6

410900

AERIAL TRACKING OF
FALLOUT BY VP-1
(FALLOUT CHARTS)
OPERATION REDWING

1956

Radioactivity Background in the Open Sea

ABSTRACT

The objectives were to: (1) survey the gamma radiation from fallout-contaminated ocean areas by means of aerial detectors and (2) from the aerial detectors make air-absorption measurements so that the data might be related to the dose rates at 3 feet above the sea.

Radiation detectors were mounted in P2V-5 aircraft that surveyed the ocean areas of expected fallout after Shots Cherokee, Zuni, Flathead, Navajo, Mohawk, and Tewa. A control center coordinated all air and surface radiation-survey activities to insure complete coverage of the fallout area. The contamination densities in the delineated areas were related to the percentage of the total yield that produced fission products. Gamma-isodose plots were prepared from data obtained during Shots Zuni, Flathead, Navajo, and Tewa. No fallout could be located following Shot Cherokee and only on atoll islands after Shot Mohawk.

Zuni, a land-surface shot, contaminated 13,400 naut mi^2 of ocean with 48 percent of its fission-product yield.

Navajo, a water-surface shot, contaminated 10,500 naut mi^2 with 50 percent of the fission-product yield. After Flathead, another water-surface shot, the outer boundary could not be determined because of contamination of project aircraft on D + 1 day by airborne radioactive material that resulted in a high background. However, extrapolated values indicate 29 percent of its fission-product yield was present as fallout in the local area. The fallout from the water-surface shots was concentrated primarily in the more remote areas, and a relatively small amount fell close to ground zero.

Tewa, a reef shot, contaminated 43,500 naut mi^2 of ocean with 28 percent of the fission-product yield.

Helicopters and P2V-5 aircraft were used to gather data for air-absorption measurements.

The aerial-survey technique may be used directly for radiological surveys over land. Over the sea, the depth of mixing of the fallout in the water volume must be determined before the survey results may be converted to equivalent land-fallout contours and contamination-density distributions. Data on depth of mixing was obtained from samples of sea water collected by the U.S. Naval Radiological Defense Laboratory and the Scripps Institute of Oceanography. Repeated aerial surveys provided information on the stability of the contaminated volume.

[redacted]

35D

PREFACE

Patrol Squadron ONE, U.S. Navy, operated the aircraft used for the aerial surveys. The author gratefully acknowledges the diligence and high professional competence which contributed so much to the project's operations.

Commander Kelly, USN, was the Air Officer on the staff of Commander, Task Group 7.3. His efforts were responsible for the fulfillment of the project's aircraft requirements.

Members of the Health and Safety Laboratory, U.S. Atomic Energy Commission, who participated in the field operations, and whose contributions are gratefully acknowledged are I. Whitney, G. Hamada, S. Tarras and T. French of the Analytical Branch, H. Sadowski and F. Wilson of the Instruments Branch and K. O'Brien of the Radiation Branch.

Chapter 2
PROCEDURE

2.1 SHOT PARTICIPATION

Prior to the operation, aerial surveys were scheduled to follow Shots Cherokee, Zuni, Flathead, Navajo, Apache (secondary participation), and Tewa. Because Shot Cherokee was delayed, Program 2 requested that the project add Shot Lacrosse to its schedule in order to give the aerial survey an opportunity to obtain operational experience. However, this survey was cancelled, because flight clearance below 1,000 feet in the region of Eniwetok Atoll could not be obtained.

A change in the Apache scheduling introduced a conflict with the project's participation during Navajo. The new schedule called for dual capability involving both Eniwetok and Bikini Atolls. Participation in Apache was therefore, canceled.

Because of the long waiting period between Flathead and Navajo, the project requested secondary participation in Shot Mohawk.

Preshot surveys were flown before the Navajo and Tewa shots, based on a Program 2 request, to define the background status resulting from the flow of contaminated lagoon water over the reef at Bikini.

Helicopter missions, for altitude absorption data, were originally scheduled after Shots Seminole, Mohawk, and Navajo. The mission for the latter was subsequently canceled at the request of the project, because of a shortage of personnel. During June and July, it was necessary to assign two technicians to Kwajelein to service the aerial-survey equipment; therefore, they were no longer available for on-site operations.

The project operations are summarized in Table 2.1.

2.2 OPERATIONS

VP 1

Many projects in Program 2 studied different phases of fallout. Project 2.64 developed isodose plots of the contaminated area by aerial surveys. The operations were primarily to secure aerial survey data; subsidiary measurements were performed in support of this objective to correlate this data. Altitude absorption studies were required to verify the correction factors used in relating the aerial survey to a reference plane 3 feet above the surface.

2.2.1 Aerial Surveys. Four P2V-5 aircraft were assigned for the project operations, and were administratively attached to the Security Squadron, Patrol Squadron 1. Three of the aircraft were supplied from outside the squadron, and the fourth came from its assigned strength. The squadron provided all maintenance and operational control. This control was shifted to the Program 2 Control Center on the USS Estes, AGC-12, during the aerial-survey flights. The Air Operations Officer, Task Group 7.3, assumed primary radio guard during this period.

The plan of the project air control in the Program 2 Control Center is shown in Figure 2.1. The communication routing is shown in Figure 2.2. The telemeter operator logged all incoming radiation readings, which were immediately recorded on a time-based continuous plot. Navigational information was received from the radio operator on Channel C (6693 kc). The Project 2.64 Operations Officer correlated the navigational and radiation data on the rough flight-control chart. The plotter transferred this information to the tactical isodose plot, under the supervision of the 2.64 Project Officer, who used the flight and isodose charts to determine the next area of search for each aircraft. The operations officer laid out the required navigational ref-

erences for the designated flight legs and transferred this information to the working flight log. The Task Group 7.3 Air Operations Officer reviewed the legs for flight safety, and the information was relayed to the appropriate aircraft by the radio operator.

D-day flights used one aircraft, with a second aircraft on standby. The flights were limited to the upwind areas until active fallout had ceased. Surface ship reports, received by the Proj-

TABLE 2.1 SUMMARY OF PROJECT OPERATIONS

Shot	Date	Time	Location	Aerial Survey	Altitude Absorption
Cherokee	21 May	0551M	Bikini	D-day D+1	
Zuni	28 May	0566M	Bikini	D-day D+1 D+2 D+3	
Seminole	6 June	1255M	Eniwetok		D-day
Flathead	12 June	0626M	Bikini	D-day D+1 D+2	
Mohawk	3 July	0606M	Eniwetok	D+1	D+2
Navajo	11 July	0556M	Bikini	D-3* D-2* D-day D+1 D+2 D+3	
Tewa	21 July	0546M	Bikini	D-1* D-day D+1 D+2 D+3 D+4	

* Preshot surveys of lagoon water outside the Bikini Atoll.

ect 2.63 representatives in the Control Center, indicated when fallout had stopped in the close-in downwind sector. The aircraft was then controlled through the area to limits described by the ship reports. The D-day flights delineated the upwind boundary and obtained some intensity readings in the radioactive area immediately downwind of ground zero.

Two aircraft were used on D + 1. One delineated the close-in radioactive area and confirmed the upwind boundary located on the previous day. The second aircraft flew an extensive search pattern to locate the edges of the contaminated area.

The D + 2 survey re-examined the overall contaminated area. One aircraft was usually sufficient. However, the Tewa pattern was so large that two aircraft were needed. Flights on subsequent days used one aircraft and tracked the area until the dose rates became too low for adequate delineation.

Survey data which delineated the outer boundary and points of interest in the fallout pattern were plotted in the control center to guide the Project 2.62 surface ships with their oceanographic surveys.

During the period prior to the next shot, each aircraft was scheduled to spend a day on Site Fred for instrument calibration and service. Two technicians calibrated each radiation detector at Kwajalein prior to and immediately following each survey flight and returned the Top Hat detectors to Site Elmer between shots, where a complete routine battery change and recalibration was performed.

2.2.2 Altitude Absorption. Because considerations of flight safety limit the minimum altitude at which aircraft can fly over water, automatic gamma monitors were mounted over the sides of two ships of Project 2.10, to measure the gamma-radiation field at 35 feet above the sea surface. This was to provide low-altitude readings simultaneous with aircraft passes in the same area at higher altitudes.

Survey aircraft made altitude-calibration passes over islands of the Eniwetok Atoll after Shot Mohawk. After Shot Tewa, the P2V-5 dropped a smoke light in the open sea to be used as a navigational reference and made altitude passes in the vicinity. These data are examined for the variation of radiation reading between different flight altitudes and given in Section 3.2.

Helicopter missions, after Shots Seminole and Mohawk, obtained data similar to the altitude-correction-calibration data collected by the survey aircraft. Because the helicopters could not safely hover at low altitudes, complete information could not be obtained. It had been planned to obtain gamma-energy spectra at various altitudes above a contaminated surface. The Top Hat dose-rate response was to be compared to the gamma-energy spectra to determine whether the assumption of air-equipment response was valid. However, instrumentation difficulties and the limitations in hovering altitudes resulted in fragmentary data. The survey using a scintameter obtained dose-rate readings at altitudes between 25 and 1,000 feet.

2.3 INSTRUMENTATION

The major instrumentation consisted of aerial radiation detectors. Scintillation survey meters and ship-mounted gamma monitors were used for measurements relating to altitude-correction factors. A spectrometer was used to obtain the distribution of the gamma energies at survey altitudes. The instruments are described in Appendix B.

2.3.1 Aerial Survey. Each of the project aircraft had the following equipment: (1) Top Hat aerial radiation detector, HASL TH-10-B (Appendix B); (2) detector control assembly, HASL TC-14-A; (3) strip-chart recorder, Esterline Angus Co., AW; (4) telemeter assembly, HASL TT-3-X; (5) power supply, HASL TB-6-A; and (6) radio transmitter, U.S. Navy ART-13. The permanent components were installed by the Overhaul and Repair Department, U.S. Naval Air Station, Alameda, California, at the air station prior to Operation Redwing. The removable components were installed by project personnel after the squadron deployed to the EPG.

The location of the assemblies is indicated in Figure 2.3. The radiation detector was mounted aft to avoid the major areas of aircraft contamination, namely, the engines, oil-cooler air intakes, leading edges of the wings, propellers, and front of the radome. The cabin intake vents were sealed to prevent contamination of the interior ductwork. The control assembly and the operator were placed forward, next to the navigator. This facilitated close correlation between the navigational and radiation reports. The remainder of the equipment was located on an available-space basis.

The relationship of the various sections, both in the aircraft and in the Program 2 Control Center, is shown in Figure 2.4. The radiation detector and its associated control assembly drives a strip-chart recorder to provide a permanent, continuous record of the radiation intensities as measured in the aircraft. This detector is nearly air-equivalent from 80 to 1,400 kev, Figure 2.5. An annular radiation shield is built into the detector to reduce the effect of aircraft contamination. The angular response due to this shield is shown in Figure 2.6.

The aircraft's radio altimeter (U.S. Navy APN-1) supplies an altitude indication to the altitude compensator, which modifies the radiation detector so that its output is a current that is proportional to the radiation which would be measured at 3 feet above the surface. As the altitude changes, the compensator corrects the resulting radiation change and keeps the ground-level reading constant.

The telemetering system did not perform satisfactorily. The radiation readings on the aircraft radiation-detector strip-chart recorder were, therefore, transmitted by voice over the navigational net. At the control center, the radiation readings were logged and immediately plotted.

2.3.2 Altitude Absorption. The automatic gamma monitors, HASL TN-4-C, were mounted on the YAG-39 and YAG-40. Each instrument was mounted at the end of a boom that was also used to suspend the depth probe of Project 2.62. The boom extended 35 feet from the side of the ship and was set at an approximate mean height of 35 feet above the sea. An Esterline-Angus strip-chart recorder was installed in the shielded control room on the ship, to continuously record the gamma dose rate. The installation of the monitors and recorders was accomplished by Project 2.10.

Scintameter survey meters, HASL TH-3-B and TH-7-A, were used for helicopter operations. Gamma dose rate was measured at various altitudes over contaminated water and land surfaces.

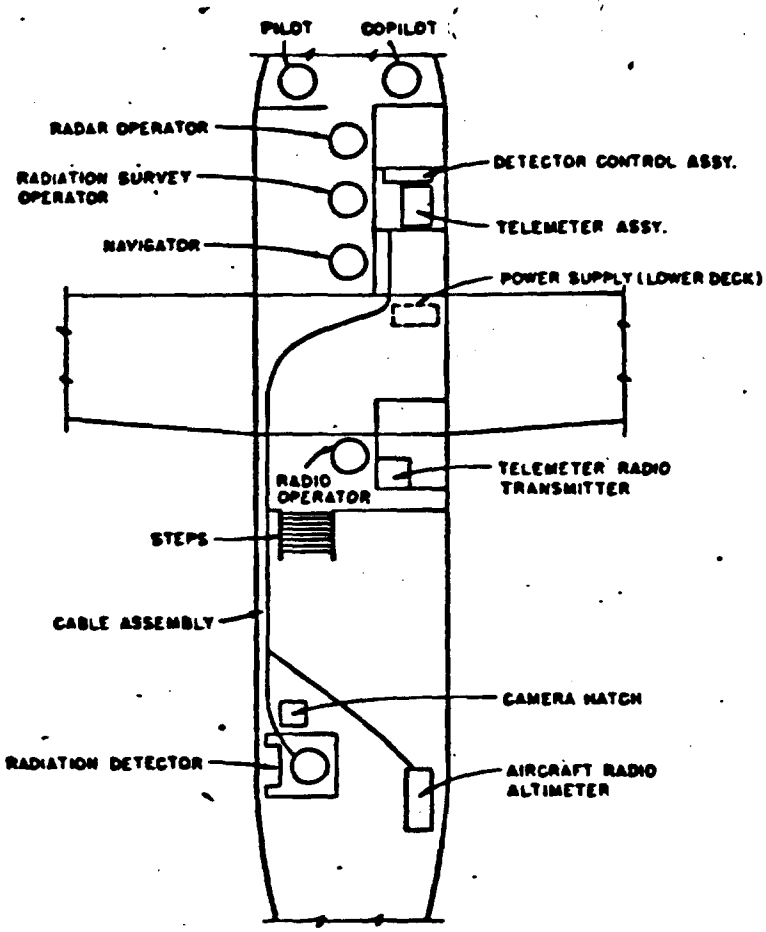


Figure 2.3 Radiation-survey-equipment mounting locations in P2V-5 aircraft.

A gamma spectrometer, HASL TM-10-A, which consists of a scintillation head, pulse-height analyzer, and a recorder, was loaded into the same helicopter. The 28-volt power in the helicopter was converted to 115 volts, 60 cps, by a separate inverter to supply the spectrometer. The count rate at various energy levels was observed on a meter as the base line automatically swept through an energy scan from 50 kev to 3 Mev.

The survey aircraft had the same instrumentation as described in the previous section, plus a scintameter survey meter, TH-3-B.

2.4 REQUIRED DATA

The project operations were directed mainly toward obtaining isodose plots of the gamma

As discussed in Section 3.1.2, the distribution of gamma energies was estimated from the visual observations of a meter on the gamma spectrometer. Observations at 500 and 800 feet above Site Sally on Mohawk D + 2 showed a general response where the predominant portion of the energy spectrum fell between 350 and 600 kev.

3.3 DISTRIBUTION OF FALLOUT

The isodose charts contained in this section have been referred to H + 24 hours and gamma dose rate at 3 feet above the surface. The decay correction is based on $t^{-1.2}$. The flight altitude was 300 feet for all surveys, so the altitude correction is based on a factor of 2.5.

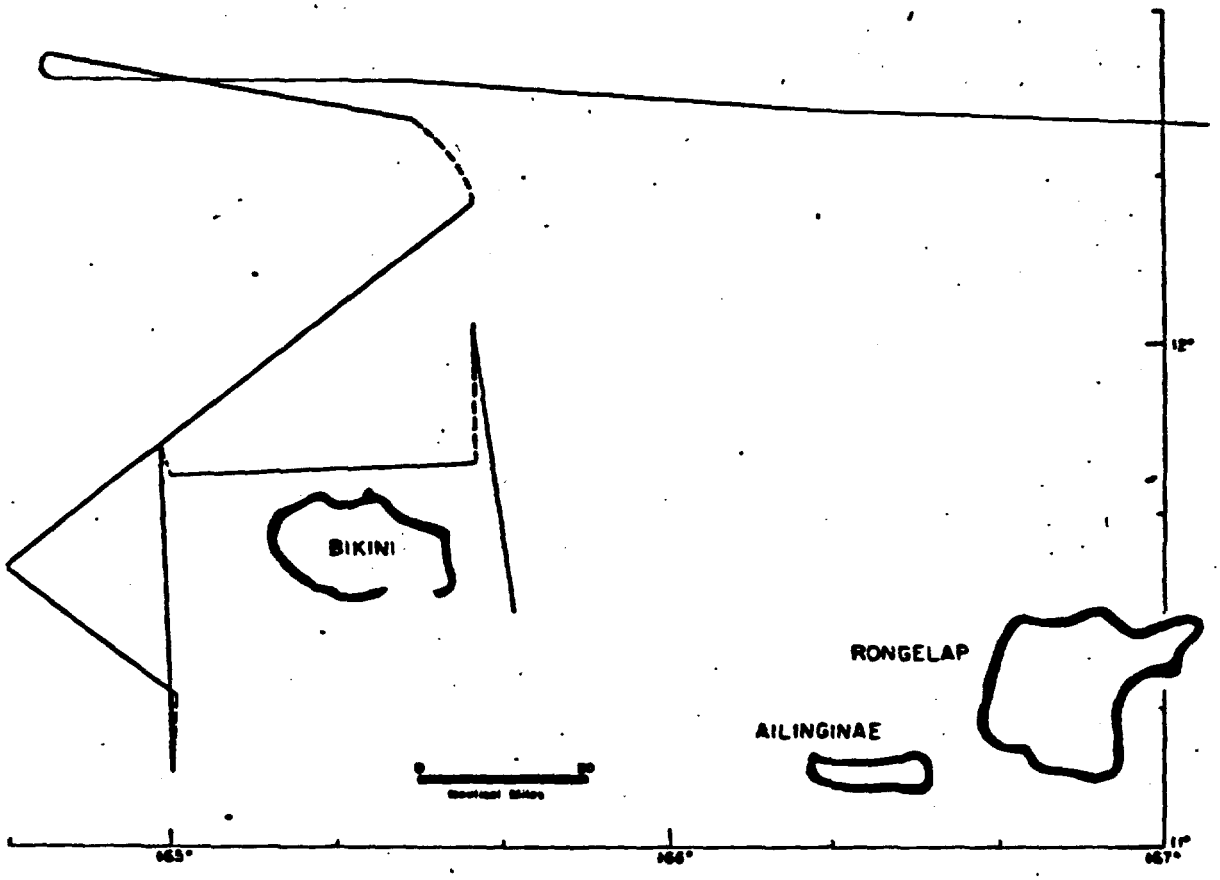


Figure 3.5 Flight pattern, Shot Cherokee D-day.

The EOB is based on a minimum detectable limit by the detector of 0.01 mr/hr. This converts to 0.025 mr/hr at the surface. Where there are no flight legs in a position to close an isodose plot, dotted lines indicate the estimated position. The estimates are based on previous days' results wherever possible. Contamination enclosed within an isodose bounded area is calculated on the basis of the average gamma intensity between consecutive isodose lines, and a contamination density of 0.4 megacurie/naut mi^2 for 1 mr/hr of gamma dose rate (Section 1.3.1).

3.3.1 Shot Cherokee. The D-day flight encountered no radiation intensities above the detectable limit. The flight pattern is included to show the area searched (Figure 3.5). The D + 1 flight was used for instrument check, because no contamination was found on the previous day.

3.3.2 Shot Zuni. The D-day flight examined the region in the vicinity of the atoll (Figure 3.6). Because there was not enough data to develop isodose plots, radiation profiles have been plotted along the flight legs.

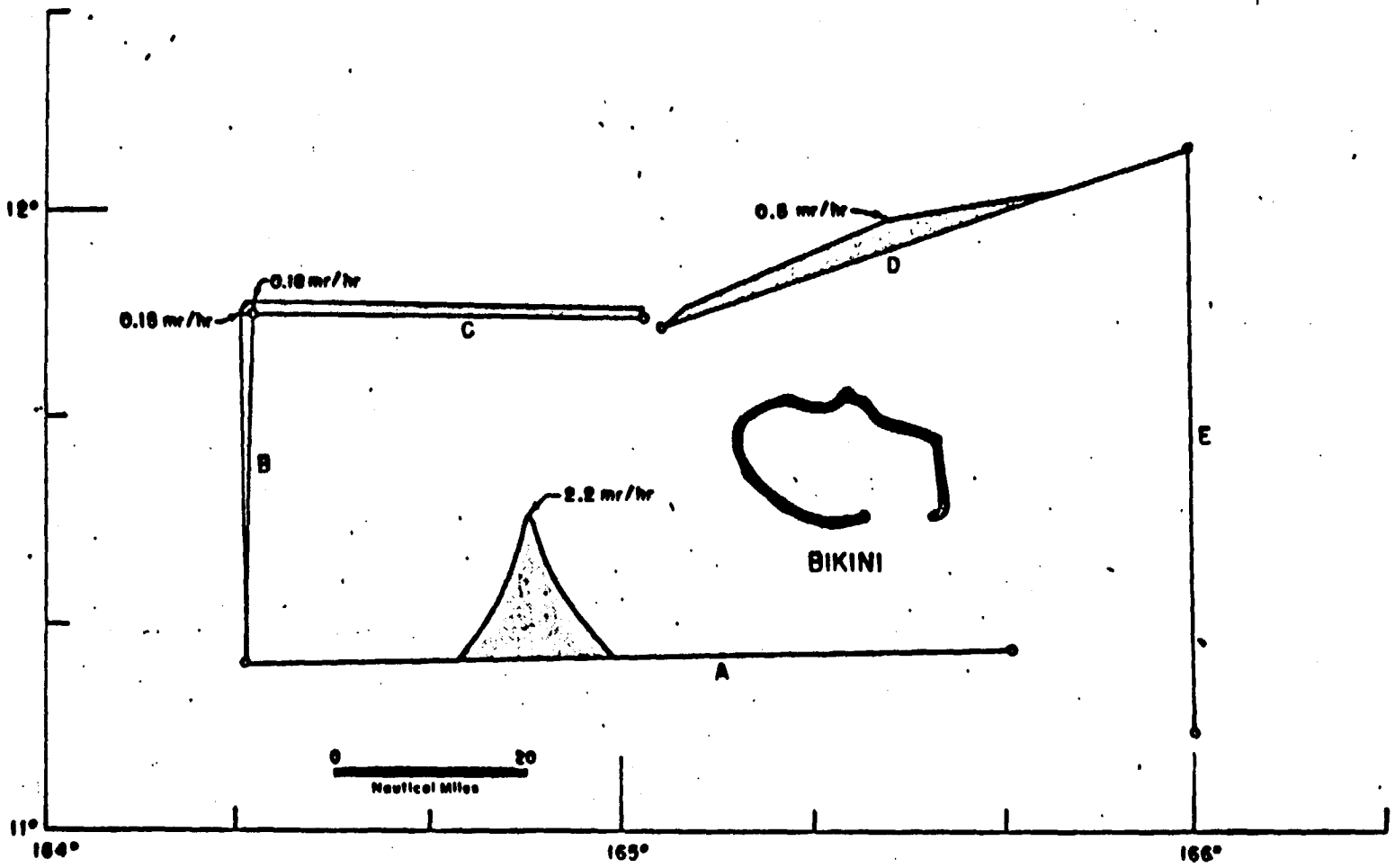


Figure 3.6 Flight pattern, Shot Zuni, D-day. All readings referred to H + 24 hours and 3 feet above surface.

