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ANALYSIS OF RADIATION EXPOSURE FOR NAVAL PERSONNEL AT OPERATION CASTLE

Science Applications International Corporation
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19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Film badge doses are reconstructed for sixteen ships and the residence islands of Enewetak and Kwajalein Atolls resulting from the six nuclear detonations comprising Operation CASTLE (March-May 1954). Fallout from Shots BRAVO and ROMEO was the major source of contamination on most of the ships and islands. Varying amounts of fallout from Shots UNION, YANKEE, and NECTAR contributed somewhat to the total doses of the shipboard and island-based personnel; no fallout was experienced as a result of Shot KOON. Shipboard personnel received additional exposure from hulls and salt water piping systems that had become contaminated from operating in the radioactive waters of Bikini Lagoon.

From the reconstructed radiation environments, both topside and below, an equivalent film badge dose is calculated and compared to actual dosimetry data. Agreement is very good during badged periods when the ships received significant fallout. When topside intensities

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were not documented, generally late in the operation when intensity levels were low, agreement is not as good. Calculated ship contamination doses of significance are in excellent agreement with limited available dosimetry data.

Calculated average doses for shipboard personnel range from a low of 0.19 rem for the crew of the USS LST-825 to a high of 3.56 rem for the crew of the USS PHILIP. Average doses on the residence islands of Enewetak and Kwajalein Atolls are 1.09 rem and 0.32 rem, respectively.

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SECTION 1
INTRODUCTION

Operation CASTLE was a series of atmospheric nuclear tests conducted by the Atomic Energy Commission (AEC) at the Pacific Proving Grounds (PPG) during the Spring of 1954. Radiological safety procedures included the issuance of film badges to approximately 10 percent of the personnel throughout the operation and to individuals during periods of potentially significant radiation exposure. Cohort badging, i.e., one badge worn by one individual in a group, was the primary means of determining individual exposures. Recorded dosimetry data and medical record data for personnel aboard most of the ships involved in the operation are sufficient to accurately determine their radiation exposure. There were, however, sixteen ships involved (either directly or indirectly) for which available dosimetry data are insufficient to assess the exposures of crew members assigned to them. Consequently, where film badge coverage is incomplete, it is necessary to reconstruct the radiation dose. This report describes the operation, the radiological situation, and the time-space relationships of each ship with respect to the radiological environment. The results are portrayed as equivalent film badge doses for the crews of each of the 16 vessels of interest.

Because some personnel of the naval contingent were assigned to the residence islands of Enewetak and Kwajalein Atolls, the radiation environments on both atolls are also reconstructed. Plans had also called for the use of the residence islands of Bikini Atoll (Eneman and Eneu Islands), but heavy contamination following the first shot (BRAVO) required a conversion from land-based to ship-based operations. Personnel could go ashore on Bikini only for short periods of time and then, only when accompanied by a trained rad-safe monitor (Reference 1). Film badges were generally issued to personnel going ashore and exposures are documented. Because of this, the reconstruction of the Bikini radiation environments are not addressed in this report.

1.1 BACKGROUND

There were six shots in the CASTLE test series: BRAVO, ROMEO, KOON, UNION, YANKEE, and NECTAR. The first five were detonated on Bikini Atoll and

Shot NECTAR was detonated on Enewetak. Figure 1-1 depicts the locations of Bikini and Enewetak with respect to the other atolls comprising the northern Marshall Islands. Figures 1-2 and 1-3 show the main features of Bikini and Enewetak, respectively, and the locations of the CASTLE detonations. The pertinent details of each test are summarized in Table 1-1 (Reference 2).

Table 1-1. Operation CASTLE shot data.

Shot Name	Local Date (time)	Yield	Location
BRAVO	1 Mar 54 (0645)	15 Mt	Bikini
ROMEO	27 Mar 54 (0630)	11 Mt	Bikini
KOON	7 Apr 54 (0620)	110 Kt	Bikini
UNION	26 Apr 54 (0605)	6.9 Mt	Bikini
YANKEE	5 May 54 (0610)	13.5 Mt	Bikini
NECTAR	14 May 54 (0620)	1.69 Mt	IVY MIKE Crater, Enewetak

1.2 NAVAL PARTICIPATION

The devices were tested by a joint military and civilian organization designated as Joint Task Force Seven (JTF-7). Although military in form, it was comprised of military, civil service, and contractor personnel. JTF-7 was organized into five main task groups with Task Group 7.3 being the naval contingent. Most of the approximately 6000 personnel assigned to TG 7.3 were aboard the various task group ships; however, approximately 650 were stationed on Enewetak and Kwajalein Atolls. Table 1-2 is a summary of the atolls and ships for which dose reconstructions are specifically addressed in this report. Also tabulated are the approximate number of personnel assigned to each.

1.3 METHODOLOGY

The procedures developed in previous dose reconstruction efforts have been adapted to the shipboard radiological environments of Operation CASTLE (References

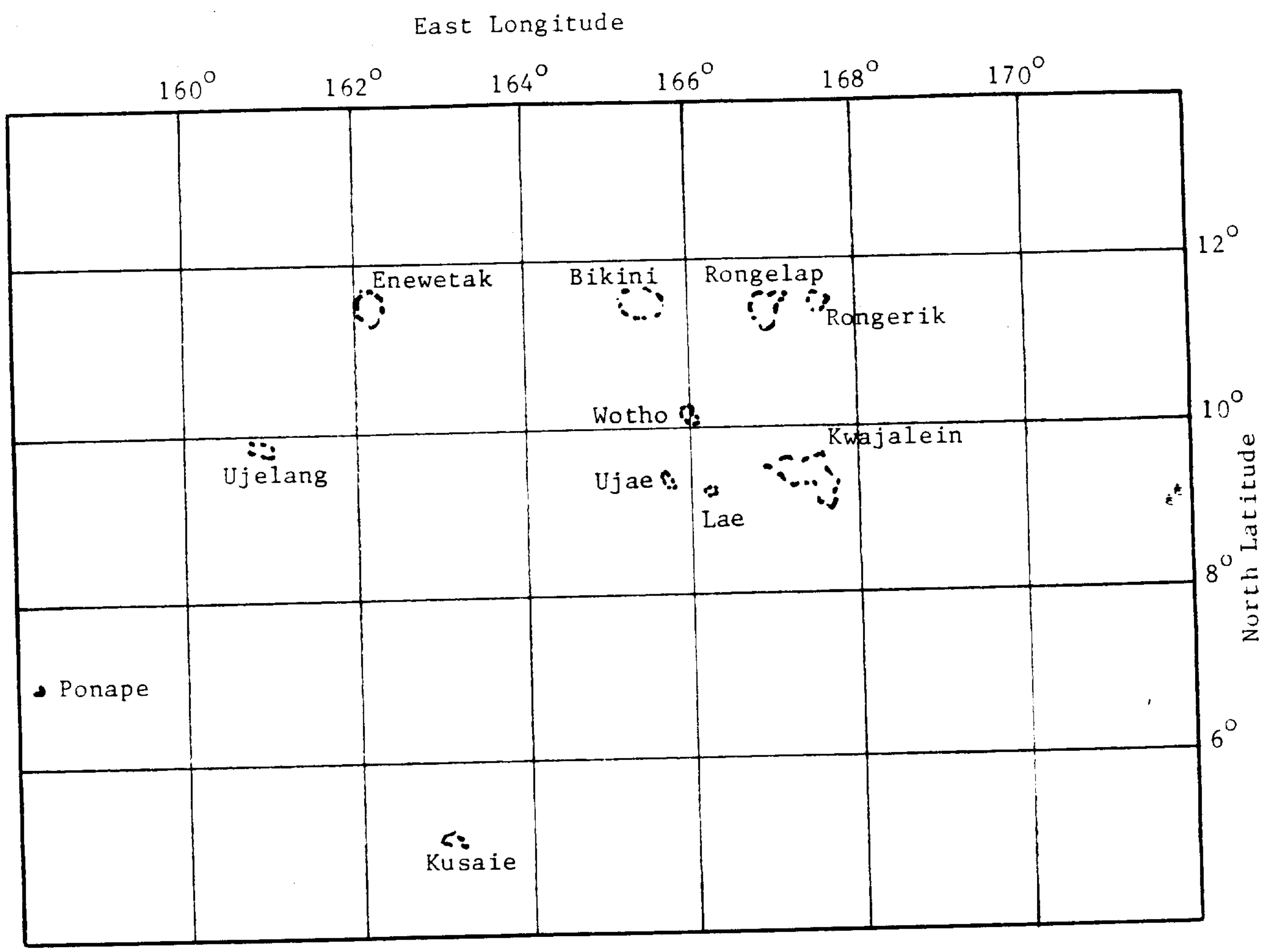

Figure 1-1. Northern Marshall Islands.

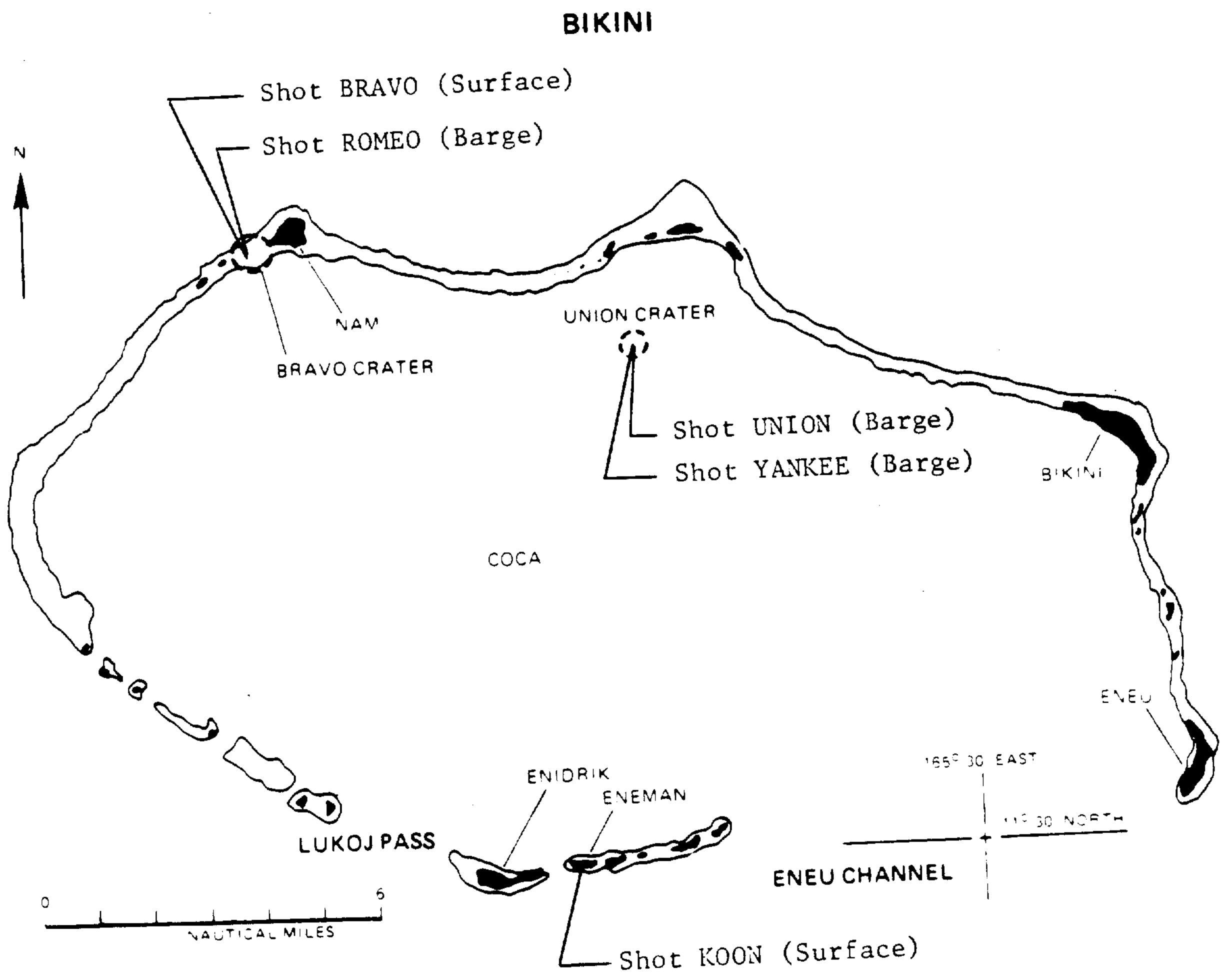

Figure 1-2. Bikini Atoll, Operation CASTLE shot locations.

