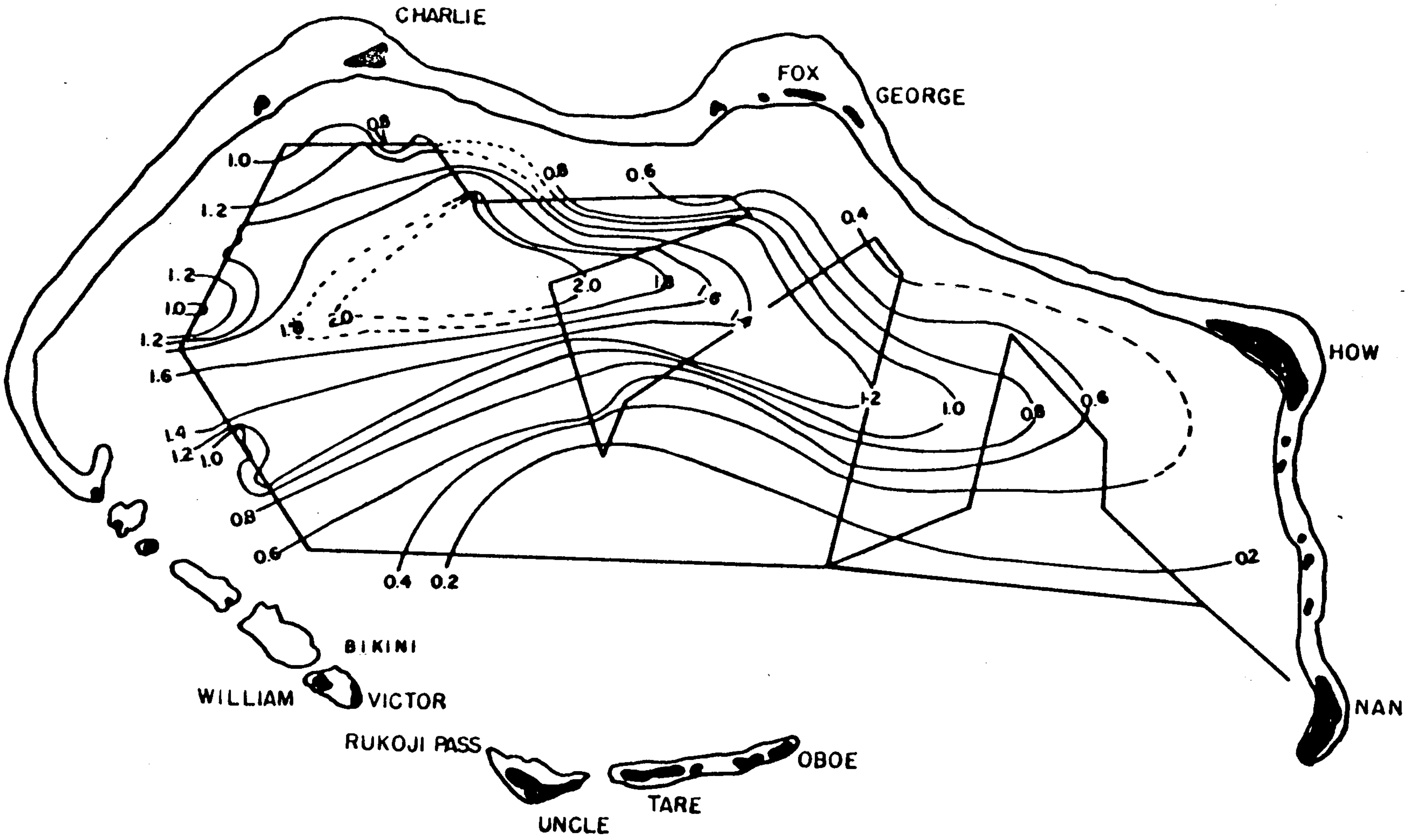


Figure 3.4 Observed surface radioactivity (mr/hr) at 11 days after Shot Flathead.

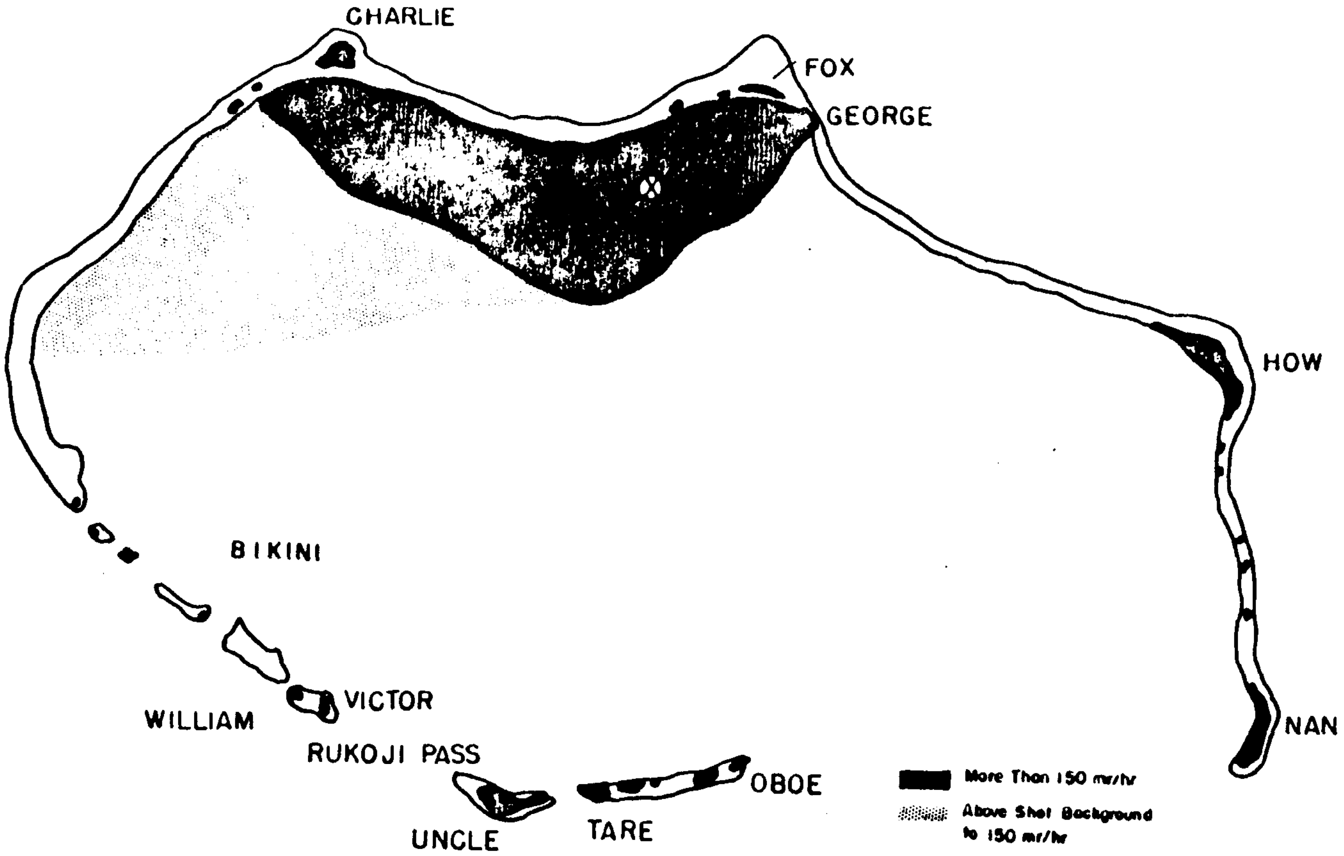


Figure 3.5 Area of contamination resulting from Shot Dakota, June 26, 1956 (D day).

Chapter 4
DEEP-MOORED INSTRUMENT STATIONS

This chapter is restricted to a report on a methodology of some significance in future planning. The results as pertain to survey of fallout are reported elsewhere by Project 2.63, as well as in Chapter 2 of this report.

4.1 OBJECTIVES

The objective of the deep-moored instrument stations was to provide a number of instrument platforms in fixed geographical position for the determination of areal distribution of and for sampling fission products. It was planned that these moorings should last the length of the operation. In conjunction with providing a moored instrument platform and appurtenances for installation, it was necessary to develop gear capable of recovering the instrumented skiffs in a minimum amount of time after each shot.

The principal instrumentation installed on these stations for determining areal distribution of fallout was the responsibility of Project 2.63 and is covered in Reference 7. In addition, the results of the penetration meters that were installed on several of the skiffs by Project 2.62 has been presented in Chapter 2 of this report. Figure 4.1 shows the location of instruments and collectors that were mounted on the moored skiff.

4.2 BACKGROUND

Determination of the areal distribution of fission products from nuclear devices tested in the EPG has always been hampered by the absence of land masses to act as, or to support, collecting stations. Moored collection stations in the lagoon have been a part of each series beginning with Operation Crossroads, but these, together with reef and island stations, have been inadequate to give more than meager close-in and "upwind" coverage for detonations of multimegaton range. In addition, the use of the ocean surface itself, as a collector, is subject to many difficulties, and the fallout material undergoes a number of alterations of form and distribution in the sea prior to the time that survey ships or aircraft can be brought in. Manned, shielded ships constitute floating laboratories that can be placed directly under the fallout, but these can by no means provide the areal coverage necessary to explore the distribution of particles in the fallout area.

The requirement for additional, more-numerous, and less-complex collecting platforms has long been recognized. It has been considered that these would be most useful in the moderately close-in range, where the coarser particles fall. Here the survey vessel is limited by the rapid penetration of the particles through the surface layers of the sea.

During Operation Castle, Project 2.5a attempted to use free-floating buoys as collectors and telemetering stations (Reference 10). It was attempted to lay these in the days prior to the detonation in such a way that they would float into position and cover the desired area at shot time. Aside from its being greatly influenced by the complexity of the currents in the area, this system also committed the project to recover and re-lay the buoys following any postponement. Thus, this vigorous approach to the problem met with limited success.

It was apparent that if platforms could be moored in the area, many of the problems could be obviated. This would require mooring surface platforms in water as deep as 2,500 fathoms in the region of Bikini Atoll.

The history of mooring in deep water is limited. It generally is considered, for example, that a depth of 100 fathoms limits the installation of military moored mines. Cable-laying craft occasionally have moored in water as deep as 2,000 fathoms and commonly installed temporary markers at depths somewhat shallower than this. Usually, they attempt to isolate the cable between two shallower points, however, and not to work at extreme depths. Oceanographic vessels have been moored in depths up to about 2,900 fathoms using their tapered dredging cables. Both Scripps and Woods Hole oceanographic institutions have dropped slack moorings in water of all depths. Such moorings have not been particularly useful, principally because their great scope has made it difficult to ascertain whether or not they were dragging (thus limiting their use as reference navigational markers and current measuring platforms) and because of their short life engendered by surging and chaffing.

These two difficulties can be met by the installation of taut moorings, where the principal tensile stresses are carried by a submerged float below the limit of the wave motion of sea and swell. Scripps installed about four such moorings on the 700-fathom seamounts to the north of Eniwetok prior to Shot Mike, Operation Ivy (Reference 11). These platforms bore wave recorders, but it was evident that they also acted as fallout collectors, although no fallout instrumentation was installed thereon. During Operation Castle, Scripps also had experience with mooring skiffs in the lagoon for long periods of time and had solved some of the chaffing problems associated with this type of mooring subjected to extensive wave action. These two areas of experience were combined for Operation Wigwam, in which about seven skiffs were taut moored in approximately 2,000 fathoms. These skiffs bore strobe lights and were installed for use as navigational aids. They survived heavier weather than that for which they had been designed and performed their task, despite a high mortality from engagements with some of the heavier elements of the United States Navy.

On the basis of these experiences, it was decided to moor a moderate number of platforms in the deep ocean to the north of Bikini Atoll during Operation Redwing for the documentation of fallout.

4.3 THEORY

One of the technical problems of installing a taut mooring in water more than 2,000 fathoms deep is shown in Figure 4.2. Here is depicted the ultimate tensile strength necessary for a steel wire to be used at any depth in the sea when bearing an additional load equal to its weight. Also shown is the percentage of ocean area at a depth greater than the ordinate. Using the allowable depth of mooring as a criterion, it is apparent that wire with an ultimate strength of 100,000 psi can be safely used to a depth of about 1,700 fathoms, or in about 30 percent of the ocean. A wire with an ultimate stress of 180,000 psi, however, can be employed to 3,000 fathoms, or used in 99 percent of the sea area. The wire used during Redwing had an ultimate strength of about 260,000 psi.

The above relates solely to the quasi-static stresses produced in lowering the mooring wire. Other dynamic stresses become important as soon as the anchor reaches bottom. Also, an allowance must be made for weakening of the wire by handling and by corrosion.

The area presented by such a wire to the horizontal drag forces can be quite large. For example, 15,000 feet of $\frac{1}{8}$-inch wire, as used during Operation Redwing, presents a projected area of about 160 ft^2 of form drag area, or about that of a large barge. Fortunately, water velocities at great depths are low; hence, the large area presented is not a great problem.

Such horizontal forces must be resisted at the anchor; thus, as horizontal forces increase, the anchor weight and the lowering stresses must be increased. Also, the excursion of the mooring and changes in float submergence are functions of the tensile stresses and the horizontal drags. Hence, the strength-to-drag ratio of the wire is important. This can be expressed as:

$$R = \frac{s \pi t^2}{4\ Cdt} \quad \text{or } R \approx s\, t \text{ for constant range of Cd}$$

Where: R = strength/drag ratio
t = thickness of wire, inches
s = ultimate stress, psi
Cd = drag coefficient

The wire used had a thickness of $\frac{1}{8}$ inch and an ultimate strength of 260,000 psi and, hence, a strength-to-drag ratio of about 32,000. In order to obtain the same geometry using a common wire rope with an ultimate strength of 125,000 psi, the diameter required would be more than $\frac{1}{4}$ inch, the total weight of the installation increased by a factor of 5, and the mooring limited to a depth of about 2,200 fathoms.

The configuration of the mooring can be determined graphically for any set of conditions. This permits the determination of total excursion, depth of submersion of intermediate float, stress, etc. An example of such a graphical configuration is shown in Figure 4.3.

It is apparent that one of the problems of taut mooring, that of the high stresses in lowering, could be ameliorated by the use of a mooring line whose density was closer to unity. Some suitable material eventually may become available, and SIO is investigating the use of a spun-glass lines impregnated with flexible plastic. Nylon line cannot be used for taut moorings because of its extensibility and its low strength-to-drag ratio. The submerged float cannot be permitted to surface nor to descend to more than about 500 feet. Hence, the uncertainty of the dimensional stability of the system cannot exceed about 250/15,000 or about 2 percent. Nylon's extensibility and creep exceeds this by a factor of 20 to 40, a large part of which is unpredictable.

4.4 OPERATIONS

Initial plans called for the installation of sixteen stations to be anchored within a 30-mile radius of the average geographic surface zero and in the area of expected fallout north of Bikini. Figure 4.4 shows the geographic location of these stations for Shot Cherokee. The details of description, operation, and installation of deep-moored instrument stations are covered in Appendix B.

4.4.1 USS Sioux.

The ship assigned to this task was the USS Sioux (ATF 75). Certain modifications and installations were necessary before the ship could be used. A hydrographic winch, a work platform, a ramp on the stern for use in retrieving the instrument skiffs, and all allied equipment necessary for the installation were installed aboard in San Diego prior to the ship's departure for the EPG.