The D + 1 flights located the EOB and delineated the contaminated areas (Figure 3.7). A contaminated patch was suspected to be northeast of Bikini, based on the control center plots. During the data reduction, a navigational reporting error was discovered which changed the relatively isolated patch from the northeast to a position almost due east of Bikini.

TABLE 3.2 ALTITUDE RADIATION DATA OVER WATER

Altitude	mr/hr*	mr/hr†	mr/hr‡
ft			
1,000			0.41
800			0.52
700	0.12	0.225	
600	0.135	0.225	1.1
500	0.135	0.29	
400	0.175	0.38	2.1
300	0.175	0.42	
200	0.225	0.62	1.4, 1.7§
50			2.6, 3.0§

* Tewa + 3, 12-01 N, 164-41 E, Top Hat detector in P2V-5.

† Tewa + 3, 12-11 N, 165-02 E, Top Hat detector in P2V-5.

‡ Seminole D-day, off Janet, scintameter, TH-3, in helicopter.

§ Values from repeat runs.

The D + 2 flights (Figure 3.8) investigated the northeast sector without discovering contamination. The eastern contamination was not suspected until the data-reduction period, so no further examination was scheduled in that sector.

The D + 3 flights (Figure 3.9) reconfirmed the hot area. No further flights were scheduled,

TABLE 3.3 SUMMARY OF FALLOUT DISTRIBUTION, ZUNI

Isodose	Area	Difference Area	Average	Contamination
mr/hr	mi²	mi²	mr/hr	mc
D+1				
1.25	165	165	1.25	83
0.25	4,677	4,512	0.59	1,065
0.125	8,433	3,756	0.18	270
0.025	13,683	5,250	0.06	126
				1,544 mc at H + 24 hours
D+3				
0.75	757	757	1.25	379
0.25	6,775	6,018	0.50	1,204

as low intensities were encountered on this day.

The fallout distribution is summarized in Table 3.3.

3.3.3 Shot Flathead. The D-day flight discovered relatively high dose rate just west of Bikini (Figure 3.10). The position immediately adjacent to the reef indicated that this could be lagoon water passing over the reef, rather than fallout. This area was not completely mixed,

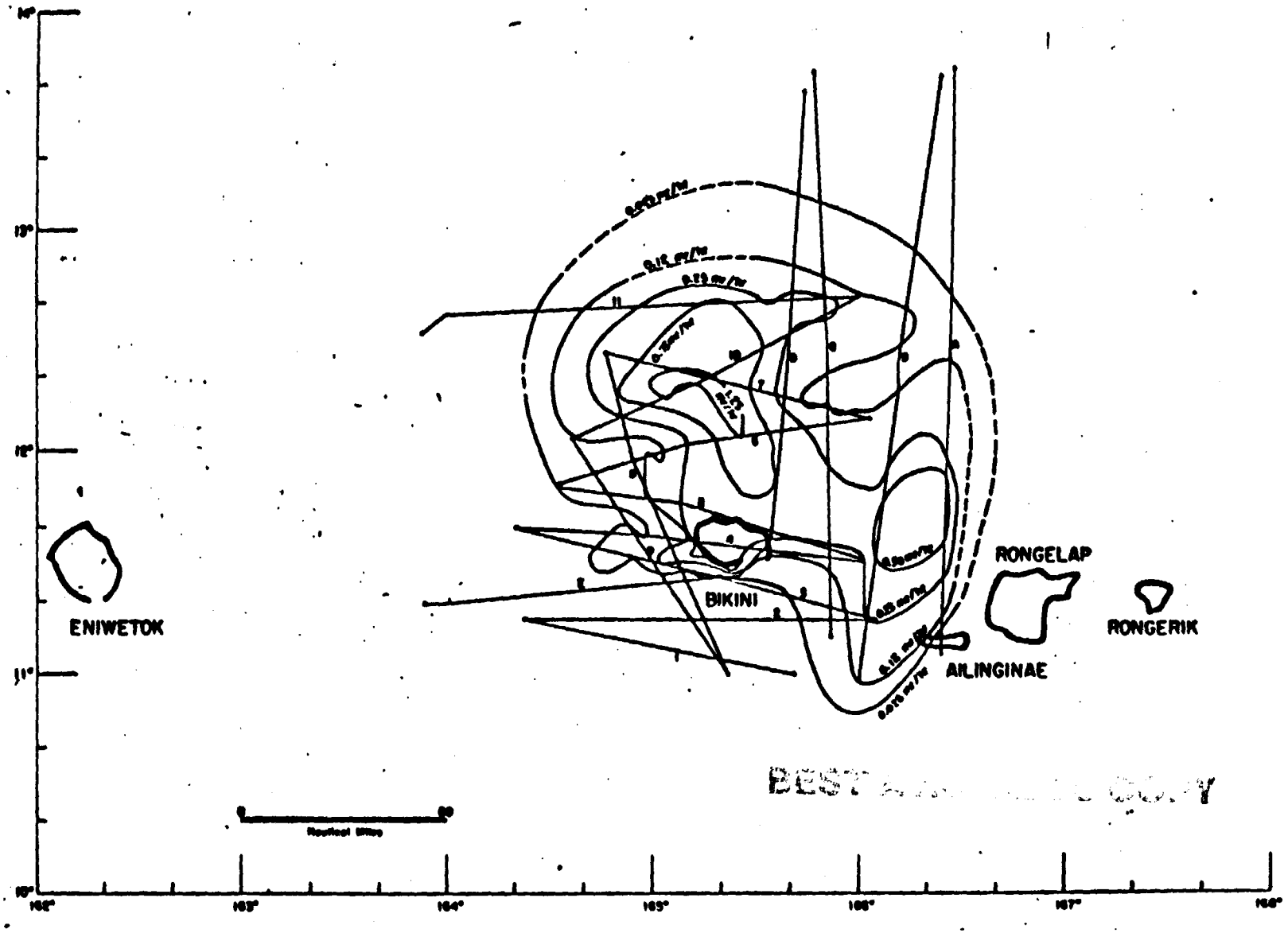


Figure 3.7 Flight pattern, Shot Zuni, D+1 day. All data readings referred to H+24 hours and 3 feet above surface. Numbers show legs flown by Aircraft 1, letters show legs flown by Aircraft 2.

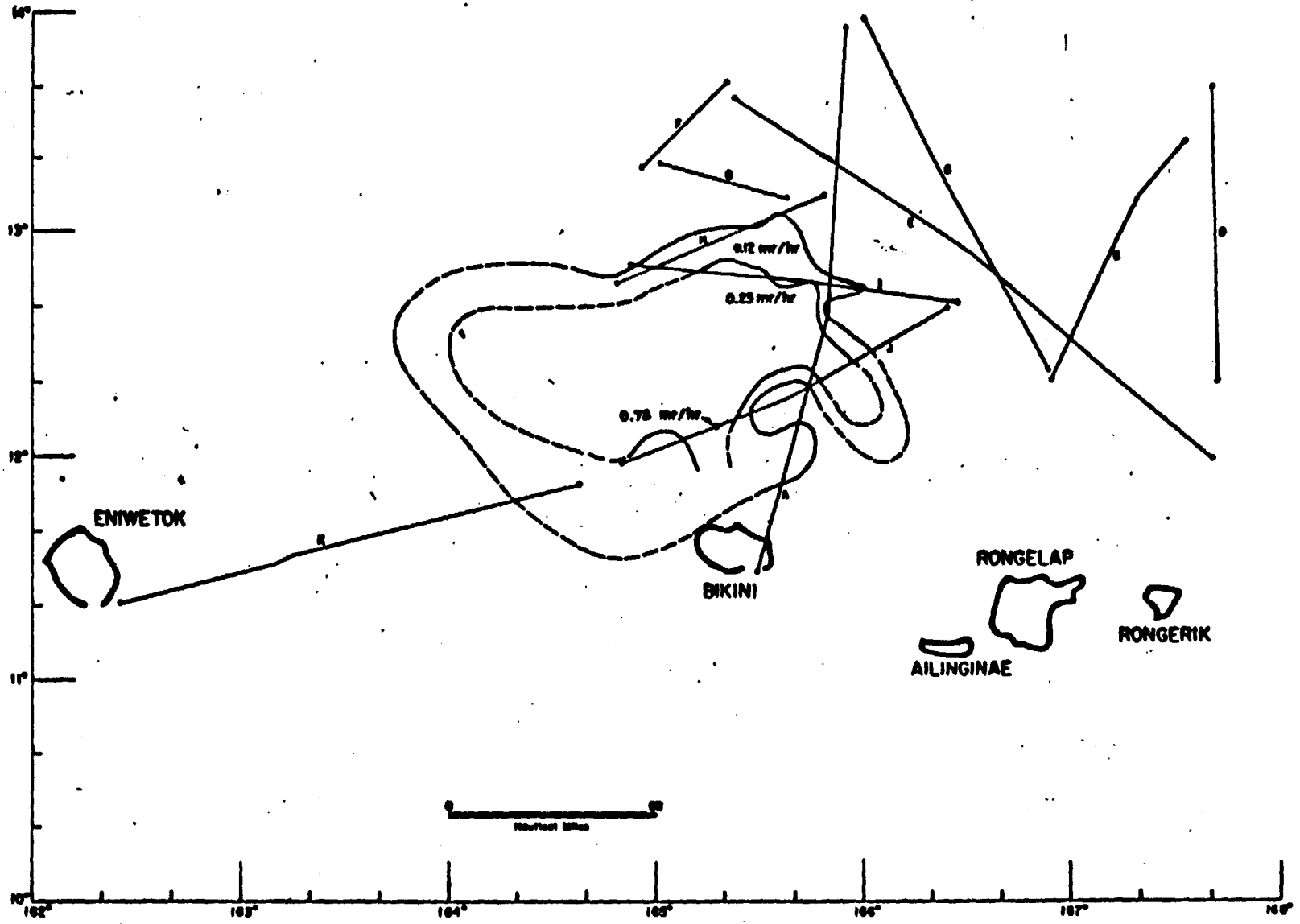


Figure 3.8 Flight pattern, Shot Zuni, D + 2 days. Letters indicate flight legs. All data readings referred to H + 24 hours and 3 feet above surface.

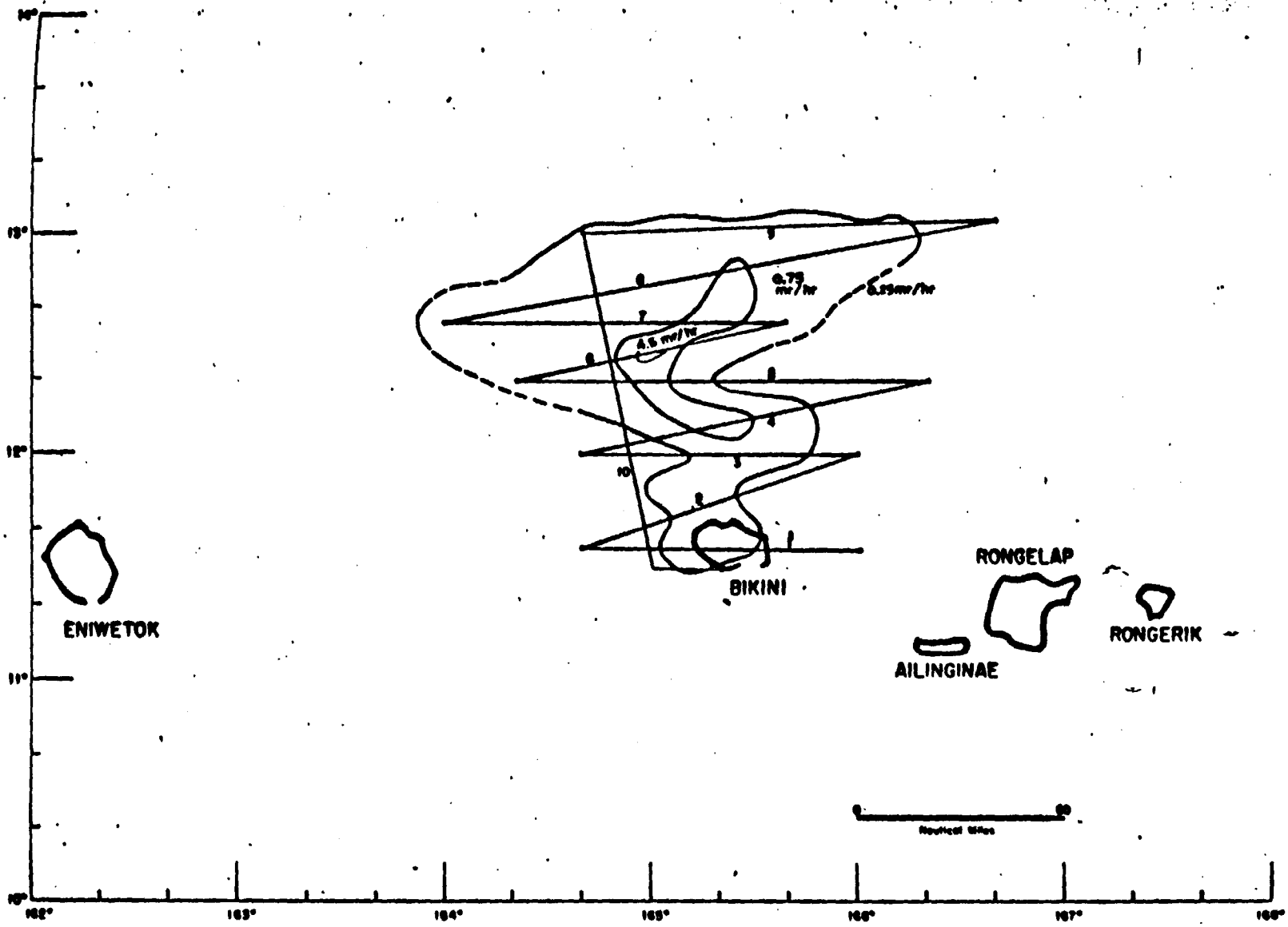


Figure 3.9 Flight pattern, Shot Zuni, D+3 days. Numbers indicate flight legs. All data readings referred to H+24 hours and 3 feet above surface.

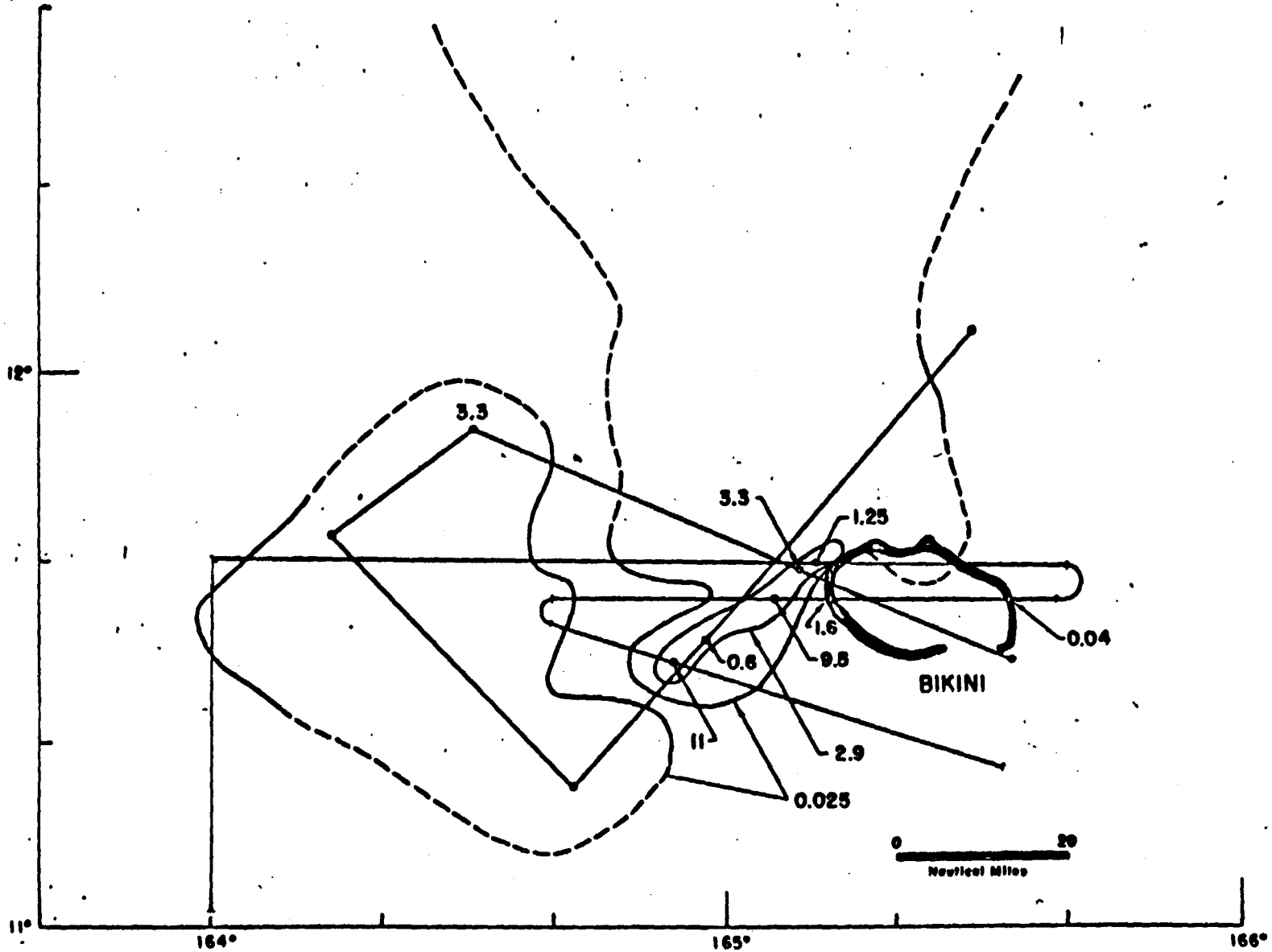


Figure 3.10 Flight patterns, Shot Flathead, D-day. Numbers shown are readings in mr/hr.

as the D + 1 survey does not indicate comparable dose rates. The aircraft encountered active fallout and became contaminated. A replacement aircraft was flown to the survey area. This also became contaminated. At no time was the level in the aircraft allowed to exceed 20 mr/hr.

Both aircraft on the D + 1 flights (Figure 3.11) were also lightly contaminated. Active fallout was encountered 100 miles northwest of Bikini at H + 30 hours. The northwest sector was closed, as far as aerial surveys on D + 1 were concerned. As indicated on the chart, it was not possible to close the isodose plot at that time.

The project had four aircraft to choose from for the D + 2 flight, all reading a background of approximately 0.1 mr/hr inside the detector shielding. The survey for this day could not detect any surface contamination reading above a minimum detectable limit of 0.25 mr/hr at 3 feet from the surface. Table 3.4 summarizes the fallout distribution.

TABLE 3.4 SUMMARY OF FALLOUT DISTRIBUTION, FLATHEAD

Isodose	Area	Difference Area	Average	Contamination
mr/hr	mi^2	mi^2	mr/hr	mc
D+1				
0.2	383	383	0.368	56
0.1	908	525	0.148	31
0.05	3,350	2,442	0.074	73
0.025	11,000*	7,650*	0.037	115
				275 mc at H+24 hours

* Based on estimated position of isodose line.

The EOB is roughly estimated and may not be representative of the actual extent of the contamination.

3.3.4 Shot Mohawk. A survey of the islands of Ediwetok Atoll was flown on D+1. The island readings are shown in Figure 3.12. The readings are referred to 3 feet above the surface of the islands by a factor of 5.8 for the 300-foot flight altitude (Figure 1.2). Sites Fred and Elmer were excluded from the survey pattern, because a 300-foot flight altitude would have interfered with the air traffic in the vicinity. The open-sea aerial survey could find no detectable contamination in the area searched (Figure 3.13).

3.3.5 Shot Navajo. A background survey was made on D−1 day to determine if the hot intensities, reported by Project 2.62, adjacent to the reef after Shot Flathead, could have come from contaminated water crossing the reef. This flight (Figure 3.14) subsequently became a D−3 survey because of postponement of the shot. The next flight (Figure 3.15) became the D−2 survey, again because of a postponement. The aircraft flight, on the day which would have resulted in a D−1 survey, was not completed because of malfunction.