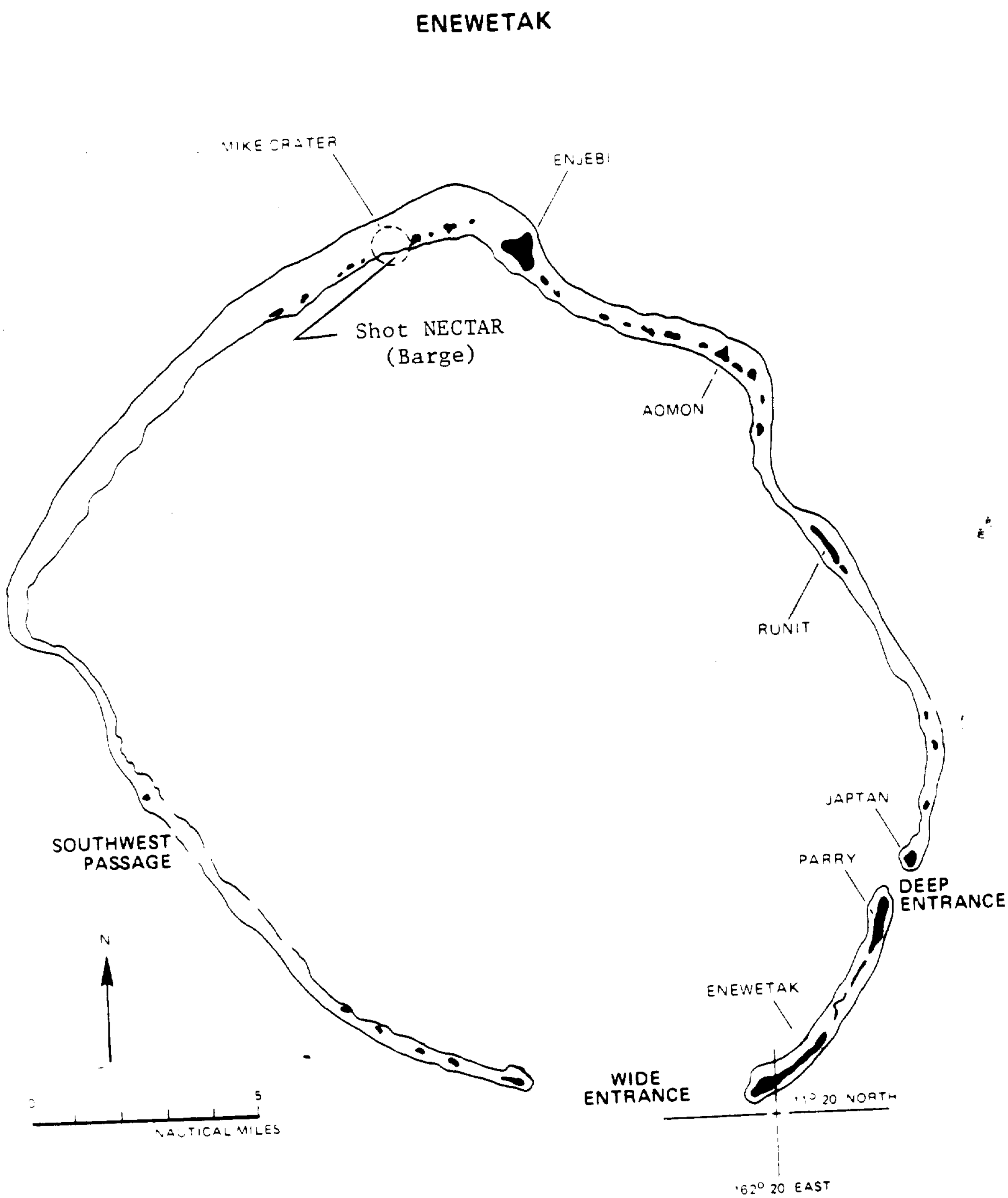

Figure 1-3. Enewetak Atoll, Operation CASTLE shot location.

Table 1-2. Atolls and ships for which dose reconstructions are applicable.

	Personnel Assigned
Island-Based Personnel	
Enewetak Atoll (Enewetak, Parry, and Japtan Islands)	241
Kwajalein Atoll	418
Shipboard Personnel	
USS APACHE (ATF-67)	82
USS BAIROKO (CVE-115)	892
USS BELLE GROVE (LSD-2)	338
USS CURTISS (AV-4)	708
USS EPPERSON (DDE-719)	307
USS ESTES (AGC-12)	647
USNS FRED C. AINSWORTH (TAP-181)	197
USS GYPSY (ARSD-1)	68
USS LST-551	105
USS LST-762	128
USS LST-825*	108
USS LST-975*	110(est)
USS NICHOLAS (DDE-449)	273
USS PHILIP (DDE-498)	263
USS RENSHAW (DDE-499)	259
USS SIOUX (ATF-75)	86
TOTAL	5230

*Not assigned to TG 7.3

Source: Reference 1

3, 4, 5 and 6). Figure 1-4 depicts the steps taken in calculating personnel film badge doses. These steps are pursued to a level of detail governed by the availability of data. Sufficient data were recorded at the time and enough have survived to understand the ship and land operations and to characterize the radiation environment. Individual ship deck logs serve as an authoritative source of ship position and activity.

Radiation intensity data and crew activity scenarios are applied to reconstruct the time-dependent radiation environment for an average crewman on each of the sixteen ships of interest. Characterization of the radiation environment starts with the determination of on-deck intensities from radiological survey data. The periodic shipboard surveys, in conjunction with fallout time-of-arrival data and nearby island surveys, serve to define the topside intensity as a function of time. At times following the last reported shipboard survey, a power law function determined from Bikini Atoll radiological data is utilized. Despite significant differences in decay rate between ship and shore because of early-time washdown, decontamination, and weathering, late-time decay, mostly from insoluble particles adhering to shipdeck or soil, is taken to be the same. As ships operated in the contaminated waters of Bikini Lagoon, their hulls and salt water piping systems accumulated radioactive materials, thus increasing the radiation exposure to crew members while below deck. The radiation environment due to ship contamination is derived from a previously-developed ship contamination model (Reference 6). Specific data regarding the development of the time-dependent radiation environments are presented in Section 2.

Shipboard radiation surveys indicated a considerable variation in topside intensities because of ship geometry, redistribution of fallout during washdown and decontamination, and non-uniform adherence of fallout particles to ship materials. If only an average survey reading was reported, this value is used. In those cases where readings were taken at many predetermined positions on the ship's exposed surfaces, they represent the topside radiation field. The ship's crew is presumed to have been located at random positions when on deck; thus, the mean survey readings, appropriately decayed, are used to determine the mean intensities encountered by the crew when on deck. The distribution of survey readings suggests a distribution in radiation exposure to the crew. Uncertainties associated with mean survey readings

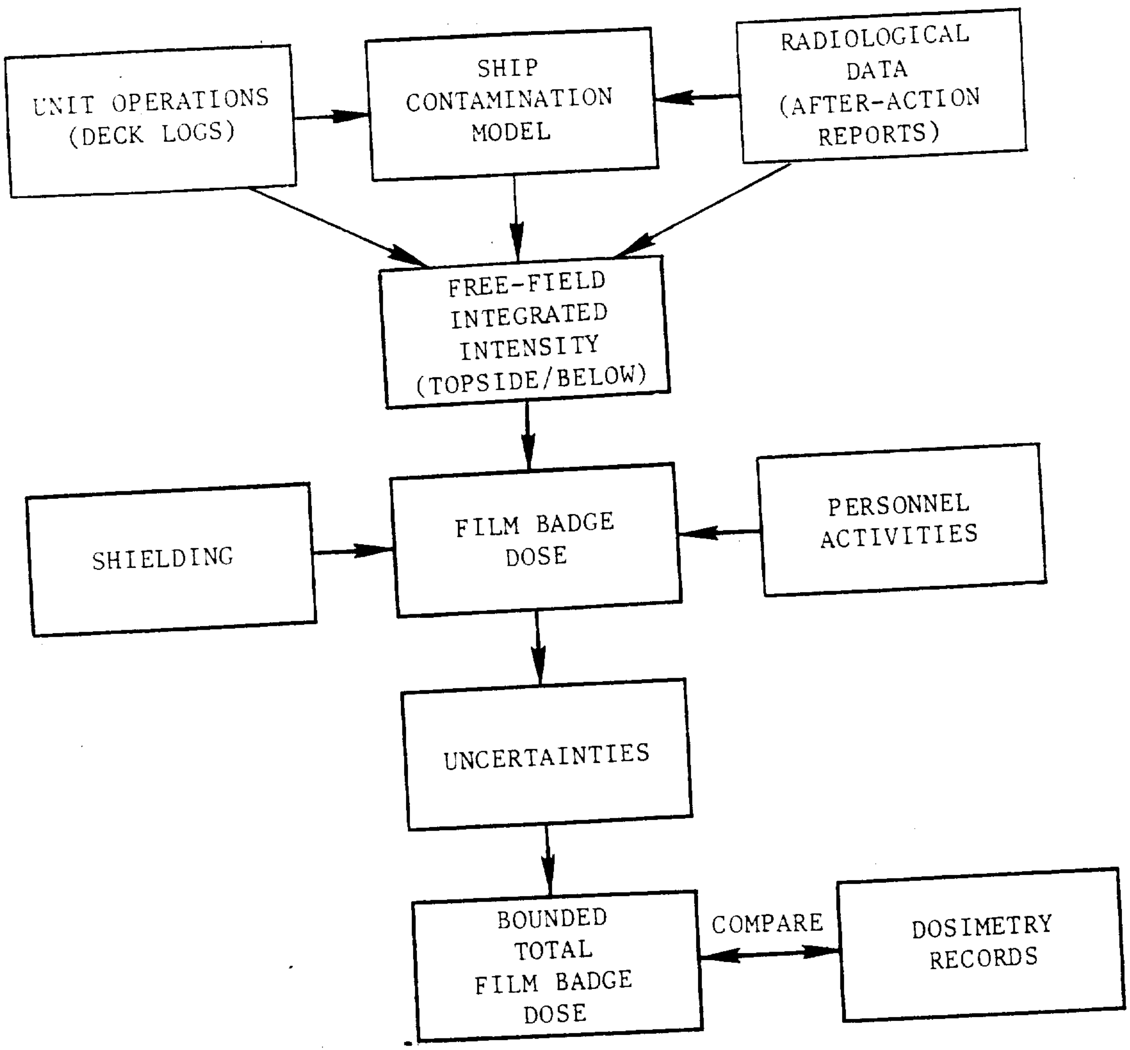

Figure 1-4. Operation CASTLE dose reconstruction methodology.

topside, as well as those associated with various parameters in the ship contamination model, are addressed in the uncertainty analysis.

The analysis of radiation exposure to the crew also requires estimation of radiation intensities below deck (due to fallout) and the apportionment in time of crew activities below and on deck. A ship-shielding factor is defined as the ratio of intensity below to the mean intensity topside. This factor, previously determined for each type of ship of interest in References 3, 4, 5 and 6, is roughly 0.1 and is nearly constant over the usual crew locations within a ship. Variations in this value, due primarily to different main deck thicknesses, are treated as an uncertainty in Section 4. Specific durations of topside exposure are given in ship logs for shot day (rarely thereafter) when the radiological situation altered the normal pattern of duties. For other days, and when unspecified, the topside intervals are taken to be 0800-1200, 1330-1700, and 1800-2000 hours, which amount to 40 percent of a day.

The mean film badge dose to the crew is obtained from time integration of intensity for all intervals below (including the shielding factor) and on deck; a conversion factor is used to account for body shielding by the badge wearer (Reference 7). To facilitate the calculation, the daily fractional topside duration, rather than each specified interval, is used on the third and subsequent days after burst, when the lower intensity lessens the need for such precision in timing. Because the specified intervals are nearly centered around midday, this approximation is suitable by the third day.

Day-by-day and cumulative film badge doses to the average crewman of each ship are calculated and presented in Section 3. Calculations are continued through 31 May 1954 when the roll-up phase was drawing to an end. An uncertainty analysis of the dose calculations is provided in Section 4. In Section 5, the available dosimetry records are analyzed and compared with the calculated doses. Conclusions and a total dose summary are presented in Section 6.

SECTION 2
SHIP OPERATIONS AND RADIATION ENVIRONMENTS

This section describes the movements of the TG 7.3 ships at the Pacific Proving Grounds during Operation CASTLE and correlates these movements with the radiation environment following the six detonations in the test series. Ship movements are reconstructed primarily from data contained in the deck logs of the sixteen ships of interest (References 8 and 9). The shipboard radiation environments resulting from radioactive fallout are reconstructed based on available radiological survey data. In the absence of ship-specific radiological data, topside radiation environments are inferred from those of other nearby ships or island data from Enewetak, Kwajalein, and Bikini Atolls, as appropriate. In addition, as ships operated in the contaminated waters of Bikini Lagoon, their hulls and interior salt water systems became radiologically contaminated exposing personnel below to varying degrees of radiation. The radiation environments below are derived from a previously-developed ship contamination model.

2.1 SHIP OPERATIONS

Exclusive of the landing craft and small boats belonging to the boat pool, TG 7.3 had 31 surface craft in the Pacific Proving Grounds for Operation CASTLE. This reconstruction focuses on sixteen of the ships: APACHE (ATF-67), BAIROKO (CVE-115), BELLE GROVE (LSD-2), CURTISS (AV-4), EPPERSON (DDE-719), ESTES (AGC-12), FRED C. AINSWORTH (TAP-181), GYPSY (ARSD-1), LST-551, LST-762, LST-825*, LST-975*, NICHOLAS (DDE-449), PHILIP (DDE-498), RENSHAW (DDE-499), and SIOUX (ATF-75).

The AINSWORTH served as living quarters afloat for the bulk of the support personnel. The two tugs, APACHE and SIOUX, placed and retrieved floating instrumentation. The GYPSY, a salvage lifting vessel, performed salvage operations in the lagoon and assisted in decontaminating the harbor craft and small boats that were

* Not assigned to TG 7.3.

left in Bikini Lagoon during shots detonated there. The BAIROKO provided helicopters and a radiological laboratory. The BELLE GROVE provided the boat pool, both personnel and small craft. The CURTISS transported the test devices and the associated personnel of TG 7.1. The ESTES was the JTF-7 flagship and also provided headquarters facilities for the staffs of TG 7.1 through 7.4 during operations at Bikini. The destroyers EPPERSON, NICHOLAS, PHILIP, and RENSHAW provided surface security patrols and performed plane guard, escort, and air control station duties. LST-551 and LST-762 provided interatoll transportation. The LST-825 and LST-975 were transient ships not attached to TG 7.3 and thus had no operational assignments with respect to the rest of the task group (Reference 1).

Because the first five shots were detonated at Bikini, the majority of the ships operated in the vicinity of Bikini until after Shot YANKEE on 5 May. Exceptions to this were the LST-551 and LST-762 which, except for trips to Bikini between shots, remained at or near Enewetak. The LST-825 departed Enewetak the day after Shot BRAVO enroute to Japan and LST-975 did not arrive in the PPG until approximately 1 May. Two of the four destroyers were always on patrol either in the Enewetak area or far from Bikini at the time of the five Bikini events. Following Shot YANKEE, most of the ships began to shift operations to Enewetak where Shot NECTAR was detonated on 14 May.