4.4.2 Initial Installation.

The instrument skiffs were shipped to Bikini, and the instruments were installed thereon at the staging area at Site Nan. As soon as two or three of the instrument skiffs were completely outfitted, they were placed aboard the Sioux and taken to the mooring area north of the atoll. There, at the predetermined geographic positions, the deep moorings were installed, and the skiffs were attached to these moorings.

During the initial installations, none of the fallout instrumentation was armed. A few days prior to the first shot, the Sioux made a trip into the area and all of the instruments were armed.

4.4.3 Maintenance of Instrument Skiffs.

Between subsequent shots, the procedure for recovery and rearming the instrument skiffs was as follows:

The Sioux approached the nylon painter, which led from the instrument skiff to the subsurface float. The painter was picked up well ahead of the skiff, the skiff detached. Another skiff with instruments armed was then attached to the painter leading from deep mooring and launched from the fantail of the Sioux. The time required to make this exchange was 15 minutes. The detached skiff was then pulled up on the retrieving ramp and decontaminated, if necessary. It was then brought aboard, the instruments recovered or the data recorded, and the instrument skiff completely readied and rearmed to be launched as replacement for the next skiff recovered.

Occasionally, the instrument skiffs broke away from the moorings. In this case, a complete, new mooring had to be installed at a distance of about 2 miles from the previous mooring.

Recovery of instruments and records after each shot was started on the morning of D + 1 and usually required 2 to 3 days for the complete recovery and rearming operation.

4.5 INSTRUMENTATION

The instruments used for the collection of fallout and for measuring fallout time of arrival at these stations were supplied and maintained by Project 2.63.

The instrument designed for determination of early penetration from the deep moored stations, the penetration meter, is described in Chapter 2.

The instruments and the components for installing and maintaining the instrument skiffs are fully described in Appendix B.

4.6 RESULTS AND DISCUSSION

4.6.1 Summary of Shot Participation. The skiff stations were activated for participation in five shots. Tables 4.1 through 4.5 summarize instrumentation of these stations. For results of fallout measurements and sampling, see Reference 7.

Shot Cherokee (Figure 4.4). Seventeen stations were activated. Sixteen of these were installed north of the atoll. The seventeenth was placed south of Site Tare for subsequent use during Shot Zuni. Six stations were recovered in the west sector before damage to the instrument skiff-retrieving ramp interrupted the recovery program. None of the time-of-arrival devices (Project 2.63) was triggered. No further stations were recovered, owing to the time required for repairs on the ramp.

Shot Zuni (Figure 4.5). Sixteen stations were activated. Samples and radiation readings were recovered from fourteen of these stations. Station AA had been run down, and Station VV had capsized probably from the shock waves. Station VV was in the mooring installed south of Site Tare especially for this shot; consequently, the only records south of the atoll were lost. The capsized skiff was recovered, and the mooring was abandoned after this shot.

Shot Flathead (Figure 4.6). Fifteen stations were activated. Samples and readings were recovered from fourteen of these stations. Station MM was never located.

Shot Navajo (Figure 4.7). Thirteen stations were activated. Samples and readings were recovered from all of these stations.

Shot Tewa (Figure 4.8). Seventeen stations were activated. Three were new stations WW, XX, and YY, moored just prior to the shot to allow better coverage to the west. Samples and readings were recovered from all these stations.

4.6.2 Summary of Moorings and Problems Encountered. The main objective of the deep-mooring work was to install moorings that would maintain instrument platforms lasting for the length of the operation.

Seventeen moorings were put in, starting about the middle of April. At the termination of this series of tests, eight of the original moorings were still in use. Station VV was required for Shot Zuni only and was abandoned after that detonation. The other eight moorings were replaced, some several times. The stations most frequently replaced appeared to coincide with the area of heaviest surface traffic, which was not surprising in view of the difficulties encountered during Operation Wigwam. In all, a total of thirteen remoorings was made. There were several causes for these stations' failures. Skiffs adrift from four of these stations were recovered. Two of these indicate the station was run down by larger vessels, as evidenced by damage to the skiff and the nylon pennant. The other two skiffs recovered had all but a few feet of their full nylon pennant, indicating the possibility of chaffing at the deep float. Air search located the wreckage of another skiff, which had apparently been run down. In all, 33 moorings were laid during this series of tests.

After the series, recovery of the subsurface float and a short length of the 0.120-inch mooring wire was attempted to aid in the evaluation of the mooring system. Three such assemblies were recovered from stations that had been in place since April. The subsurface floats showed no wear or damage and only slight fouling. One of the subsurface floats, which was coated with polyester resin, appeared as clean as when installed.

The special 0.120-inch-wire clamps and the 0.120-inch mooring wire were in good condition. The problems of electrolysis appear to be solved. Cursory examination indicated that these moorings were capable of staying in many more months.

At present, the most vulnerable point in the mooring system lies in the possibility of the nylon pennant fouling on the subsurface float and eventually chaffing through. This fouling can occur only during the laying of the mooring. It was essential, therefore, that a constant strain be maintained on the nylon pennant as the subsurface float was being lowered. This fouling occurred several times while the subsurface float was still in sight, and the float was hauled in and cleared.

On those stations where wire rope was used, another cause of fouling, as evidenced by a recovered nylon pennant, was the torque from twisting during lowering that was not relieved by the swivels in the system. Galvanized marine swivels are notorious for their lack of performance As a result, when the float was at its depth and the mooring wire was cut, the subsurface float would spin, winding the nylon pennant about the float and causing eventual failure. Of course, under certain static conditions of current and weather, a slack nylon pennant might be subject to fouling. To prevent this, the floating characteristics of nylon were aided by small plastic floats spaced along the pennant, and a large glass ball was situated so that a constant strain was kept on the pennant.

4.6.3 Reliability of Station Positions. The Sioux (ATF-75) was equipped with BAS-4 loran and an AN/SPS-5B radar. The loran was checked and calibrated just prior to this operation. The radar was of a recent type, just installed; however, very few of the stations were in close enough to the atoll to permit radar positioning. No trouble was experienced with the loran, and station positions checked out very well. The positions of the stations were frequently checked. They usually plotted within a mile of the original position. The standard deviation of the DAS-4 loran as checked in the area was plus or minus 1.2 miles. In practice, station positions were considered unchanged if the loran fix checked within a mile; however, if on recovery the fix change exceeded a mile, a new position was noted for the station. Several stations dragged about ½ mile a day during the first few days they were anchored; however, after this initial dragging the stations stayed in place.

4.6.4 Locating Instrument Skiffs. The Sioux experienced no difficulty in locating the instrument skiffs, either by day or night. Radar pickup on the skiff's reflector under nominal sea conditions was about 8 miles. At night, the small (0.8-ampere) light on the skiff was visible about 5 miles. At times, aircraft reconnaissance was utilized as a check on the stations. This reconnaissance by aircraft equipped with radar was effective, and in calm weather the stations could be located at about 40 miles. It was found that aircraft without radar were definitely handicapped in such a search.

4.6.5 Servicing Instrument Skiffs. The recovery and servicing of instrument skiffs after each shot went very well. The Sioux was able to recover and service six to eight stations per day. The fallout collector samples and the AFOAT samples were sent out on a D+4 flyaway. No difficulty was encountered in meeting this schedule, except following Shot Cherokee. Damage to the skiff-retrieving ramp prevented complete recovery after that shot. On the basis of the experience gained in recovery and servicing on this operation, it is believed that twenty instrument skiffs would be the maximum one ship could service in 3 days, assuming the distances as used during Operation Redwing are not greatly altered. The system of hauling the instrument skiffs on board for servicing was highly satisfactory. This reduced the time spent on station during previous operations by roughly 75 percent. The skiff-retrieving ramp worked well, even in rough weather. Obviously, there are weather limitations, but none were experienced on this operation.

4.6.6 Operating Conditions. The weather conditions at the EPG during this test series were moderate, and winds were probably never stronger than 35 knots. It is doubtful that the present size of mooring wire would hold up under gale conditions, but such a taut wire mooring is easily devised. Essentially, this would involve increasing the size of the mooring wire and some of the components. Extreme weather conditions would probably preclude the use of a commercial skiff hull as the instrument platform. Some form of buoy might well be used as the instrument platform, since it could be designed to be more easily serviced in heavy weather.

Many of the instrument platforms were moored on this operation in water as deep as 3 miles; however, this is not necessarily the maximum depth attainable. On the basis of depth, the present type of mooring could be used in 99 percent of the ocean areas of the world.

TABLE 4.1 INSTRUMENTATION AND RADIATION DATA ON DEEP-MOORED STATIONS, SHOT CHEROKEE

Station	Mooring North	Position East	Recovery Position	TOAD Time Recovery/Reading	Remarks
PP	11-52.0	165-22.8			No record. Could not locate.
KK	12-02.0	165-40.0			
LL	13-04.0	165-56.1			
DD	12-11.5	165-40.0	Unchanged	Not triggered	
FF	12-03.5	166-13.9			
HH	12-01.3	165-22.9	Unchanged	Not triggered	
UU	11-42.5	165-47.5			
SS	11-50.0	165-58.0			
TT	11-50.8	166-15.0			
MM	11-52.6	164-58.3	Unchanged	Not triggered	
BB	12-11.6	165-10.0			Capsized.
AA	12-06.1	164-47.0	Unchanged	Not triggered	
RR	11-50.7	165-39.5			
GG	11-57.8	165-13.8	Unchanged	Not triggered	
EE	12-11.3	165-57.3			
CC	12-11.3	165-23.0			
VV	11-21.7	165-19.5			

TABLE 4.2 INSTRUMENTATION AND RADIATION DATA ON DEEP-MOORED STATIONS, SHOT ZUNI

Station	Mooring North	Position East	NBS Film Badge	Recovery Position	Monitor Reading on Skiff Deck (mr/hr)		TOAD Time Recovery/Reading	FOC Bottle (mr/hr)		Remarks
					Open	Closed		Open	Closed	
KK	12-02.0	165-40.0	X	Unchanged	380	40	NI	1	1	
LL	12-03.0	165-56.1	X	Unchanged	2.5	2	Malfunction	4	3.5	
DD	12-11.5	165-40.0	X	Unchanged	4.4	7.5	NI	14	4	
FF	12-03.5	166-13.9		Unchanged	4	2	Not triggered	2.5	1	
HH	12-01.3	165-22.9	X	Unchanged	1,000	90	Not triggered	2	2	
UU	11-42.5	165-47.5	X	Unchanged	10	0	Malfunction	0	0	
SS	11-50.0	165-58.0	X	Unchanged	2	2	Not triggered	0	0	
TT	11-50.8	166-15.0	X	Unchanged	2	0	Malfunction	0	0	
MM	11-52.6	164-58.3	X	Unchanged	16	2	D+ 2 0811 1-23-22	2	2	
BB	12-11.6	165-10.0	X	Unchanged	400	90	D+ 2 1510 1-5-25	4	4	
AA	12-06.1	164-47.0	X		Lost					Skiff lost. No records.
RR	11-50.7	165-39.5	X	Unchanged	400	44	D+ 3 1111 3-03-30	0	0	
GG	11-57.8	165-13.8	X	Unchanged	800	4	D+ 2 1725 1-09-31	6	6	
EE	12-11.3	165-57.3	X	Unchanged	1.75	1.5	Malfunction	5	0	
CC	12-11.3	165-23.0	X	Unchanged	640	100		34	22	
VV	11-21.7	165-19.5	X							Skiff capsized. No records.

TABLE 4.3 INSTRUMENTATION AND RADIATION DATA ON DEEP-MOORED STATIONS, SHOT FLATHEAD

Skiffs were fire hosed prior to monitoring.

Station	Mooring North	Position East	NBS Film Badge	Recovery Position	Monitor Reading on Skiff Deck (mr/hr) Open	Monitor Reading on Skiff Deck (mr/hr) Closed	TOAD Time Recovery/Reading	Remarks
PP	11-50.5	165-23.9	X	Unchanged	900	65	Not triggered	
KK	12-02.0	165-40.0	X	Unchanged	50	10	Not triggered	
LL	12-03.0	165-56.1	X	Changed	8	2	Not triggered	
DD	12-11.5	165-40.0	X	Unchanged	30	2	Not triggered	
FF	12-03.5	166-13.9	X	Changed	20	4	Not triggered	
HH	12-02.0	165-21.6	X	Unchanged	800	60	D+ 1 1425 1-02-46	
UU	11-42.5	165-47.5	X	Changed	16	3	Not triggered	
SS	11-50.0	165-58.0	X	Changed	65	10	Not triggered	
TT	11-50.8	166-15.0	X	Unchanged	36	6	Not triggered	
MM	11-52.6	164-58.3	X	Changed				Skiff not located.
BB	12-11.6	165-10.0	X	Unchanged	3,000	200	Malfunction	
AA	12-06.1	164-47.0	X	Unchanged	1,700	220	D+ 1 0732 0-16-01	
RR	11-50.7	165-39.5	X	Changed	22	6	Not triggered	
EE	12-11.3	165-57.3	X	Unchanged	8	4	Not triggered	
CC	12-11.3	165-23.0	X	Changed	800	120	D+ 1 1315 1-02-05	Skiff was adrift near position.