The background surveys were coordinated with a Project 2.62 ship survey. Because the shape and position of the contaminated area varied from day to day, it is possible that the variation may have been a function of the surface winds. An outline of the area, based on the ship data has been included as Figure 3.16. The agreement between these plots appears good, in view of the 12-hour displacement between the ship and aerial survey.

The D-day survey (Figure 3.17) located the estimated upwind boundary. On D+1, the flights covered an area of 10,000 mi^2 but did not close the 0.025 mr/hr isodose line in the northwest sector (Figure 3.18). The D+2 chart (Figure 3.19) shows that this isodose extended farther than estimated on the previous days. The narrow 1.25 mr/hr line extending to the west of the atoll had disappeared. Reef readings have been included in this chart.

The summary of the fallout distribution (Table 3.5) indicates considerable instability in the contaminated area during the aerial-survey operations. As experienced after the previous water

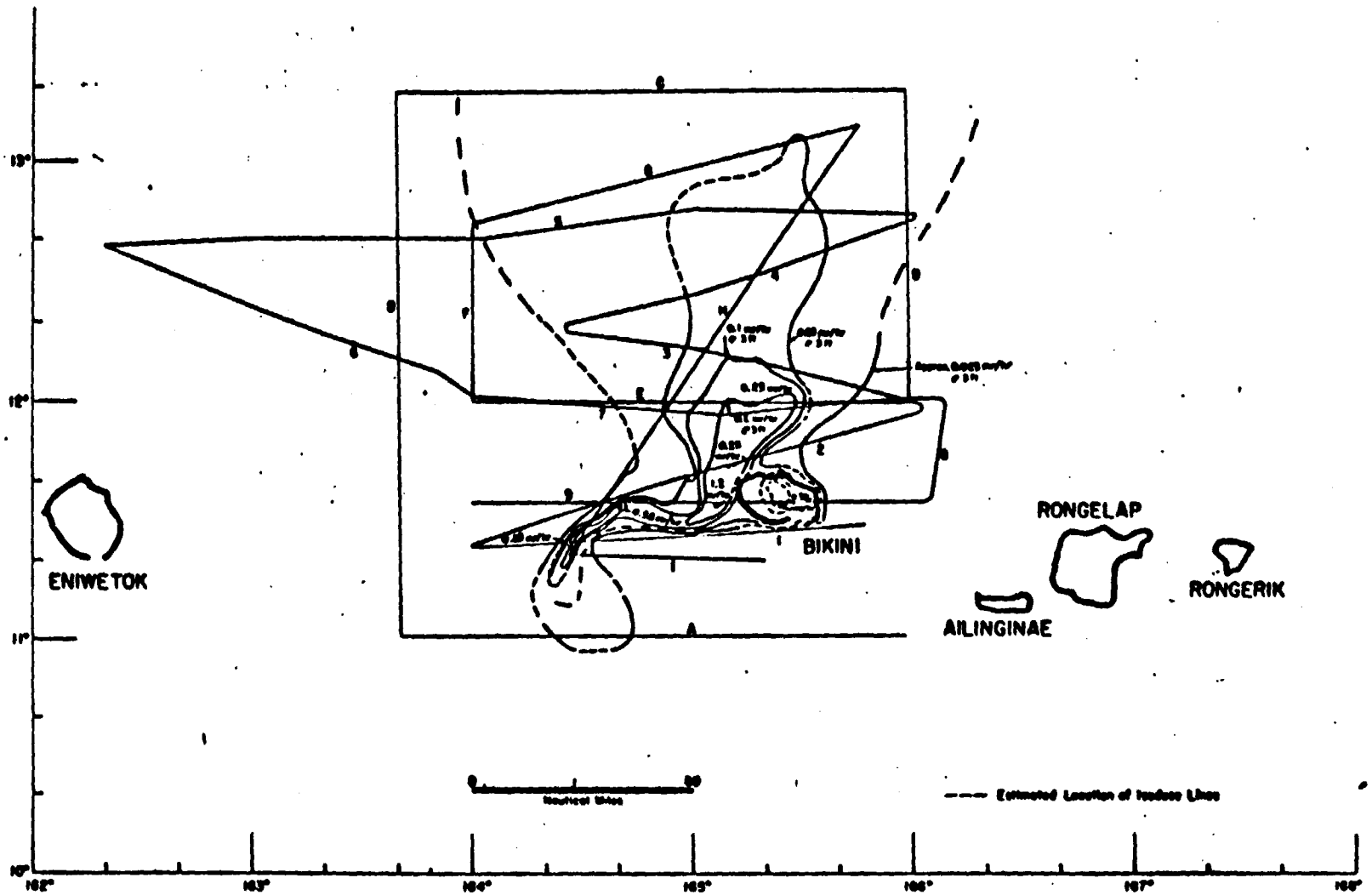


Figure 3.11 Flight pattern, Shot Flathead, D+1 day (H+24 to H+35 hours). Numbers show legs flown by Aircraft 1; letters show legs flown by Aircraft 2. Isodose values referred to: H+24 hours and 3 feet above surface. Airborne contamination encountered H+28 to H+30 hours.

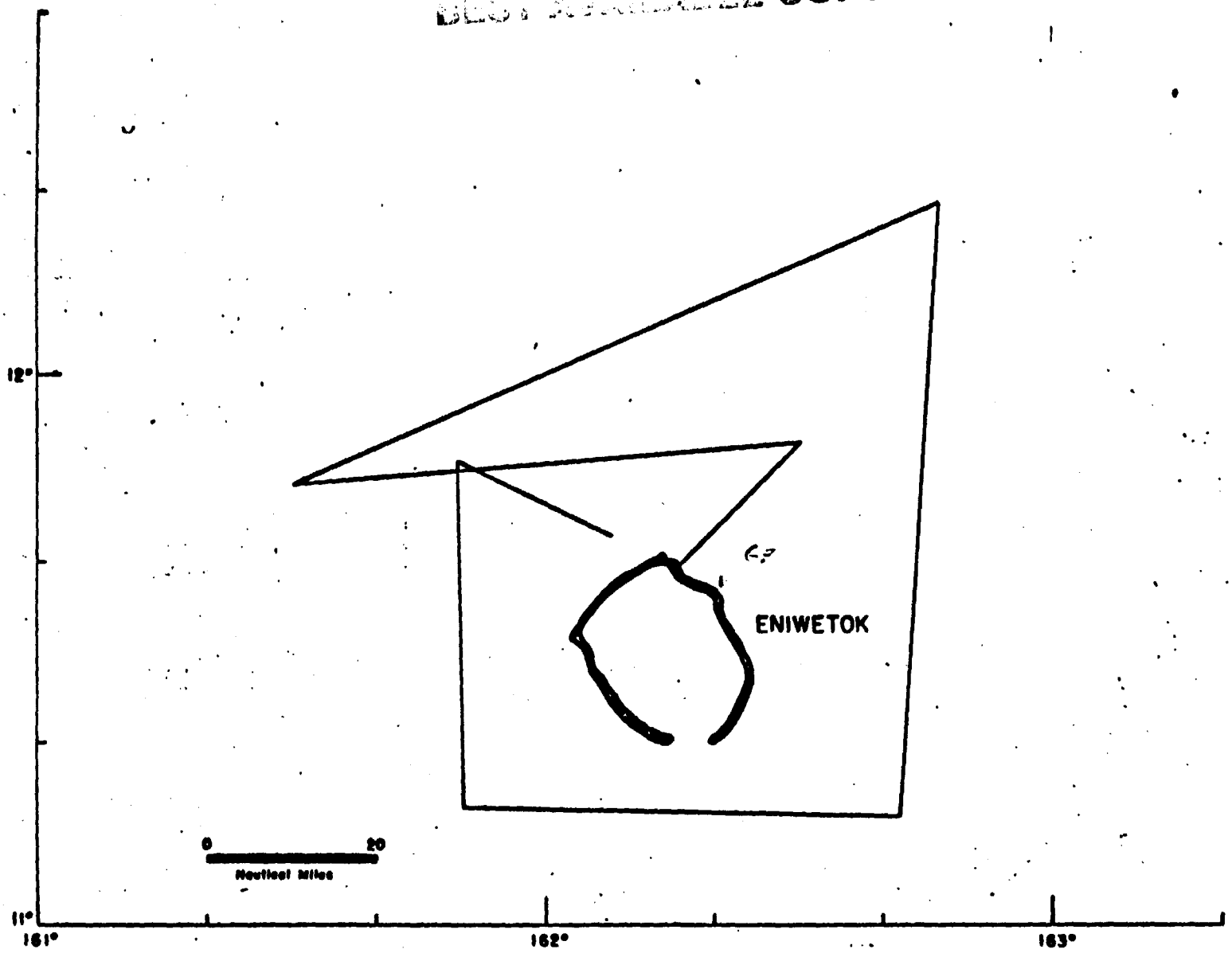


Figure 3.13 Flight pattern, Shot Mohawk, D+1 day.

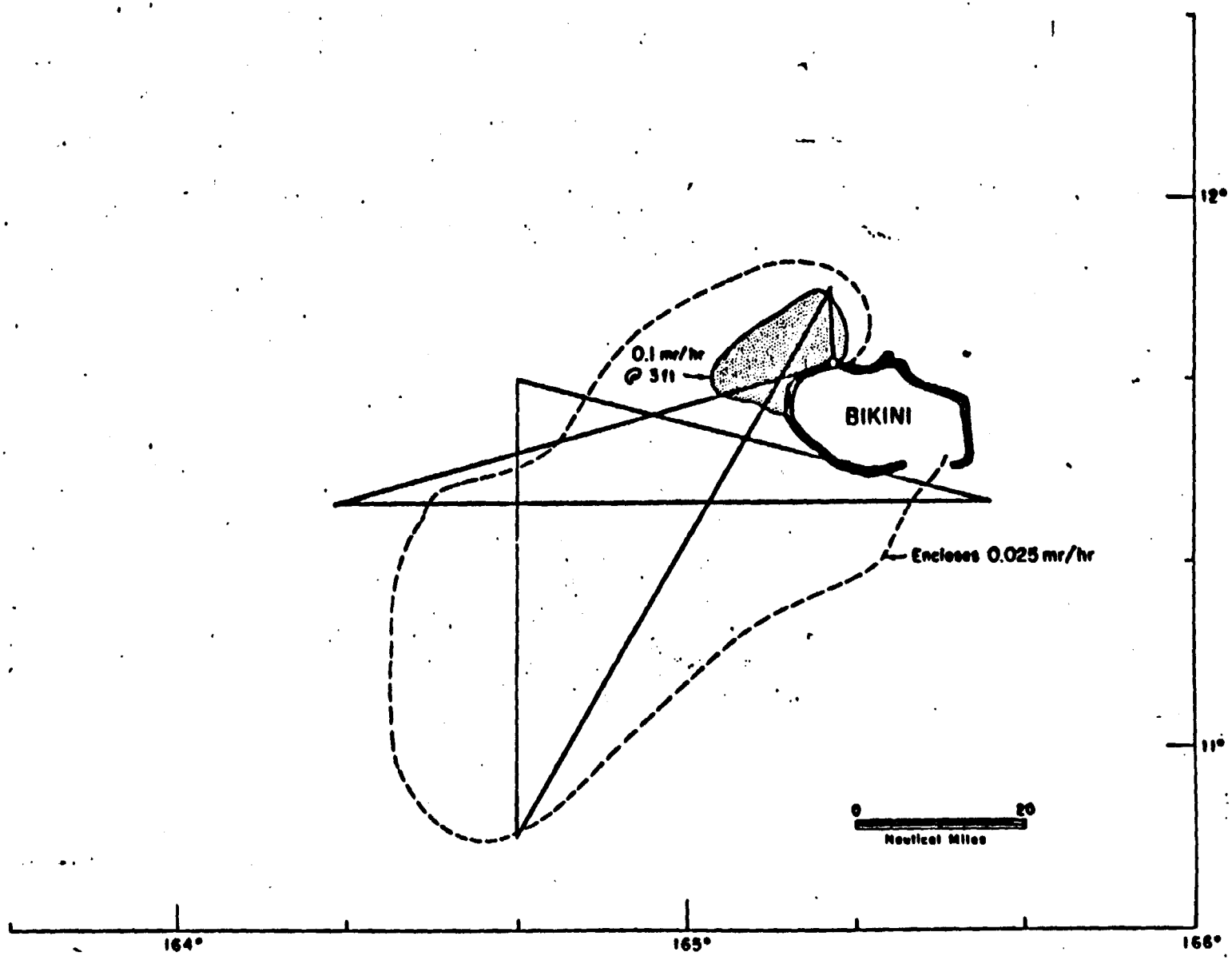


Figure 3.15 Aerial survey ("flush" flight pattern) Shot Navajo D−2 days. All readings referred to 3 feet above the surface and time of survey.

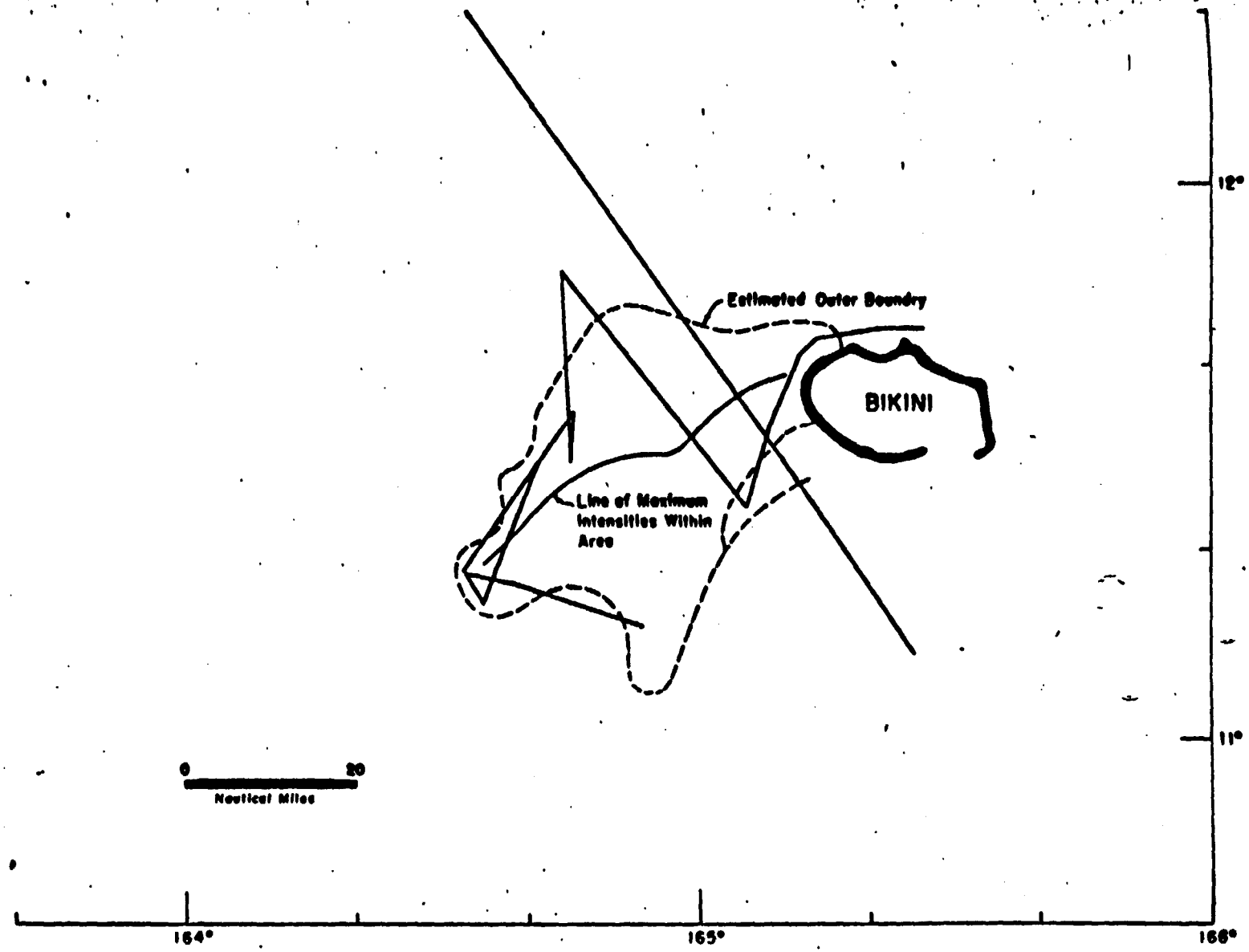


Figure 3.16 Ship pattern derived from data received from Project 2.62. Shot Navajo, D−2 days.

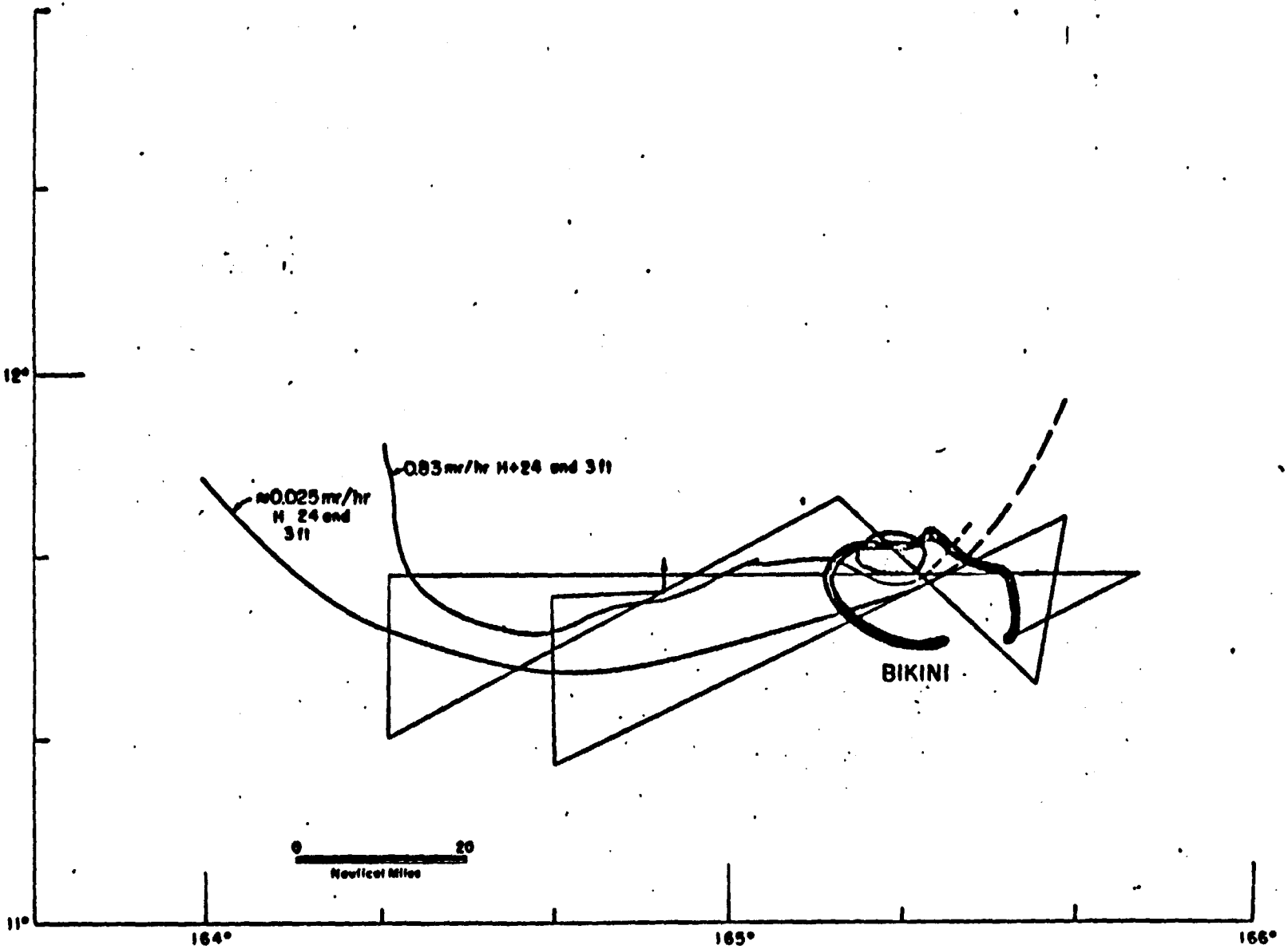


Figure 3.17 Flight pattern, Shot Navajo, D-day.