During Bikini operations the AINSWORTH, BAIROKO, BELLE GROVE, CURTISS and ESTES were normally anchored in Bikini Lagoon except for late on D-1 and well into D-Day during which time they, along with the other ships operating in the vicinity of Bikini, took assigned stations to the southeast of the atoll, some 30 to 50 nautical miles from surface zero. All personnel evacuated Bikini aboard TG 7.3 ships the night before each shot; return to Bikini anchorages was planned for the afternoon of D-Day.

2.1.1 Shot BRAVO

Shot BRAVO was detonated at Bikini Atoll at 0645 hours, 1 March 1954. Nine of the task group ships were operating in the southeast quadrant off Bikini (see Figure 2-1), having departed Bikini the night before. With the exception of the NICHOLAS,

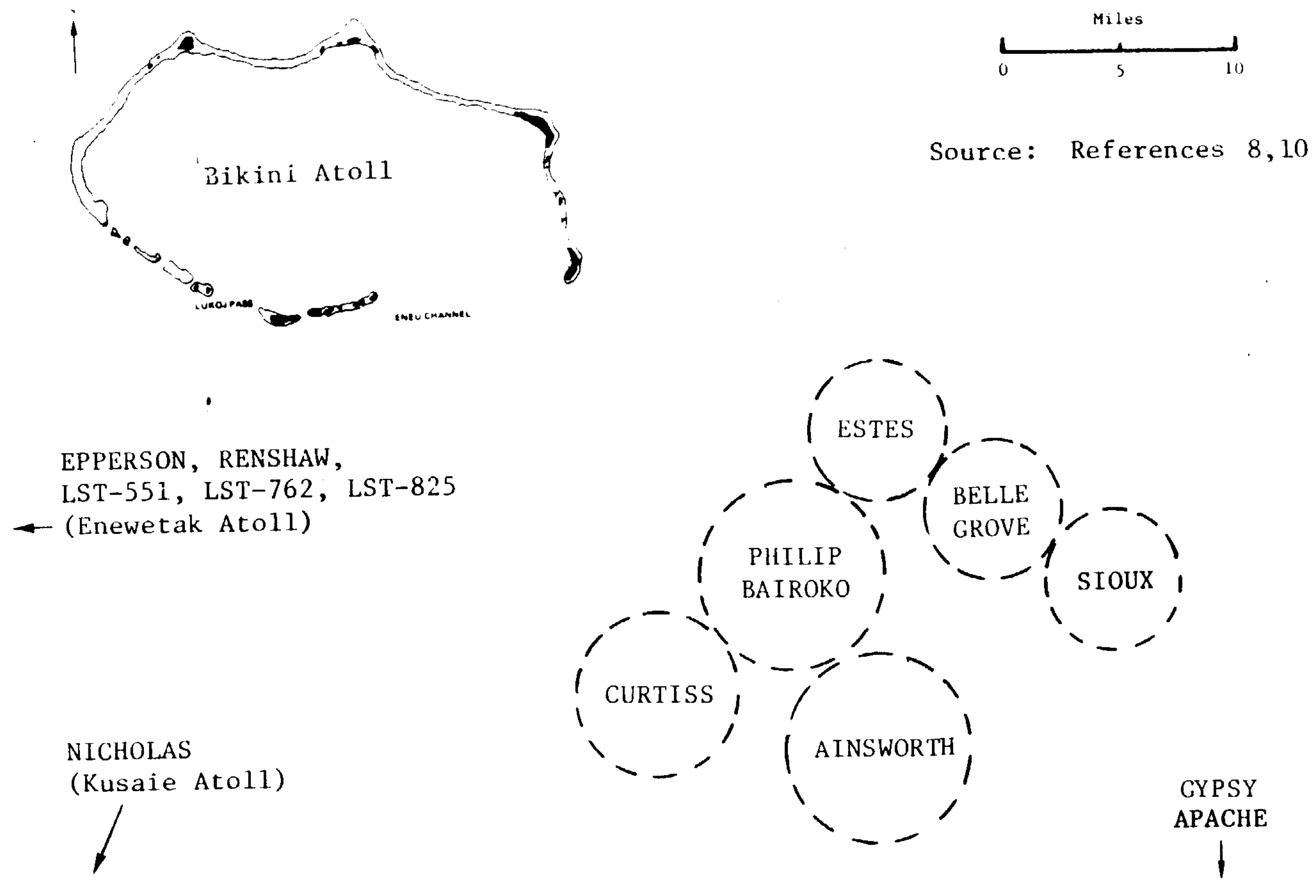

Figure 2-1. Locations of various TG 7.3 ships at the time of Shot BRAVO.

which was in the vicinity of Kusaie Atoll, the remaining ships were at or near Enewetak. Those in the vicinity of the Bikini were:

AINSWORTH	BELLE GROVE	GYPSY
APACHE	CURTISS	PHILIP
BAIROKO	ESTES	SIOUX

They remained in their assigned areas until about 0800 hours when the first onset of fallout occurred. By 0815 hours all were proceeding southward with their washdown systems activated. The southward movement was terminated about 1000 hours and the ships began moving northward again to resume their assigned stations.

Shortly after noon, a second period of fallout deposition began. The affected ships again activated their washdown systems and maneuvered at various courses and speeds to enhance its effectiveness.

Some ships reported encountering intermittent periods of fallout later during the afternoon in the Bikini area. Others enroute to Enewetak encountered fallout between 2200 hours, 1 March and 0100 hours, 2 March. These were the AINSWORTH, BAIROKO, CURTISS, and ESTES, which had begun their movement to Enewetak between 1700 and 1900 hours when it became evident that, due to the severity of the contamination in the lagoon, they could not reenter the lagoon as planned. The SIOUX proceeded to retrieve buoys in support of Project 2.5a, and moved generally north and west of Bikini Atoll. The other ships in the Bikini area appear to have remained generally on station.

At the time of Shot BRAVO, the EPPERSON, LST-551, LST-762, LST-825 and the RENSHAW were in the vicinity of Enewetak Atoll. The EPPERSON was patrolling close to the atoll while the RENSHAW was midway between Enewetak and Bikini. The LST-551 was about 30 miles west of Enewetak and the LST-762 and LST-825 were beached or anchored off Parry Island the whole day. About 2100 hours the RENSHAW began to patrol the area close offshore of Enewetak Atoll. Between 1800-2300 hours, the residence islands of Enewetak (Enewetak and Parry Islands) recorded a period of fallout deposition.

The APACHE, BELLE GROVE, PHILIP, and SIOUX remained in the Bikini area overnight. On 2 March the APACHE maneuvered slowly westward toward Enewetak and the SIOUX continued its retrieval of buoys for Project 2.5a until about 2000 hours, at which time it also headed for Enewetak. The BELLE GROVE moored in Bikini Lagoon at 0844 hours and the GYPSY reentered the lagoon approximately 4 hours later. The PHILIP continued patrolling off Bikini until about 1900, when it entered the lagoon and anchored. About 2145 hours, the PHILIP got underway for Rongelap Atoll where it evacuated personnel to Kwajalein.

The EPPERSON, LST-551, LST-762, LST-825, and the RENSHAW, all near Enewetak on shot day, were joined on the morning of 2 March by the AINSWORTH, BAIROKO, CURTISS, and ESTES. At approximately 0823 hours, the LST-825 departed Enewetak enroute to Japan. Late in the afternoon on 2 March, the BAIROKO, ESTES, and LST-762 departed Enewetak for Bikini, arriving there on 3 March. The LST-551 departed Enewetak on 3 March and arrived at Bikini the following day.

2.1.2 Shot ROMEO

When Shot ROMEO was detonated at Bikini Atoll at 0630 hours, 27 March, nine of the ships were operating in assigned areas southeast of Bikini Atoll. They were:

AINSWORTH	BELLE GROVE	ESTES
APACHE	CURTISS	NICHOLAS
BAIROKO	EPPERSON	SIOUX

The GYPSY had departed Bikini on 26 March and was enroute to Kwajalein when Shot ROMEO was detonated. The AINSWORTH, BAIROKO, BELLE GROVE, EPPERSON, and ESTES returned to the Bikini Lagoon anchorage area early in the afternoon; the CURTISS and the NICHOLAS returned late in the afternoon. At midday the APACHE and the SIOUX began buoy retrieval operations. The APACHE proceeded west of Bikini while the SIOUX proceeded north. About 1600 hours the EPPERSON departed the lagoon to begin patrolling north of the atoll.

About 1600 hours on 27 March, at a point some 30 miles west southwest of the ROMEO GZ, the APACHE recorded the peak intensity during a period of fallout which had begun about an hour earlier. At this time the ship began to proceed to the northwest. At approximately noon on the following day, the APACHE was operating some 60 miles northwest of the ROMEO GZ when it encountered another period of fallout. The ship proceeded southwestward until about 1600 hours, when the peak intensity was recorded; it then proceeded southward out of the fallout area. Later that evening the APACHE changed course for Enewetak.

The EPPERSON encountered fallout in its patrol area at approximately 1600 hours when it was about 26 miles north of the ROMEO GZ. At 1933 hours, this ship also activated its washdown system. The following morning, when the EPPERSON was patrolling five to ten miles north of Bikini Atoll, it received more fallout between 0700-0800. Fallout during the same period was detected by the PHILIP south of Bikini Atoll, but was not noted by any of the ships anchored in the Bikini Lagoon (AINSWORTH, BAIROKO, BELLE GROVE, ESTES, and LST-551).

Around 2000 hours the CURTISS and NICHOLAS departed Bikini for Enewetak, arriving there at approximately 0700 hours on 28 March. The NICHOLAS remained at anchor until the afternoon of the 29th; the CURTISS got underway for Bikini about 1900 hours on the 28th and arrived at 0730 hours on the 29th.

At shot time the RENSHAW was on station midway between Enewetak and Bikini Atolls. About 1845 hours it took a station south of Eneman Entrance to Bikini Atoll. LST-762 was anchored off Enewetak Island and remained there for the next four days. LST-551 was at anchor in Enewetak Lagoon at shot time, but got underway for Bikini at 1017 hours. The PHILIP, which was patrolling eastward of the Deep Entrance to Enewetak Atoll at shot time, joined the LST-551 in formation bound for Bikini at 1035 hours. Between 1400-2400 hours these two ships encountered minor fallout; peak intensities were recorded about 1800 hours when they were some 70 miles east of Enewetak. After they arrived at Bikini at approximately 0700 hours on 28 March, the PHILIP began to patrol off Eneman Island while the LST-551 entered the lagoon and beached itself on Eneman.

Around 2400 hours, the SIOUX began encountering fallout of increasing intensity in the area 30-40 miles northeast of Bikini. The ship proceeded slowly northwestward until approximately 1200 hours on 28 March, then southeastward during the afternoon, receiving fallout throughout the day. The SIOUX also received fallout during the morning of 29 March while enroute to Enewetak from Bikini.

The PHILIP briefly entered the lagoon between 1300-1415 hours on 28 March, then resumed its patrol to the south of Eneman Island. The EPPERSON entered the lagoon about 2000 hours and remained there overnight. The RENSHAW was relieved by PHILIP at 1415 hours and proceeded to the anchorage area for the night.

During the night of 28-29 March, fallout was recorded on all ships in Bikini Lagoon between approximately 2200-0830 hours. The BELLE GROVE, moored to buoy "Y", set condition ABLE at 2200 hours. The BAIROKO, in berth "Z", turned on its washdown system twice--at 0130 and 0320 hours. The LST-551, beached on Eneman Island, set condition ABLE and took rad-safe measures at 0315 hours. The EPPERSON put to sea between 0630-0900 hours to wash down the ship (washdown was completed about 0735 hours).

About 1500 hours the LST-551 got underway for Enewetak and the BELLE GROVE followed approximately three hours later. Thus, on the night of 29-30 March, the ships in the Bikini area were the AINSWORTH, BAIROKO, CURTISS, EPPERSON, ESTES, PHILIP, and RENSHAW. Those in the Enewetak area were the APACHE, LST-551, LST-762, NICHOLAS, and SIOUX, with the BELLE GROVE enroute. The GYPSY departed Kwajalein at 1922 hours on 29 March enroute to Ailinglapalap Atoll to perform salvage operations; it was not affected by the fallout on Kwajalein during 30-31 March.

2.1.3 Shot KOON

Shot KOON was detonated at Bikini Atoll at 0620 hours, 7 April 1954. Eight of the ships of interest were operating in the Bikini area. They were:

AINSWORTH	CURTISS	NICHOLAS
BAIROKO	EPPERSON	SIOUX
BELLE GROVE	ESTES	

At shot time, all except the NICHOLAS were in assigned areas southeast of Bikini Atoll. They remained there until around midday, when they reentered the lagoon as planned. The NICHOLAS, which was patrolling approximately midway between Bikini and Enewetak at shot time, proceeded to Bikini during the afternoon and anchored in the lagoon at 1915 hours.

Five other TG 7.3 ships were either at or enroute to Enewetak at shot time. These were:

APACHE	LST-762	RENSHAW
LST-551	PHILIP	

The APACHE, enroute to Enewetak from Bikini, was about 25-30 miles east of Enewetak at shot time. The other ships were all anchored/beached at Enewetak or Parry Islands.

The GYPSY, having completed salvage operations at Ailinglapalap Atoll on 1 April, returned to Kwajalein where it was anchored when Shot KOON was detonated. On 9 April, the GYPSY departed Kwajalein enroute to Pearl Harbor. This ship did not return to the PPG during Operation CASTLE.

Fallout from Shot KOON moved generally to the north of Bikini (as predicted) and none of the ships operating in the vicinity of Bikini, Enewetak, or Kwajalein Atolls received significant fallout following this test.