TABLE 4.4 INSTRUMENTATION AND RADIATION DATA ON DEEP-MOORED STATIONS, SHOT NAVAJO

Station	Mooring North	Position East	NBS Film Badge	AFOAT Sample	Recovery Position	Monitor Reading on Skiff Deck (mr/hr) Open	Monitor Reading on Skiff Deck (mr/hr) Closed	TOAD Time Recovery/Reading	FOC Bottle (mr/hr) Open	FOC Bottle (mr/hr) Closed	Remarks
PP	11-52.0	165-22.8	X	X	Unchanged	2,000	120	D+ 1 1747 1-10-26	50	32	Barnacle samples from nylon line.
KK	12-02.0	165-40.0	X	X	Unchanged	300	25	D+ 1 1440 0-0-0	60	10	
LL	12-02.7	165-56.1	X	X	Unchanged	10	10	D+ 1 1255 10-16-36	10	2	Barnacle samples from nylon line.
DD	12-11.5	165-40.0	X	X	Unchanged	86	14	D+ 2 0823 0-00-07	4	2	
FF	12-03.5	166-14.2	X	X	Changed	78	8	D+ 1 1113 0-0-20	8	3	
HH	12-02.0	165-21.6	X	X	Unchanged	540	52	D+ 2 1013 0-0-0	10	8	
UU	11-43.1	165-47.0									Station not activated.
TT	11-50.8	166-15.0	X	X	Unchanged	98	10	D+ 1 1947 0-0-0	10	4	
MM	11-52.7	164-56.0	X	X	Unchanged	2,000	200	D+ 1 1955 1-09-39	10	6	
BB	12-11.5	165-07.5	X	X	Unchanged	200	20	D+ 2 1228 0-0-0	6	4	
AA	12-05.4	164-44.9	X	X	Changed	220	30	D+ 2 1450 2-23-56	10	8	
RR	11-52.3	165-39.7	X	X	Unchanged	540	40	D+ 1 1545 0-0-0	14	5	
EE	12-11.3	165-57.3	X	X	Unchanged	84	10	D+ 2 0642 0-0-0	6	2	
CC	12-11.8	165-20.9	X	X	Unchanged	180	20	D+ 2 1108 0-0-0	8	4	

TABLE 4.5 INSTRUMENTATION AND RADIATION DATA ON DEEP-MOORED STATIONS, SHOT TEWA

Station	Mooring North	Position East	NBS Film Badge	AFOAT Sample	Recovery Position	Monitor Reading on Skiff Deck (mr/hr)		TOAD Time Recovery/Reading	FOC Bottle (mr/hr)		Remarks
						Open	Closed		Open	Closed	
PP	11-52.0	165-22.8	X		Unchanged	740	160	D+ 2 1610 0-0-0	90	46	*
KK	12-02.0	165-40.0	X	X	Unchanged	240	14	D+ 1 1628 0-0-57	2	2	
LL	12-02.7	165-56.1	X	X	Unchanged	12	1	D+ 1 1214 0-23-56	0	0	
DD	12-11.5	165-40.0	X	X	Unchanged	120	10	Not triggered			
FF	12-03.7	166-12.6	X	X	Unchanged	0	0	Not triggered	0	0	
HH	12-02.0	165-21.6	X	X	Unchanged	3,000	320	D+ 1 2140 1-13-39	16	6	
TT	11-50.8	166-15.0	X	X	Unchanged	0	0	Not triggered	0	0	
MM	11-52.7	164-56.0	X	X	Unchanged	800	200	D+ 2 1918 2-11-34	78	56	
BB	12-11.5	165-07.5	X	X	Unchanged	3,800	380	D+ 1 1943 0-0-54	160	98	
AA	12-05.9	164-45.8	X	X	Unchanged	140	38	D+ 2 2100 2-10-16	12	8	
RR	11-52.3	165-39.7	X	X	Unchanged	86	14	Not triggered			
GG	12-01.1	165-10.2	X	X	Unchanged	580	120	D+ 2 1755 22-09-16	48	32	
EE	12-11.3	165-57.3	X	X	Unchanged	64	10	Not triggered	4	2	
CC	12-11.8	165-20.9	X	X	Unchanged	2,000	200	D+ 1 1822 1-08-23	14	7	
WW	11-43.2	165-11.5	X		Unchanged	400	40	D+ 2 1440 2-09-04	100	80	
XX	11-41.2	164-55.1	X		Unchanged	720	140	D+ 2 1225 0-05-25	42	22	*
YY	11-54.0	164-36.4	X		Unchanged	1,200	80	D+ 2 1020 6-02-26	74	70	

* Scripps Institution of Oceanography penetrometers on Stations PP and XX.

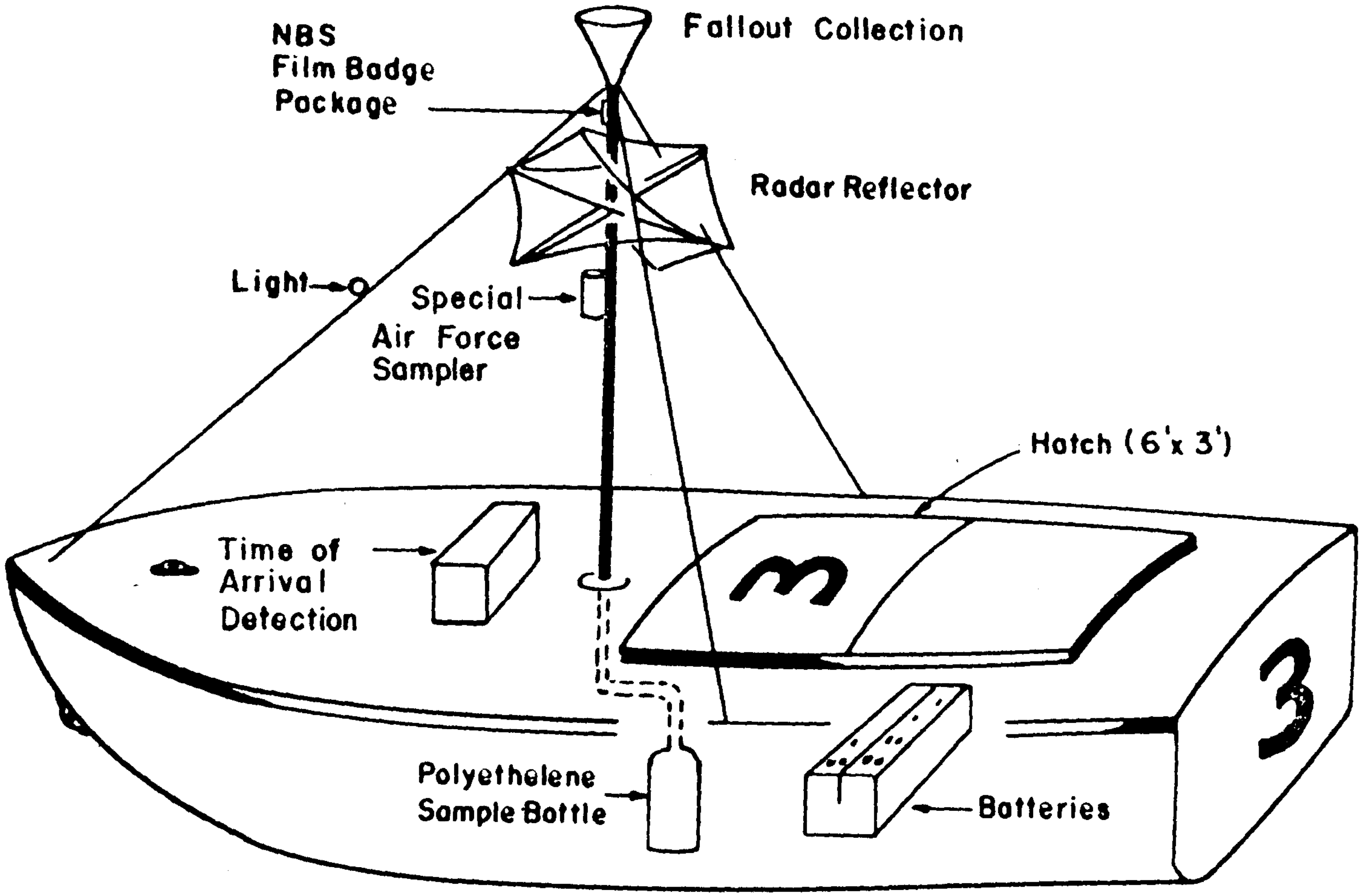


Figure 4.1 Location of instruments on deep-moored skiffs.

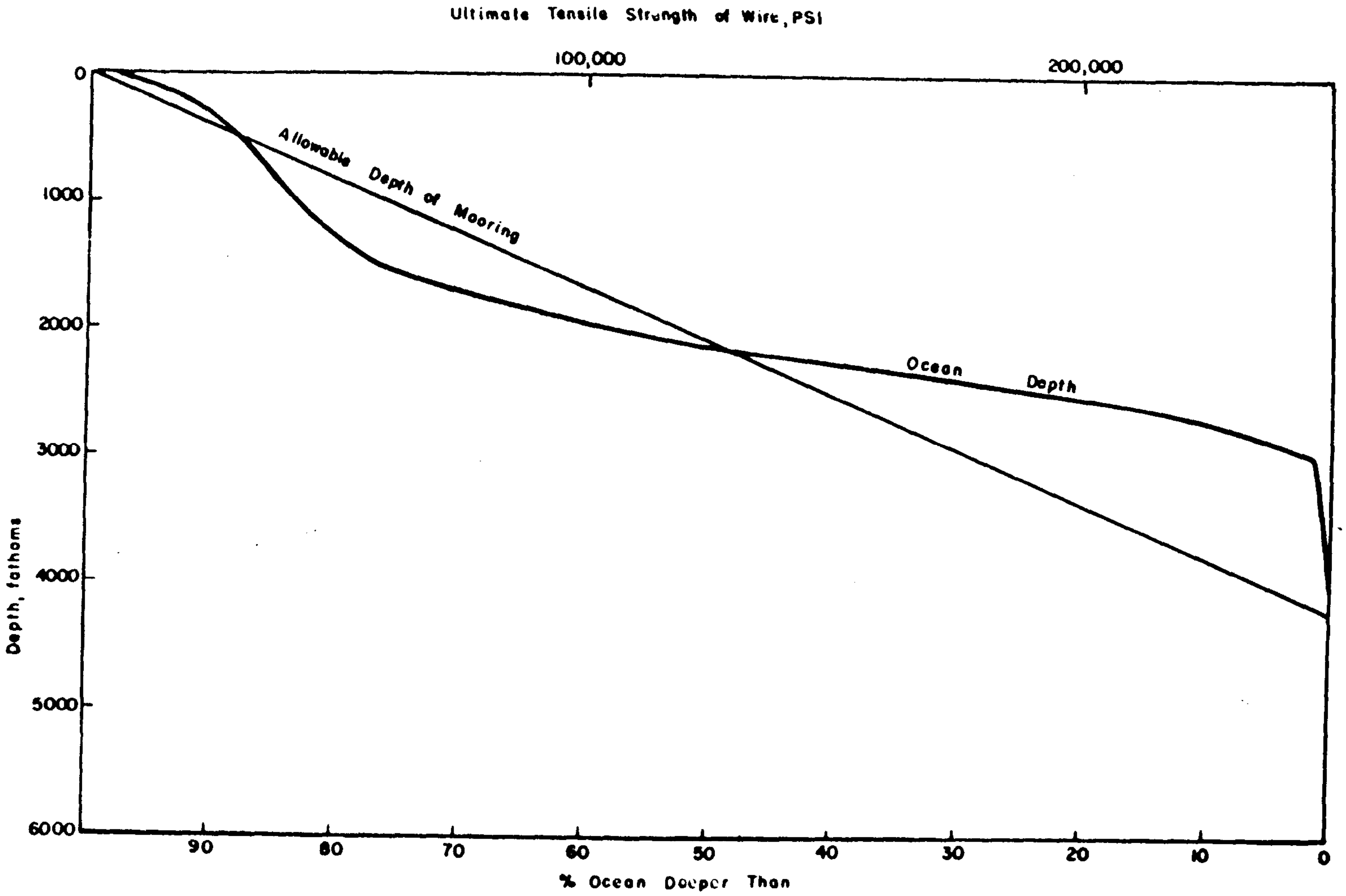
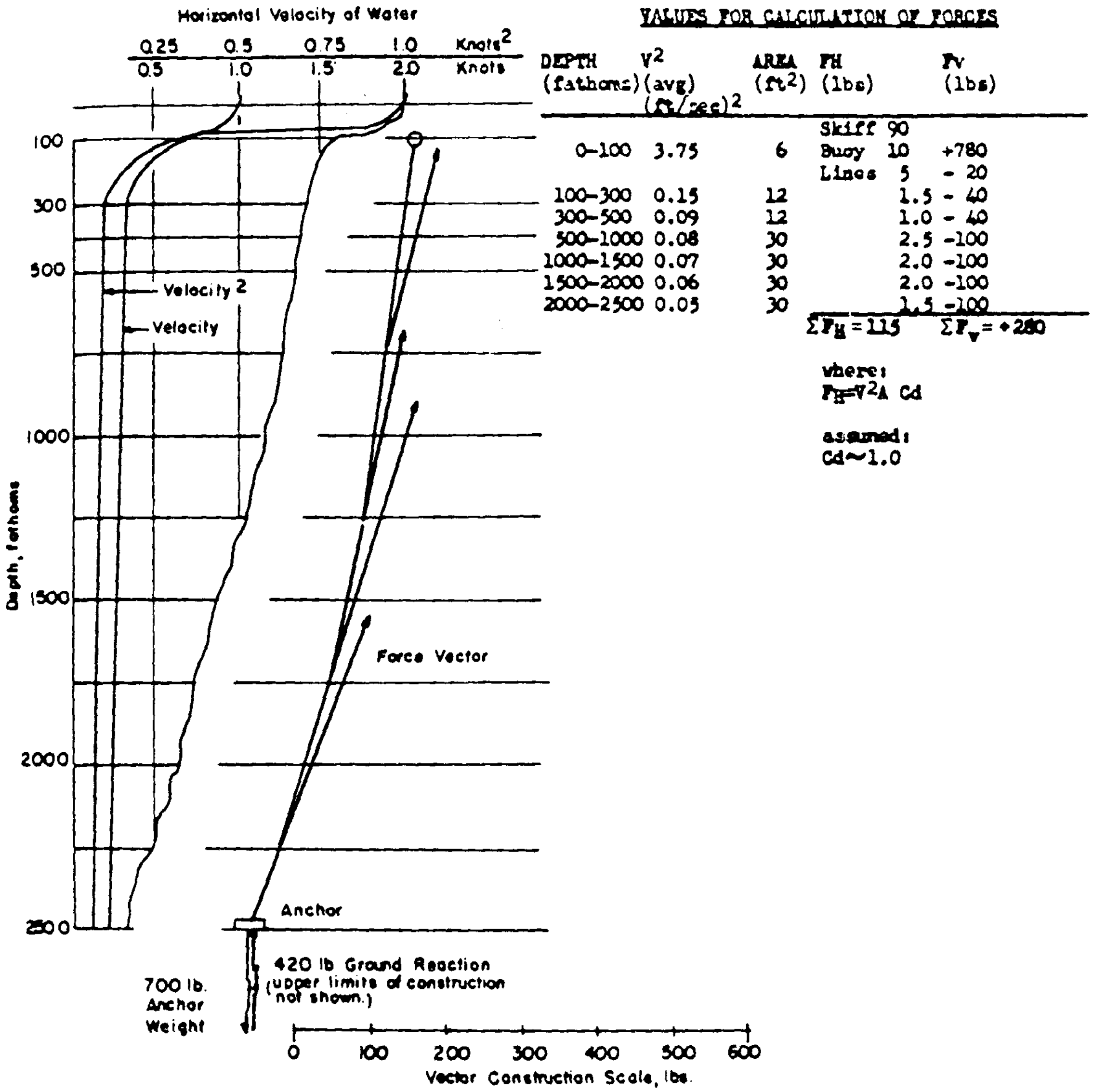


Figure 4.2 Allowable depth of mooring versus ultimate tensile strength of wire.



VALUES FOR CALCULATION OF FORCES

DEPTH (fathoms)	V^2 (avg) $(ft/sec)^2$	AREA (ft^2)	FH (lbs)	Fv (lbs)
			Skiff 90	
0-100	3.75	6	Buoy 10	+780
			Lines 5	- 20
100-300	0.15	12	1.5	- 40
300-500	0.09	12	1.0	- 40
500-1000	0.08	30	2.5	-100
1000-1500	0.07	30	2.0	-100
1500-2000	0.06	30	2.0	-100
2000-2500	0.05	30	1.5	-100
			$\Sigma F_H = 115$	$\Sigma F_v = +280$

where:
$F_H = V^2 A\ Cd$

assumed:
$Cd \sim 1.0$

Figure 4.3 Graphical construction of deep mooring configuration.