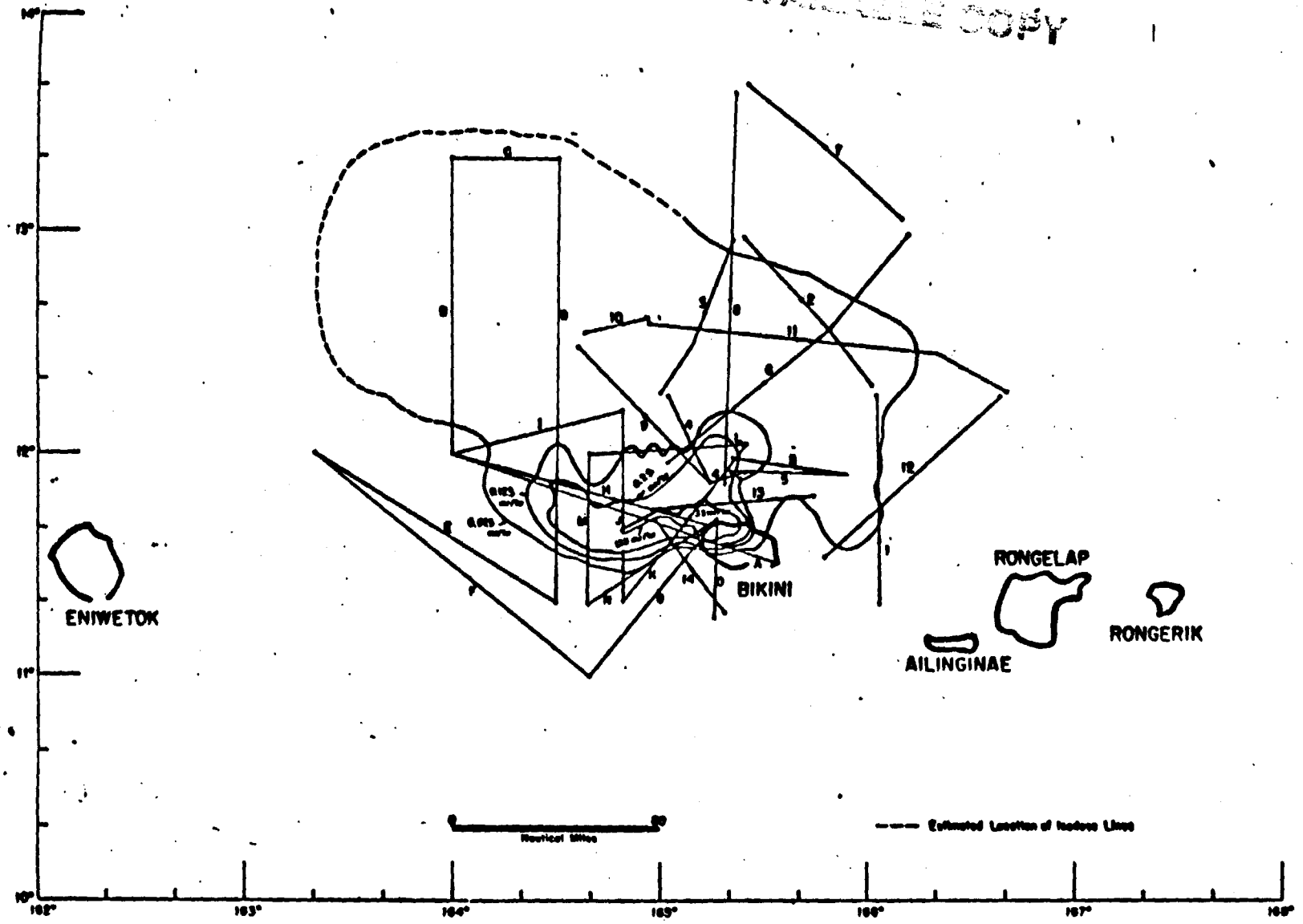


Figure 3.18 Flight pattern, Shot Navajo, D+1 day. All data readings refer to H+24 hours and 3 feet above surface. Numbers show legs flown by Aircraft 1, letters show legs flown by Aircraft 2.

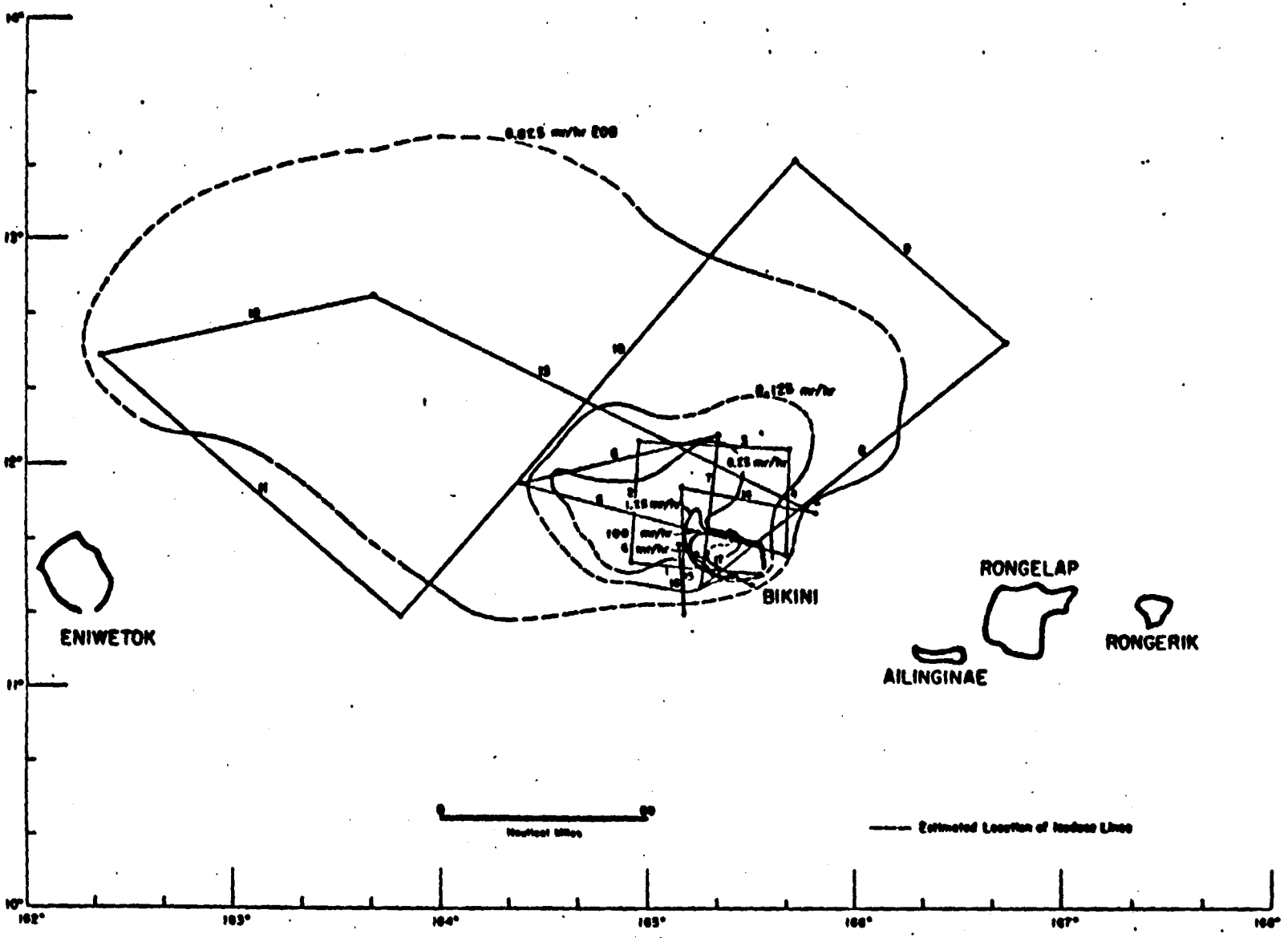


Figure 3.19 Flight pattern, Shot Navajo, D+2 days. All data readings refer to H+24 hours and 3 feet above surface. Numbers show legs flown by aircraft.

shot, Flathead, much of the fallout remains airborne. Thus, fallout and mixing in the sea could be expected to persist well into D+1.

3.3.6 Shot Tewa. A D-1 survey (Figure 3.20) defined the background status to the west of the atoll, prior to the shot. The D-day flight (Figure 3.21) located the upwind boundary. The

TABLE 3.5 SUMMARY OF FALLOUT DISTRIBUTION, NAVAJO

Isodose	Area	Difference Area	Average	Contamination
mr/hr	mi²	mi²	mr/hr	mc
D+1				
1.25	158	158	1.35	85
0.25	958	800	0.75	240
0.125	1,788	830	0.18	60
0.025	10,490*	8,702	0.06	209
				594 mc at H+24 hours
D+2				
1.25	90	90	1.35	49
0.25	1,267	1,177	0.75	353
0.125	3,263	1,996	0.18	144
0.025	20,930*	17,667	0.06	424
				970 mc at H+24 hours

* Based on estimate of isodose position.

D+1 survey (Figure 3.22) discovered a contaminated area extending over 200 miles west of Bikini. The outside boundary could not be closed on this survey, because of the far-out sector contained active fallout from Shot Huron. The D+2 survey (Figure 3.23) extended the estimated position of the EOB. The isodose was still not completely closed. The aircraft was not allowed to lose radio contact, so the survey covered only the area out to 275 miles from Bikini.

The 0.25 mr/hr isodose extended into the far northwest sector on D+1. By D+2, the position had shrunk to approximately a third of the enclosed area. The predicted pattern shows that this far-out material could not be expected to arrive before H+19 hours. Thus, it is probable that the readings in the area on D+1 were due to material that was not completely mixed. By D+2, some 30 hours had elapsed, and mixing was probably complete.

The D+3 and D+4 surveys, Figures 3.24 and 3.25, delineated the hot area, permitting an examination of the shape and position of these inner areas from D+1 through D+4. Table 3.6 summarizes the fallout areas throughout the shot participation.

3.4 SAMPLES OF CONTAMINATED SEA WATER

Duplicate samples of sea water were furnished to this project by the U.S. Naval Radiological Defense Laboratory (NRDL) and by Scripps Institution of Oceanography (SIO) from their sea-sampling programs. After the close of Operation Redwing, these samples were analyzed for beta activity in the particulate and salt fractions at the HASL.

3.4.1 Gamma Radiation as a Function of Beta Activity. The analysis of each sample, the gamma intensity estimated at each sampling location, and the comparison of these results are contained in Appendix D. A straight averaging of the beta activity and the estimated gamma intensity yields a figure of 4×10^6 (dis/min)/liter per mr/hr. The wide variability of the comparison for each sample obviates definite conclusions. However, much of the data falls within ± 50 percent of the theoretical calculation of 4.43×10^6 (dis/min)/liter of beta activity per mr/hr of gamma activity 3 feet above the surface. Thus, these results may be considered indicative of validity of the assumption.

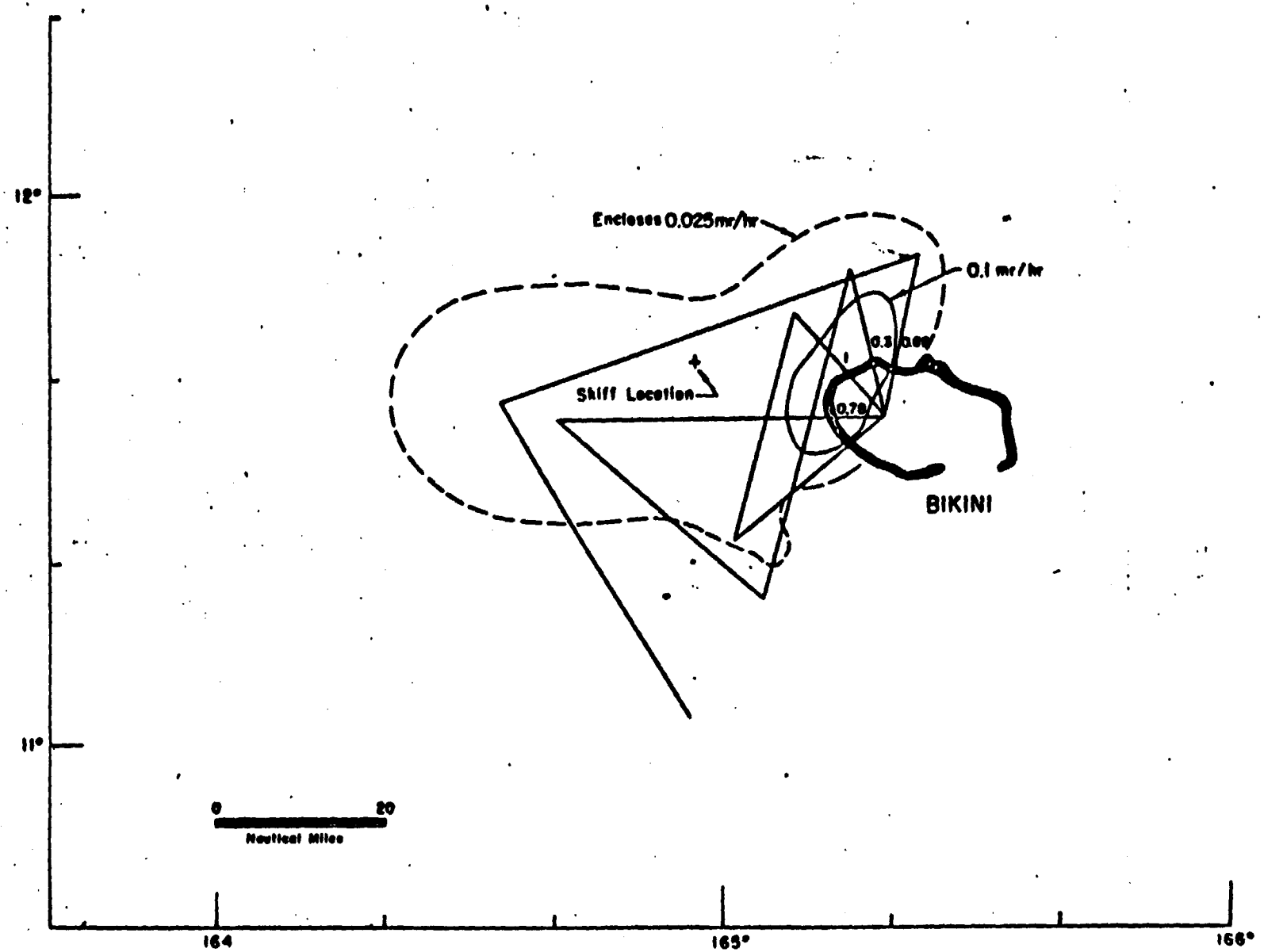


Figure 3.20 Flight pattern, Shot Tewa, D−1 day. All readings in mr/hr at 3 feet at time of survey.

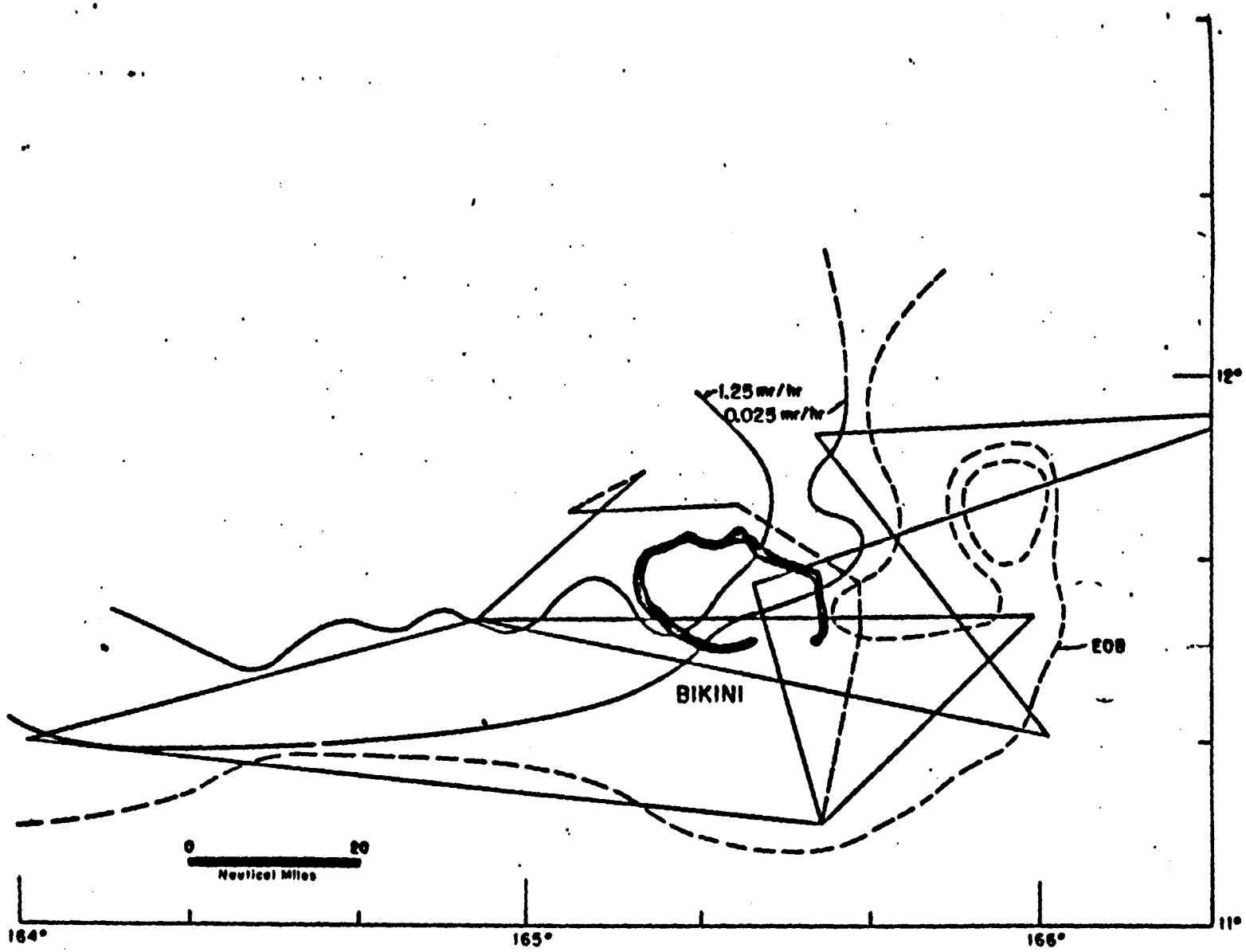


Figure 3.21 Flight pattern, Shot Tewa, D-day. All readings referred to H+24 hours and 3 feet above surface.

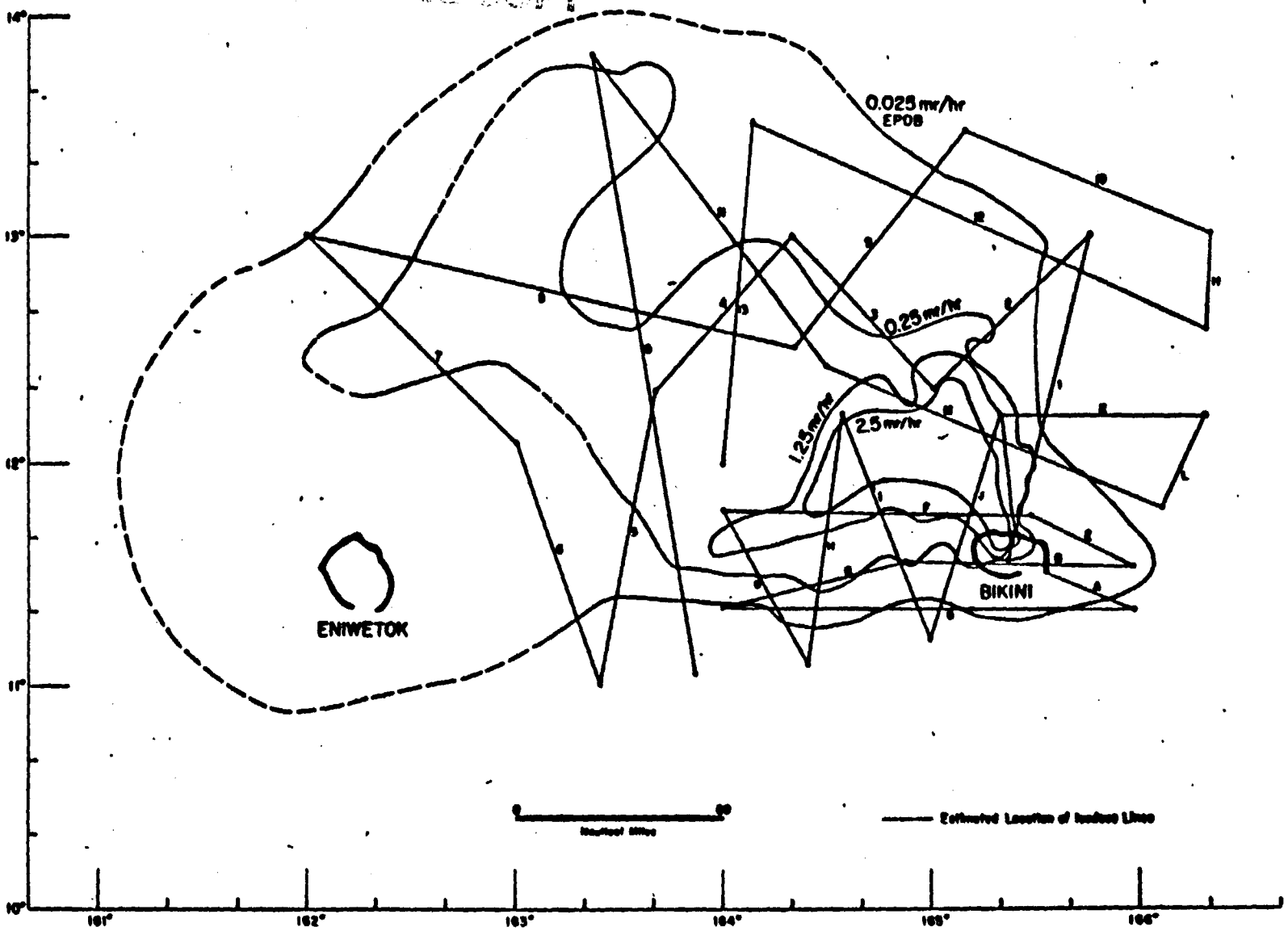


Figure 3.22 Flight pattern, Shot Tewa, D+1 day. All data readings refer to H+24 hours and 3 feet above surface. Numbers show legs flown by Aircraft 1; letters show legs flown by Aircraft 2.