2.1.4 Shot UNION

Shot UNION was detonated at Bikini Atoll at 0605 hours, 26 April 1954. Seven of task group ships of interest were operating in the Bikini area. These were:

AINSWORTH	CURTISS	PHILIP
BAIROKO	ESTES	NICHOLAS
BELLE GROVE		

At shot time, all of these ships except the NICHOLAS were in their assigned areas southeast of Bikini; the NICHOLAS was again on patrol midway between Bikini and Enewetak Atolls. During the afternoon of 26 April, the PHILIP began patrolling off Bikini and the other ships entered and anchored in Bikini Lagoon. The NICHOLAS, while still on station midway between atolls, encountered fallout between 1313-1429 hours, during which time its washdown system was activated.

The APACHE was at Kwajalein Atoll at shot time. The remaining five task group ships of interest were at or near Enewetak Atoll: the EPPERSON on patrol north of Enewetak and the LST-551, LST-762, RENSHAW, and SIOUX at anchor off Parry and Enewetak Islands.

With the exception of the NICHOLAS, the remaining twelve ships in the vicinity of Bikini and Enewetak Atolls received no significant fallout following Shot UNION, the major portion of the radioactive cloud having moved generally to the north.

2.1.5 Shot YANKEE

Shot YANKEE was detonated at Bikini Atoll at 0610 hours, 5 May 1954. Eight of the task group ships of interest were in their assigned areas southeast of Bikini Atoll. They were:

AINSWORTH	CURTISS	RENSHAW
BAIROKO	ESTES	SIOUX
BELLE GROVE	PHILIP	

The PHILIP and RENSHAW remained on patrol off Bikini until the morning of 6 May, while the SIOUX remained at sea retrieving instrumentation. The remaining five ships in the vicinity of Bikini reentered the lagoon for a short period of time during the late afternoon of 5 May to transfer passengers. Because lagoon water contamination levels were still quite high, the decision was made not to reenter the lagoon on a permanent basis until the following morning. None of these ships received any fallout due to Shot YANKEE.

The APACHE was berthed at Kwajalein Atoll on 5-6 May, during which time this atoll received minor secondary fallout from the YANKEE cloud.

The EPPERSON and NICHOLAS were patrolling off Enewetak at shot time while LST-551 was anchored at Enewetak throughout the day. None of these ships received fallout following Shot YANKEE.

The LST-762 had departed Enewetak on 27 April enroute for Pearl Harbor. Due to engine failure and other equipment malfunctions, the ship was taken in tow on 5 May by LST-975 which was enroute from Japan to Pearl Harbor. During the morning of 6 May, LST-762 commenced monitoring for fallout. The ship, still under tow by LST-975, was about 700 miles east of Bikini at the time. By early afternoon, washdown* of the weather decks on both ships was initiated and continued intermittently until 0930 hours, 7 May.

2.1.6 Shot NECTAR

Following Shot YANKEE on 5 May, the task group ships began to shift operations to Enewetak Atoll where Shot NECTAR was to be detonated on 14 May. The BELLE GROVE, CURTISS, EPPERSON, ESTES, AINSWORTH, LST-551, NICHOLAS, RENSHAW, and SIOUX had all arrived at Enewetak by 13 May. The APACHE and PHILIP remained in the vicinity of Bikini until they departed the PPG for Pearl Harbor on 14 and 15 May, respectively. The BAIROKO was enroute to Bikini from Kwajalein on 14 May, while LST-762, still under tow by LST-975, was approximately midway between Johnston Island and Pearl Harbor.

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*Only LST-762 was equipped with a washdown system; the crew of LST-975 used fire hoses.

When Shot NECTAR was detonated at 0620 hours on 14 May, seven of the ships were in their assigned operational areas southeast of Enewetak. These were:

CURTISS	LST-551	SIOUX
ESTES	NICHOLAS	RENSHAW
AINSWORTH		

The EPPERSON and BELLE GROVE were enroute to Ujelang and Rongerik Atolls, respectively. Within several hours after the detonation, all ships that were southeast of Enewetak, except the NICHOLAS, reentered the lagoon; the NICHOLAS did not get back into the lagoon until late afternoon. The EPPERSON returned to Enewetak from Ujelang late in the afternoon on 14 May, while the BELLE GROVE did not return until the morning of 16 May. The BAIROKO had arrived at Enewetak from Bikini during the morning of 15 May.

Between 1830-2100 hours on 14 May, light fallout from the NECTAR cloud was experienced on the residence islands of Enewetak. The CURTISS, ESTES, and AINSWORTH had departed Enewetak for San Francisco, San Diego, and Pearl Harbor, respectively, before the fallout began. The EPPERSON, NICHOLAS, and RENSHAW did not depart the lagoon until approximately 2200 hours enroute to Pearl Harbor and could have experienced the fallout. Similarly, LST-551 and SIOUX remained at, or in the vicinity of, Enewetak until 16 and 17 May, respectively, and they too, probably received the fallout on 14 May. The LST-551 departed Enewetak for Ponape Atoll while the SIOUX departed for Bikini. As stated earlier, the BAIROKO and BELLE GROVE did not return to Enewetak until 15 and 16 May, respectively, well after the fallout had ceased. The BELLE GROVE departed Enewetak for Bikini on 16 May and the BAIROKO got underway to San Diego on 17 May.

2.2 RADIATION ENVIRONMENTS

Extensive radiation intensity readings obtained on How Island (Bikini Atoll) following Shot BRAVO indicated decay rates that varied considerably from the traditional $t^{-1.2}$ rule (Reference 11). Average values for the decay exponent (k) obtained with several gamma ionization time-intensity meters on Bikini (Reference 11) are as follows:

$$
\begin{array}{rll}
3 < t \leq 10 & \text{hours;} & k = -1.19 \\
10 < t \leq 48 & \text{hours;} & k = -0.82 \\
48 < t \leq 480 & \text{hours;} & k = -1.50 \\
t > 480 & \text{hours;} & k = -1.20
\end{array}
$$

A varying decay of this type is consistent with the presence of Np-239 ($t_{1/2}$ = 56 hr) and U-237 ($t_{1/2}$=160 hr), which are both generated in significant quantities from neutron capture in uranium. After several half-lives, when the presence of these two radioisotopes no longer dominate the decay rate, it approaches the traditional $t^{-1.2}$ value. In the absence of radiological survey data, the time-dependent decay rate is used in reconstructing the radiation environments on the ships and atolls covered in this report. Generally, radiological data on the residence islands of Enewetak and Kwajalein support a $t^{-1.5}$ decay rate between 48 and 480 hours after detonation; shipboard data indicate slightly greater decay rates ($t^{-1.6}$ to $t^{-1.9}$) during the same period. The steeper shipboard decay rates can be attributed to a combination of the increased effectiveness of "weathering" on a ship's surfaces (as opposed to island soil), and to decontamination being carried out onboard the ships.

All of the ships addressed in this report encountered fallout following one or more of the six CASTLE detonations. In most instances, particularly where significant fallout was encountered, shipboard radiological data are available to define the topside radiation environment. In some instances, however, shipboard environments must be inferred from radiological data obtained on nearby islands, such as the residence islands of Enewetak and Kwajalein Atolls. For each atoll and ship, an average intensity curve is presented showing the free-field radiation intensity as a function of time after each shot that resulted in significant fallout. The intensity curves are then time-integrated to yield a daily free-field integrated intensity for each atoll/ship through 31 May 1954, when the roll-up phase was nearly complete.

The water in Bikini Lagoon also became contaminated following several of the five detonations conducted there. As ships steamed or anchored in the contaminated water, radioactive materials began to accumulate on the hulls below the water line and in the saltwater systems within the ships. As a result, radiation intensities below deck began to increase, adding to the crew's exposure. When compared to the topside radiation environments resulting from Shot BRAVO and Shot ROMEO fallout, this radiation was "considered more of an operational nuisance than a hazard" (Reference 12).

The same phenomenon was observed on the ships at Operation CROSSROADS conducted at Bikini Atoll in 1946. A model was developed in Reference 6 to determine personnel exposure aboard the ships at CROSSROADS due to ship contamination. Because only limited lagoon water contamination data have been found for Operation CASTLE, this model cannot be applied directly to the ships participating at this operation; however, several simplifying assumptions concerning the degree of contamination can be made, which allows portions of the model to be used.

Two basic assumptions are made in developing the ship contamination model. The first is that the mixture of fission products present in the accumulated radioactive material on the hull and in the piping of a ship decayed radiologically as $t^{-1.3}$. This decay rate was verified experimentally for fission products deposited in seawater and on the decks of target ships at CROSSROADS. The second assumption involves the rate of contamination buildup on the hull and interior piping. The radioactive buildup on a previously uncontaminated ship is assumed to be initially proportional to the radiation intensity of the water surrounding the ship, but, as buildup progresses, a limiting or saturation value of contamination is approached asymptotically. The occurrence of such a saturation effect is indicated by hull intensity readings taken on various ships after their departure from the lagoon following CROSSROADS operations. Based on these assumptions, the exterior gamma intensity of the hull $I_h(t)$ of a contaminated ship at time t is given by:

$$I_h(t) = St^{-1.3}\left[1-\exp\left\{-\frac{C}{S}D_w(t)\right\}\right], \qquad (1)$$

where C and S are constants, and

$$D_w(t) = \int_0^t t^{1.3}\, I_w(t)\, d\ . \tag{2}$$

Here $I_w(t)$ is the intensity of the surrounding water at time t; hence, this quantity is dependent on the contaminated water and on the ship's path through that environment. It is evident that, as a ship spends sufficient time in contaminated water, D_w becomes large and the hull intensity approaches a saturation value:

$$I_h\,(t) \longrightarrow St^{-1.3}. \tag{3}$$

The constants S and C were evaluated from CROSSROADS support ship intensity data, as discussed in Reference 6. The derived values are given below.

$$S = \begin{array}{l} 1800\ \text{mR-day}^{0.3} \text{ for destroyers,} \\ 1570\ \text{mR-day}^{0.3} \text{ for all other ships.} \end{array} \tag{4}$$

$$C = 11.0\ \text{day}^{-1} \text{ for all ships.} \tag{5}$$

It was also observed at Operation CROSSROADS that steaming in clean water reduced the accumulated contamination by about half during the first day after departing the lagoon, but that subsequent steaming had a much smaller effect. In the model, it is assumed that both hull and piping intensities were reduced to half their departure values during the first day after departure from the lagoon, and that subsequent decay while out of the lagoon followed the $t^{-1.3}$ decay rate.

The exterior hull gamma intensity (I_h) is then used to determine the average interior ship intensity. This analysis, as described in detail in Reference 6, results in an apportionment factor F_a, which relates average interior intensities (I_i) to exterior hull gamma intensities (I_h) by the relation:

$$I_i = F_a I_h. \tag{6}$$

Therefore the interior intensity at any time t after the detonation is given by:

$$I_i(t) = F_a S t^{-1.3} \left[1 - \exp\left\{ -\frac{C}{S} D_w(t) \right\} \right] . \qquad (7)$$

Since detailed radiological data for the waters of Bikini Lagoon are not available for Operation CASTLE, several assumptions are made in order to apply the CROSSROADS ship contamination model to the ships at CASTLE. It is documented that the anchorage areas in the lagoon became contaminated to varying degrees following Shots BRAVO, UNION and YANKEE. The assumption is made that ships entering the lagoon after each of these shots would reach the saturation level of contamination if they remained in the lagoon. The rate and level at which hulls become saturated is dependent on the intensity of the water surrounding the ship. At CROSSROADS, it was found that ships remaining in radioactive lagoon water generally reached saturation within one or two days. Based on these observations, this analysis assumes that the ships' hulls approached saturation linearly over a one-day period, i.e., any ship remaining in the lagoon for 24 hours became saturated. This assumption allows (high-sided) exposure estimates to be calculated without detailed knowledge of the water environment, leading to:

$$I_i(t) = F_a S t^{-1.3}. \qquad (8)$$

It is further assumed that, upon departing the contaminated lagoon water, hull and piping intensities were reduced by one-half, and that subsequent decay while out of the lagoon followed the $t^{-1.3}$ decay rate.

With these assumptions, the model developed for CROSSROADS ships is used to estimate the personnel exposure at Operation CASTLE due to contaminated lagoon water. Values of S and F_a (from Reference 6) for pertinent ship types are given below.

Ship Type	S (mR-day$^{0.3}$)	F_a	$F_a S$
CVE	1570	0.10	160
TAP, LSD, AV	1570	0.15	240
AGC	1570	0.20	310
LST	1570	0.33	520
ATF, ARSD	1570	0.39	610
DDE	1800	0.39	700

Discussions of the lagoon contamination following Shots BRAVO, UNION, and YANKEE, and pertinent assumptions concerning these environments, are as follows:

Shot BRAVO

Documentation (e.g., Reference 1) indicates that the water throughout the lagoon became contaminated by BRAVO plus three days (4 March); however, little is known of the water intensity levels. Therefore, it is assumed that ships entering the lagoon on or after 4 March became contaminated to the saturation level one day after entry into the lagoon.

Shot UNION

The water in the vicinity of the anchorage area was relatively free of contamination following this shot. However, five days after the shot (1 May), messages indicate that lagoon contamination was presenting more of a problem. For the present analysis, it is assumed that contamination spread to the anchorage area five days after the shot, and ships that entered the lagoon on or after 1 May reached a saturation level of contamination after one day of exposure to this water.

Shot YANKEE

Documentation indicates that the water in the anchorage areas became contaminated the day of Shot YANKEE (5 May). For this analysis, it is assumed that any ship entering the lagoon after the shot reached saturation if it remained there for a day or more.

Also following Shot YANKEE, the SIOUX encountered contaminated water while steaming outside of the lagoon. The water intensities are recorded in detail in Reference 13 (see Figure 2-30). With this information, the full contamination model in Reference 6 is applied to calculate the crew's exposure.

In order to demonstrate the inferred build-up and decay of the intensity below deck as a ship enters and leaves contaminated water (the Bikini anchorages), calculations are detailed for the USS CURTISS, a typical ship. The deck log of the CURTISS (AV-4) indicates that this ship entered Bikini Lagoon fifteen times during Operation CASTLE, remaining in the lagoon for various periods (see Section 2.2.6). When the ship remained in the lagoon for 24 hours or more, it is assumed the hull reached the saturation level with the intensity below deck given by:

$$I_i(t) = 240\ t^{-1.3}, \tag{9}$$

where 240 is the product of F_a and S. Upon leaving the lagoon, it is assumed that the intensity was immediately reduced by a factor of two. If the ship had not reached saturation, i.e., it remained in the lagoon for less than 24 hours, the intensity after departing the lagoon is one-half the intensity it reached during the linear one-day buildup period.