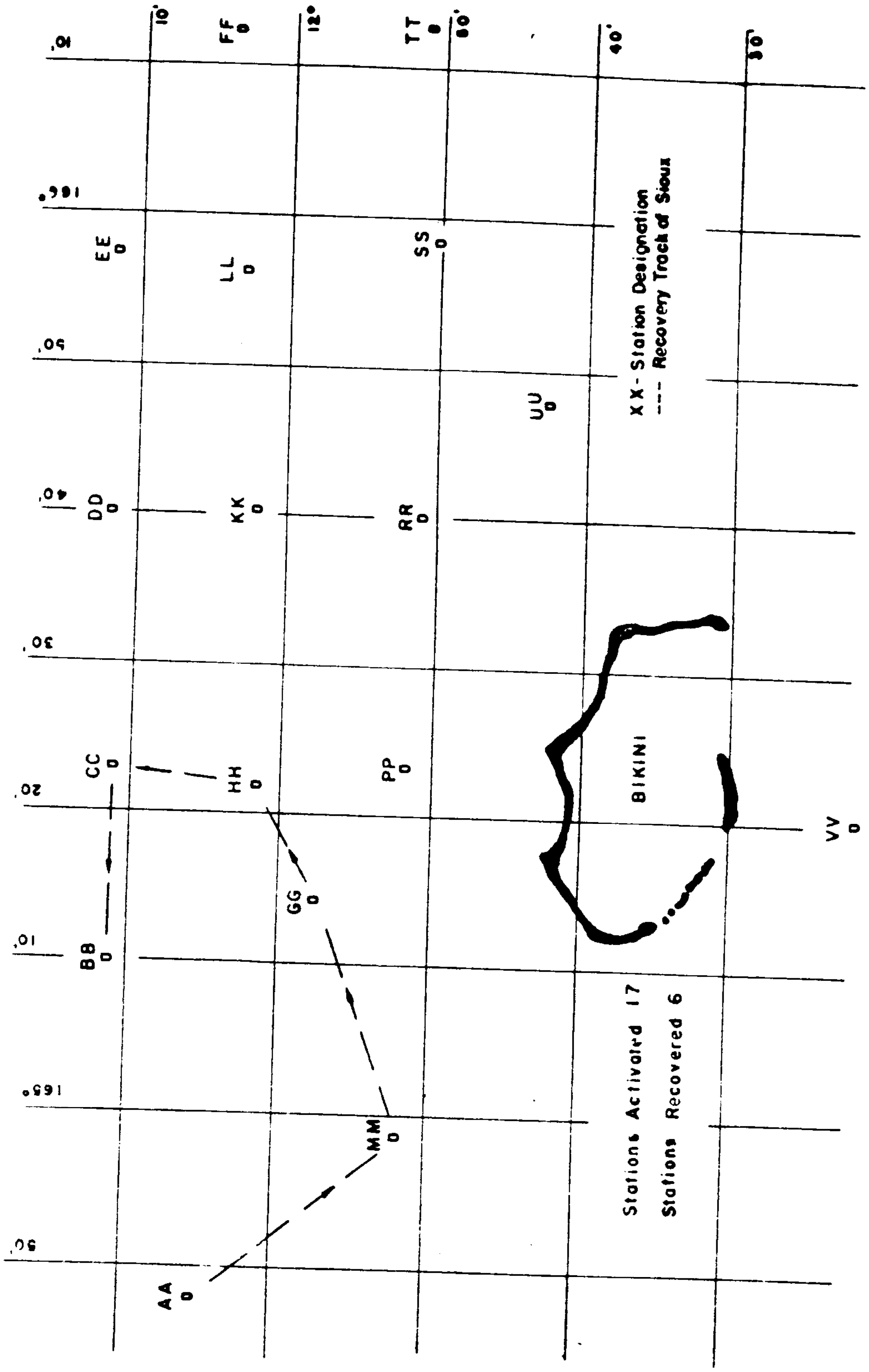


Figure 4.4 Skiff distribution for Shot Cherokee.

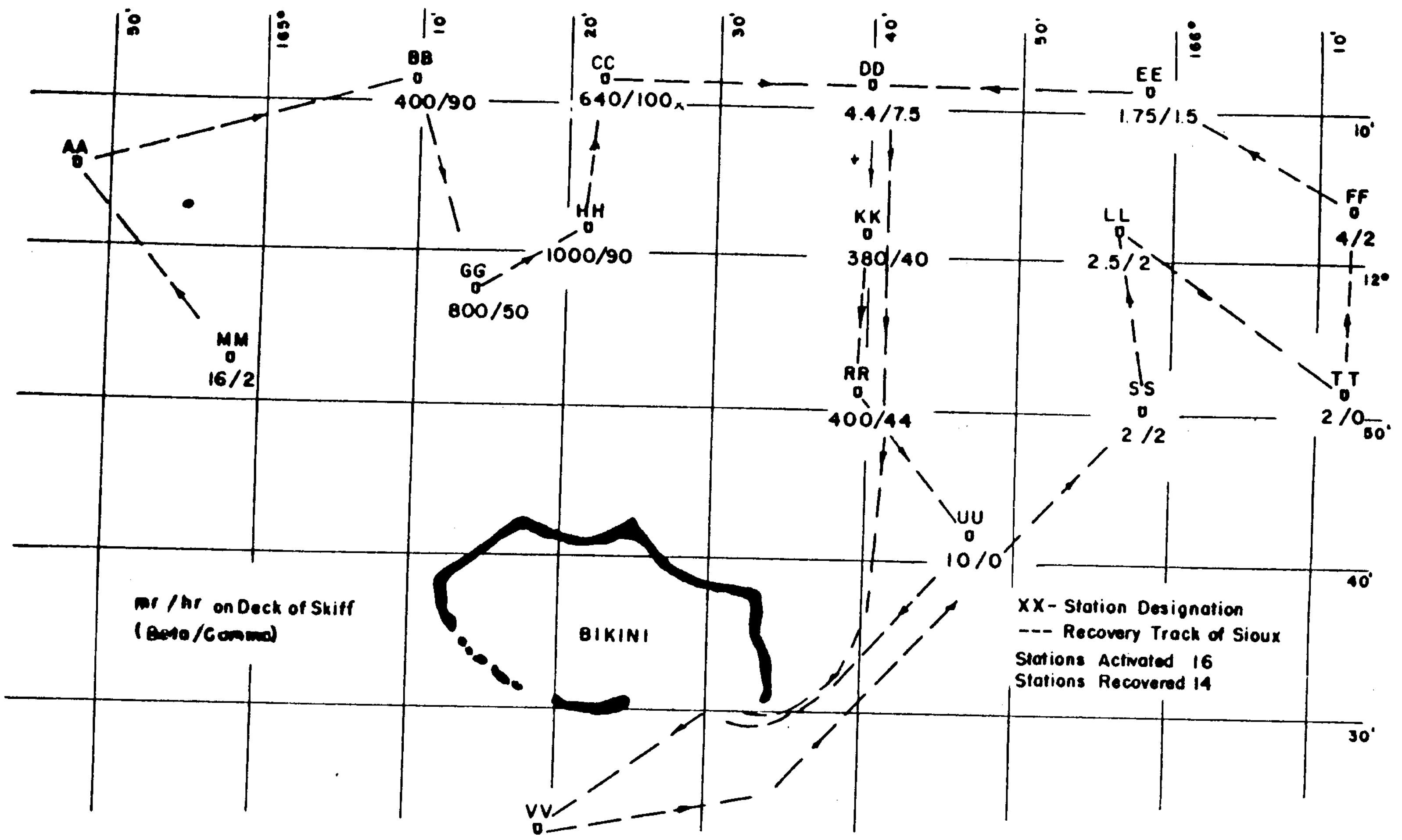


Figure 4.5 Skiff distribution and fallout contamination for Shot Zuni.

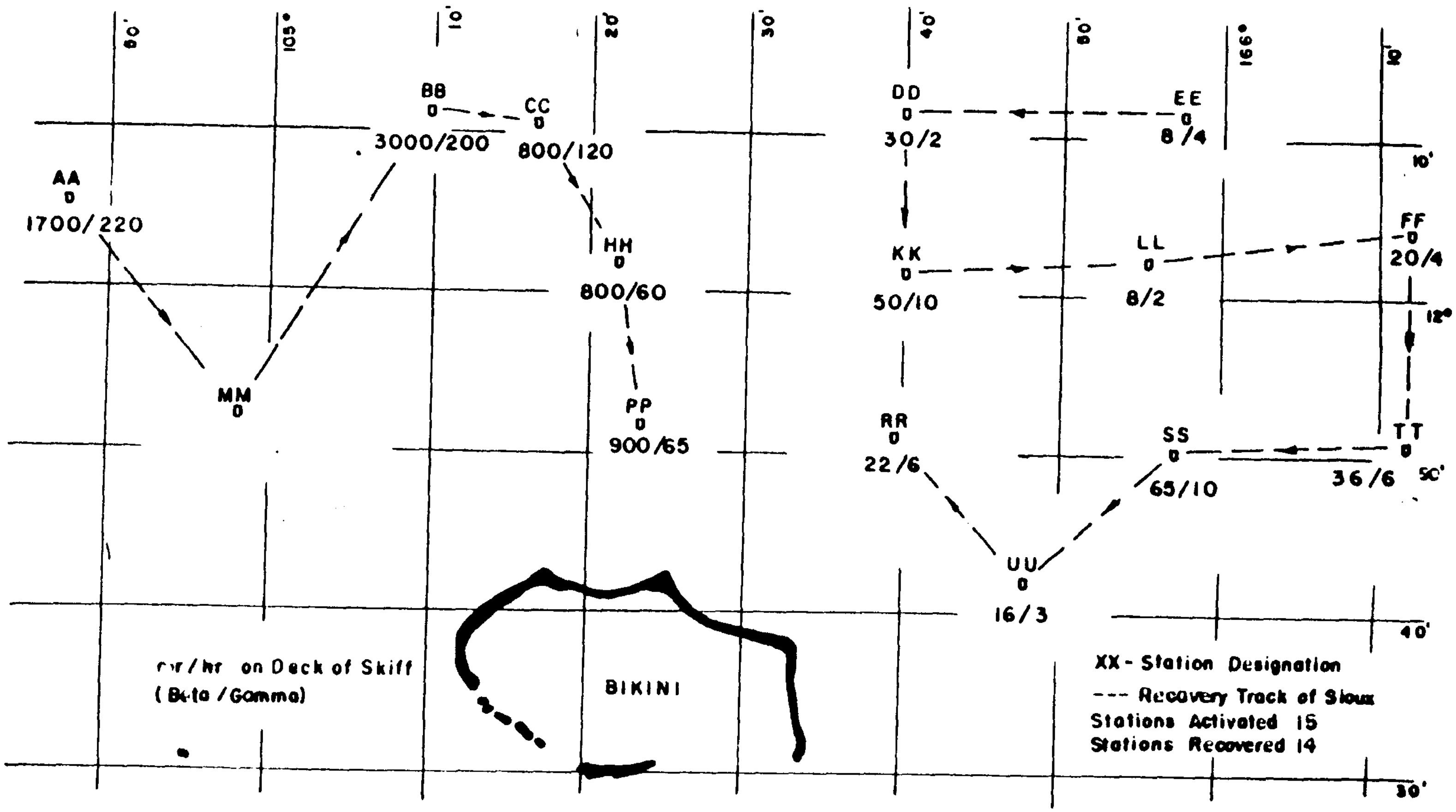


Figure 4.6 Skiff distribution and fallout contamination for Shot Flathead.

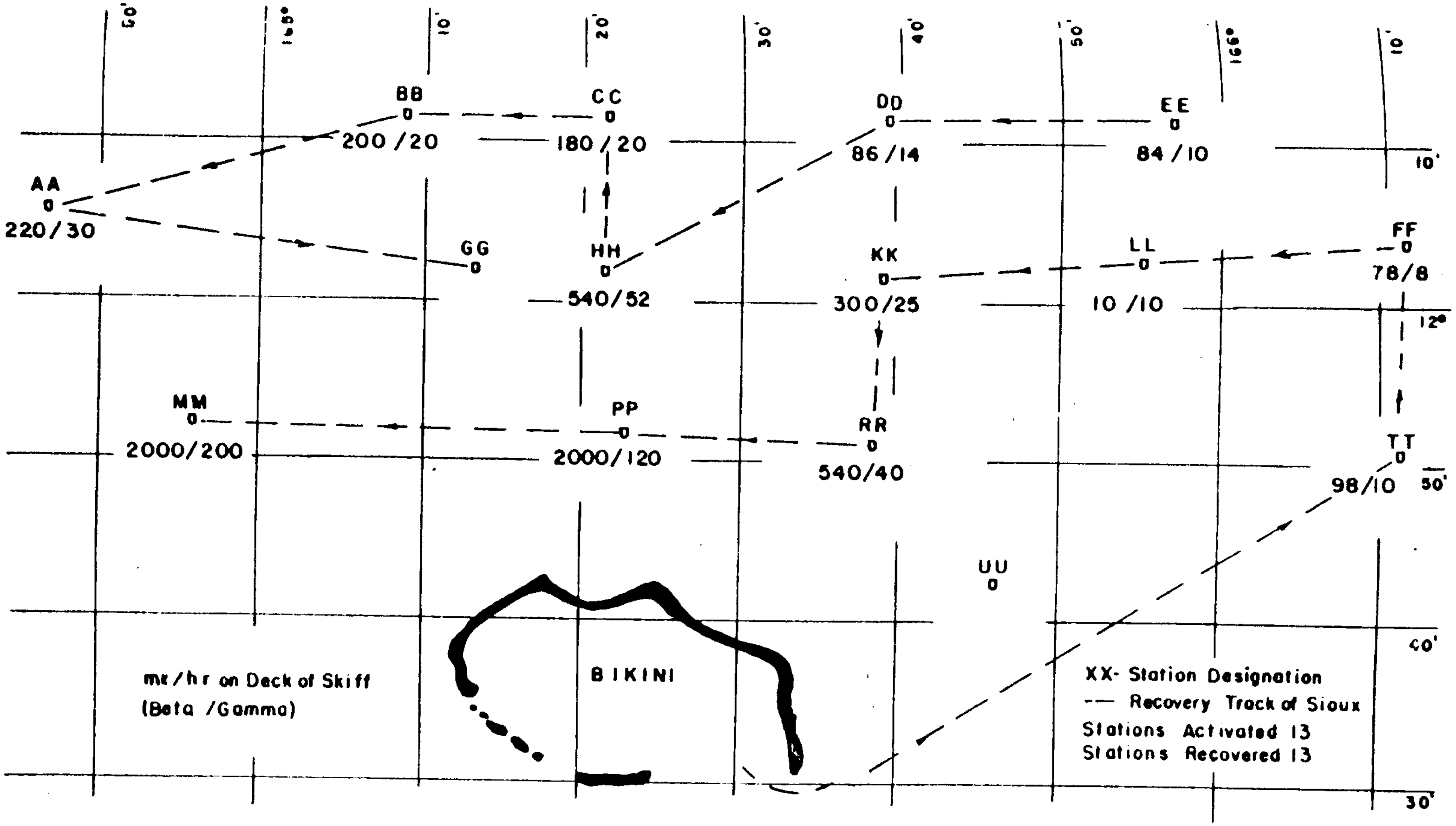


Figure 4.7 Skiff distribution and fallout contamination for Shot Navajo.