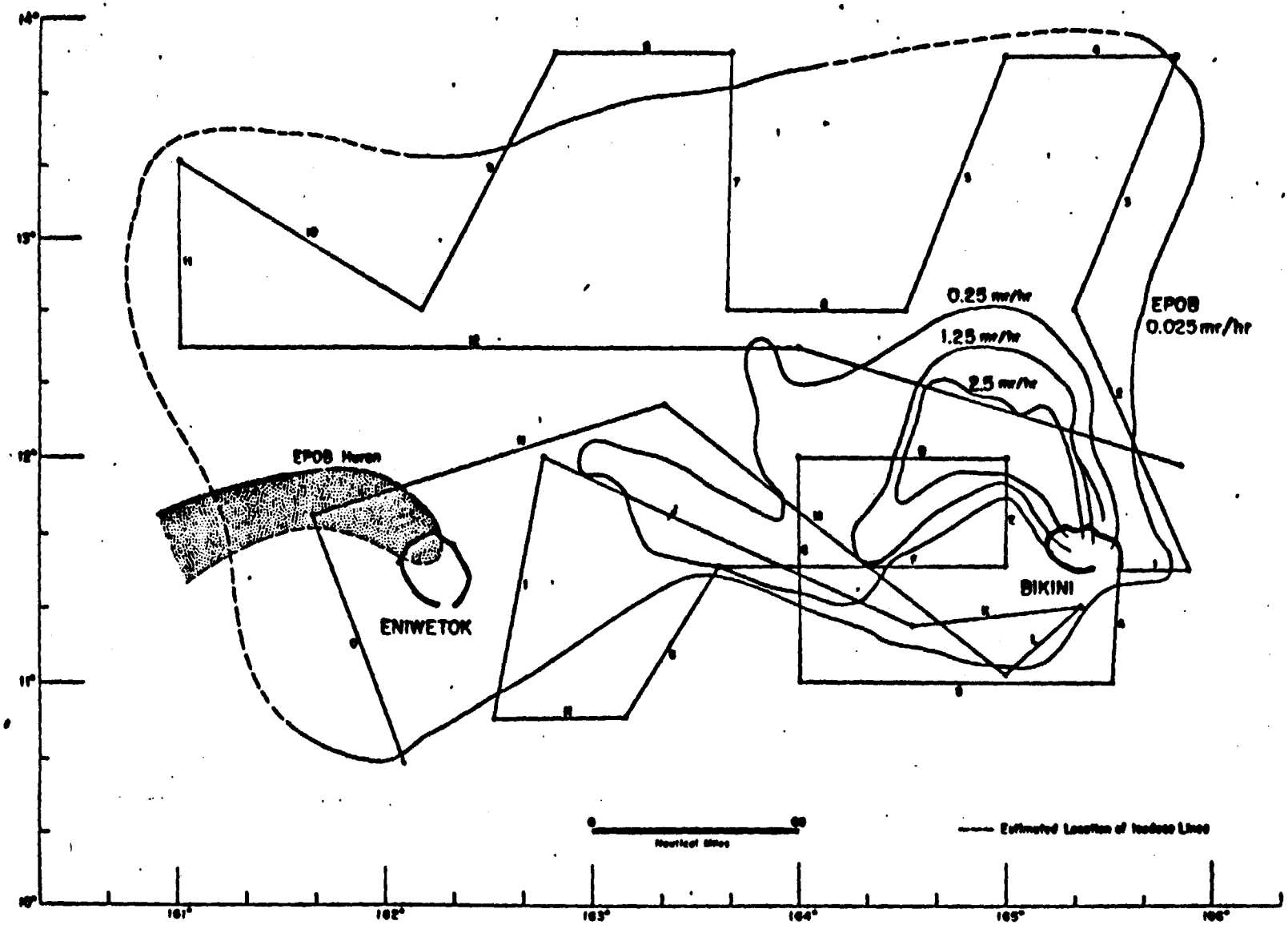


Figure 3.23 Flight pattern, Shot Tewa, D+2 days. All data readings refer to H+24 hours and 3 feet above surface. Numbers show legs flown by Aircraft 1; letters show legs flown by Aircraft 2.

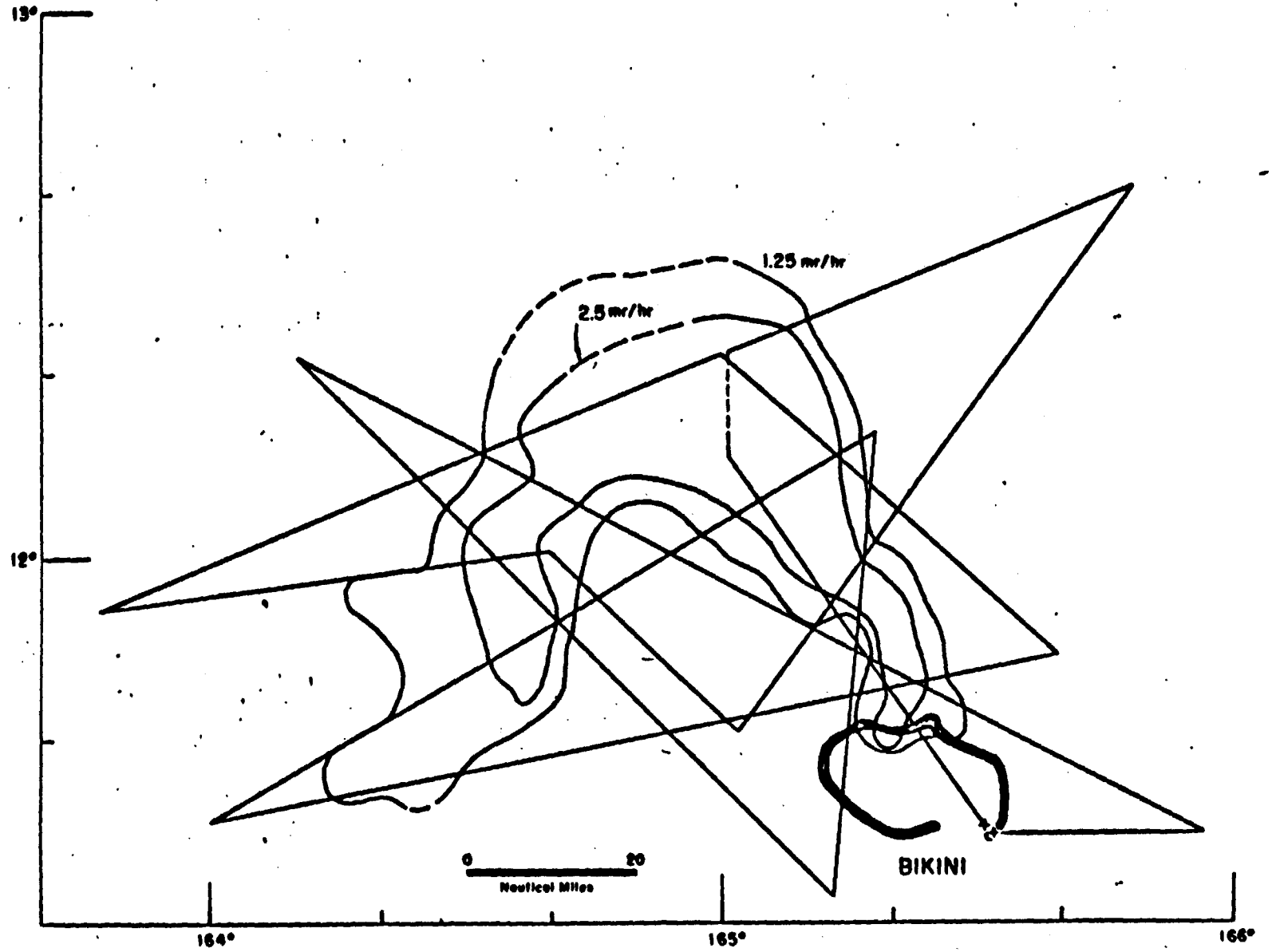


Figure 3.24 Flight pattern, Shot Tewa, D+3 days. All readings referred to H+24 hours and 3 feet above surface.

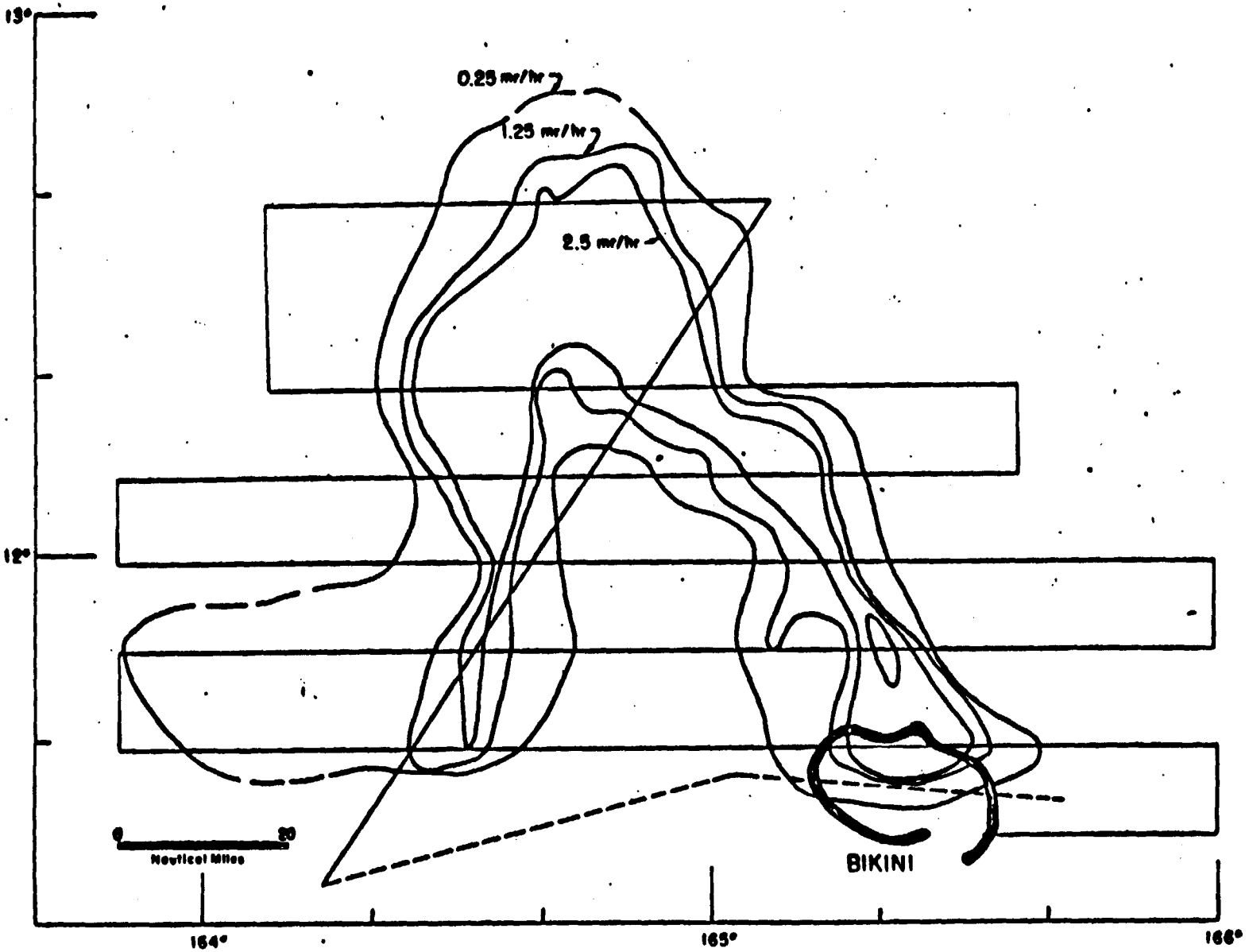


Figure 3.25 Flight pattern, Shot Tewa, D+4 days. All readings referred to H+24 hours and 3 feet above surface.

[redacted]

Chapter I
RADIOACTIVITY BACKGROUND in the OPEN SEA and LAGOONS of the ENIWETOK PROVING GROUND AREA

1.1 OBJECTIVE

A survey of the EPG was undertaken during the months of April and May 1956 to determine the radioactivity background prior to the 1956 test series. The program included radioactivity background studies of the water in the open ocean, the waters of the lagoons, the sediments on the ocean and lagoon floors, and the biological life associated with the above areas.

1.2 BACKGROUND

A study of radioactive contamination requires an understanding of the existing background intensities of both naturally occurring and artificially produced radioisotopes. In an area where physical changes are constantly taking place, it is desirable to make rapid in situ measurements.

The concentration of trace amounts of isotopes has been observed in marine organisms. Laboratory experiments have shown the uptake and absorption of strontium and yttrium by brown and green algae, vanadium by tunicates, and zinc and strontium by fish. During Operation Wigwam, thousandfold concentrations of the fission products were observed in some organisms, while other organisms from the same water mass showed little or no uptake of the radioactive isotopes over the same period of time (Reference 1).

The Japanese survey ships Shunkotsu-Maru during May and June of 1954, the Daifuji-Maru during December 1954, and the Kagoshima University training vessel, Keiten-Maru, during November and December 1954 and January 1955, detected radioactive contamination in the Western Pacific and Coral Sea sea water, plankton, and edible fish (Reference 2). The concentration of radioactivity detected in zooplankton was about 1,000 times, and in some cases as much as 10,000 times, more than that in the sea water they inhabited. Hundredfold variations of gross radioactivity were noted from one species to another.

Commercially important tuna were found to contain some artificial isotopes. Radiozinc was detected in the viscera of several fish. Zn^{65} apparently was highly concentrated in certain organs of Katsuwonus pelamis (skipjack tuna) and Parathunnus sibi (big-eyed tuna). Although Zn^{65} is not a fission product, it has been detected by several investigators (Reference 3).

During March and April 1955, the U.S. Coast Guard cutter Taney on Operation Troll traversed the Pacific Ocean collecting samples of water and plankton for radioanalysis. Widespread low-level activity was found to exist in the Pacific Ocean. Water activity

[redacted]

ranged from 0 to 570 (dis/min)/liter. Unsorted zooplankton ranged from 3 to 140 dis/min per gram wet weight. Radiochemical analysis of the plankton showed 80 to 90 percent of the activity to be Ce^{144} and Pr^{144} with some Sr^{90} present (Reference 4).

1.3 THEORY

The state of a mixture of fission products changes following entrance into the ocean. Physical and biological separations then begin to occur producing depletions in one phase and concentrations in others. Such occurrences should be taken into consideration in the studies of fallout patterns in a given area.

Studies of the predominant chemical species resulting from an underwater burst of an atomic device indicate that some of the long-lived fission products should be soluble in sea water, while others should be insoluble. Table 1.1 gives the chemical species and physical state of those elements which may be present 2 years after an atomic explosion (References 5 and 6).

TABLE 1.1 ESTIMATED PREDOMINANT REACTION PRODUCTS OF LONG LIFE ISOTOPES IN SEA WATER TWO YEARS AFTER A NUCLEAR EXPLOSION

Element	Half Life	Predominant Reaction Products	Predominant Physical State	Contribution to Total Fission Product Activity
				pct
Ce^{144}	282 days	CeO_2	Solid	27
Pr^{144}	17 minutes	Pr_6O_{11}	Solid	27
Pm^{147}	2.6 years	Pm_2O_3, $Pm_2O_3 \cdot xH_2O$	Solid	15
Sr^{90}	28 years	Sr^{+2}	Ionic	6.3
Y^{90}	64 hours	Y_2O_3, $Y_2O_3 \cdot xH_2O$	Solid	6.3
Cs^{137}	33 years	Cs^+	Ionic	4.0
$Ba^{137\,m}$	2.6 minutes	Ba^{+2}	Ionic	3.6
Ru^{106}	1.0 years	RuO_2, (Ru, $Ru_2O_3 \cdot xH_2O$)	Solid	3.3
Rh^{106}	30 seconds	Rh_2O_3, $Rh_2O_3 \cdot xH_2O$ (Rh)	Solid	3.3
Kr^{85}	10.6 years	Kr	Gas, dissolved	1.0
Nb^{95}	35 days	Nb_2O_5, $Nb_2O_5 \cdot xH_2O$	Solid	0.8
Zr^{95}	65 days	ZrO_2, $ZrO_2 \cdot xH_2O$	Solid	0.4
Eu^{155}	1.7 years	Eu_2O_3, $Eu_2O_3 \cdot xH_2O$	Solid	0.2
Sm^{151}	73 years	Sm_2O_3	Solid	0.2
Sb^{125}	2.7 years	Sb_2O_3, (Sb_2O_4)	Solid	0.15
Zn^{65}	245 days	ZnO, $Zn(OH)_2$	Solid	—
Co^{57}	270 days	$Co(OH)_2$	Solid	—
Co^{60}	5.2 years	$Co(OH)_2$	Solid	—
Mn^{54}	290 days	Mn_3O_4 (Mn^{+2})	Solid, ionic	—

As shown in Table 1.1, cesium and strontium, which are soluble in sea water, are more likely to be widely dispersed and homogeneously distributed throughout the hydrosphere than other elements. Cesium is chemically similar to potassium, which is present in the sea to the extent of 388 mg/liter, while natural strontium is present as 13 mg/liter.

The addition of 1 μc of cesium per liter would add 12.5×10^{-6} mg to the potassium. One μc of radiostrontium per liter would increase the strontium content by 7.3×10^{-6} mg. In addition, strontium is similar to calcium and is so used by organisms. How-

ever, organisms discriminate somewhat against strontium and hence, in the presence of the calcium in sea water, radiostrontium behaves as if it were even more highly diluted insofar as organisms are concerned; that is, Cs^{137} and Sr^{90} in the sea water act as if they were diluted more than a millionfold by natural, similar, or identical chemical elements. Even if the biological requirements of an organism were high for these elements, the abundance of the natural elements in sea water and the extreme dilution of the radioactive isotopes act adversely towards the concentration of the radioelement by an organism.

Nevertheless it is observed that trace elements in sea water may be highly concentrated in certain organisms over the amount in the water. This can be understood from the following numerical examples. Zinc concentration in sea water is about 5×10^{-3} mg/liter, cobalt about 5×10^{-4} mg/liter, and cerium about 4×10^{-4} mg/liter. The addition of 1 μc of Zn^{65} (0.12×10^{-6} mg) per liter would increase the zinc concentration by 0.002 percent and 1 μc of Co^{60} (0.86×10^{-6} mg) per liter would increase the concentration of cobalt by 0.17 percent. Although the ratio of the radioisotope to the stable isotope is still low, the total isotopic abundance in the sea is so low that an organism requiring this element for growth must absorb a relatively large proportion of the total amount in the water to supply its body needs.

Most of the elements shown in Table 1.1 appear to exist in sea water as insoluble oxides and hydroxides. These insoluble species would probably be strongly adsorbed on particulate matter such as colloidal ferric hydroxide.

The natural radioactivity of sea water is due chiefly to K^{40}, Rb^{87}, and the members of the uranium and thorium series. C^{14}, H^3, and some of the rare earths contribute a small amount.

A separation of the daughters of uranium occurs in the oceans, resulting in a concentration of radium in recent sedimentary deposits. Both radium and potassium are highly concentrated by some species of marine algae. In order to compare fission product contamination with the activity of the natural background, the properties and concentrations of some of the natural radioactive isotopes in the oceans are given in Table 1.2 (References 7 and 8).

In order to determine the natural radioactivity of several uncontaminated phosphorite and manganese nodules, an approximate analysis was made on samples obtained off the coast of California and from the northern Pacific. These analyses showed the presence of K^{40}, radium, and thorium with their decay products, as follows:

Phosphorite rock California Coast	Manganese Nodule Ranger Bank, California Coast	Manganese Nodule Horizon, North Pacific
90 total (γ/min)/gm (0.1 to 2.2 Mev)	7.2 total (γ/min)/gm (0.1 to 2.2 Mev)	34 total (γ/min)/gm (0.1 to 2.2 Mev)
K^{40} present but obscured by radium	0.3 pct K^{40} 3.3 $\mu\mu$c K^{40}/gm	1.2 pct K^{40} 10 $\mu\mu$c K^{40}/gm
34 $\mu\mu$c Ra^{226}/gm	2.5 $\mu\mu$c Ra^{226}/gm	$\approx$ 2.7 $\mu\mu$c Ra^{226}/gm
2.6 $\mu\mu$c Th^{232}/gm	0.3 $\mu\mu$c Th^{232}/gm	16 $\mu\mu$c Th^{232}/gm

Only the K^{40} concentration of 74 (γ/min)/liter of sea water or 640 (β/min)/liter should be encountered during field measurements of the uncontaminated surface waters. The dissolved uranium and radium concentrations are below the levels of detectability as outlined in Section 1.5. The radium and thorium concentration, on the other hand, may be sufficient to interfere with gross fission product analysis of the sediments.

1.4 OPERATIONS

During the months of April and early May 1956 the research vessel Horizon undertook a cruise throughout the EPG in order to measure the amounts of radioactivity associated with the oceanic environment. A study was made of the radioactivity of the water, sediments, marine life, and air in the EPG. The positions of observations are shown in Figure 2.1.

The Horizon was equipped with devices for sampling, storage, and assay of marine specimens. Water samples were collected from the surface, near bottom, and intermediate depths with 1-liter Nansen bottles at thirty stations. Duplicate vertical water sample profiles were taken for radioassay and for salinity determinations. Surface water samples of 5 liters were obtained in the open ocean and lagoons.

Zooplankton were collected at seventeen stations with a standard 1-meter diameter nylon plankton net towing obliquely from approximately 280 meters depth to the surface in 15 minutes time while the vessel proceeded at about 2 knots. The main portion of the net was made of Nitex cloth, 60 mesh per inch, and the cod end, of the same material, 90 mesh per inch. The net was designed to sample organisms larger than 0.5 mm.

TABLE 1.2 CONCENTRATIONS OF SOME NATURAL RADIOISOTOPES IN THE OCEAN

K^{40} isotopic abundance	0.1174 pct
K^{40} half life	1.28×10^{9} years
K^{40} specific negatron activity	27.3 ± 3.1 (β/gm K)/sec
K^{40} specific gamma activity	3.24 ± 1.5 (γ/gm K)/sec
K^{40} specific gamma activity	194 ± 9 (γ/min)/gm K
Potassium concentration in sea water	380 mg/kg
K^{40} concentration in sea water	74 (γ/min)/liter
K^{40} concentration in sea water	640 (β/min)/liter
K^{40} concentration in sea water	325 $\mu\mu$c/liter
Rb^{87} concentration in sea water	6 $\mu\mu$c/liter (no gamma)
Average uranium concentration in Pacific water	2.82×10^{-6} gm/liter
Average radium concentration in Pacific water	3.1×10^{-14} gm/liter
Activity ratio radium/uranium	0.16 in sea water
Activity ratio radium/uranium	6.4 in pelagic sediments
Radium concentration in clay sediments	10 to 20 $\times 10^{-12}$ gm/gm dry clay
Uranium in deep sea sediments	1.5 to 2.5 $\times 10^{-6}$ gm/gm dry clay
Thorium in deep sea sediments	5×10^{-6} gm/gm dry clay
Thorium in manganese nodules	24 to 124 ppm (Reference 8)

Ten vertical phytoplankton net hauls were taken in the open ocean and in Bikini and Ailinginae Lagoons. The net used was a 17-cm diameter, No. 20, phytoplankton net filter, having a mesh size of 70 μ and filtering approximately 1,500 liters of water per haul. No identification of the contents was attempted and no means were available to separate inorganic debris from living organisms.