Figure 2-2 depicts the below deck intensity for the CURTISS through 31 May, resulting from hull contamination. The integrated intensities are detailed for each period in and out of the lagoon (see Section 2.2.6). The maximum below deck intensity measurement following Shot BRAVO was obtained in the engineering spaces in the vicinity of a contaminated auxiliary condenser on the CURTISS and was 2 mR/hour (48 mR/day). Shown in Figure 2-2, it is consistent with the observation in Reference 6 that, in general, engineering spaces in the vicinity of contaminated piping and salt water systems would have intensities approximately 1.5 times the average below deck intensity. (Although the actual date of the measurement is not known, it is assumed that it corresponded to the time of first hull saturation following Shot BRAVO.)

Similar ship contamination curves are derived for each ship that entered Bikini Lagoon during Operation CASTLE. These curves are time-integrated to yield a daily free-field integrated intensity below through 31 May 1954. Integrated intensities topside and below are detailed in the following sections for each ship that received fallout and/or entered the contaminated waters of Bikini Lagoon.

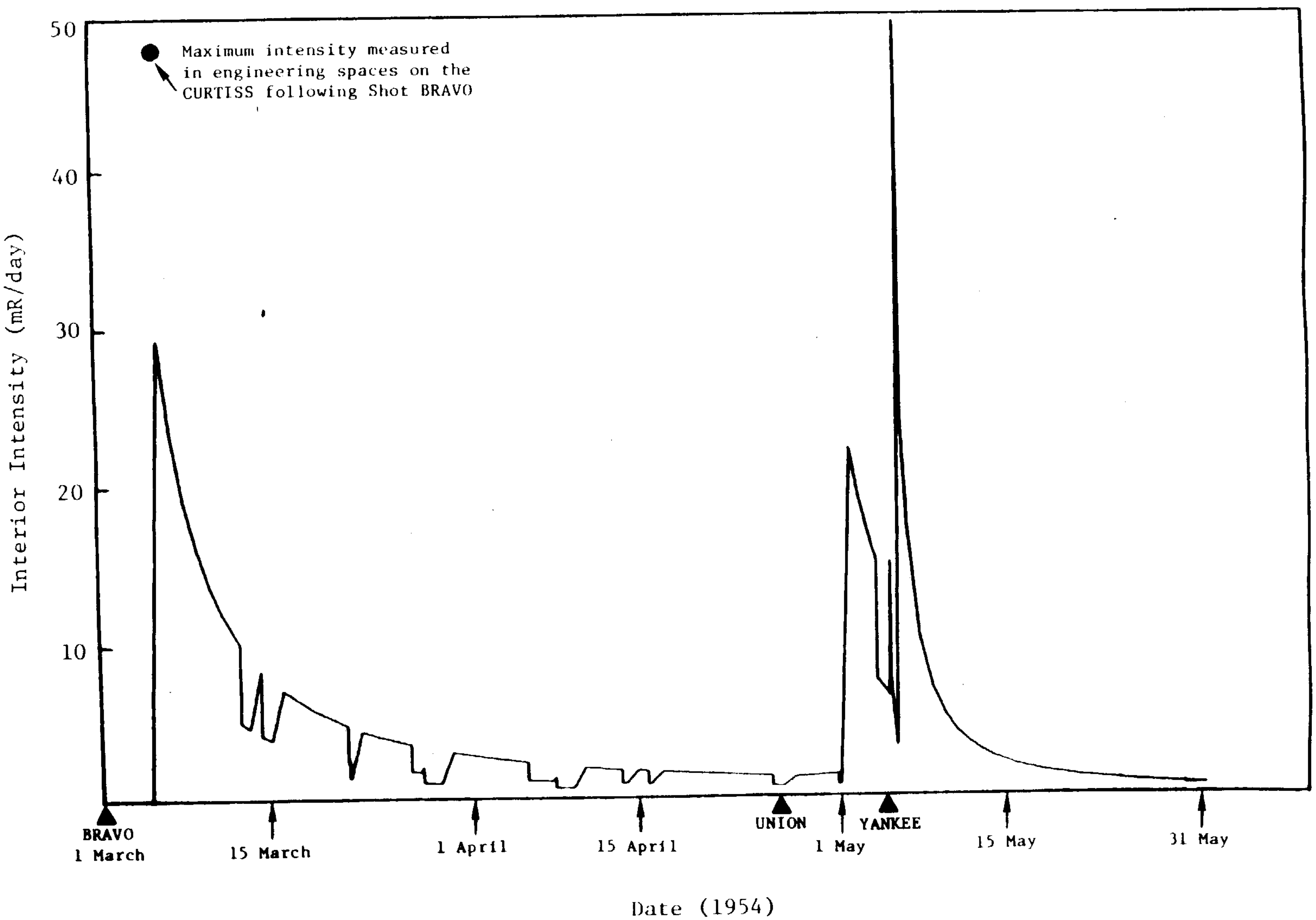

Figure 2-2. Average intensity below deck on the USS CURTISS due to ship contamination.

2.2.1 Enewetak Atoll

Of the six shots, BRAVO, ROMEO, and NECTAR caused measurable fallout on the residence islands of Enewetak Atoll. Generally, such fallout was secondary (onset was well after the time of detonation) and relatively minor in nature. At the time it was considered a "nuisance factor" (Reference 12). Fallout on Enewetak from Shots UNION and YANKEE was apparently even less significant as evidenced by the conflicting reports of the minor contamination following these two shots (References 10 and 14).

Fallout from Shot BRAVO began on Enewetak at approximately 1745 hours on 1 March, 11 hours after the shot (Reference 10). Soon after, average gamma intensities were 3-4 mR/hr and by 2300 hours, when fallout stopped, average intensities were 10 mR/hr with a maximum intensity of 15 mR/hr being reported. Figure 2-3 depicts the free-field radiation intensity on the residence islands (Parry and Enewetak) of Enewetak Atoll. Radioactive decay after 2300 hours is inferred from decay rates measured during the same time period on Bikini Atoll.

Fallout on Enewetak from Shot ROMEO came in two distinct "waves". It began at approximately 1700 hours on 27 March and peaked at 2100 hours with average intensities of 3 mR/hr being reported on Parry Island (Reference 12). Another period of fallout began during the late evening of 28 March and did not peak until noon on 30 March, at which time the average island intensities were approximately 9 mR/hr; maximum intensities were reported to be 15 mR/hr. Figure 2-4 depicts the radiation intensity for Enewetak Atoll. It is seen from the figure that BRAVO fallout contributed but little to the intensity after Shot ROMEO.

The TG 7.2 unit history for Operation CASTLE (Reference 14) indicates that Enewetak Island may have received contamination following Shots UNION and YANKEE. It states, "The radiation level, however, did not become significant. Following UNION, a peak intensity of four milliroentgens per hour (mR/hr) was received, and following YANKEE, the peak reading was only one mR/hr." Although these levels are not high, they are contradictory to those given in the JTF-7 rad-safe

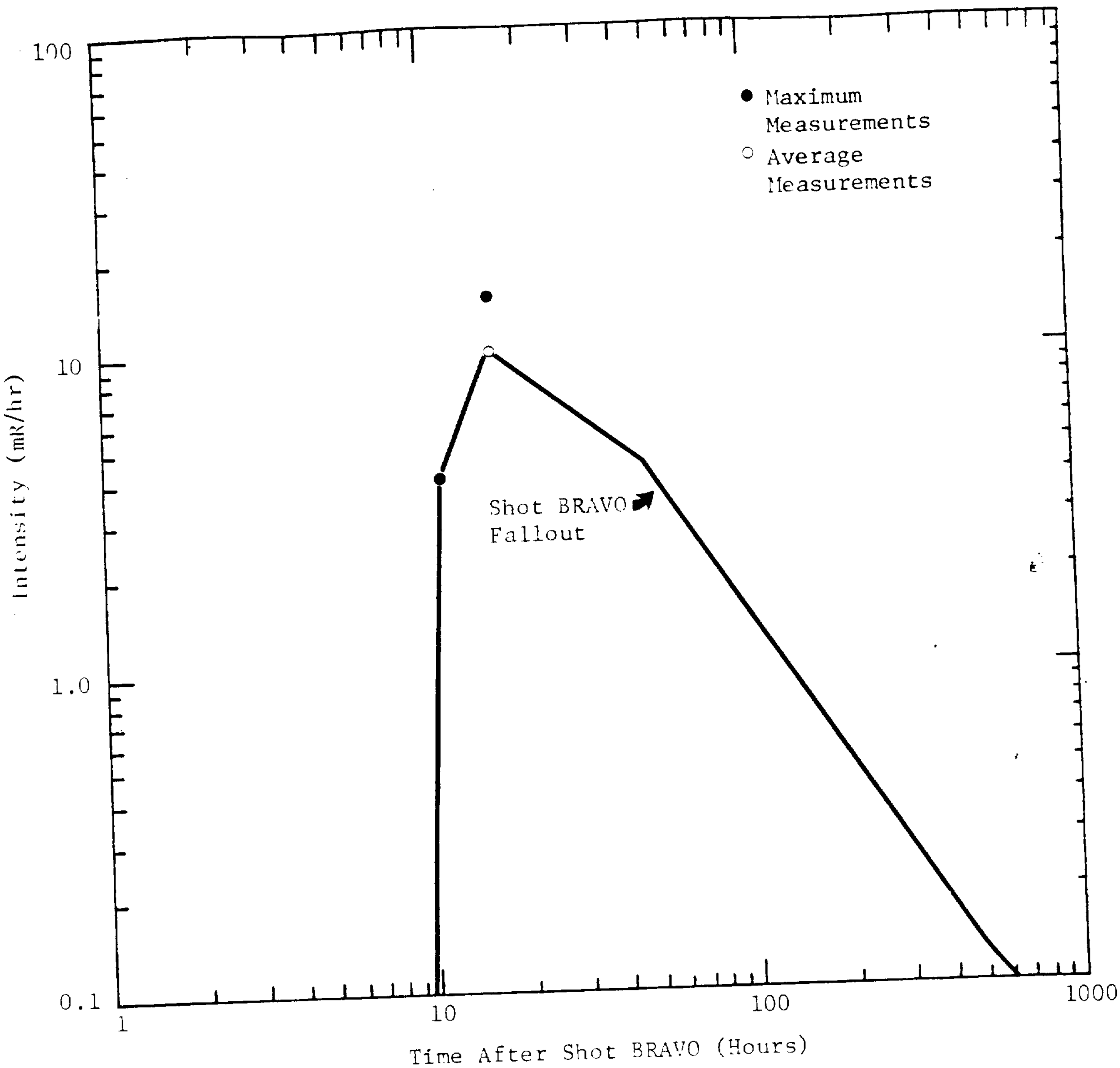

Figure 2-3. Parry and Enewetak Island intensity following Shot BRAVO.

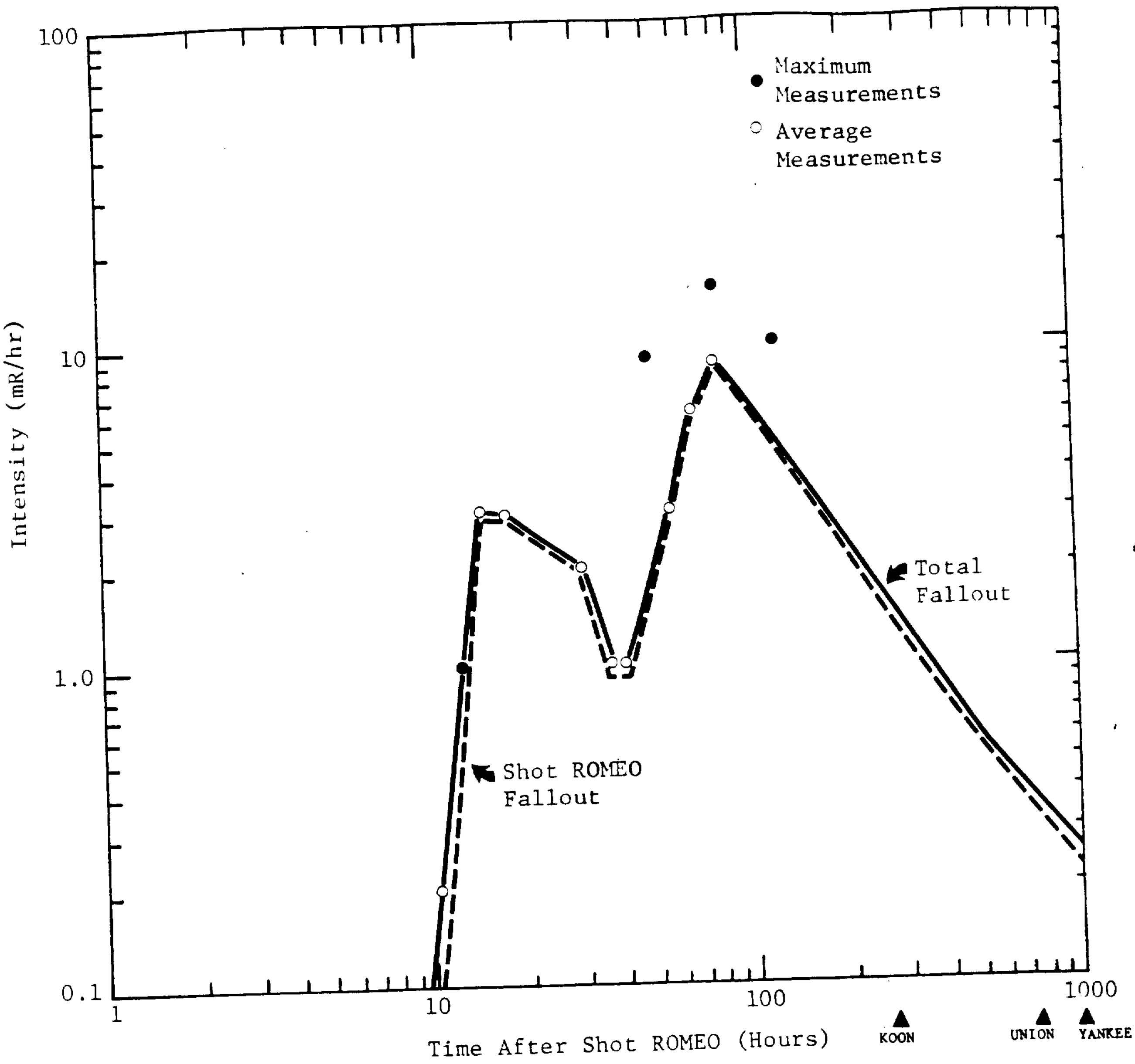

Figure 2-4. Parry and Enewetak Island intensity following Shot ROMEO.

final report (Reference 10) which states, "At 1900M on shot day (UNION) a report was received from the rad-safe monitoring team at Enewetak to the effect that Fred (Enewetak Is.), Elmer (Parry Is.), and Ursula (Rojoa Is.) were reading background." Reference 10 also states that, "By noon on shot day (YANKEE), it was evident that Enewetak would not be contaminated. This was confirmed at 1900M (shot day) by a report from the rad-safe alert system at Enewetak, indicating Fred, Elmer and Ursula with negative contamination." Since fallout arrival times and durations were not detailed in Reference 14, the reported contamination was probably due to cloud "shine" as small portions of the radioactive cloud passed near Enewetak. Aircraft cloud tracking information in Reference 10 indicates that the UNION cloud drifted to the north of Enewetak while the YANKEE cloud drifted to the south of the atoll. Any dose received by island-based personnel from these two shots would have been insignificant compared to BRAVO and ROMEO fallout and is not considered in this report.