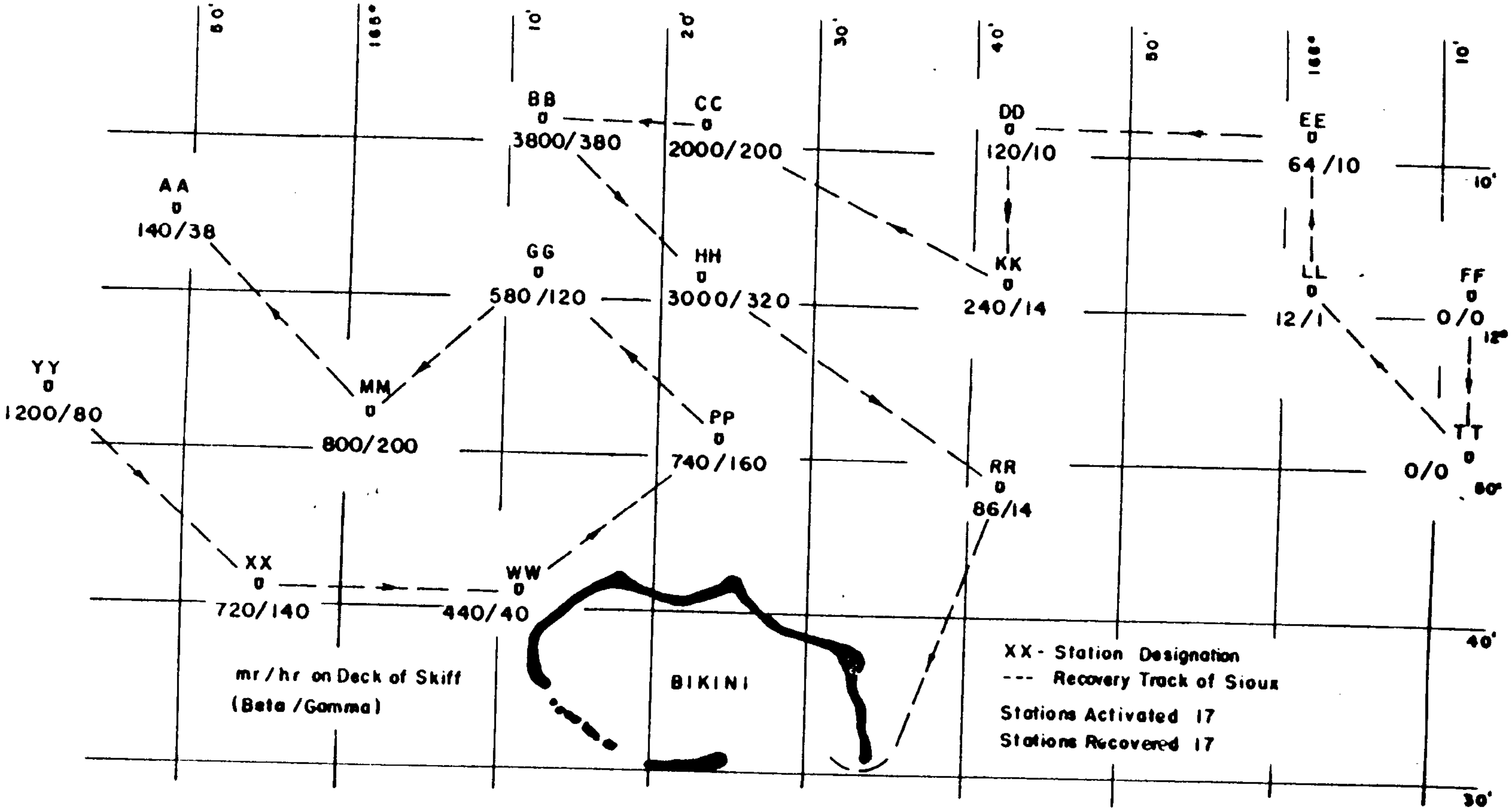


Figure 4.8 Skiff distribution and fallout contamination for Shot Tewa.

Chapter 5
RADIOLOGICAL INVESTIGATION of the MARINE ENVIRONMENT

5.1 OBJECTIVES

A modest radiochemical program was established in order to obtain information concerning the distribution of radioactive contamination of an in situ marine environment. This work was to be accomplished aboard ship. The objectives of the program were to sample the air over the sea surface, water from various depths, sediments from the ocean floor, and marine organisms for (1) the determination of gross radioactivity and (2) an examination of chemical or nuclide partition among the various phases of the hydrosphere from both Redwing and previous operations.

5.2 BACKGROUND

The oceanographic conditions and background radioactivity prior to Operation Redwing have been described in Reference 2, which details the sampling techniques, shipboard operations, instrumentation, and preliminary results.

The study of the fallout problems of the fission products may be carried out in specific detail in the laboratory and in retrospect after a nuclear detonation has occurred; but in so doing, localized and transitory effects may be lost. The possibility of studying the fallout conditions as they occur is desirable in the ocean, where continuous changes take place. The ultimate fate of the fallout fission products is important with respect to the contamination of the ocean waters and of food fish. The manner in which the radioactive isotopes enter the food chain may be studied by early sampling and analysis of water, particulate matter, and planktonic organisms.

Mixed zooplankton collected around Bikini Atoll between 29 May and 8 June 1956 displayed levels of activity ranging from 10^4 β dis/min in the southeast to 2×10^6 β dis/min per wet gram northwest of the atoll. At Zuni + 10 hours 1.2×10^6 β dis/min of fission products were detected in gross zooplankton, with individual organisms displaying 10^4 and 10^5 β dis/min, corresponding roughly to the surface area of the plankton. The inability to accurately determine milligram weights aboard ship prevented correlation of activity with mass.

At H + 16 hours, fallout occurred aboard the M/V Horizon, producing a gamma background that prevented the use of gamma counting. The gamma energy spectrum of a 1-gram drained wet weight sample of mixed zooplankton collected at 11° 27′ N, 164° 33′ E on 7 June 1956 is shown in Figure 5.10. The complexity of the spectrum and the high background shown by the lower curve prevented any identification of the nuclides present by gamma counting alone. After 16 months' decay, the gamma spectrum of this sample indicated the presence of Ce^{144}, Ru^{106}, Zr^{95}, Mn^{54} and Zn^{65} as shown in Figure 5.11.

Between Shots Flathead, 12 June 1956, and Navajo, 11 July 1956, a hydrographic survey was undertaken between 11° and 13° N and 163° and 165° 40′ E during which water and plankton were collected for radioassay. The relative activity of gross plankton varied from 3×10^4 $(\gamma/\text{min})/\text{gm}$ at 11° N 165° 40′ E to a maximum of 5×10^6 $(\gamma/\text{min})/\text{gm}$ at 12° 30′ N 165° E with 1.5×10^5 $(\gamma/\text{min})/\text{gm}$ detected along the 163° E western boundary of the survey from 11° N to 13° N between 30 June and 7 July 1956. Radiochemical analysis on 1 January 1957 showed almost constant ratios of Ce^{141}, Ce^{144}, Sr^{89}, Ru^{103}, Ru^{106}, and Zr^{95}, with traces of Mn^{54} and Zn^{65} among eight samples. Eleven months after collection at 12° N 165° E, on 6 July 1956, Sample S-44 assayed 1,300 dis/min Ce^{144}, 28 dis/min Sb^{125}, 300 dis/min Ru^{106}, 310 dis/min Zr^{95}, 26 dis/min Mn^{54}, 330 dis/min Zn^{65}, and 52 dis/min Co^{60} per gram.

Barnacles collected in the open ocean northwest of Bikini Atoll at 12° 27′ N 165° 56.1′ E on 12 July 1956 after a nine-week period of growth during testing displayed 1,700 dis/min Ce^{144}, 1,100 dis/min Sb^{125}, 12,000 dis/min Ru^{106}, 3,000 dis/min Ru^{103}, 1,000 dis/min Zr^{95}, 5,700 dis/min Mn^{54}, 3,000 dis/min Zn^{65} and 160 dis/min Co^{60} per wet gram of body.

Tridacna clam livers collected in Bikini Lagoon during June 1956 and assayed 1 January 1957 showed cobalt contamination of the order of 50,000 dis/min Co^{60} and 14,000 dis/min Co^{57} per gram of the dry organ similar to the pre-Redwing specimens with the addition of only a few percent of Ru^{103} and Zr^{95}. On the other hand, a young, 3-inch tridacna clam collected off site in late July 1956 and assayed 6 March 1957 showed predominately recent 71-day 140×10^3 dis/min Co^{58}, 20×10^3 dis/min Mn^{54}, 30×10^3 dis/min Ru^{106}, with Ce^{144}, Zr^{95}, and Zn^{65} also present.

After completion of Redwing testing, a survey of plankton across the equatorial Pacific showed 2,500 (dis/min)/gm at 11°N 160°E to 10 dis/min at 11° S 164°E. Figure 5.5 gives the total dis/min of Ce^{144}, Ru^{103}, Ru^{106}, Zr^{95}, Mn^{54}, Zn^{65}, Co^{57}, Co^{58}, and Co^{60} per gram drained plankton with the percentage of Zn^{65} given in parenthesis. Duplicate samples taken a month apart at 11°N 164° E showed chiefly uranium fission products with 17 percent Zn^{65} at first sampling and then the nonfission products, cobalt, manganese, and zinc with 70 percent Zn^{65} in the sample collected 3 September 1956. The Co^{60} concentration in the Equapac plankton ranged from 1 to 4 percent. One sample, rich in pteropods, from 11°N 160°E assayed 16 percent Co^{60} and 22 percent Zn^{65}. Samples from the two adjacent stations assayed 90 percent and 83 percent Zn^{65}, and 1 percent and 0.7 percent of Co^{60}. The cobalt concentration appears to be related to the pteropod population. If this is true, then perhaps Co^{60} could be used as a tracer for measuring the mass movement of a pteropod colony, which may tend to retain the radioactive material within a given mass of water.

5.3 THEORY

A partition of chemical species should occur between the air and water interface of the oceans, where solution and precipitation take place. This process of separation continues to take place in the water, wherein temperature, pressure, and pH effects come into action. A separation of the more-soluble from the less-soluble compounds will tend to concentrate certain isotopes in one phase or another. Biological fractionation and concentrations will occur through the specific ingestion and absorption of certain elements by marine bacteria and plankton. Specific radionuclides will be concentrated in such organs as the liver and skeleton of commercially important food fish. An attempt was to be made to determine the distribution of the radioactivity among the various marine phases.

5.4 OPERATIONS

5.4.1 Airborne Analysis.

Airborne particulate matter was sampled after each shot with a vacuum pump and Millipore aerosol filters. A known rate of air volume was filtered for a known period of time. In most instances, air was sampled for an hour at the rate of 20 liters/min. During periods of high airborne activity, samples were taken for particulate size determination by filtering the air through a series of three graded filters, ranging from approximately 10 to 0.45 microns. These filters have not been calibrated and give only an approximate indication of the particle sizes retained. Decay curves were plotted for several of the samples to determine if any differentiation existed between various samples.

5.4.2 Water Analysis.

Water samples were obtained from the sea surface and from various depths over varying times. Surface water was collected and stored in polyethylene bottles for later analysis. Depth samples were taken with Nansen bottles. Whenever possible, samples were worked up without storage to prevent any possible change or adsorption by the storage container.

The water was counted for gross activity and was filtered for particulate size study. Two methods were used for counting the water. In cases where the activity was considerably higher than background, an aliquot of the water was evaporated (in a drying oven) to salt, which was then counted. In cases where such treatment gave inaccurate counting rates, the water was treated with ferric ammonium sulfate and ammonium hydroxide to carry down the radioactive species. The precipitate thus obtained from 1 to 10 liters of water was then counted for beta and gamma radiation. Some of the samples were filtered through a series of graded filters in order to determine if any relationship existed between particulate matter and total activity. Standard chemical group separations of the $Fe(OH)_3$ precipitates were begun aboard ship and completed ashore at a later date. Decay curves were plotted for both beta and gamma radiation where conditions permitted counting aboard ship. The salinity of the samples was determined by chlorinity analysis and was compared with gamma activity to see if any relationship existed between radioactivity and salinity with depth.

5.4.3 Particulate Analysis. The particulate matter from sea water was filtered through graded Schleicher and Schuell (SS) filters. A series of SS membrane filters were used in a vacuum-filtration apparatus. These filters ranged in porosity from 1.0 to 0.1 microns. Further filtration of the filtrate from the above series was accomplished with graded ultrafine SS filters ranging from a mean porosity of 0.1 to 0.01 microns. The water was filtered under a pressure of 1,000 psi in an ultrafilter pressure device. Sea water was also filtered through cellulose and Millipore filters to compare their retention and adsorption properties. Number 20 phytoplankton nets were used to filter the phytoplankton from the surface waters. The resulting hauls were filtered through a Millipore filter and counted for the beta and gamma activity. Radioautographs were attempted from the filters in order to impress the image of the active particulate matter on film. Kodak high-contrast lantern slides were used.

5.4.4 Sediment Analysis. A gravity-coring device was used to sample the ocean floor. Lagoon sediments were collected with a bottom grab and by skin divers. The sediments were counted for beta and gamma activity. Radioautographs of vertical core sections were made to determine the penetration of Ru^{106} through the surface of the pelagic sediments.

5.4.5 Biological Sampling. Extensive sampling of zooplankton was made to determine the gross contamination of the marine life in the EPG. Plankton was netted with a 1-meter-diameter net used to collect zooplankton from the surface to 300 meters. A 0.8-gram portion of the mixed plankton was dried on a copper planchet and counted for both beta and gamma activity. Decay curves were run on the gross plankton. Individual organisms were selected from the mixed samples, dried under an infrared lamp, and counted for radioactivity. Gamma energy spectrum analysis and chemical group separations were run on gross zooplankton to identify specific isotopes.

A varied assortment of flying fish, squid, lobsters, coconut crabs, water fowl, lagoon fish, molluscs, algae, barnacles, and calcareous coral were obtained and assayed for fission products and induced radioactivity.

5.5 INSTRUMENTATION

The M/V Horizon was equipped with an elementary radiochemistry laboratory, which was capable of collecting samples, weighing or measuring, drying or ashing of organic matter, separation of periodic groups, and counting both beta and gamma radiation. Gamma energy spectra were studied with a single-channel, step-pulse-height analyzer. A 2½-inch, sodium iodide, well-type crystal, bonded to a Dumont 6292 photomultiplier tube was used to detect the gamma photons.

Gross beta counts were made with a 1.4 mg/cm^2 mica-end-window G-M tube driving a decade scaler. The tube was shielded by a 2-inch-thick, lead sample holder.

Gamma rays were counted with a 2-inch-lead-shielded, 1½-inch sodium iodide crystal, RCA 5819 photomultiplier tube, preamplifier, and decade scaler. Several laboratory survey meters were available for monitoring and rough estimation of samples.

The RCL 256 channel pulse height analyzer and shielded, low-level 3-inch sodium iodide counter was used for checking the gamma energy spectrum results and for intercalibration of the 2½-inch, NaI, single-channel analyzer.