Three samples of the deep-sea fauna were obtained in the area, using a 10-foot Isaacs-Kidd midwater trawl as the sampling device. The depths sampled ranged from 730 to 2,560 meters. The trawl fished continuously during the time required for lowering and retrieving, therefore it is not possible to state with certainty at what depth any individual was captured. However, as the trawl remained at the towing depth for 10

hours, it is reasonable to assume the major portion of each sample was taken at that depth.

Benthic organisms were collected in three bottom dredges south and east of Bikini Atoll at depths of 1,400 to 3,600 meters. A few living sponges, gastropods, brittle stars, and foraminifera were obtained. Bottom-dwelling organisms in Bikini and Ailinginae Lagoons were obtained by skin diving and bottom samplers.

Surface organisms were sought with lights and dip nets at every night station. However, few specimens were obtained in this manner in the EPG open sea area. Flying fish were numerous during the day but avoided the lights at night. Diurnally migrating fish also failed to come to the night light. Other marine organisms were obtained by line or spear fishing.

A series of seventeen samples of the ocean floor were taken around Bikini Atoll with a gravity coring device. The samples consisted of small bits of coral, basalt, manganese nodules, coarse coral sand, shell fragments, and fine globigerina ooze (fossils of minute organisms of the order Foraminifera). Several of the cores were lost because of the inability of the core barrel to penetrate hard sediments, or because of the core-catcher's inability in retaining the coarse sand found at some of the stations. In the latter case, only a few grains were saved for identification of the bottom sediment and these were insufficient for accurate radioassay. The bottom water trapped above the cores was filtered and evaporated for assay; the suspended sediment removed from this water was saved for analysis.

A number of samples of the Bikini Lagoon floor were collected with a snap type of bottom sampler. One sample of sediment was obtained from Ailinginae Lagoon. The samples consisted chiefly of fine coral sand and foraminifera mixed with fragments of coral and shells.

Miscellaneous samples of plant and animal life from Site Nan at Bikini Atoll and Sifo Island at Ailinginae Atoll were collected for analysis and comparison with the marine organisms.

Equipment was set up for collecting air-borne particulate matter aboard the Horizon. A series of samples were obtained at various localities by drawing 1,000 liters of air through a Type AA millipore filter.

The Horizon surveyed the radioactivity levels of the EPG over a 6-week period ending 15 May 1956, prior to Shot Cherokee, the first major nuclear event of the 1956 test series.

1.5 INSTRUMENTATION

1.5.1 Data Requirements. The determination of the ambient radioactivity required the measurement of the activity and the radioisotopic concentration in a large number of samples. In the EPG, the background measurement was made difficult by the wide variation in character of samples which had to be taken.

Gross beta counting may be used for comparing the activity of samples containing many of the fission products. When beta counting is resorted to, for the identification of the isotopes present in a sample, a combination of gross counting, chemical separation, half-life measurements, and beta-absorption curves is required. In addition, beta counting requires preparation of thin samples and close control over geometry and self absorption. These processes require techniques which are difficult to perform rapidly aboard a ship.

Gamma counting, on the other hand, is less restricted by self absorption and thus gamma counting simplifies field measurements of large specimens by eliminating extensive sample preparation. The determination of the total gamma count over a known

energy range may be used to compare the activity of similar samples containing the same gamma-emitting isotopes. The conversion of total gamma counts to curies requires a knowledge of the energy spectra observed by the counter, an identification of the radionuclides present, and a knowledge of the nuclear level schemes of each isotope. In many cases, the rapid determination of radioisotopes in the field may be performed by measuring the energy of the gamma photons emitted from specimens. The gamma energy spectrum, combined with a simple chemical group separation or ion exchange separation, often is sufficient to quantitatively identify a mixture of fission products.

1.5.2 Instrument Types. Radiation detection and assay equipment was selected for rapid estimates of radioactive substances on board ship. Gross counts were made for both beta and gamma radiation. Differential gamma pulse height analyses were run on those samples that were sufficiently active to produce significant results.

An end-window Geiger-Müller tube, with a mica window of 1.4 mg/cm^2 thickness, was used to count the beta particles. The counting tube was shielded by 2 inches of lead to reduce the background due to cosmic and external radiation to about 25 cpm. The sample planchets were mounted in a plastic and aluminum shield to reduce the effect of scattering and bremsstrahlung.

Gamma radiation was detected and counted with a Harshaw 1½-inch diameter NaI (Tl) scintillation crystal, shielded by lead and plastic, an RCA 5819 photomultiplier tube, and a preamplifier. Both beta and gamma counters were connected to a decade scaler. The gamma background count varied from 95 to 110 cpm aboard this ship at sea compared to the 150 cpm background experienced in a concrete building at La Jolla, California.

Gamma energy spectrum studies were made with a Harshaw 1¾ inch by 2 inch NaI (Tl) well-type scintillation crystal and Dumont 6292 photomultiplier tube, mounted together with its cathode follower in a 2¼-inch thick lead shield and feeding into a commercial, automatic, single-channel, stepwise type of pulse height analyzer; and the information was read on a decade scaler, and a digital printer.

The counters and associated electronic equipment operated on the ship's 110 volt ac power supply through isolation transformers. No difficulty was encountered with variations of supply voltage. The instruments were mounted in an air-cooled counting room separated from the main laboratory.

1.5.3 Instrument Calibration. The beta counters were calibrated with a commercial UX_2 beta source. The calibration was also checked with known amounts of potassium carbonate in order to correct for self absorption and geometry variations among different samples of salts or dried tissues. Self absorption curves were run with aliquots of a standardized Sr^{90} solution added to simulated samples.

The calibration of the gross gamma counter involved considerable difficulties. Originally a Co^{60} calibrated commercial standard was used. The Co^{60} source was subsequently discovered to be in error. A pair of Co^{60} sources, from the same company, calibrated in the same units, were found to differ by a factor of 2. Secondary standards of Zn^{65}, Cs^{137}, Ce^{144}, Ru^{106}, and Co^{60} and K_2CO_3 were prepared and calibrated by gamma energy spectrum analysis using a calibrated Ra^{226} (+ decay daughters) standard. A subsequent check against a set of calibrated gamma sources showed an absolute standardization of less than 10 percent error.

The calibration of the gross gamma count for energies between 0.075 and 1.5 Mev was valid only when measuring isotopes with energy and nuclear level scheme similar to the standard. Zn^{65}, Co^{60}, and Cs^{137} were used as standards when determining the

gammas emitted, per gram, of biological specimens containing the same nuclides. Ce^{144} and Ru^{106} were used as standards for comparison to the activity of the sediments and coral.

The gamma pulse height analyzer was calibrated for energies and efficiencies using a series of Ce^{144}, Ru^{106}, Cs^{137}, Zn^{65}, Co^{60}, K^{40}, and Ra^{226} standards. The error of standardization for the number of gammas emitted per source was less than 10 percent. The accuracy of the conversion of gammas per minute to microcuries depends upon the currently accepted values for the nuclear level schemes of the isotopes (References 9, 10 and 11).

1.5.4 Preparation of Samples. The samples to be counted for radioactivity were weighed, dried at 110 C, in some cases ashed, and counted on aluminum or stainless steel planchets. The samples for beta analysis were generally ashed to as small a volume as possible. The samples for gamma analysis were usually counted dry; however, for chemical analysis, or for reducing the volume of large specimens, they were ashed.

Samples of sea water were collected, filtered through millipore filters, evaporated to dryness and counted for beta and gamma activities. Millipore filters were also assayed. Large volumes of water of low activity were treated with a ferric hydroxide and barium carbonate precipitation to carry down the less soluble fission products in a small mass of carrier (Reference 12).

The zooplankton samples, in most cases, were assayed without sorting into like kinds of organisms. The bulk of these samples consisted of small crustaceans. Large, individual animals were removed for separate assay. Upon completion of gross counting, all the dried zooplankton samples were combined and ashed in $HClO_4$ and HNO_3 acids. The ashed mixture was then analyzed for specific isotopes by gamma energy analysis. The results were then substantiated by hydrogen sulfide chemical group separation.

Large marine organisms were either ashed whole or their various organs dissected for determination of the distribution of activity within the organism.

The phytoplankton and suspended sediments were filtered on a millipore filter and counted directly. Self absorption was negligible because of the small volume of matter present on each filter; however, the small mass introduced errors in the determination of the weight of the particulate matter.

The bottom sediments were weighed, dried, and counted under conditions of standard geometry for the total gamma photons emitted per unit mass of dry sample. The pelagic cores were frozen, sliced into 3-mm sections, weighed, dried, and counted for gross gamma count and for gamma energy spectrum.

Samples of the air-borne particulate matter taken over the lagoons and over the open sea on millipore filters were counted without further preparation.

1.5.5 Chemical Separations. In order to substantiate the gamma energy spectrum analysis, samples showing different gamma energy peaks were dried, then wet ashed with nitric and perchloric acid. The resulting solutions were separated into hydrogen sulfide groups (References 12 and 13). Each H_2S group was reexamined with the pulse height analyzer and then was purified into the suspected element (References 13 and 14) and counted for beta and gamma activities.

1.5.6 Reporting of Data. The water sample results are reported as gamma rays emitted per liter of sea water compared to a Co^{60} and Zn^{65} standard. The instrument

background has been subtracted from all values. The reported values include the naturally occurring isotopes as well as the artificial contamination.

The plankton, fish, and clams are reported as gammas emitted per minute per gram of wet weight compared to either a Co^{60} or a Zn^{65} standard.

The bottom sediments, shells, coral, and algae are reported as gammas per minute per gram compared to Ru^{106} and Ce^{144} sources. In all cases the gammas include all photons between 0.075 and 1.5 Mev.

The results of the gamma spectrographic analyses and radiochemical analyses are reported as $\mu\mu c$ of the individual isotopes contained per gram of living organ or organism.

The sediments are reported as gamma photons emitted per gram of dry matter or as $\mu\mu c$ of a specific isotope per gram of dry sediment.

All reported values have been extrapolated to 1 May 1956.

1.6 RESULTS AND DISCUSSION

1.6.1 Radioactivity of the Open Ocean Waters. Throughout the EPG area the radioactivity of the sea water was found to be fairly uniform. The surface water varied from 100 (γ/min)/liter in the eastern area to 400 (γ/min)/liter west of Bikini Atoll, or from one to five times the natural potassium gamma background of 74 (γ/min)/liter of sea water. Surface water at several stations was filtered through a millipore filter in order to determine if the activity was present in the upper layers as dissolved substances or as particulate matter greater than 0.5 micron diameter. Most of the activity was found to be in the dissolved phase. For example, at Station 14 at the surface, the water emitted 300 γ/min from 2 liters; the activity of the suspended particulate and colloidal matter in the 2 liters was 45 γ/min or 15 percent. For subsurface water at Station 27, the total activity in 6 liters of water taken as a vertical column from depths between 50 and 1,500 meters was 1,030 γ/min from 6 liters, while that of the particulate matter was only 20 γ/min from 6 liters, or 2 percent.

Vertical profiles of radioactivity for ten stations are shown in Table 1.3. The radioactivity of the sea water in this table is expressed as total gamma photons (0.075 to 1.5 Mev) emitted per liter of water, standardized against Co^{60} and Zn^{65} calibrated sources. The values reported include the natural K^{40} gamma activity. No positive identification of the radioisotopes present in the sea water was completed. The activity of the water was constant with the exception of one layer of water between 800 and 1,200 meters found northwest of Bikini Atoll at Stations 6, 7, 8, and 29. This mass of water, situated on the edge of a large eddy current found around Bikini, appeared to be two to four times as active as the surface water.

The salinity values for Station 29 are listed in Table 1.3. There appeared to be no relationship between the variation in radioactivity with the slight variation that exists in salinity.

Radiochemical analysis of gross zooplankton (Table 1.4) showed a hundredfold concentration of artificial radioactivity over the total radioactivity of the water from which the plankton was taken. The radionuclides detected in the zooplankton were Mn^{54}, Zn^{65}, Co^{57}, Co^{60}, and a trace of the rare earths.

The probable error of the measurements of surface water activity, excluding the alkali metals, by $Fe(OH)_3$ precipitation was kept below 20 percent. The radioassay of 150 to 750 ml subsurface samples by evaporation and direct gamma counting of the resulting salt entailed a probable counting error of 30 to 50 percent and occasionally over 100 percent.

1.6.2 Lagoon Waters. The radioactivity of the waters enclosed within Bikini and Ailinginae Lagoons, as shown in Table 1.5, ranged from seven to fourteen times the natural potassium gamma background and from three to seven times the average radioactivity of the surface water surrounding the lagoons. No difference was detected between the lagoon water at Site Elmer, Eniwetok, and the surrounding ocean water, perhaps due to the exchange of water permitted by the wide, deep channel nearby. The radioactivity of the lagoon water, in contrast with the open ocean water, was associated with the suspended particulate matter. The residue from 6 liters of filtered surface water, emitting a total of 4,660 γ/min, showed 2,720 γ/min, or 56 percent associated

TABLE 1.3 GAMMA RAYS EMITTED PER MINUTE PER LITER OF EPG OPEN SEA AREA WATERS

The values of (γ/min)/liter (0.075 to 1.5 Mev) have been corrected to account for a 22 percent efficiency and a 41 percent geometry of the scintillation counter when standardized with Co^{60} and Zn^{65}. The average background due to instrument noise and cosmic rays has been subtracted from the reported values. The natural K^{40} background of 74 (γ/min)/liter of sea water has not been subtracted and is included in the above figures.

Depth	Stations										Salinity for Station 29
	6	7	8	9	12	14	25	27	28	29	
meter											pct
0	207	237	133	105	147	150	170	30	90	230	34.56
50	—	—	130	—	175	—	—	140	—	90	34.58
100	—	—	217	−150	−125	65	55	60	−60	—	35.01
125	—	—	0	—	—	—	—	—	—	—	35.25
150	—	—	—	—	—	—	—	170	−90	235	35.12
200	—	—	170	105	150	200	—	—	—	205	34.58
250	125	—	—	—	—	—	−68	—	—	175	34.43
300	—	—	—	—	—	—	—	—	—	187	34.41
400	—	—	—	45	195	140	—	195	—	205	34.60
500	170	—	—	—	—	—	175	—	157	−120	34.58
600	—	—	—	—	—	245	—	—	—	170	34.59
800	427	370	—	110	235	—	—	250	—	417	34.58
1,000	—	790	435	230	45	—	325	—	185	260	34.59
1,200	620	—	—	—	—	205	—	—	—	195	34.60
1,400	267	290	60	—	45	—	267	217	200	260	34.63
2,000	140	290	60	—	—	—	—	—	—	—	—
3,000	205	157	150	—	—	—	—	—	—	—	—
4,000	—	165	187	—	—	—	—	—	—	—	—
Bottom Depth, meters	3,560	4,300	4,600	4,200	5,200	5,100	4,300	3,400	4,800	1,440	

with the insoluble fraction. Subtracting the K^{40} contribution from the total, 62 percent of the artificial radioactivity was retained by particulate matter larger than 0.5 micron in diameter.

An analysis of the particulate matter in the lagoon water showed 85 percent Ce^{144} and 15 percent Ru^{106} of the gamma-emitting isotopes. The soluble fraction was not identified.

1.6.3 Marine Organisms of the Open Sea. The assay of the oceanic fauna consistently showed the presence of artificial radioactive contamination. Zooplankton from water of an average activity of 173 ± 85 (γ/min)/kg (Table 1.3) showed an average of 18,000 ± 4,000 (γ/min)/kg (Table 1.4) or more than a one-hundredfold concentration over that of water. Neglecting the K^{40} activity of the plankton (0.08 to 0.8 (γ/min)/gm) and subtracting the K^{40} activity (74 (γ/min)/liter) from the water, unsorted zooplankton, on the basis

TABLE 1.4 RADIOACTIVITY ASSAY OF PLANKTON SAMPLES FROM THE EPG AREA

a. Mixed Zooplankton

Station	Zn^{65} Standard	Station	Zn^{65} Standard
	(γ/min)/gm		(γ/min)/gm
5	2 ± 6.3	16	18 ± 2.3
7a	55 ± 6.7	19	22 ± 1.7
7b	40 ± 3.5	21	11 ± 3.6
9	25 ± 2.2	24	1.4 ± 3.4
11	8 —	25	14 ± 4.3
12	9 ± 4.2	26	11 ± 4.4
13	2.2 ± 4.2	28	6 ± 3.8
14	4 ± 4.1	29	7.5 ± 2.7
15	−2 ± 3.2	30	94 ± 5.1

b. Radiochemical Analysis of Gross Zooplankton, 1 May 1956

Ce^{144}	Trace
Mn^{54}	0.59 μμc/gm
Zn^{65}	4.9 μμc/gm
Co^{57}	≈0.2 μμc/gm
Co^{60}	≈2.1 μμc/gm

c. Individual Organisms

Station	Organism	(γ/min)/gm	Station	Organism	(γ/min)/gm
4	Phytoplankton	≈0	13	Phytoplankton	≈21
7	Eel larvae	85	15	Salps	0
7	Physalia	1	19	Pteropods	32
7	Polychaeta	1	19	Calanoid copepods	17
7	Myctophid	15			
7	Sagitta	0	27	Phytoplankton	≈5
7	Crab larvae	43	30	Myctophid	12
12	Pteropods	36	30	Pteropods	77
15	Sagitta	0	30	Copepods	61

of drained wet weight, concentrated the artificial radioisotopes 175 times above that found in the same amount of sea water they inhabited.

A hundredfold variation of radioactivity was detected among different genera with the concentration over that of sea water ranging from zero to a thousandfold. Table 1.4 gives the gamma activity of seventeen bulk zooplankton samples, as well as the activity of selected organisms separated from the gross samples. Station positions are shown in Figure 2.1. The highest activity was detected in the mucus and filter-feeding pteropods and filter-feeding copepods both of which feed upon microscopic organisms and suspended detritus. The lowest activity was found in the filter-feeding salps and the rapacious, plankton-feeding Sagitta, both of which have a high water content.

A radiochemical and gamma spectrographic analysis of the combined zooplankton samples from seventeen stations showed the presence of Ce^{144}, Mn^{54}, Zn^{65}, Co^{57} and Co^{60} in the amounts given in Table 1.4. Cs^{137} was not detected and no analysis was made for radiostrontium.

As shown in Table 1.3, the levels of activity of the water were quite low throughout the entire area studied. However, it is significant that the greatest activity was found

TABLE 1.5 RADIOACTIVITY OF LAGOON WATERS

Station	Depth	(γ/min)/liter *	Probable Error
			pct
Bikini Atoll, Site Nan	Surface	575	27
Bikini Atoll, Site Charlie	Surface	810	20
Bikini Atoll, Site Charlie	Near shore 1 meter deep	1,065	15
Bikini Atoll, mid lagoon	Surface	645	23
Ailinginae	Surface	535	30
Eniwetok Atoll, Site Elmer	Surface	200	42

* The values of (γ/min)/liter (0.075 to 1.5 Mev) have been corrected to account for a 22 percent efficiency and a 41 percent geometry of the scintillation counter when standardized with Co^{60} and Zn^{65}. The average background due to instrument noise and cosmic rays has been subtracted from the reported values. The natural K^{40} background of 74 (γ/min)/liter of sea water has not been subtracted and is included in the above figures.

within the influence of the eddy system around Bikini, Ailinginae and Rongelap Atolls (Figures 2.5 to 2.9). It is probable that within this area the supply of radioactivity in the ocean was being constantly renewed by tidal flow from Bikini and neighboring atolls to the east. Swept into the eddy where it does not escape for an extended period of time, crop after crop of the short-lived plankton becomes contaminated.

Organisms from three samples of the deep-sea fauna, obtained by trawling at depths from surface to 730 to 2,560 meters, showed activity levels similar to those of the zooplankton from the upper water levels. Selected fish and planktonic organisms sorted from one trawl are listed in Table 1.6. As in the case of near surface zooplankton, the pteropods contained the greatest amount of radioactive material per gram of tissue on a wet weight basis. The activity is listed in Table 1.6 as total gammas, compared to a Zn^{65} standard, emitted per minute per gram of wet tissue.

1.6.4 Marine Organisms of the Lagoons. While the water of Bikini Lagoon varied from 0.5 to 1 (γ/min)/gm, the marine organisms varied from 100 to 50,000 (γ/min)/gm, showing apparent concentrations of gamma-emitting isotopes to factors of 10^2 to 10^5 above the waters in which they were taken. The lagoon fishes remain in the lagoon during their entire life while the water is continuously being renewed from the outside ocean. Although the specific activity of the marine organisms at the time of capture was much greater than that of the lagoon water, the concentration of the activity in the organisms over that of the water may not have been so great at an earlier date when the activity of the water was greater. The marine organisms remaining in the lagoons may represent the contamination level of an earlier mass of water which was subsequently swept out of the lagoon.