Shot NECTAR, the only shot in the CASTLE series detonated at Enewetak, produced very little fallout on the residence islands in the southern portion of the atoll. Radiation intensities on Parry Island began to increase at 1830 hours on 14 May and peaked at 2 mR/hr at approximately 2100 hours the same day (Reference 12). Radioactive decay after 2100 hours (H+14.6) is assumed to follow the Bikini rates as it did with the previous shots. Figure 2-5 depicts Shot NECTAR fallout and its relationship with background intensities from Shots BRAVO and ROMEO. The solid curve is the total intensity resulting from fallout from all three shots.

The intensity curves in Figures 2-3, 2-4, and 2-5 have been time integrated from the beginning of fallout through 31 May 1954. Daily contributions to the free-field integrated intensity from each source have been summed and are tabulated in Table 2-1.

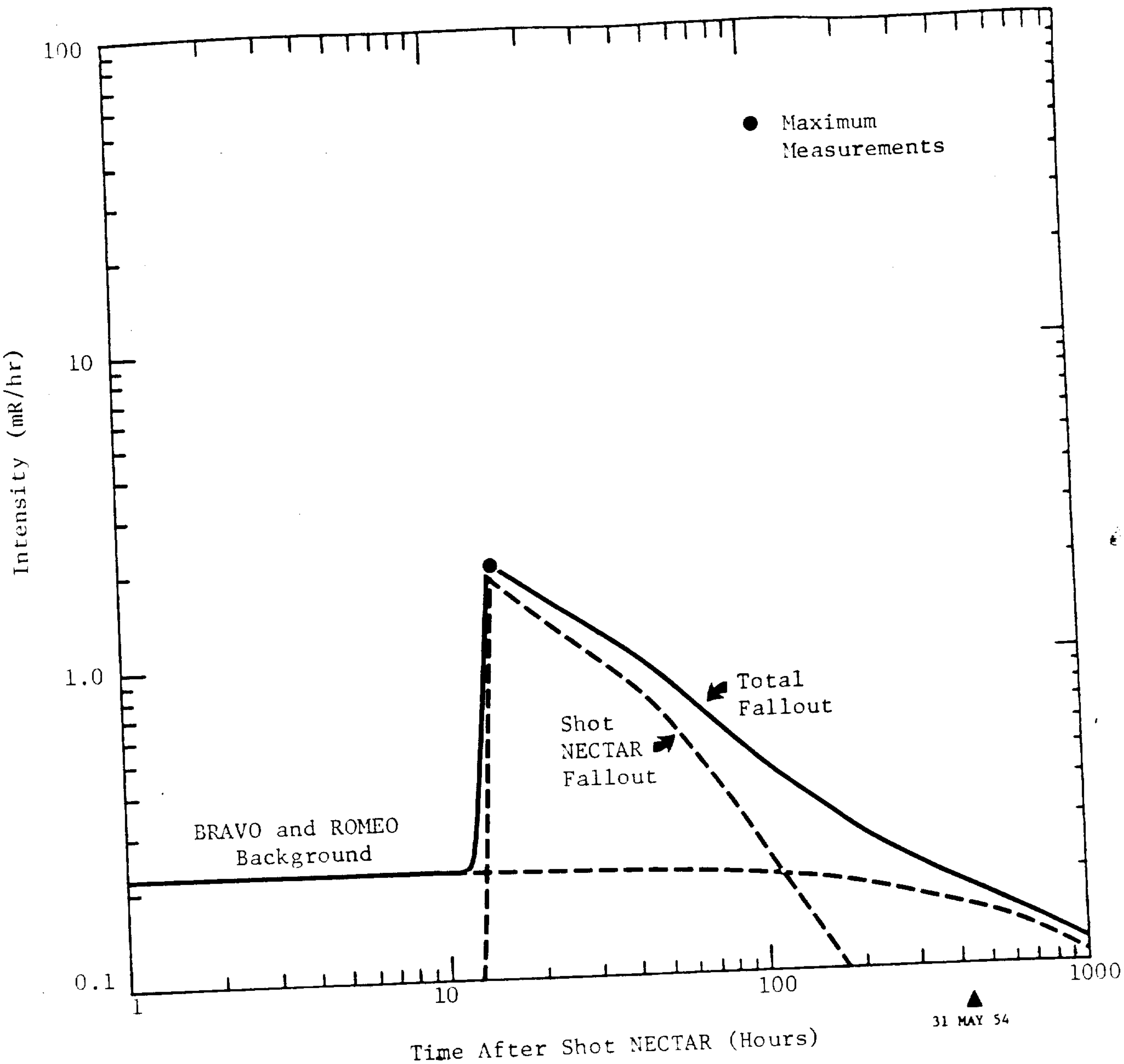

Figure 2-5. Parry and Enewetak Island intensity following Shot NECTAR.

Table 2-1. Daily integrated intensity, residence islands of Enewetak Atoll.

March	Integrated Intensity (mR)	April	Integrated Intensity (mR)	May	Integrated Intensity (mR)
1 (BRAVO)	47.4	1	101.7	1	7.6
2	153.5	2	78.4	2	7.3
3	85.3	3	63.0	3	7.1
4	48.9	4	52.0	4	6.9
5	32.4	5	44.1	5 (YANKEE)	6.6
6	23.5	6	37.9	6	6.5
7	18.0	7 (KOON)	33.1	7	6.3
8	14.4	8	29.2	8	6.1
9	11.8	9	26.1	9	6.0
10	10.0	10	23.5	10	5.9
11	8.5	11	21.3	11	5.7
12	7.4	12	19.5	12	5.6
13	6.5	13	17.8	13	5.4
14	5.8	14	16.5	14 (NECTAR)	11.7
15	5.2	15	15.3	15	30.2
16	4.7	16	14.3	16	19.0
17	4.3	17	13.5	17	12.9
18	3.9	18	12.9	18	10.1
19	3.6	19	12.2	19	8.6
20	3.3	20	11.6	20	7.6
21	3.0	21	11.1	21	6.9
22	2.9	22	10.6	22	6.5
23	2.7	23	10.2	23	6.0
24	2.6	24	9.7	24	5.7
25	2.4	25	9.4	25	5.3
26	2.3	26 (UNION)	9.0	26	5.2
27 (ROMEO)	14.5	27	8.7	27	5.0
28	43.1	28	8.4	28	4.8
29	67.2	29	8.1	29	4.7
30	180.0	30	7.8	30	4.5
31	139.7			31	4.3

2.2.2 Kwajalein Atoll

On Kwajalein Atoll, measurable fallout occurred after Shots BRAVO, ROMEO, and YANKEE, while Shots KOON, UNION, and NECTAR produced no fallout. As on Enewetak, all fallout was secondary in nature and low in intensity.

The Naval Station at Kwajalein provided basing support to Patrol Squadron TWENTY-NINE (VP-29) during Operation CASTLE (Reference 15). This squadron supported the AEC's worldwide fallout monitoring program with aerial radiation survey flights following each of the CASTLE events. The results of these survey flights, which included Kwajalein, were converted to ground intensities using experimentally-determined air-ground correction factors (Reference 10). In some instances, actual ground survey data for Kwajalein were recorded. These comprise the primary source of intensity data used for dose reconstructions. In addition, a few intensity readings taken at the Naval Station were also recorded in Reference 10. The intensity data are summarized below.

Date (Time)	Intensity (mR/hr)	Notes
2 Mar (1800)	0.6	actual ground survey reading
4 Mar (1200)	0.5	actual ground survey reading
19 Mar (1200)	0.1	based on aerial survey reading
30 Mar (1545)	0.05	actual ground survey reading
31 Mar (1545)	1.0-3.0	on beaches (ground)
3 Apr (1354)	1.4	based on aerial survey reading
8 Apr (1453)	0.53	based on aerial survey reading
12 Apr (1200)	1.5	annoted in Ref. 2 as probably erroneously high (ground)
12 Apr (1452)	0.4	based on aerial survey reading
21 Apr (1435)	0	probably not actually zero (aerial)
1 May (1200)	0.1	actual ground survey reading
6 May (1455)	0.4	based on aerial survey reading
6 May (1645)	1.0	maximum ground survey intensity
7 May (1800)	4.5	highly questionable ground intensity reading
8 May (1335)	0.2	based on aerial survey reading
15 May (1335)	0.1	based on aerial survey reading
16 May (1236)	0.08	based on aerial survey reading

The onset of fallout following Shot BRAVO did not occur until approximately 0800 hours on 2 March. By 1800 hours, ground surveys on Kwajalein recorded average intensities of 0.6 mR/hr. The next survey, at noon on 4 March, indicated a slight drop in intensities to 0.5 mR/hr; an aerial survey on 19 March indicated a further reduction to 0.1 mR/hr. Figure 2-6 depicts the radiation environment on Kwajalein resulting from Shot BRAVO as inferred from the survey data. The 4 March intensity of 0.5 mR/hr has been extrapolated back to 2000 hours, 2 March, using the decay exponents derived from the Bikini fallout data (Section 2.2). This indicates that the fallout on Kwajalein probably did not peak until shortly after the survey conducted at 1800 hours on 2 March. The 19 March intensity derived from the aerial survey data appears somewhat higher than would be expected if the 4 March intensity is extrapolated forward with time using the Bikini decay data. Much more significance is attached to actual ground readings, when available, than to ground intensities derived from aerial survey data.

Secondary fallout from Shot ROMEO did not arrive at Kwajalein until 3 days after the detonation. A ground survey on Kwajalein at 1545 hours, 30 March, indicated an intensity of 0.05 mR/hr, approximately twice the Shot BRAVO background at that time. Subsequent surveys on 31 March revealed intensities of 1-3 mR/hr. Aerial surveys on 3, 8, and 12 April establish a rate of decay for the ROMEO fallout that is proportional to $t^{-1.5}$; a ground survey reading of 0.1 mR/hr on 1 May supports the decay rate established from the aerial surveys. Figure 2-7 depicts the total fallout on Kwajalein following Shot ROMEO and the individual contributions from Shots BRAVO and ROMEO.

Minor fallout also occurred on Kwajalein approximately one day after Shot YANKEE. Surveys conducted during the afternoon of 6 May indicated maximum ground intensities of 1.0 mR/hr. Average intensities of 0.4 mR/hr were derived from aerial surveys. Subsequent aerial surveys on 8, 15, and 16 May revealed that YANKEE fallout also decayed approximately proportional to $t^{-1.5}$. Figure 2-8 shows the YANKEE fallout on Kwajalein as derived from the aerial and ground survey data. Also shown are the contributions from BRAVO and ROMEO fallout to the total.

The intensity curves defining the radiation environment on Kwajalein during Operation CASTLE are time integrated, by day, through 31 May. Daily integrated free-field intensities are summed and tabulated in Table 2-2.