5.6 RESULTS AND DISCUSSION

5.6.1 Airborne Activity. Table 5.1 presents the results of a portion of airborne particulate samples collected on aerosol Millipore filters. The sampling was begun at shot time and carried on for 24 hours or longer. An increase is shown in the air counts from 7 to 15 hours after detonation, depending upon the position of the ship. Sixteen hours after Shot Zuni, the M/V Horizon received dry particulate fallout. Following the fallout, the background of the ship was found to be from 5 to 30 mr/hr, as measured with a survey meter. The gamma background of the lead-shielded scintillation counters rose to 10^6 counts/min, preventing any low-level counting. After several days, the level had dropped to a point where beta counting was possible with an instrument background of 250 to 500 counts/min. The best record of airborne activity was obtained from Shot Dakota, while the ship was moored at Site Elmer. Figure 5.1 shows the record of the airborne activity during a time when the instrument background had decayed to about 1,500 counts/min gamma. Figure 5.2 gives the decay curves for three Dakota air samples. For each sample the radioactive decay constant K, as described in Section 2.6.12, is indicated. A peculiar abrupt change in slope occurs in each case. This could have been due to an instrument error. However, curve D-1 appears to have a smooth transition between the two slopes.

Figure 5.3 gives the decay curves for the particulate matter filtered through a Millipore filter following Shot Tewa. The decay constant K is again indicated, but since both gamma and beta activity are shown in this figure, the gamma decay is labelled γK and the beta, βK. The decay curves are presented with those of the feathers of a live bird that had been singed by the shot. Some fractionation had taken place.

Table 5.2 gives a comparison of the beta activity with particle size range for three filters in series.

The particulate samples shown in Table 5.1 were insufficient for a complete chemical analysis. A gamma spectrum of a series of air samples collected at Site Elmer from 10 to 20 hours after Shot Dakota and analyzed 25 August 1956 showed the presence of 150 to 135 Mev photons of Ce^{141} and Ce^{144}, 420 dis/min Ru^{103}, 610 dis/min Zr^{95} per 10^4 liters of air; no Ba^{140} was detected.

An analysis of the singed feathers of a live water fowl caught 23 July 1956 at 11°53′N, 165° 12.8′E and analyzed 23 June 1957 gave 0 dis/min Ce^{144}, 110 dis/min Ru^{106}, 30 dis/min Zr^{95}, 45 dis/min Mn^{54}, and 400 dis/min Zn^{65}. The absence of the rare earths and the predominance of Zn^{65} suggests that the activity may have been internal, rather than from airborne particulate matter.

5.6.2 Water Analysis. Elemental iodine is readily adsorbed on polyethylene. Sodium iodide carrier was added to some of the water samples to reduce the oxidation and adsorption loss of I^{131}. Visible discoloration of the containers by free iodine was observed in most instances.

Mn^{54} was identified in a number of samples of sea water. This isotope, probably existing as Mn^{+7}, appears to be reduced to insoluble MnO_2 on the organic surface of polyethylene storage bottles. After one year storage, a 1-liter bottle containing 30×10^{10} atoms of Mn^{54} in sea water had adsorbed 16 percent of the manganese as MnO_2.

Shot Cherokee, 21 May 1956, produced insufficient oceanic contamination along the track of the M/V Horizon for an accurate assay.

Shot Zuni, 28 May 1956, produced airborne activity detected at H + 10 hours at 12° 02′N, 165° 32′E. At H + 15 hours fallout occurred aboard the M/V Horizon. The instrumental background of the gamma scintillation counters and pulse height analyzer increased from 110 counts per minute to over 10^6 counts per minute in spite of 2 inches of lead shielding. Water samples collected subsequent to Shot Zuni were processed, but were not assayed aboard ship. Gross beta counting of evaporated water samples was used for comparative evaluation of total activity and of chemical group activities.

The average values of four surface water samples collected along the Horizon track 28 May to 1 June 1956 and analyzed 1 June 1957, assayed 8,300 (dis/min)/liter Ce^{144}, 1,250 (dis/min)/liter Ru^{106}, none of the Cs^{137}, less than 400 (dis/min)/liter Mn^{54}, and a trace of Zn^{65}. A depth of 80 meters at the same stations gave 5,000 (dis/min)/liter Ce^{144}, 2,250 (dis/min)/liter Ru^{106}, 500 (dis/min)/liter of Cs^{137}, 300 (dis/min)/liter Mn^{54}, and about 200 (dis/min)/liter of Zn^{65}. At 80 meters' depth, 33 percent of cerium, 8 percent of ruthenium, 45 percent of manganese, and 100 percent of the zinc were removed from the water by filtration through a 0.5 micron Millipore filter. No significant variation of activity or isotopic concentration was observed with depth above the thermocline. The activity below the thermocline was insufficient for radiochemical analysis.

Shot Flathead, 12 June 1956, produced widespread oceanic contamination presisting until the next event in the area northwest of Bikini Atoll between 11° to 14°N and 163° to 166° E. Variations of surface water activity ranged from 10^2 to 3×10^5 relative counts per minute at 49 stations between 30 June and 7 July 1956. A typical surface water sample, collected 15 June 1956 at 12° 24′ N, 164° 30′ E and analyzed 15 June 1957 showed the presence of 3,800 dis/min Ce^{144}, about 600 dis/min Ru^{103}, 2,560 dis/min Ru^{106}, 390 dis/min Cs^{137}, and 1,400 dis/min Zr^{95} per liter of sea water. Mn^{54}, Sb^{125}, Zn^{65} and Co^{60} were not detected above the 100 to 200 (dis/min)/liter lower limit of detectability for this sample.

The vertical distribution of total activity northwest of Bikini Atoll at H + 400 to H + 600 hours was constant or decreased to the thermocline, reached a minimum at 200 or 300 meters, and increased to a maximum of one to four times the surface activity at a depth of 500 to 800 meters. In general, the point of minimum radioactivity coincided with the salinity minimum. This maximum pool of deep water contamination coincides with the deep water area of contamination found northwest of Bikini Atoll in April 1956 prior to Operation Redwing. Figure 5.4 shows the relative variation of radioactivity with depth at three stations between 12° and 13°N at 164° to 165° E. These are compared to the average April 1956 values in the same general areas.

Shot Navajo, 11 July 1956, produced from 1×10^5 to 3×10^7 (counts/min)/liter of surface water along the Horizon track west of Bikini Atoll at H + 2 and H + 3 days. Vertical water profiles indicated uniform contamination to the thermocline below which the gross activity increased 2 to 3 fold reaching a maximum between 500 and 800 meters. The deep water activity, exhibiting the same order of magnitude as observed in a pre-Navajo survey and having a half life three to five times greater than the 70-hour half life observed in the surface water at H + 60 hours, probably originated prior to Shot Navajo, which might be expected also to contribute to the subthermocline contamination.

The analyses of water samples at various depths for three stations west of Bikini Atoll are shown in Table 5.3. The values are reported as of 1 July 1957. A substantial portion, about 37 percent of the total gamma-emitting isotopes, are radioisotopes not ordinarily associated with fission products, with Mn^{54} contributing about 30 percent of the total activity.

Shot Tewa, 21 July 1956, produced approximately the same level of oceanic contamination west of Bikini as the previous Navajo test. A sample of surface water collected 22 July 1956 at 12° 05′ N, 165° 16′ E assayed 16×10^6 (γ/min)/liter at H + 54 hours. The sediment filtered from the same volume of water through a 0.5 micron filter counted 4.8×10^6 (γ/min)/liter at H + 54 hours. The analysis of this sample, presented in Table 5.4 shows the presence of Ce^{144}, Ru^{103}, Ru^{106}, Cs^{137} and Zr^{95} after 10 months of decay. Mn^{54} is present only to the extent of 3 percent of the total gamma emitters, as compared to 30 percent in the Navajo samples. The Mn^{54} may have originated in a previous test.

Bikini Lagoon water contamination between shots appeared to be largely associated with suspended particulate matter, with the greatest concentration of activity located near the floor of the lagoon. An analysis of bottom water is shown in Table 5.5. On a volume basis, 43 percent of the activity of one bottom water sample collected on 29 May 1956 at 11° 30′ 02″ E was associated with the suspended particulate matter in the 0.5-to-10-micron range. On a weight basis, 0.2 percent of the activity was dissolved in the water, 7 percent was associated with the 10-to-

1,000-micron range, and 92.5 percent was associated with the 0.5-to-10-micron particulate matter.

Subsequent to Operation Redwing, surface-water samples were collected off Site Elmer in Eniwetok Lagoon on 1 September 1956. An analysis of this water on 1 June 1957 indicated 187 dis/min Ce^{144}, 160 dis/min Ru^{106}, 52 dis/min Cs^{137}, less than 15 dis/min Mn^{54}, less than 30 dis/min Zn^{65}, and 80 γ/min of K^{40} per liter of sea water.

During the interval between 28 November and 11 December 1956, a series of cores and bottom samples were obtained in the vicinity of 11° 18′ N, 162° 57′ E. An analysis of the water obtained from over the surface of 12 cores indicated the presence of 105 dis/min of the rare earths, 26 dis/min of the alkali earths, 4 dis/min of the alkali metals, 90 dis/min of Ru^{106}, 7.5 dis/min Zr^{95}, 12 dis/min Zn^{65}, and 690 dis/min K^{40} per liter of bottom water on 20 July 1957. Most of this contamination was associated with the finely divided sedimentary matter stirred up from the disturbed surface of the cores.

In August 1956, the M/V Horizon undertook an equatorial Pacific expedition (Equapac), during which water and plankton were collected and assayed for radioactivity. Along the entire track from 11°N to 11°S at 164°E, and 5°S to 11°N at 157°E, radioactivity was detected in the plankton. Fission-product radioactivity was detected in the surface water and at 500 meters' depth between 3° and 11°N. Only a trace amount of activity was detected south of the equator. The concentration of Ce^{144}, Ru^{103}, Ru^{106}, Zr^{95}, Mn^{54}, Zn^{65}, Co^{57}, Co^{58}, Co^{60} isotopes in 1 gram of plankton (drained wet weight) over the activity of 1 gram of sea water ranged from 2×10^3 to 150×10^3, with the average concentration factor of 2×10^4 for 28 Equapac stations. The radioactivity of gross zooplankton offers a more easily measurable index of oceanic contamination than the time-consuming analysis of sea water. Figure 5.5 presents the activity per wet gram of zooplankton, or the approximate activity per 20 liters of surface water.

5.6.3 Suspended Particulate Matter. Filtration of sea-water samples through 0.5 micron Millipore filters removed from 25 to 75 percent of the radioactivity. Duplicate samples from the same station varied by a factor of two. Figure 5.6 gives the gamma spectra of the soluble and particulate fractions of a Tewa surface water sample. In general, the activity associated with the particulate matter was greater in the surface water than in the deeper water. Radioautographs of the suspended surface matter showed inhomogeneous "hot spots" corresponding to the larger diatoms, dinoflagellates, and radiolaria.

Scavenging the sea water from all depths with $Fe(OH)_3$ carrier removed from 60 to 75 percent of the activity. Zirconium, manganese, and the rare earths were almost quantitatively removed. The percentage of ruthenium recovered varied greatly from sample to sample. Natural K^{40} and the long-lived cesium and strontium isotopes are not recovered by filtration.

Filtration through a series of graded SS ultra filters at 1,000 psi showed that 25 to 50 percent of the activity was retained with particulate matter greater than 0.5 microns. Several percent of the radioactivity was retained in each size range down to 0.01 microns. Zr^{95}, Ru^{103}, and Ce^{141} were identified in the 3-to-0.75-micron range. Ruthenium and cerium were identified in the 0.75-to-0.5-micron region. Ruthenium and manganese were identified on all the remaining filters between 0.5 and 0.01 microns.

Table 5.6 shows a typical distribution of radioactivity with particle size between 3 and 0.01 microns for a Navajo sample of surface water and 50-meter water. Filtration through a series of three 0.5 micron Millipore filters retained 33 percent of the activity on the top filter, 0.03 percent on the middle filter, and 0.03 percent on the bottom filter. At H + 75 hours the top filter exhibited a 4-day half life, whereas the middle and bottom filters showed about a 95-day half life, with Mn^{54} being the most prominent isotope.

5.6.4 Lagoon Sediments. Prior to Shot Cherokee, 21 May 1956, the predominant isotopes detected in the Bikini Lagoon sediments were Ce^{144}, ranging from 1×10^3 (dis/min)/gm in the southeastern section to 40×10^3 (dis/min)/gm in the northwestern area, and Ru^{106} contributing about a fourth as much activity as the cerium. Traces of Sb^{125}, Mn^{54}, and Zn^{65} were also found in the sediments. In several bottom samples obtained near Sites Charlie and Oboe, Sr^{90}, Cs^{137}, and Sb^{125} contributed 30 to 40 percent of the total activity associated with a mixture of sand and water from the sediments. The rare earths and Ru^{106} contributed the remaining activity. The strontium, cesium, and antimony were dissolved in the water associated with the bottom sand, but nevertheless appeared to be trapped within the sediments. One sediment water sample collected off Site Charlie 4 May 1956 and analyzed 15 May 1956 assayed 2.5×10^5 dis/min Sb^{125} and 5×10^5 dis/min Cs^{137} per liter. Immediately following Cherokee no change was detected in the Bikini Lagoon sediments.

Subsequent to Shot Zuni, 28 May 1956, young fission products were detected in the western portion of the lagoon, with the older Ce^{144} and Ru^{106} still predominating. Table 5.5 presents an analysis of the bottom water and sediments from the southern portion of the lagoon following Shot Zuni. About 90 percent of the activity is associated with the finely divided particulate matter stirred into the water during collection, with less than 10 percent associated with the coarse coral particles in the 10-to-1,000-micron range.

During the Redwing testing, the shells from living organisms in Bikini Lagoon displayed predominately the pre-Redwing fission products Ce^{144} and Ru^{106}. Coral skeletons also showed Ce^{144}, Ru^{106}, Mn^{54}, and Zn^{65} of the order of 1 to 20 dis/min of each isotope per gram. On the other hand, corralline algae and green algae growing on the above shells and coral showed the presence of Ce^{141}, Ru^{103}, I^{131}, Ba^{140} and Zr^{95} immediately following Zuni and subsequent shots.

5.6.5 Pelagic Sediments. A survey of the background radioactivity of the pelagic sediments throughout the EPG in April 1956 prior to Redwing showed widespread artificial radioactivity on the ocean floor in the survey area between 162° and 170°E and between 10° and 15°N. Ru^{106} and Ce^{144} were each present in quantities amounting to 10 to 1,000 (dis/min)/cm^2 of the ocean floor. Traces of Sb^{125}, Zn^{65} and Mn^{54} were also detected.

Sediments collected northeast of Bikini Atoll in the vicinity of 13°N and 165°E following Shots Zuni and Flathead (12 June 1956) showed no detectable recent fission-product activity. The predominent older Ru^{106} and Ce^{144} may have obscured 1 or 2 percent of any recent addition of Ce^{141}, Ru^{103} and Zr^{95}.

During the Equapac cruise in August 1956, sediment cores were taken at 6° 30′ S 164° E; 5° S 156° 20′ E; 2° S 157° E, 0° S 157° E; 11° 43′ N 166° 15′ E; and 11° 44′ N 166° 13′ E. South of the equator, no fission-product activity was detected above the lower limit of detectability of 2 ± 2 dis/min Ru^{106}/cm^2. A trace of Ce^{144} and Ru^{106} of the order of 2 to 6 (dis/min)/cm^2 was observed at 0° 157° E. At 6° N 157° E, 15 dis/min Ce^{144}/cm^2 and 18 dis/min Ru^{106}/cm^2 were detected. A core collected north of Ailinginae Atoll at 11° 44′ N 166° 13.5′ E on 4 September 1956, assayed on 6 March 1957, 470 dis/min Ce^{144} and 252 dis/min Ru^{106}/cm^2 of ocean floor. No evidence of fission products originating during Redwing was detected in the Equapac pelagic sediments within 6 weeks following Shot Tewa. Figure 5.7 shows a typical gamma energy spectrum of a deep sea sediment collected in the EPG immediately following Operation Redwing.