The predominant radioisotopes within the lagoons were: Ce^{144} and Ru^{106} in the water and suspended particulate matter, Zn^{65} in the fish, Co^{60} in the mollusks, Ce^{144} in the

TABLE 1.6 RADIOACTIVITY ANALYSIS OF SOME OCEANIC FAUNA NEAR BIKINI ATOLL. DEPTH OF CAPTURE FROM 0 TO 730 METERS

Organism	(γ/min)/sample	(γ/min)/gm of Live Tissue, Zn^{65} Standard
Argyropelecus species (Hatchet fish)	72	9
Melanocetus species (Angler fish)	17	2
Lampanyctus species (Lantern fish) (6 young)	55	6.2
Shrimp (Mysidacea)	133	18
Tunicate, colonial	39	6
Siphonophore bracts	2	5
Physalia (Portugese man-o-war)	0.5	0.2
Jellyfish (unidentified)	84	41
Pteropods (3 small)	35	100
Jellyfish (75 grams)	875	11.6
Octopus and squid (combined)	97	1.3
Cyclothone	40	23

coral and shells, and Ru^{106} in the calcareous algae and finger snails (Genus Pterocera). Tables 1.7 and 1.8 list the radioactivity levels of various organisms from the southeastern and northwestern areas of Bikini Lagoon.

Of the various organisms collected, the mollusks proved to be the most radioactive. Their activity was most pronounced in the livers or digestive organs which were fifty to one hundred times more active than an equal weight of the other portions of the body or shell.

Table 1.9 gives the gamma activity of certain Ailinginae Lagoon organisms which appear to be about one tenth as radioactive as Bikini Lagoon organisms. The fins and liver of a skipjack tuna caught in the entrance to Ailinginae were the most radioactive among the specimens assayed. Table 1.11 indicates that the Zn^{65} contamination of this

TABLE 1.7 RADIOACTIVITY LEVELS OF CERTAIN ORGANISMS FROM BIKINI LAGOON SOUTHEASTERN AREA

Sample	Ru^{106}, Zn^{65} Standards	Sample	Zn^{65}, Co^{60} Standards
	(γ/min)/gm		(γ/min)/gm
Algae, green, off Tridacna shell	210	Snail, gastropod	
Algae, calcareous	1,050	Foot	1,260
Algae, Halimeda	1,700	Liver	460
Beche-de-mer (sea cucumber)	110	Gills	5,800
Bivalve clam body	400	Kidney	36,300
Bivalve clam shell	105	Stomach	2,500
Bivalve body, 11 deg, 33 min, 26 sec N, 165 deg, 33 min, 03 sec E	3,300	Opercular valve	430
		Siphon	540
Bivalve shell	750	Tridacna clam	
Coral, disk	500	Gills	355
Coral, pink, reef	506	Liver	37,000
Finger snail, viscera	1,800	Mantle	186
Finger snail, foot	430	Adductor muscle	173
Finger snail, feces	1,200	Stomach	687
Fish larvae	480	Tridacna liver	
Hermit crabs	1,540	From Bikini	36,000
Myctophid (lantern fish)	0	From Site Item	30,800
Sea urchin, young	150	From Site King	45,400
Squid	620	From Site Love	19,200
		From Site Mike	15,900
		From Site Nan, lagoon	25,400
		From Site Nan, ocean	18,000

TABLE 1.8 RADIOACTIVITY LEVELS OF CERTAIN ORGANISMS FROM NORTHWEST BIKINI LAGOON

Sample	Ru^{106} Standard	Sample	Zn^{65}, Co^{60} Standard
	(γ/min)/gm		(γ/min)/gm
Algae, pink	307	Hermit crabs	3,045
Algae, Halimeda	1,500	Jellyfish	1,860
Algae, Halimeda	450	Myctophid	470
Algae, Halimeda	5,200	Phytoplankton, mid lagoon	≈180
Cowrie shell	102	Phytoplankton, Site Charlie	≈3,800
Coral, red, skeleton	1,050	Sea urchins	770
Coral, dead	2,600		
Foraminifera plus coral fragments	1,030		
Foraminifera plus coral fragments	1,860		
Foraminifera plus coral fragments	830		
Foraminifera plus coral fragments	10,000		

Ailinginae tuna (14,000 $\mu\mu$c/gm of caudal fin) was the same as the Zn^{65} contamination of a tuna from Bikini Lagoon which assayed 16,000 $\mu\mu$c/gm of caudal fin. The relative values of (γ/min)/gm in Table 1.9 have been corrected for the counting efficiency of the principal isotopes detected in the same or similar specimens.

A radiochemical and gamma spectrographic analysis of various EPG organisms shown in Table 1.11 and in less detail in Table 1.9 indicates the presence of Mn^{54}, Co^{57}, Co^{60}, Zn^{65}, Ru^{106}, Ce^{144}, and Cs^{137}, with considerable variation among different organisms. Only the long-lived parent radionuclide has been considered for μc computation. Most of the radioactivity detected in the marine organisms was not direct fission activity but instead was probably induced and spallation products of elements associated with the 1954 nuclear devices. The high concentration of zinc and cobalt isotopes in fish and mollusks was probably due not so much to a high production yield but to bio-

TABLE 1.9 RADIOACTIVITY LEVELS OF CERTAIN ORGANISMS FROM AILINGINAE LAGOON

Organism	(γ/min)/gm	Principal Isotopes	Organism	(γ/min)/gm	Principal Isotopes
4-inch Tridacna liver	1,120	Co, Zn	Phytoplankton and inorganic matter	20	Ce, Ru
4-inch Tridacna muscle	456	Co	Phytoplankton and inorganic matter	134	Ce, Ru, Zn
8-inch Tridacna liver	3,800	Co, Zn	Phytoplankton and inorganic matter	84	Ce, Ru
8-inch Tridacna muscle	7	—	Phytoplankton and inorganic matter, surf	480	Ce, Ru
8-inch Tridacna mantle	5	—	Coral, lagoon, white	23	Ce, Ru
8-inch Tridacna liver	2,360	Co, Zn	Coral, lagoon, pink	20	Ce, Ru
Hippopus liver	1,600	Co, Zn	Coral, lagoon, green	21	Ce, Ru
Hippopus gills	108	—	Coral, ocean, white	11	Ce, Ru
Hippopus muscle	11	—	Coral, ocean, pink	20	Ce, Ru
Hippopus stomach	230	Co, Ru, Ce	Algae, ocean, green	28	Ru, Ce
3-inch Hippopus liver	122	Co, Zn	Algae, lagoon, green	59	Ru, Ce
3-inch Hippopus mantle	23	—	Lobster, ocean side	250	Ru, Ce
3-inch Hippopus stomach	23	—	Coconut crab	205	Cs, Ce, Ru
4-inch Mullet, whole	536	Zn, Ru	Coconut, green	47	Cs
4-inch Mullet, viscera	1,224	Zn, Ru	Coconut, milk	51	Cs
Beche-de-mer	29	Ru, Ce	Coconut, ripe	85	Cs
			Pandanus fruit	47	Cs, Ce

logical requirements of some fish and mollusks for these isotopes. Various portions of tuna taken from sea water containing 5×10^{-7} percent zinc have been shown to contain 0.1 to 1 percent zinc (Reference 1), thereby concentrating elemental zinc by a factor of 10^7.

Table 1.11 also indicates a concentration of cobalt in the livers of some fish. This may be due more to a diet of cobalt-contaminated food than direct concentration over that of the water. Clams and mollusks contained chiefly Co^{57} and Co^{60}. The basses and snappers, which feed on mollusks and small crustaceans, as well as fish, showed equal amounts of Co^{60} and Zn^{65}, while the tuna contained chiefly Zn^{65}.

The variation of cobalt and zinc in fish and clams is visibly demonstrated by the gamma energy spectrum of unprocessed, dried livers of bass, tuna, and the tridacna

clam as shown in Figures 1.2 and 1.3. The raw data show Co^{57} (off scale) and Co^{60} in the tridacna liver, a mixture of Co^{57}, Co^{60}, and Zn^{65} in a bass liver, and Zn^{65} with a trace of cobalt in the tuna liver.

The liver of the tuna contained traces of Co^{57} and Co^{60}, but the remainder of the fish, particularly the epidermis and skeleton, was found to contain essentially radiopure Zn^{65}. The distribution of radioactivity in various organs of different species of fish is shown in Tables 1.10 and 1.12. In general, the gall bladder, liver, and spleen exhibited the greatest concentration of activity with lesser amounts of activity in the epidermis, fins, and vertebral column. On a gram basis the least activity was found in the edible muscle. On the other hand, because of quantity, the total activity of the muscle may be 30 to 50 percent of the total activity of the whole fish.

At Ailinginae Atoll only a slight difference in the gross activity of corals and clams was noted between specimens from the lagoon side and those from the ocean side of the reef.

Two fish of different feeding habits taken from the same reef near Bikini Island showed different qualities of contamination. Although the organs of both fish showed the same level of gamma contamination (Table 1.12), the radiochemical analysis of the combined organs of each fish (Table 1.11) indicated the presence of Zn^{65} in the detritus-feeding goat fish and Mn^{54}, Co^{57}, Co^{60}, Zn^{65}, Ru^{106} and Ce^{144} in the plankton-feeding mullet.

Tridacna clam livers were found to be the most radioactive item throughout the EPG lagoons with a range of activity from 1,000 to 45,000 (γ/min)/gm and as high as 10^7 γ/min per whole liver. Co^{60} was identified as the principal isotope with Co^{57}, Ru^{106}, Zn^{65}, and Mn^{54} present in the liver and muscle; traces of Ce^{144}, Co^{60}, and Mn^{54} present in the shell, and Ce^{144}, Ru^{106}, Co^{57}, Co^{60}, and Zn^{65} in the stomach. The ratio of Co^{60} to Co^{57} appeared as a constant 4.2 as of 1 May 1956.

Phytoplankton and inorganic particulate matter filtered from the lagoon water, contained chiefly Ce^{144} and Ru^{106} with no detectable amounts of Co^{60} or Zn^{65}. The fact that water-filtering organisms, such as mullets and tridacna clams, contain large amounts of Co^{60} and Zn^{65} which are undetectable in the water, indicates that these radioisotopes nevertheless were probably present in the water either as dissolved or particulate inorganic matter, or as dissolved or particulate organic matter. Possibly the cobalt and zinc isotopes were picked up at an earlier date when the water was first contaminated.

The coral, mollusk shells, and calcareous algae exhibited Ce^{144} and Ru^{106} in varying amounts with cerium predominating in the coral and shells and ruthenium predominating in the algae. Bottom organisms such as the beche-de-mer (sea cucumber), finger snail, spiny lobster, sea urchin, and foraminifera exhibited varying amounts of Ce^{144} and Ru^{106} with a trace of Zn^{65} present in the forams.

1.6.5 Deep Sea Sediments. Coring and dredging results clearly indicated the presence of a considerable amount of radioactive contamination on the sea floor in an arc extending northwest to northeast of Bikini. This coincided to a large extent with the Operation Castle fallout pattern; in addition, the Bikini eddy may have permitted the water to remain in approximately the same area until the additional settling of particulate matter occurred.

Figure 1.5 gives the gamma activity per gram of sediment at seventeen stations throughout the EPG. The most active sample, C-10A, obtained from 1,460 meters depth at Station 29 northwest of Bikini Atoll emitted 2,450 (γ/min)/gm of dry weight. An analysis of C-10A gave 1,910 $\mu\mu$c Ce^{144}, 1,180 $\mu\mu$c Ru^{106}, 60 $\mu\mu$c Zn^{65}, and 70 $\mu\mu$c Sb^{125} per gram of fine coral sand and foraminifera as shown in Table 1.13.

The ocean floor of the EPG as sampled by dredges and coring devices consisted of coarse coral sand, coral rock and mollusk shells near the atolls, and fine globigerina ooze on the level floor. A number of samples of manganese nodules and basalt rock were obtained in the area.

Radium and K^{40} were detected in the manganese nodules and 10 to 20 $\mu\mu c$ Ra^{226}/gm were found in the surface of the globigerina ooze. Ce^{144} and Ru^{106} were detected in the manganese nodules in amounts roughly proportional to the surface area. No radium was detected in coral sand or gastropod shells. A gamma energy spectrum analysis (Table 1.13) showed the presence of Ce^{144} and Ru^{106} in most of the sediments with traces of Zn^{65}, Mn^{54}, Sb^{125}, and possible Eu^{154} as artificial contaminants, in addition to natural Ra^{226}, K^{40}, and thorium.

TABLE 1.10 DISTRIBUTION OF RADIOACTIVITY IN VARIOUS FISH FROM AILINGINAE ATOLL IN APRIL 1956

Organ	Total Gamma		Zn^{65}	Total Gamma
	Butterfly Fish	Snapper	Skipjack Tuna	Flying Fish Ocean SW of Atoll
	(γ/min)/gm wet	(γ/min)/gm wet	$\mu\mu c$ Zn^{65}/gm	(γ/min)/gm wet
Caudal fin	1,620	96	21,400	38
Epidermis	—	—	9,400	45
Gall bladder	620	1,080	—	—
Gills	132	52	4,500	50
Kidney	420	58	—	—
Liver	1,460	760	1,200	67
Muscle	23	27	980	1
Scales	—	27	—	52
Spleen	618	880	5,850	30
Stomach	85	172	—	21
Stomach contents	(coral, algae)	(clam)	(squid, flying fish)	(plankton)
Testes	—	52	9,500	—
Vertebrae	880	38	8,100	10

A cross section of Core No. 2 and a cross section of Core No. 4 are illustrated in Figure 1.6. The water trapped over the top surface of the core was filtered through a 0.5 micron millipore filter. The suspended sediment, probably originating from the disturbance of the uppermost surface during the coring operation, was reported as (γ/min)/liter of the core water inasmuch as an accurate weight of the residue could not be determined aboard ship. The filtered water over the cores was evaporated and assayed. The cores, which consisted essentially of calcareous globigerina ooze and fine coral sand, were frozen and sliced into 3-mm sections. The outer periphery of the core was cut away and discarded to reduce contamination which may have been transferred from section to section by the barrel of the corer as it penetrated the ocean floor. The sections were assayed, giving the results shown in Figure 1.6. The activity of the core was highest in the top 3-mm layer. It then decreased with depth to a constant value of about 3 (γ/min)/gm below 20 to 40 cm. Core No. 4 showed a decrease in gross activity to the 18-mm depth where a sharp, unexplained increase occurred. The activity then diminished at a rate similar to the surface peak.

TABLE 1.11 RADIOCHEMICAL AND GAMMA SPECTROGRAPHIC ANALYSIS OF VARIOUS EPG FAUNA IN APRIL 1956

ND indicates that these isotopes were present in quantities too low to be detected.

Organism	Source	μμc/gm wet weight 1 May 1956							$\frac{Co^{60}}{Co^{57}}$
		Mn^{54}	Co^{57}	Co^{60}	Zn^{65}	Ru^{106}	Ce^{144}	Cs^{137}	
Bass liver	Enyu	ND	720	3,080	3,500	ND	ND	ND	4.25
Bass liver	Mid lagoon	ND	1,670	7,200	5,900	ND	ND	ND	4.31
Tridacna liver	Eniaido	1,154	2,080	8,670	1,600	2,000	ND	ND	4.16
Tridacna liver	Rochikari	460	870	3,700	620	760	ND	ND	4.25
Tridacna stomach	Rochikari	ND	≈13	62	32	80	646	ND	—
Tridacna muscle	Rochikari	3.4	≈4.2	16	4.6	Trace	≈1.3	ND	—
Tridacna shell	Rochikari	Trace	ND	Trace	ND	ND	−7	ND	—
Yellowfin Tuna liver	SW Enyu	ND	110	482	6,300	<70	<94	ND	4.36
Yellowfin Tuna fin	SW Enyu	ND	ND	ND	16,000	ND	ND	ND	—
Yellowfin Tuna muscle	SW Enyu	ND	ND	ND	770	ND	ND	ND	—
Skipjack Tuna liver	Ailinginae	ND	ND	Present	7,800	ND	ND	ND	—
Skipjack Tuna fin	Ailinginae	ND	ND	ND	13,800	ND	ND	ND	—
Phytoplankton and inorganic matter	NW lagoon	ND	ND	ND	ND	≈1,100	≈9,400	ND	—
Mullet (whole fish)	Bikini	29	22	96	440	48	280	ND	—
Goat Fish (whole fish)	Bikini	ND	≈3	15	636	ND	70	Trace	—
Coconut Meat	Enyu	ND	ND	ND	ND	ND	6	46	—
Brown Rat	Enyu	ND	ND	Trace	36	ND	ND	9.6	—

A gamma energy spectrum analysis of Core No. 4 showed the presence of 530 $\mu\mu$c of Ce^{144}, 470 $\mu\mu$c of Ru^{106}, and about 10 $\mu\mu$c Ra^{226} per gram of dry sediment. These values were the average through a 3-mm segment of the upper surface of the sediment. If the activity were confined within a thickness of a few microns of the upper surface, the specific radioactivity would be much higher.

1.6.6 Lagoon Sediments. A number of samples from the surface of the Bikini Lagoon floor were assayed with the results shown in Figure 1.7. The total gamma photons (0.08 to 1.5 Mev) emitted per minute per gram of dry sediment ranged from 250 to 8,300 (γ/min)/gm, with the greatest radioactivity in the west and northwestern section of the lagoon. In general, with the exception of living calcareous algae, the activity was inversely proportional to the size of the sand grains in a given weight of sample. No separation was made of the bottom organisms such as foraminifera from the inorganic sand. However, samples containing a large visible proportion of living foraminifera showed a somewhat higher activity than those samples containing no visible living organisms.

TABLE 1.12 GAMMA ACTIVITY OF MARINE LIFE IN BIKINI LAGOON, (γ/min)/gm WET WEIGHT, 1 MAY 1956

Organism	Organ							
	Epidermis	Caudal fin	Gill filaments	Liver	Muscle	Spleen	Stomach and contents	Vertebral column
Perch, unidentified	1,060	860	450	1,250	150	2,600	—	—
Sea Bass, Plectropomus	4,000	6,600	1,530	48,000	1,030	—	1,900	1,300
Lutjanus bohar	1,260	2,960	2,400	36,000	380	—	1,560	2,100
Snappers, Aprion virescens	780	1,540	1,500	20,000	200	—	600	1,250
Snapper, unidentified	860	1,700	1,440	18,000	320	—	560	1,470
Mullet, Neomyxus	1,800	2,500	—	31,000	620	—	900	2,400
Goat Fish, Upeneus	1,560	2,200	1,100	22,000	410	—	430	1,900
Tuna, Neothunnus macroptarus	11,400	25,000	5,700	11,630	1,170	6,940	—	10,700
Clam, Tridacna mantle	175	—	330	36,500	—	—	640	—

A typical gamma energy spectrum of unprocessed lagoon sediment is shown in Figure 1.1. Ru^{106} and Ce^{144} are clearly evident. The analysis of several other bottom samples is listed in Table 1.13 showing the presence of Ce^{144} and Ru^{106} in all samples other than a tridacna shell and traces of Zn^{65}, Co^{60}, Mn^{54}, and Zr^{95} in several instances.

Bottom organisms such as the sea cucumber, sea urchin and finger snail, as well as the corals and calcareous algae, exhibited Ce^{144} and Ru^{106} as the predominant radioisotopes.

Samples of beach sand and soil above the high water mark from Sifo Island at Ailinginae, Site Nan, Bikini, assayed from 50 to 350 (γ/min)/gm of Ce^{144} and Ru^{106}. A sample of beach sand from above the high water mark on Site Charlie, Bikini, exhibited 940 (γ/min)/gm while a sample from below the low water mark showed 1,210 (γ/min)/gm of Ce^{144} and Ru^{106}.

1.6.7 Miscellaneous Survey of Land Organisms. Several spot checks were made on the plant life from Enyu Island (Site Nan) in Bikini Atoll and from Sifo Island at Ailinginae. The meat of three green coconuts from Enyu averaged 107 (γ/min)/gm while the

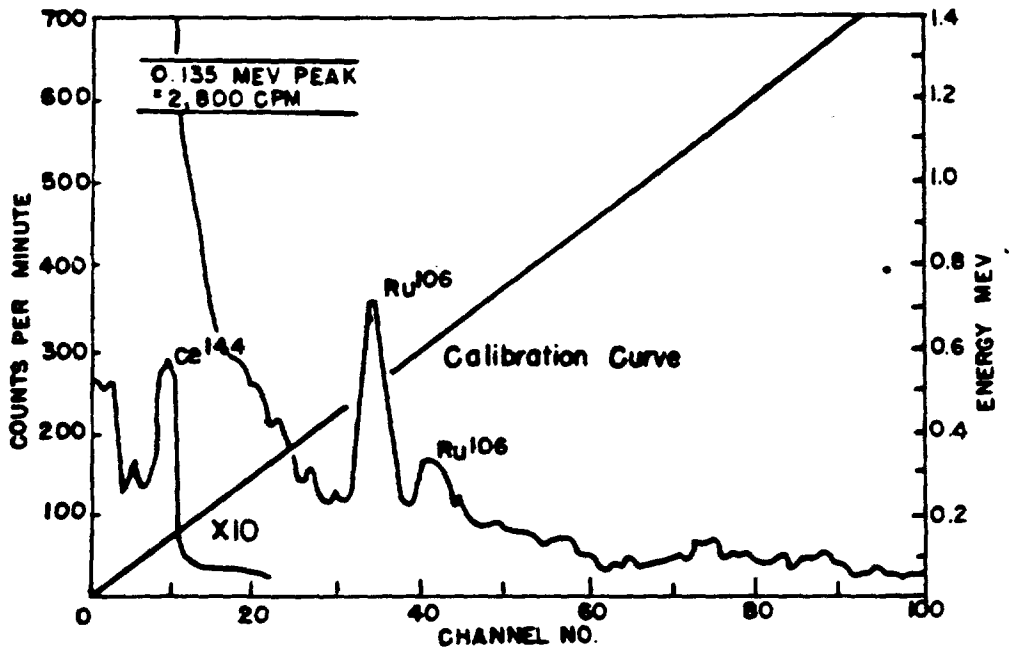


Figure 1.1 Gamma energy spectrum of NW Bikini Lagoon sediment collected 4 May 1956 and analyzed 22 May 1956.