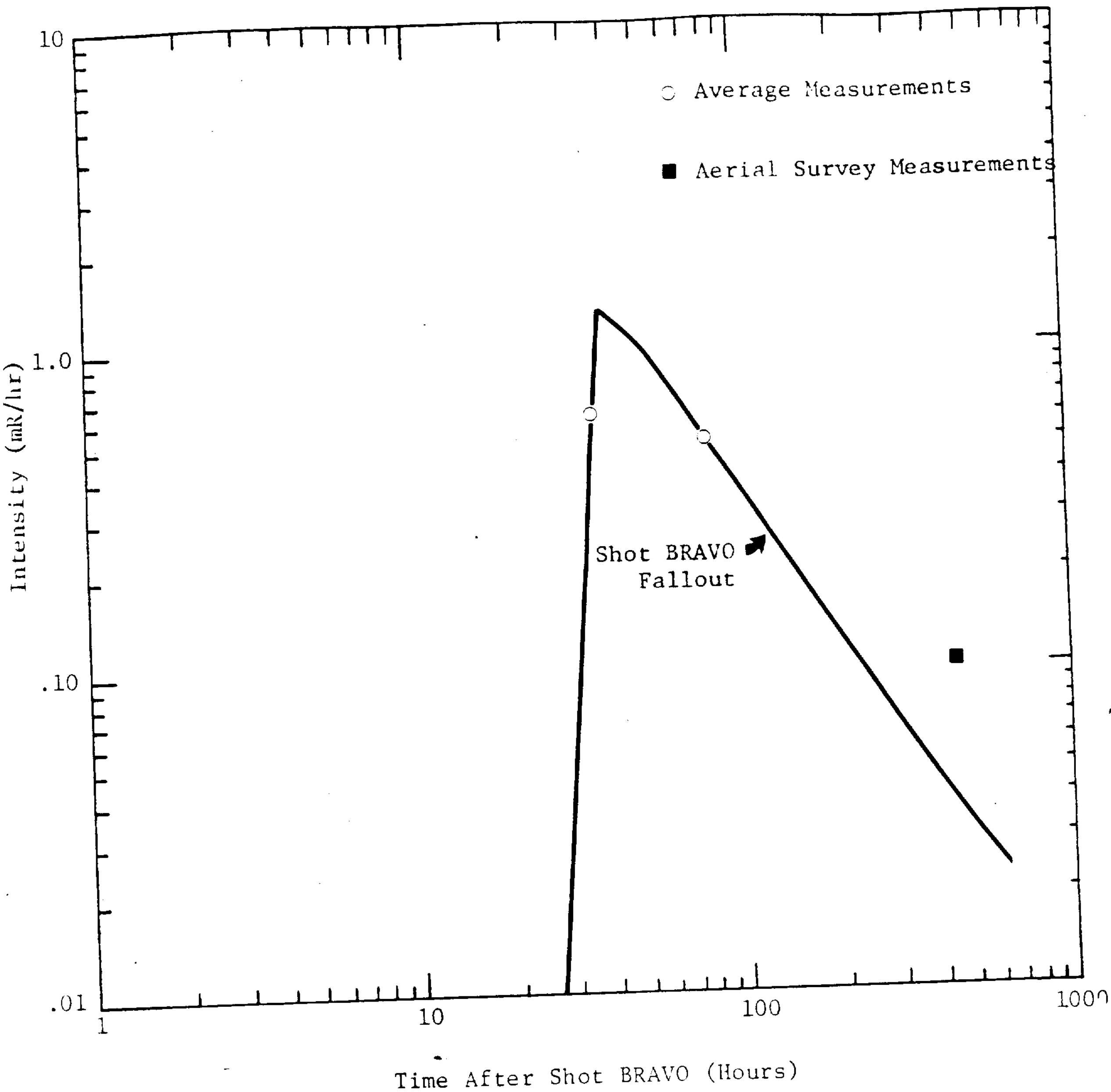

Figure 2-6. Kwajalein Atoll intensity following Shot BRAVO.

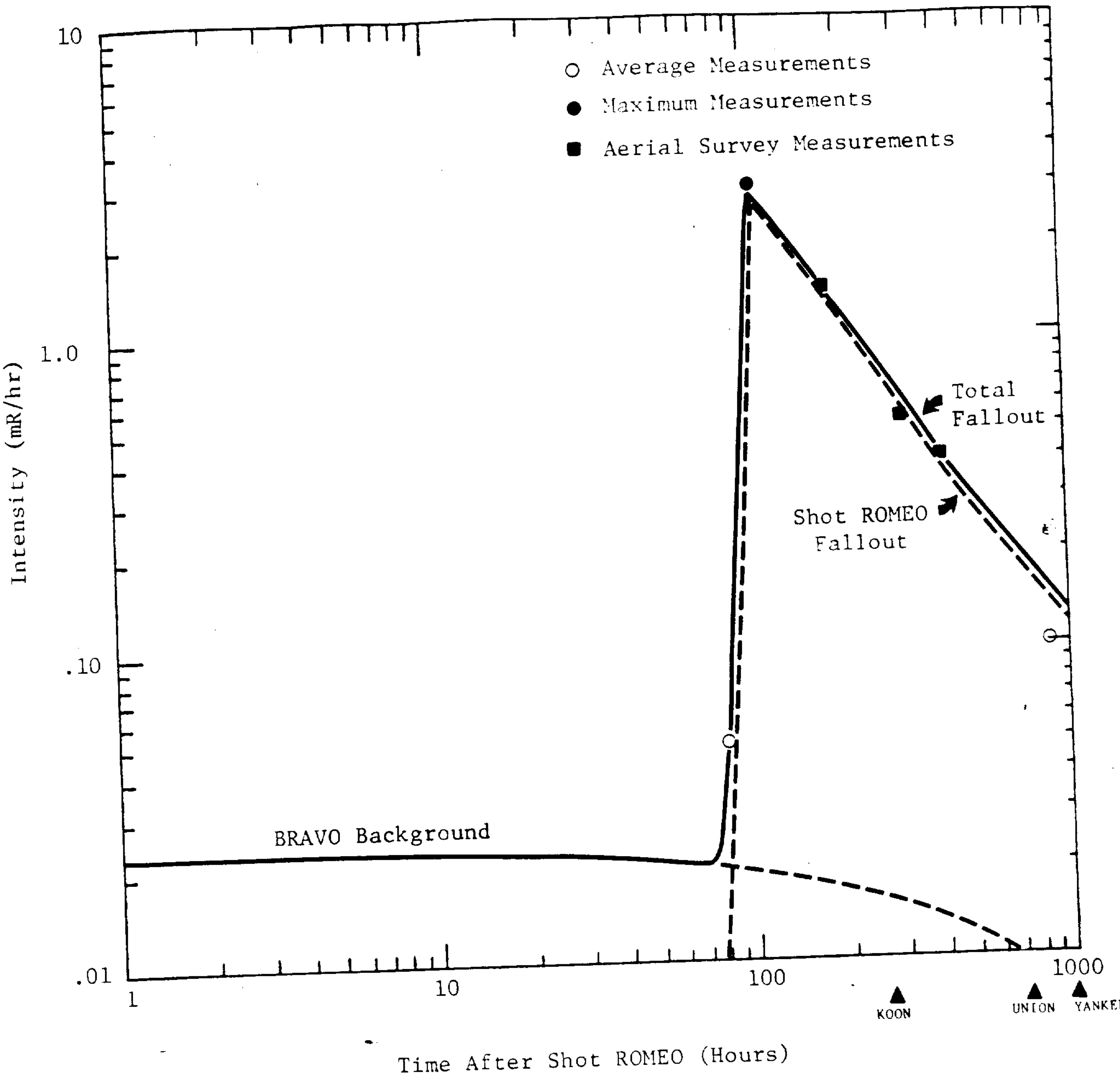

Figure 2-7. Kwajalein Atoll intensity following Shot ROMEO.

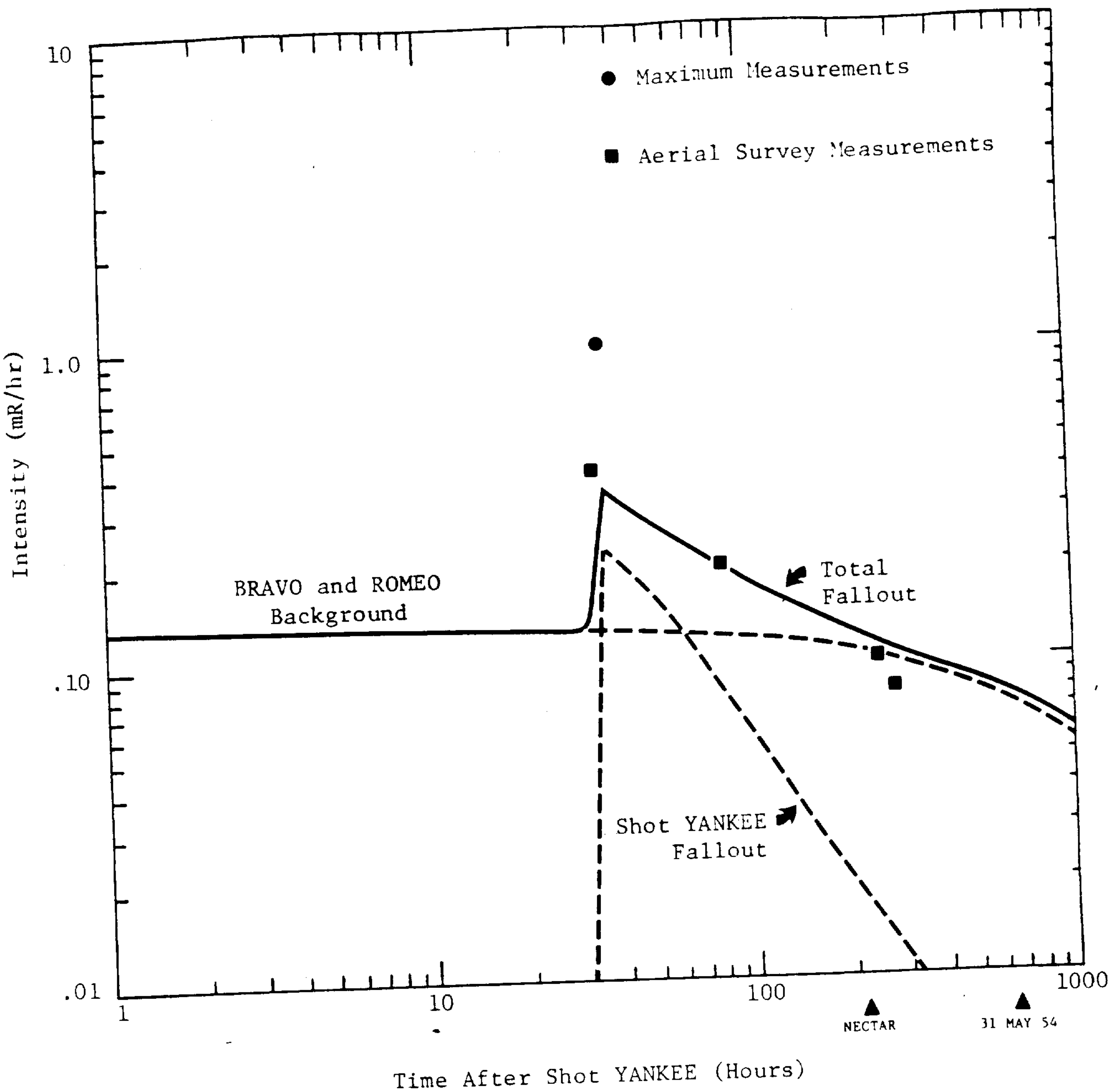

Figure 2-8. Kwajalein Atoll intensity following Shot YANKEE.

Table 2-2. Daily integrated intensity, Kwajalein Atoll.

March	Integrated Intensity (mR)	April	Integrated Intensity (mR)	May	Integrated Intensity (mR)
1 (BRAVO)	0.0	1	50.6	1	3.6
2	7.3	2	38.8	2	3.5
3	21.2	3	31.1	3	3.4
4	12.2	4	25.7	4	3.3
5	8.1	5	21.7	5 (YANKEE)	3.2
6	5.9	6	18.6	6	5.2
7	4.5	7 (KOON)	16.2	7	6.5
8	3.6	8	14.3	8	4.9
9	3.0	9	12.8	9	4.2
10	2.5	10	11.4	10	3.8
11	2.1	11	10.3	11	3.4
12	1.9	12	9.4	12	3.2
13	1.6	13	8.6	13	3.1
14	1.4	14	8.0	14 (NECTAR)	2.9
15	1.3	15	7.4	15	2.9
16	1.2	16	6.9	16	2.7
17	1.1	17	6.5	17	2.7
18	1.0	18	6.2	18	2.5
19	0.9	19	5.9	19	2.5
20	0.8	20	5.6	20	2.4
21	0.8	21	5.4	21	2.3
22	0.7	22	5.1	22	2.2
23	0.7	23	4.8	23	2.2
24	0.7	24	4.6	24	2.1
25	0.6	25	4.4	25	2.0
26	0.6	26 (UNION)	4.3	26	2.0
27 (ROMEO)	0.6	27	4.1	27	1.9
28	0.5	28	4.0	28	1.9
29	0.5	29	3.8	29	1.9
30	1.1	30	3.7	30	1.9
31	35.9			31	1.8

2.2.3 USS APACHE (ATF-67)

The APACHE encountered fallout after three of the CASTLE detonations. During the early afternoon of 1 March, while operating in an area southeast of the BRAVO GZ, the APACHE began receiving fallout at approximately 1300 hours (Reference 10). The ship's washdown system was turned on several times during the day, which helped to reduce intensities somewhat, but it was not until early in the morning on 2 March when intensities leveled off at approximately 30 mR/hr and then began to decay. Figure 2-9 depicts the average topside radiation levels on the APACHE as derived from shipboard measurements taken through 0800 hours, 8 March (Reference 10).

Approximately nine hours after Shot ROMEO, the APACHE began receiving a relatively light fallout while operating in an area southwest of the ROMEO GZ. At 1600 hours, when average intensities had reached 20 mR/hr, the washdown system was turned on for an hour which quickly reduced intensities to approximately 1 mR/hr (see Figure 2-10). No further fallout was encountered by the APACHE on 27 March. During the late afternoon and evening of 28 March, while enroute to Enewetak, the APACHE again encountered fallout from Shot ROMEO. A peak intensity of 42 mR/hr was recorded at 1600 hours (Figure 2-10), but it was not until early in the morning on 29 March, while anchored at Enewetak, that intensities were reduced below 20 mR/hr. The same fallout encountered by the APACHE while east of Enewetak eventually drifted westward resulting in fallout on Enewetak. Figure 2-4 shows a very similar fallout "pattern" as that received by the APACHE except that its time of arrival was delayed somewhat and maximum intensity levels had decayed accordingly.

The APACHE was anchored at Kwajalein when Shot YANKEE fallout occurred on that atoll. It is assumed that, while at anchor, the ship received the same fallout as Kwajalein (See Figure 2-8). None of the other shots in the CASTLE series resulted in shipboard contamination on the APACHE.