No sediments were collected in the area of maximum fallout north and northwest of Bikini Atoll after cessation of the Redwing series. There is insufficient data to determine the time of arrival of fallout on the ocean floor.

Bottom samples obtained south of Eniwetok Atoll in the vicinity of 11° 18′ N, 162° 57′ E during December 1956 and assayed 1 June 1957 showed an average of 60 dis/min Ru^{106}/cm^2 and 14 dis/min Zr^{95}/cm^2. A sponge obtained from the same area assayed 10,000 dis/min Ce^{144}, 360 dis/min Sb^{125}, 4,000 dis/min Ru^{106}, 2,000 dis/min Zr^{95}, 800 dis/min Mn^{54} and 650 dis/min Zn^{65} per gram wet weight as of 1 June 1957. Although pre-Redwing activity still predominates, fission products originating during Redwing had penetrated to the 1,000-fathom bottom southeast of Eniwetok Atoll by December 1956.

5.6.6 Radioactive Contamination of Marine Organisms. The predominant radioisotopes found in the marine organisms of the EPG, both prior to and during the Redwing testing, were not fission products, but instead were isotopes of the transition elements, cobalt, zinc, and manganese. In April 1956, the pattern of contamination exhibited chiefly Co^{57} and Co^{60} in the molluscs, Zn^{65} in the surface fish and Ce^{144} and Ru^{106} in the phytoplankton. Zooplankton collected in the open sea assayed about 10 dis/min Zn^{65}, 1.3 dis/min Mn^{54}, 4 dis/min Co^{60} and 0.4 dis/min Co^{57} per gram of living organisms.

No new fission products were detected in the lagoon organisms after Shot Cherokee and prior to Shot Zuni. Figures 5.8 and 5.9 show the typical gamma spectra of an octopus and fish larvae specimens collected 29 May 1956 from Bikini Lagoon, showing predominately old Zn^{65}, Co^{57}, Co^{60}, and Mn^{54}.

Following Shot Zuni, 28 May 1956, a number of reef fish were collected on the southern Bikini reef near Rukoji Channel. Several dead goat fish and trigger fish were also collected showing visible burns around the dorsal fins. Gamma spectrum analysis one year after the collection showed Co^{57}, Co^{60}, Mn^{54}, and Zn^{65} of the order of 2,500 (dis/min)/gm for the mixed isotopes in the liver, flesh, and bones of a burned goat fish (Upeneus sp.). Two surgeonfish (Acanthurus sp.) and a trigger fish (Valistidae) from the same reef showed high concentrations of Cs^{137}. No other specimens of marine life exhibited cesium to such a marked degree. A 175-gram surgeonfish collected 29 May 1956 assayed 1,200 dis/min Ce^{144}, 60 dis/min Ru^{106}, 330 dis/min Cs^{137}, 70 dis/min Mn^{54}, 140 dis/min Zn^{65} and 17 dis/min Co^{60} per wet gram for the entire fish. Considering the high Cs^{137}- Ce^{144} ratio, it appears unlikely that all of the cesium could have originated with Zuni. Previous biological specimens have consistently given low or negative cesium results. Possibly cesium may be concentrated and retained by these fish. A butterfly-fish (Chaetodontidae) collected at the same time assayed 38 dis/min Co^{57}, 1,700 dis/min Ce^{144}, 200 dis/min Ru^{106}, 83 dis/min Cs^{137}, 46 dis/min Mn^{54}, 145 dis/min Zn^{65}, and 7 dis/min Co^{60} per wet gram of the entire fish as of 1 June 1957 giving the isotope ratios and activity values roughly the same as in an equal weight of bottom water or in 80 grams of surface water from the same areas as shown in Table 5.5.

Immature cardinal fish collected off site in Bikini Lagoon on 2 June 1956 after Zuni were contaminated chiefly with 4,000 dis/min Zn^{65}, 70 dis/min Co^{60}, 17 dis/min Co^{57} and 75 dis/min Mn^{54} per wet gram at time of collection, producing a gamma energy spectrum similar to Figure 5.9. Although Zuni fission products were detected in the southern central lagoon 2 days after the shot, new fission products were not reflected in fish larvae off site at H + 5 days. At H + 12 days, myctophids collected by dip-netting had absorbed short-lived ($t\,{}^1/_2 = 10$ days) complex fission products of the order of 60,000 β dis/min per wet gram.

TABLE 5.1 TIME OF ARRIVAL OF AIRBORNE ACTIVITY

Shot	Hours After Shot	Latitude, N	Longitude, E	Volume of Air Samples	Beta Activity
				liter	counts/min / 1,000 liters
Cherokee	2 to 4	11-25	165-47	2,400	3.2
	16 to 18	13-06	165-23	2,400	17.0
	26 to 28	13-23	163-44	2,400	9.5
	34 to 36	15-18	163-22	2,400	0.7
Zuni	3 to 4	11-21	165-22	1,200	4.2
	7 to 8	12-07	165-39	1,200	8.3
	9 to 10	12-02	165-32	1,200	600
	10.3 to 10.5	12-02	165-32	300	1,950
	10.7 to 11.0	12-02	165-32	300	1,800
	11.0 to 11.25	12-02	165-32	300	2,040
	15.2 to 15.5	12-27	165-17	*	
Flathead	0 to 1	11-23	165-45	2,400	1.8
	5 to 7	11-20	165-39	2,400	52
	15 to 17	11-34	165-11	2,400	410
Dakota	12 to 12.25	Parry I.		300	46,700
Navajo	0 to 1	11-09	165-40	1,200	10
	15 to 16	11-48	165-06	1,200	1,350
	18 to 22	11-58	165-13	4,800	24
Tewa	6 to 17	11-29	165-58	5,000	51
	18 to 31	11-53 to 12-07	165-26 to 165-12	10,000	487

* Fallout occurred. GM background = 3,200 counts/min.

TABLE 5.2 VARIATION OF AEROSOL PARTICLE SIZE WITH ACTIVITY

Mean Diameter	Beta Activity, Counts/Min				
	Sample Z-6	Sample D-5	Sample T-1	Sample T-2	Sample T-3
micron					
5 to 10	423	744	124	254	4,720
1	723	136	109	180	150
0.45	193	61	42	51	110
Hours after detonation	9 to 10	19 to 19.5	1 to 4	6 to 7	18 to 31

TABLE 5.3 NAVAJO WATER SAMPLES DISINTEGRATIONS PER MINUTE PER LITER AS OF 1 JULY 1957

Isotope	Station N-9, 13 Jul 56	Station N-12, 13 Jul 56		Station N-16, 14 Jul 56				
	11° 44.8' N 165° 16.2' E	11° 34.7' N 165° 11.4' E		12° 08.3' N 164° 53.8' E				
	Surface	Surface	50 m	Surface	50 m	100 m	250 m	500 m
Ce^{144}	4,750	12,400	8,100	44	33	38	81	128
Co^{57}				≈4				
Sb^{125}	280	600	520	3				≈12
Ru^{103}					18			
Ru^{106}	2,250	5,000	6,200	21	24	28	66	150
Cs^{137}	610	860	1,040	4			≈8	18 ± 6
Zr^{95}	4,500	4,500	3,600	42	≈10	42	34	48
Mn^{54}	7,900	14,000	6,300	45	41	48	56	119
Co^{58}				2.4				
Zn^{65}	280	280	700	0.8				
Co^{60}	≈36	395	350	1.3				
K^{40}	670	670	670	670	670	670	670	670

TABLE 5.4 TEWA WATER SAMPLES COLLECTED 22 JULY 1956, 12° 05' N 165° 15' E

Analyzed 1 June 1957

Isotope	Unfiltered Surface Water	Filtered Surface Water		Suspended Sediment	
	(dis/min)/liter	(dis/min)/liter	pct	(dis/min)/liter	pct
Ce^{144}	4,300	0	0	3,560	100
Sb^{125}	120	*			
Ru^{103}	900	630	53	560	47
Ru^{106}	2,300	1,260	60	820	40
Cs^{137}	250	245	100	0	0
Zr^{95}	4,500	800	26	2,300	74
Mn^{54}	360	190	95	10	5
Zn^{65}	35	*		*	
Co^{60}	*	*		*	
1.2 Mev		(100γ/min)/liter	71	(40γ/min)/liter	29

* No detectable activity.

TABLE 5.5 BIKINI LAGOON BOTTOM WATER 29 MAY 1956, 11° 30′ 02″ N 165° 21′ 25″ E

Analyzed 1 June 1957

Isotope	Total Activity	Soluble Fraction		Suspended Matter		0.5 to 10 Micron Sediment	10 to 1,000 Micron Sediment	Surface Water
	(dis/min)/ml	(dis/min)/ml	pct*	(dis/min)/ml of water	pct*	(dis/min)/gm	(dis/min)/gm	(dis/min)/ml
Ce^{144}	618	306	49.5	312	50.5	385,000	34,500	7.8
Sb^{125}	113	108	95.6	5	4.4	6,150	555	
Ru^{103}	11	†	0	11	100	13,200		
Ru^{106}	74	†	0	74	≈ 100	90,000	5,600	1.2
Cs^{137}	218	218	100	†	≈ 0		322	
Zr^{95}	65	†	0	65	100	79,000	< 3,740	0.12
Mn^{54}	41	†	0	41	100	50,000	3,350	< 2.7
Zn^{65}	39	< 3	7.8	36	92.2	44,000	2,350	
Co^{60}	7.6	5.6	73.6	2	26.4	2,440	323	
K^{40}	0.7	0.7	100	†	≈ 0			
0.57 Mev ($t\frac{1}{2} \approx 60$ days)	67 γ/min	67 γ/min	100	†	0	†		
1.69 Mev ($t\frac{1}{2} = 50$ days)	28 γ/min	28 γ/min	100	†	0	†		
1.15 Mev	32 γ/min	†	0	32	100	39,000 (γ/min)/gm	≈ 700 γ/min	

* Percentage of total activity of the indicated isotope found in this fraction of the sample.

† No detectable activity.

TABLE 5.6 ACTIVITY DISTRIBUTION WITH PARTICLE SIZE, NAVAJO STATION N-12, 11° 34′ N 165° 11′ E, 13 JULY 1956

Counted 14 July 1956

Pore Size Range	Percent of Activity Retained on Filter	
	Surface Water	50-Meter Water
micron	pct	pct
3 to 0.75	26	8
0.75 to 0.5	18	15
0.5 to 0.2	3	6
0.2 to 0.08	4	2
0.08 to 0.05	2	4
0.05 to 0.01	6	0.3
Total counts/min retained on filters from 50 ml sample	18.2×10^4 counts/min	7.6×10^4 counts/min
Total counts/min in unfiltered duplicate	16.6×10^4 counts/min	7.9×10^4 counts/min

Results of three successive filtrations of a single sample through 0.5μ filters:

	Retained on Filter	Apparent half life of Activity
	pct	day
First filter	33.0	4
Second filter	0.026	95
Third filter	0.024	95

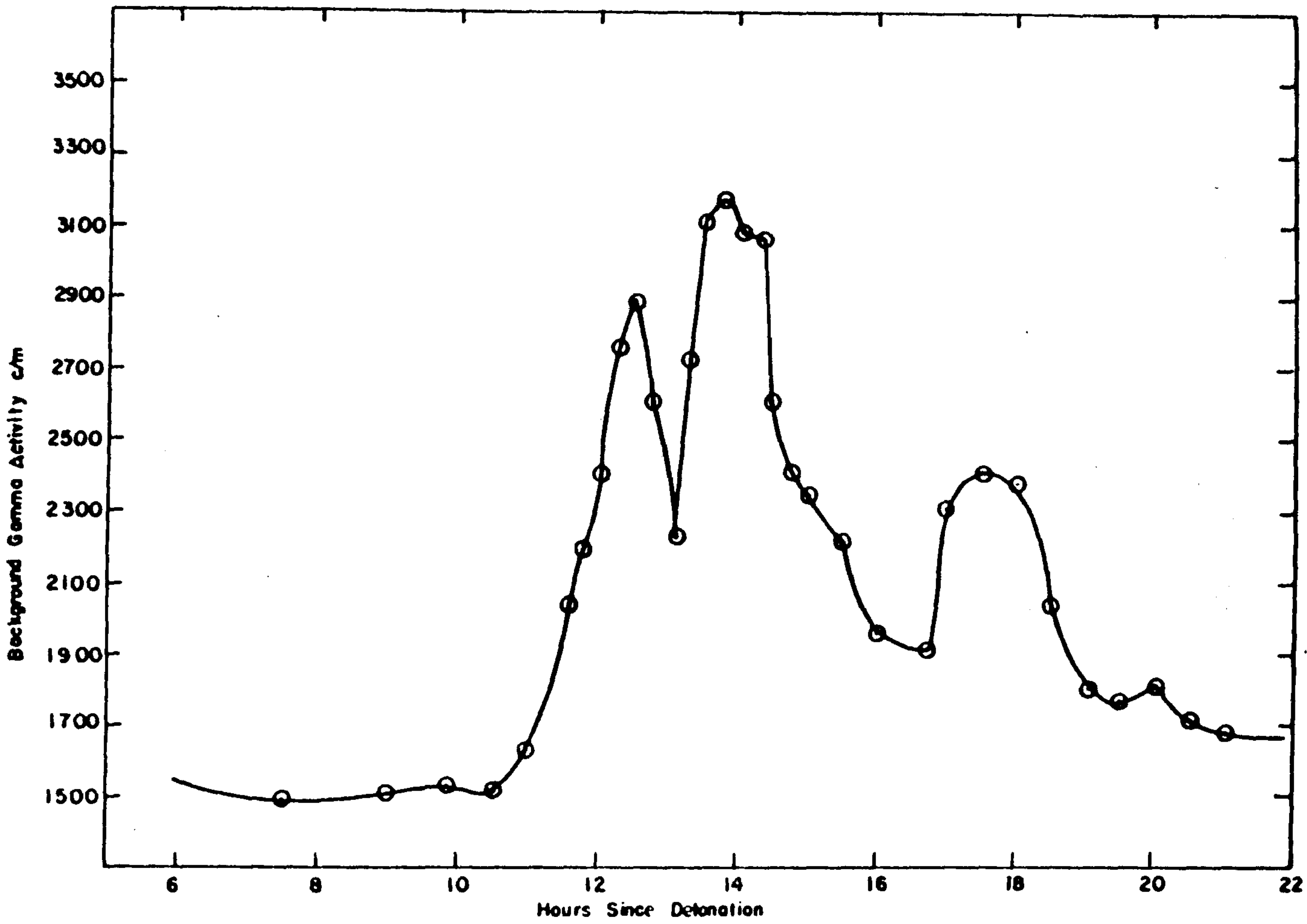


Figure 5.1 Gamma background aboard M/V Horizon at Parry Island after Shot Dakota.