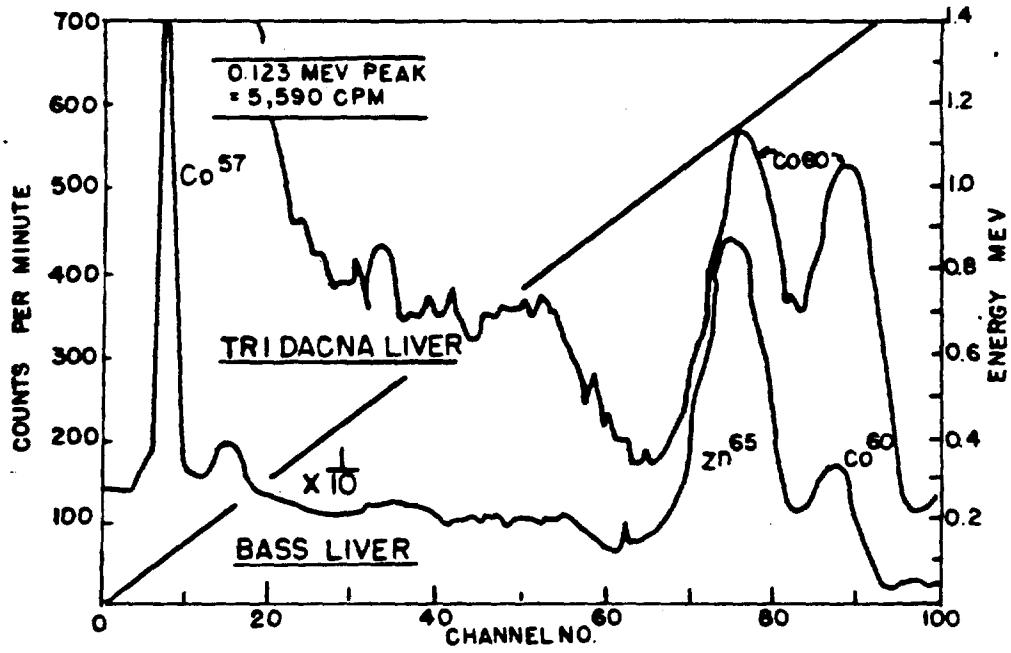


Figure 1.2 Tridacna liver from Bikini Lagoon collected 8 May 1956, analyzed 22 May 1956. Bass liver collected and analyzed 5 May 1956.

TABLE 1.13 GAMMA ENERGY SPECTRUM ANALYSIS OF EPG SEDIMENTS

ND indicates that these isotopes were present in quantities too low to be detected.

Sample Number	Position	Depth	Description	Gross (γ/min)/gm 0.08 to 1.5 Mev	μμc/gm Dry Weight on 1 May 1956				
					Ce^{144}	Ru^{106}	Ra^{226}	K^{40}	Others
		meter							
C-1	13° 35′ N, 164° 32′ E	1,390	12.3 gm manganese nodule	20	0	7.1	2.7	17.3	Mn^{54} = 0.6
C-2	12° 10′ N, 167° 05′ E	3,840	Surface of 106 cm globigerina ooze	405	440	410	20	—	—
C-4	11° 31′ N, 165° 04′ E	4,040	Surface of 46 cm globigerina ooze	575	535	468	10	—	—
C-8	11° 45′ N, 166° E	3,840	1 to 10 mm manganese granules	1,500	1,840	180	13.6	13.7	—
C-9	12° 05′ N, 166° 26′ E	3,610	1 to 10 mm coral fragments	7	ND	ND	ND	Trace	—
C-10A	11° 48′ N, 164° 04′ E	1,460	Coral sand and Foraminifera	2,450	1,910	1,180	ND	Present	Eu^{154} possible trace; Zn^{65} = 60; Sb^{125} = 70
C-14	11° 26′ N, 165° 31′ E	2,500	Globigerina ooze	272	390	100	12	Present	—
D-12	East of Site Nan	1,460	Large gastropod shells, coral chunks and forams	10 to 70	42	19	ND	—	—
D-15	South of Site Uncle	3,300	Fine sand and ooze	6	5.0	7.6	0.7	—	Eu^{154} = 0.05 to 0.1
D-15	South of Site Uncle	3,300	300 gm basalt and manganese rock	—	0.6	1.7	0.54	16	Thorium ≈ 0.36
V-6a-1	NW Bikini Lagoon	30	Forams, gastropods, sand	8,300	17,900	5,000	ND	—	—
V-6a-2	11° 41′ 16″N, 165° 16′ 45″E	30	Coarse coral granules, forams	5,100	9,400	2,000	ND	—	—
V-6b	West Tip Site Charlie	1	Coarse coral fragments	1,210	1,350	910	ND	—	Zr^{95} = 60
V-6c	West Tip Site Charlie	Beach	Coarse coral sand	940	1,090	740	ND	—	—
	Bikini Island	4	Coral disk	—	16	6.8	ND	—	Zn^{65} = 4.3; Co^{60} ≈ 0.15; Mn^{54} = 0.3
	Site How	1	Snail feces	1,200	880	131	—	—	—
	Site How	2	Tridacna shell	1.4	5.6	0	ND	Trace	—

milk from the same nuts was 135 (γ/min)/gm. Ripe coconut meat from Sifo indicated 85 (γ/min)/gm while a green kernel from the pandanus fruit emitted 47 (γ/min)/gm as shown in Table 1.9. An entire coconut crab from Sifo exhibited 205 (γ/min)/gm of Cs^{137}, Ce^{144}, and Ru^{106}.

The separation of elements among various organisms is shown in Figures 1.1, 1.2, 1.3 and 1.4. Ashes from the meat of several Enyu coconuts are shown in Figure 1.4 to contain almost exclusively Cs^{137}. The body of a brown rat from the same area, caught with a coconut-baited trap, exhibited both Cs^{137} and Zn^{65}. The μμc concentrations of the isotopes present in the coconut meat and brown rat are presented in Table 1.11. The rat which apparently fed on coconuts and plants containing Cs^{137}, probably also fed on marine organisms containing Zn^{65}.

1.6.8 Air-borne Radioactivity. Air was drawn through a Type AA millipore filter at the rate of 10 liter/min for periods of 100 minutes or longer at a number of stations in the lagoons and in the open sea. During the radioactivity background survey prior to Shot Cherokee, no air-borne radioactivity was detected.

1.7 CONCLUSIONS AND RECOMMENDATIONS

Radioactive contamination was detected throughout the EPG. The range of distribution of radioisotopes was Cs^{137} in coconuts, Cs^{137} and Zn^{65} in land organisms, Ce^{144} and Ru^{106} in soil and beach sand, Ce^{144} and Ru^{106} in lagoon water and suspended particulate matter, Zn^{65} in surface fish, Co^{60} in mollusks, Zn^{65} and Co^{60} in bottom fish, Ce^{144} and Ru^{106} in coral and calcareous algae, and Ce^{144} and Ru^{106} in bottom sediments.

The greatest concentration of radionuclides was found in clams, fish, and sediments. The least activity was detected in the oceanic water and no activity was detected in the air. The results obtained indicated that widespread radioactive contamination, non-uniform in amount and isotopic content, existed in the proving grounds during April 1956.

A separation of the fission products had taken place with concentrations of specific isotopes in specific phases. Hundred to thousandfold concentrations of radiocobalt and radiozinc were observed in clams and fish. The radioactive contamination of the sea water was low, while the zooplankton showed a hundredfold increase of radioactivity over that of the water.

The most predominant radionuclides detected in living organisms were Zn^{65}, Co^{57} and Co^{60}, none of which are fission products. The greatest total mass of radioactivity was found to be the Ce^{144} and Ru^{106} distributed over the ocean and lagoon floors.

The study of the water mass movements in the EPG before the test series was the primary task of the Scripps' vessel Horizon. Samples for radioactivity studies were collected whenever possible during the water mass survey. Because of this, the radioactivity samples were not necessarily taken in the proper places for a complete survey of this type.

Also, because of the limited equipment and personnel available for radioactive sample collection and analyses, the results cannot be used to give more than an indication of the distribution of radioactivity in the proving grounds prior to the test series.

It is recommended that a more thorough study be made of the separation of the fission products over a period of time in the ocean with emphasis on the final deposition of the radionuclides in the sediments and in the food chain. A study should be undertaken in the laboratory and in the field to determine the metabolic pathway of the long-lived nuclides through the food chain.

In order to determine oceanic fallout contours, it is necessary to perform numerous

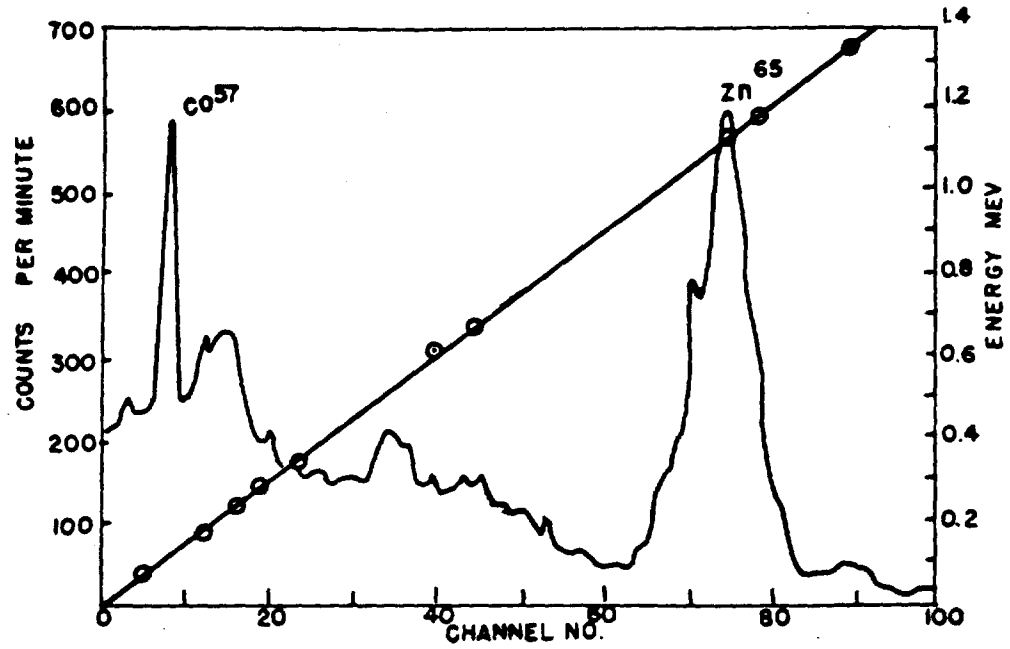


Figure 1.3 Gamma energy spectrum of tuna fish liver collected SW of Enyu Island 14 May 1956, analyzed 14 May 1956.

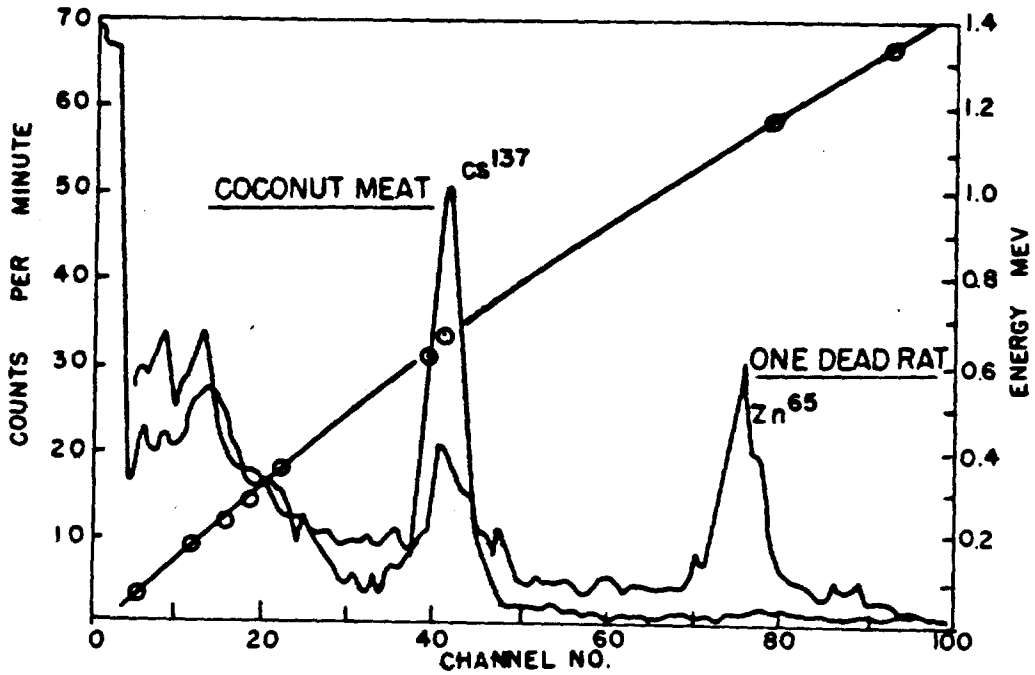


Figure 1.4 Coconut meat and brown rat collected from Enyu Island May 1956, analyzed 27 February 1957.

ENERGY MEV

ENERGY MEV

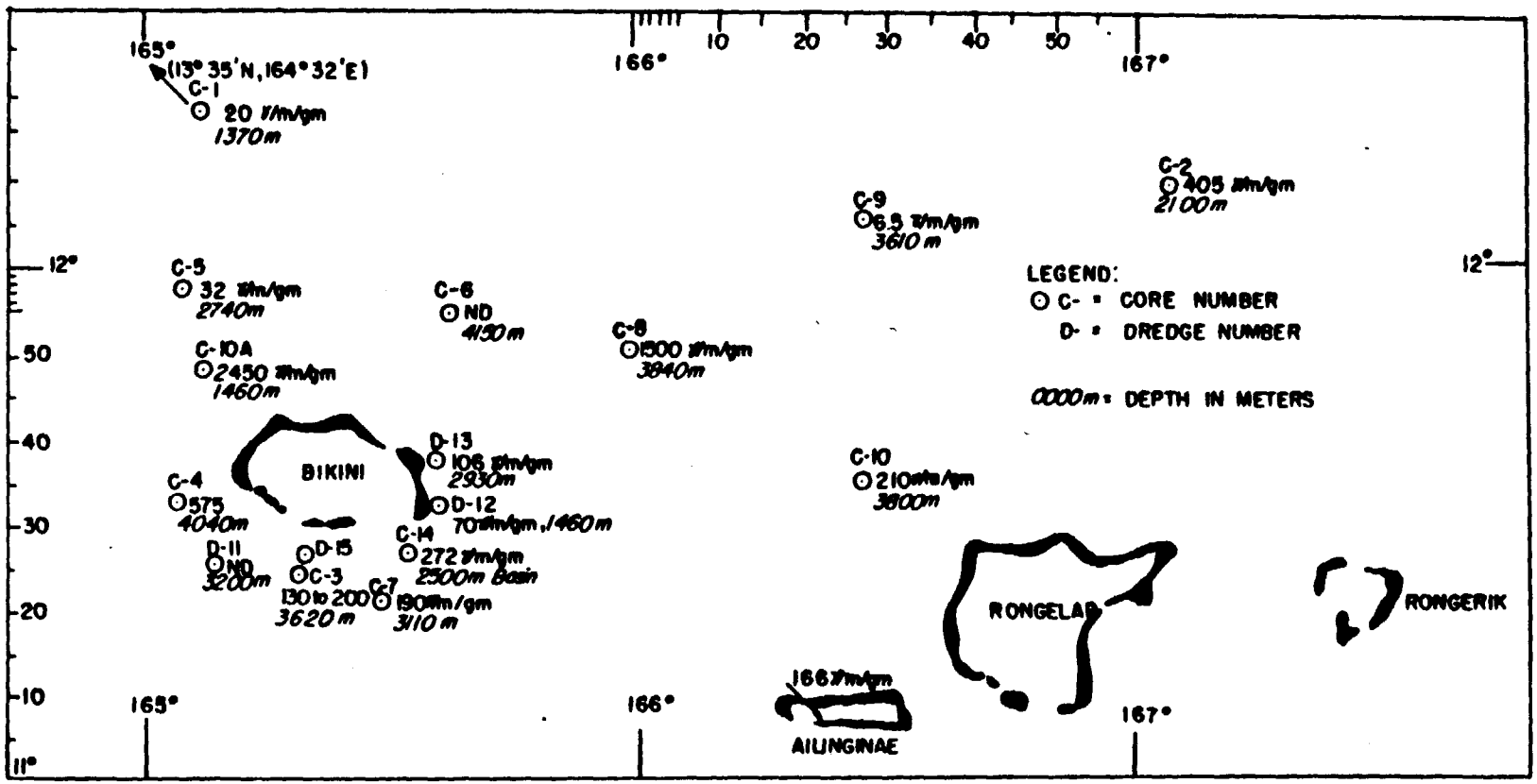
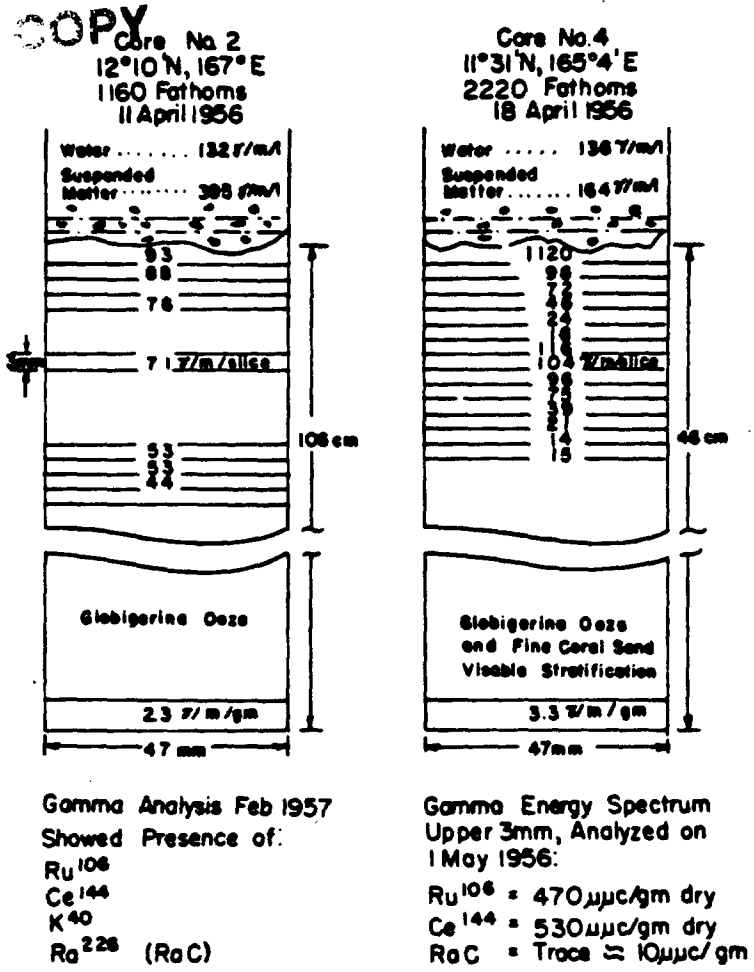


Figure 1.5 Gamma activity per gram of Eniwetok Proving Ground sediment in April 1956.



Gamma Analysis Feb 1957
Showed Presence of:
Ru^{106}
Ce^{144}
K^{40}
Ra^{226} (RaC)

Gamma Energy Spectrum
Upper 3mm, Analyzed on
1 May 1956:
Ru^{106} = 470 μμc/gm dry
Ce^{144} = 530 μμc/gm dry
RaC = Trace ≃ 10 μμc/gm

Figure 1.6 Levels of radioactivity found in deep sea sediment cores of the Eniwetok Proving Ground in April 1956.

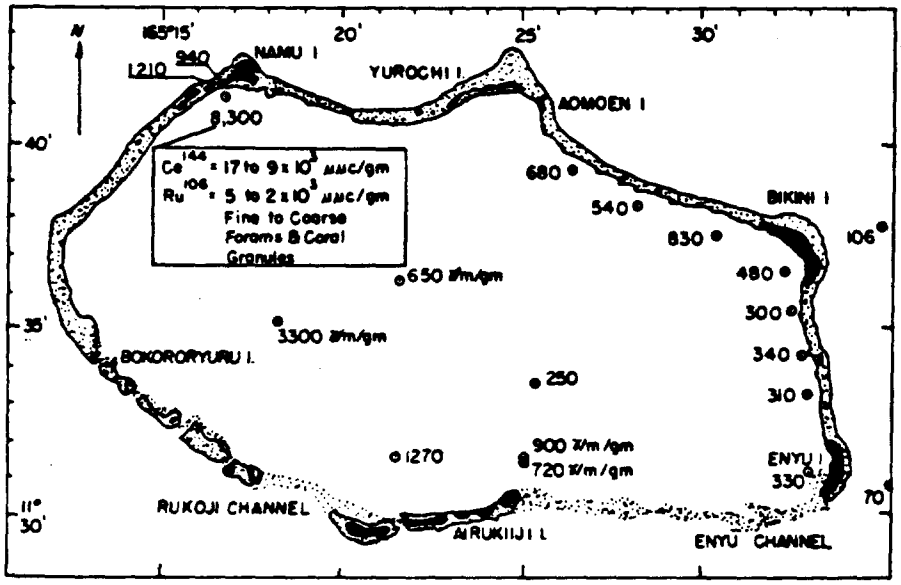


Figure 1.7 Gamma activity of Bikini Lagoon sediment in April 1956 as total gamma photons (0.08 to 1.5 Mev) emitted per minute per dry gram.

analyses of water and sediments and of organisms which may transport the radioactive materials. The methods used to detect low level radioactivity of sea water were tedious and uncertain. The activity of zooplankton could be used as an indication of contamination of the surrounding water if more information were available on the relationship of specific isotopes between the water and plankton over a long period of time. Routine methods of sea water analysis should be devised, using in situ probes or large discrete samples.

Gamma spectroscopy proved to be a valuable field tool for identification of radioisotopes. The design and construction of a large, crystal, multichannel pulse height analyzer for shipboard use would be desirable.

In future operations it is recommended that an effort be made to determine the fate of the radioactive waste products. Sufficient personnel, equipment, and shipboard time should be allocated for a systematic study of the distribution of radioactive isotopes throughout the marine environment surrounding a nuclear test area.