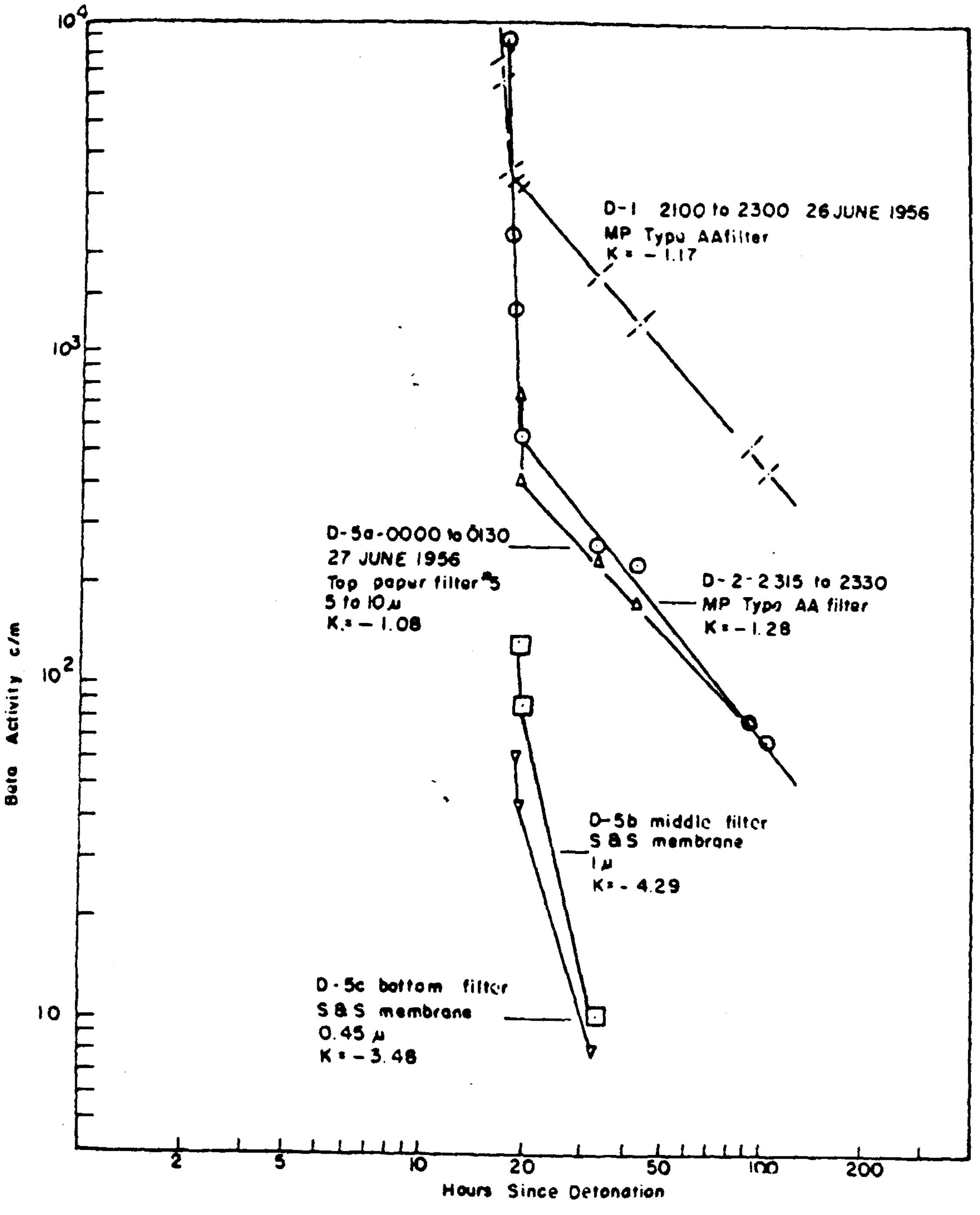


Figure 5.2 Decay curves for Shot Dakota air samples.

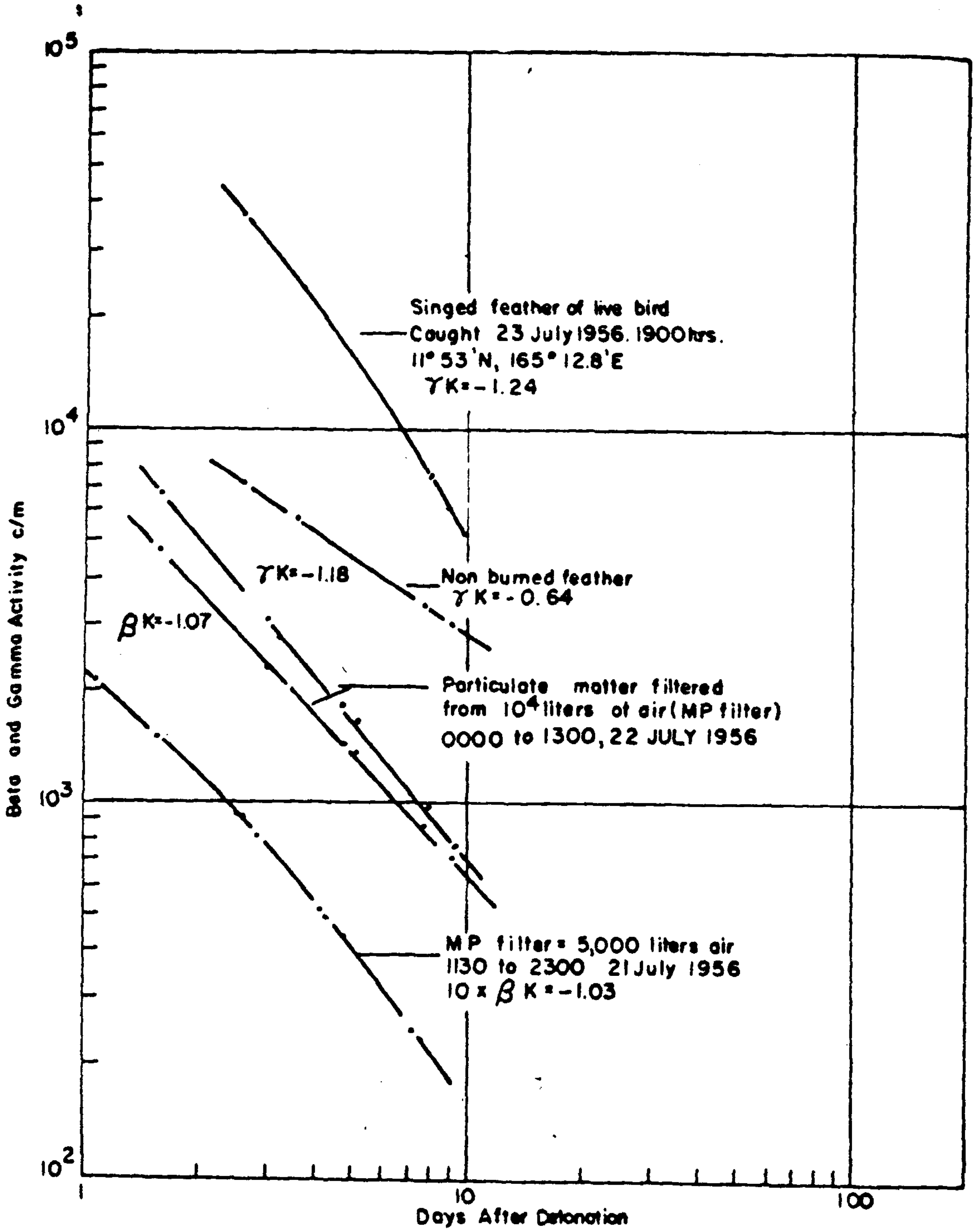


Figure 5.3 Decay curves of particulate matter filtered from air following Shot Tewa. (The decay curves of the feathers of a bird singed by the shot are also given.)

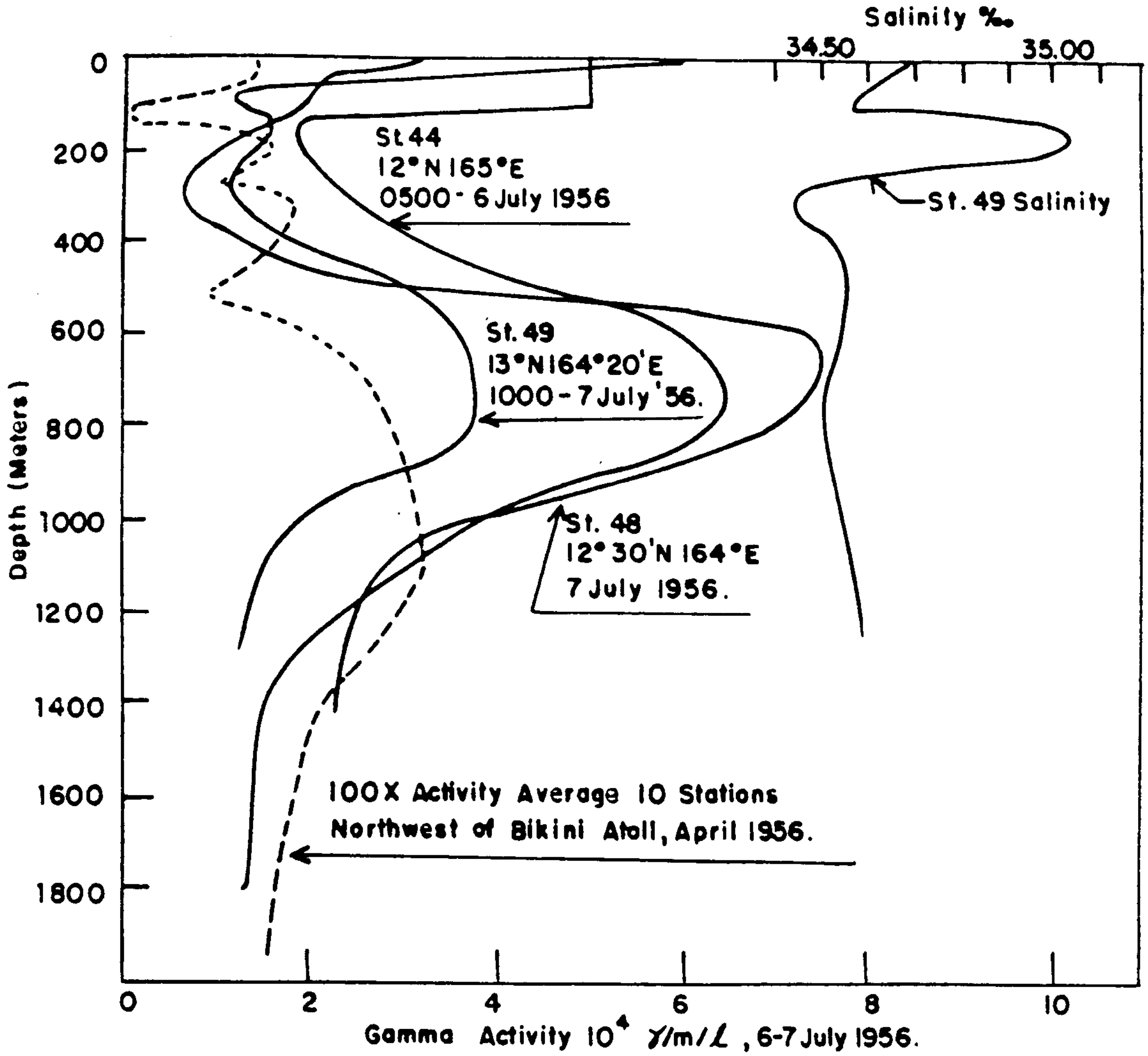
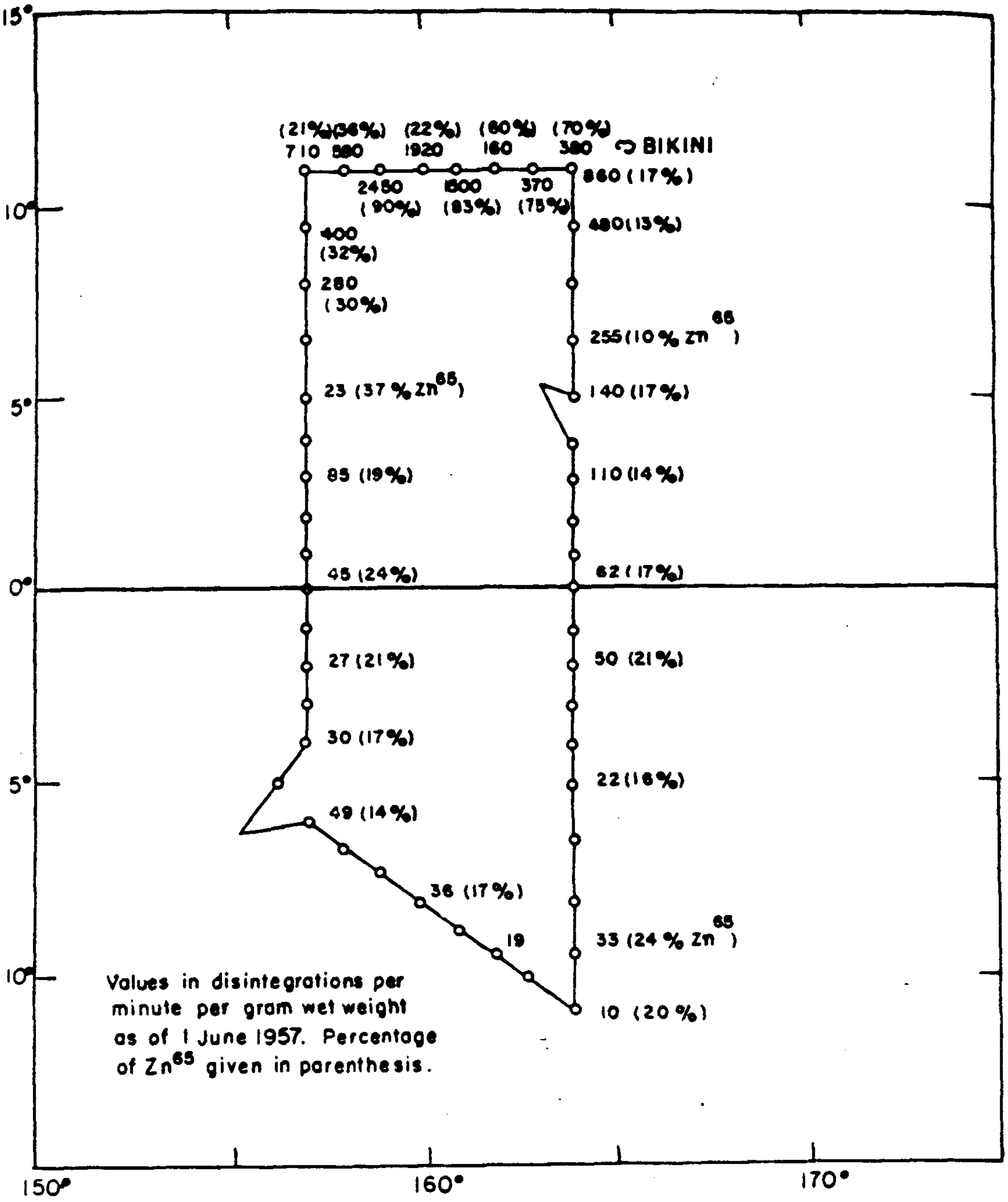


Figure 5.4 Vertical distribution of radioactivity following Shot Flathead.



Values in disintegrations per minute per gram wet weight as of 1 June 1957. Percentage of Zn^{65} given in parenthesis.

Figure 5.5 Distribution of plankton radioactivity across Equatorial Pacific.