The APACHE entered the contaminated waters of Bikini Lagoon eight times during the operation; dates and times are detailed below. Based on the ship

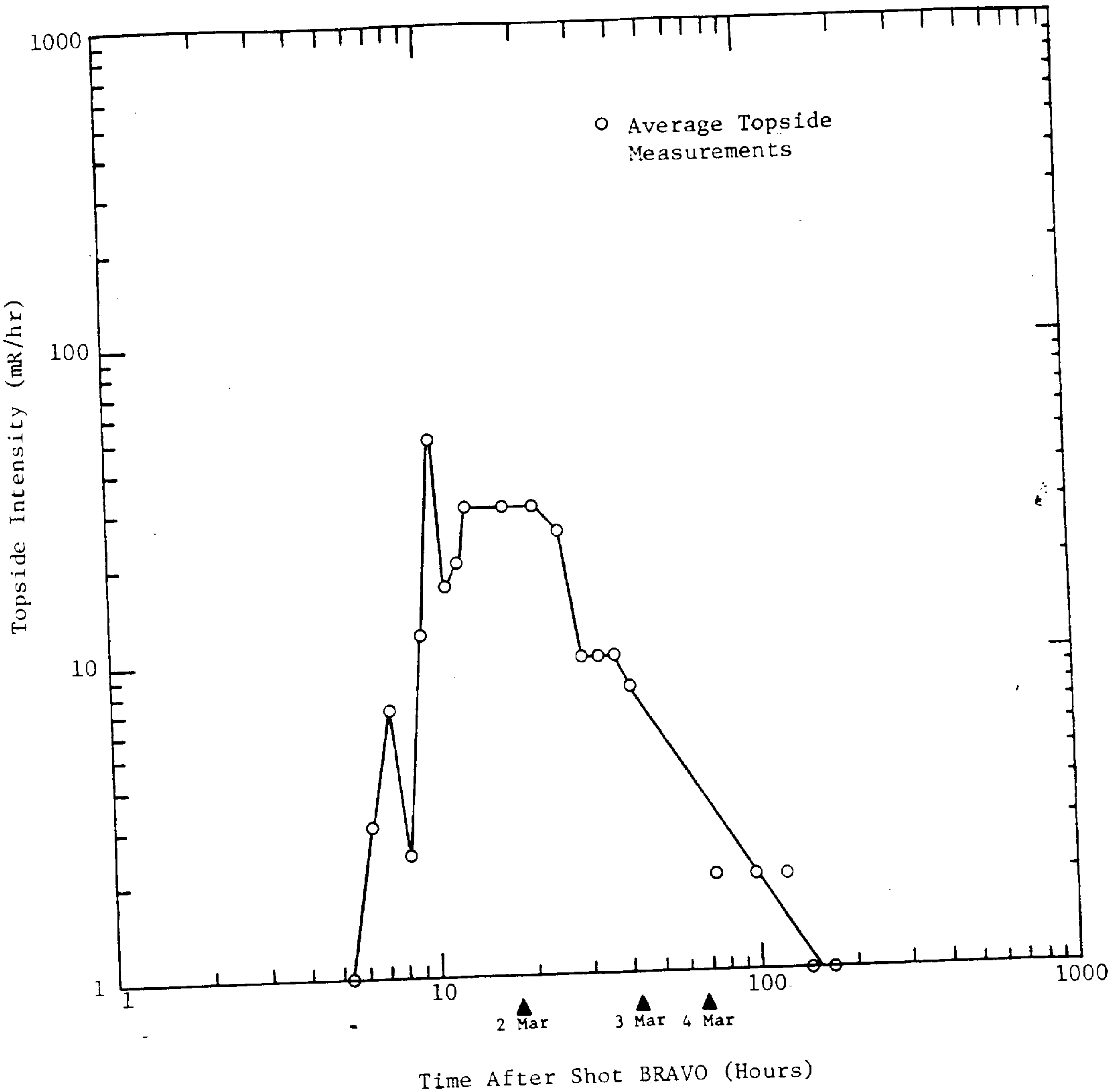

Figure 2-9. USS APACHE topside intensity following Shot BRAVO.

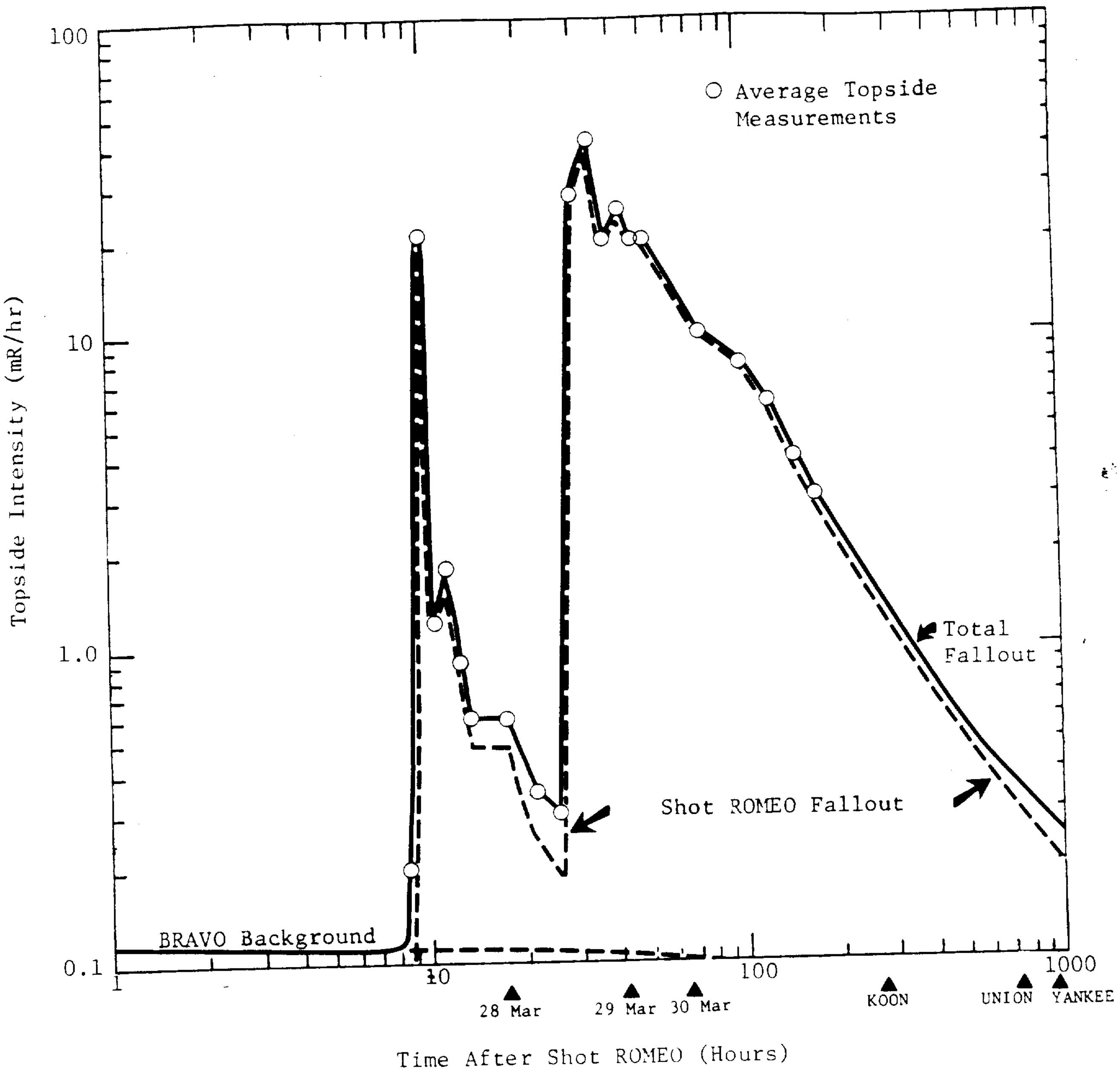

Figure 2-10. USS APACHE topside intensity following Shot ROMEO.

contamination model described earlier, the average intensity below deck due to contaminated lagoon water is calculated through the end of May. Intensities for each period in and out of the lagoon are integrated and are shown below.

	Time at Bikini Lagoon		Integrated Intensity (mR)	
Month	In	Out	In	Out
March	06/2009-09/1555		108.4	
		09/1555-11/1559		33.4
	11/1559-12/0359		8.7	
		12/0359-13/0807		11.1
	13/0807-19/0905		103.0	
		19/0905-21/1937		15.9
	21/1937-22/1924		8.5	
		22/1924-25/0720		13.0
	25/0720-26/0940		8.0	
April		26/0940-01/0830		23.9
	01/0838-05/1337		25.4	
		05/1337-13/1422		20.8
	13/1422-14/2000		4.3	
May		14/2000-07/0905		37.6
	07/0950-13/2205		450.7	
		13/2205-31/2400		152.6

Table 2-3 summarizes the daily contributions to the free-field integrated intensity on the APACHE due to fallout (topside) and ship contamination (below) from 1 March to 31 May 1954.

Table 2-3. Daily integrated intensity, USS APACHE.

March	Integrated Intensity (mR) Topside	(Below)	April	Integrated Intensity (mR) Topside	(Below)	May	Integrated Intensity (mR) Topside	(Below)
1 (BRAVO)	234.9		1	129.7	(5.0)	1	7.1	(1.4)
2	410.0		2	88.6	(6.5)	2	6.9	(1.4)
3	132.3		3	69.3	(6.4)	3	6.7	(1.4)
4	71.6		4	55.9	(6.1)	4	6.4	(1.4)
5	46.1		5	46.2	(3.8)	5 (YANKEE)	6.2	(1.3)
6	32.7	(3.0)	6	39.1	(2.8)	6	8.2	(1.3)
7	24.7	(45.8)	7 (KOON)	33.6	(2.7)	7	9.4	(58.3)
8	19.4	(44.5)	8	29.2	(2.6)	8	7.8	(115.0)
9	15.8	(26.5)	9	25.8	(2.6)	9	7.0	(86.9)
10	13.1	(16.4)	10	22.9	(2.5)	10	6.4	(66.8)
11	11.1	(14.0)	11	20.5	(2.4)	11	6.0	(53.7)
12	9.6	(11.0)	12	18.5	(2.3)	12	5.8	(44.5)
13	8.3	(15.8)	13	16.9	(2.0)	13	5.6	(31.7)
14	7.4	(19.4)	14	15.5	(4.0)	14 (NECTAR)	5.4	(16.4)
15	6.5	(18.9)	15	14.2	(2.1)	15	5.3	(14.4)
16	5.9	(17.3)	16	13.2	(2.1)	16	5.1	(12.8)
17	5.3	(16.0)	17	12.6	(2.0)	17	5.0	(11.4)
18	4.8	(14.8)	18	11.9	(2.0)	18	4.7	(10.4)
19	4.4	(7.6)	19	11.3	(1.9)	19	4.6	(9.4)
20	4.0	(6.4)	20	10.8	(1.9)	20	4.5	(8.7)
21	3.7	(4.8)	21	10.3	(1.8)	21	4.4	(8.0)
22	3.5	(9.6)	22	9.9	(1.8)	22	4.4	(7.4)
23	3.3	(5.3)	23	9.5	(1.7)	23	4.3	(6.9)
24	3.2	(5.0)	24	9.0	(1.7)	24	4.1	(6.4)
25	3.0	(7.1)	25	8.7	(1.6)	25	4.1	(6.0)
26	2.9	(5.0)	26 (UNION)	8.4	(1.6)	26	4.0	(5.7)
27 (ROMEO)	9.9	(4.3)	27	8.1	(1.6)	27	3.8	(5.3)
28	373.0	(4.1)	28	7.9	(1.5)	28	3.8	(5.0)
29	417.1	(3.9)	29	7.5	(1.5)	29	3.7	(4.8)
30	231.4	(3.7)	30	7.3	(1.5)	30	3.7	(4.5)
31	176.0	(3.6)				31	3.6	(3.2)

2.2.4 USS BAIROKO (CVE-115)

At approximately 0800 hours on 1 March, the BAIROKO began receiving heavy fallout from the Shot BRAVO cloud (Reference 10). Material Condition ABLE was set throughout the ship and all unnecessary personnel were ordered below. All ventilation was shut down to minimize contamination of spaces below the hangar deck. The ship's washdown system was activated at 0810 hours and remained on for approximately two hours, but failed to provide a sufficient volume of water to wash away the heavy fallout of contaminated coral sand (Reference 16). By this time average intensities on the flight deck were 500 mR/hr; intensities as high as 5 R/hr were measured in some of the cross deck gutters and a maximum reading of 25 R/hr was obtained from a flight deck drain. Fire hoses were broken out at approximately 1000 hours and used to wash down exposed areas for the remainder of the afternoon; by 1600 hours, average flight deck intensities had been reduced to approximately 200 mR/hr.

Another period of fallout consisting of very fine particles was encountered while enroute to Enewetak between approximately 1700 and 2400 hours, 1 March. Fire hoses were again used to wash down the flight deck, forecastle, fantail, and the bridge until approximately 1900 hours. At this time, topside intensities were still quite high (180 mR/hr), however, rad-safe personnel recommended sending all personnel who could be spared below decks because of the possibility of inhaling the extremely fine particles. No further decontamination was accomplished on 1 March (Reference 16).

At 0800 hours on 2 March, a rad-safe survey indicated that average intensities on the flight deck were from 100-200 mR/hr. Decontamination efforts were carried out all day on 2 March and, by 2000 hours, intensity levels had been reduced to approximately 30 mR/hr (Reference 16). After two more days of decontaminating the flight deck and other exposed surfaces, average intensities of approximately 10-15 mR/hr were recorded on 4 March, when decontamination was considered complete (Reference 17). Figure 2 -11 depicts the average radiation intensity on the flight deck of the BAIROKO resulting from Shot BRAVO fallout. The effectiveness of the decontamination efforts on 2 March are clearly evident by the sharp decrease in the average intensity between approximately H+28 and H+34 hours. Decontamination

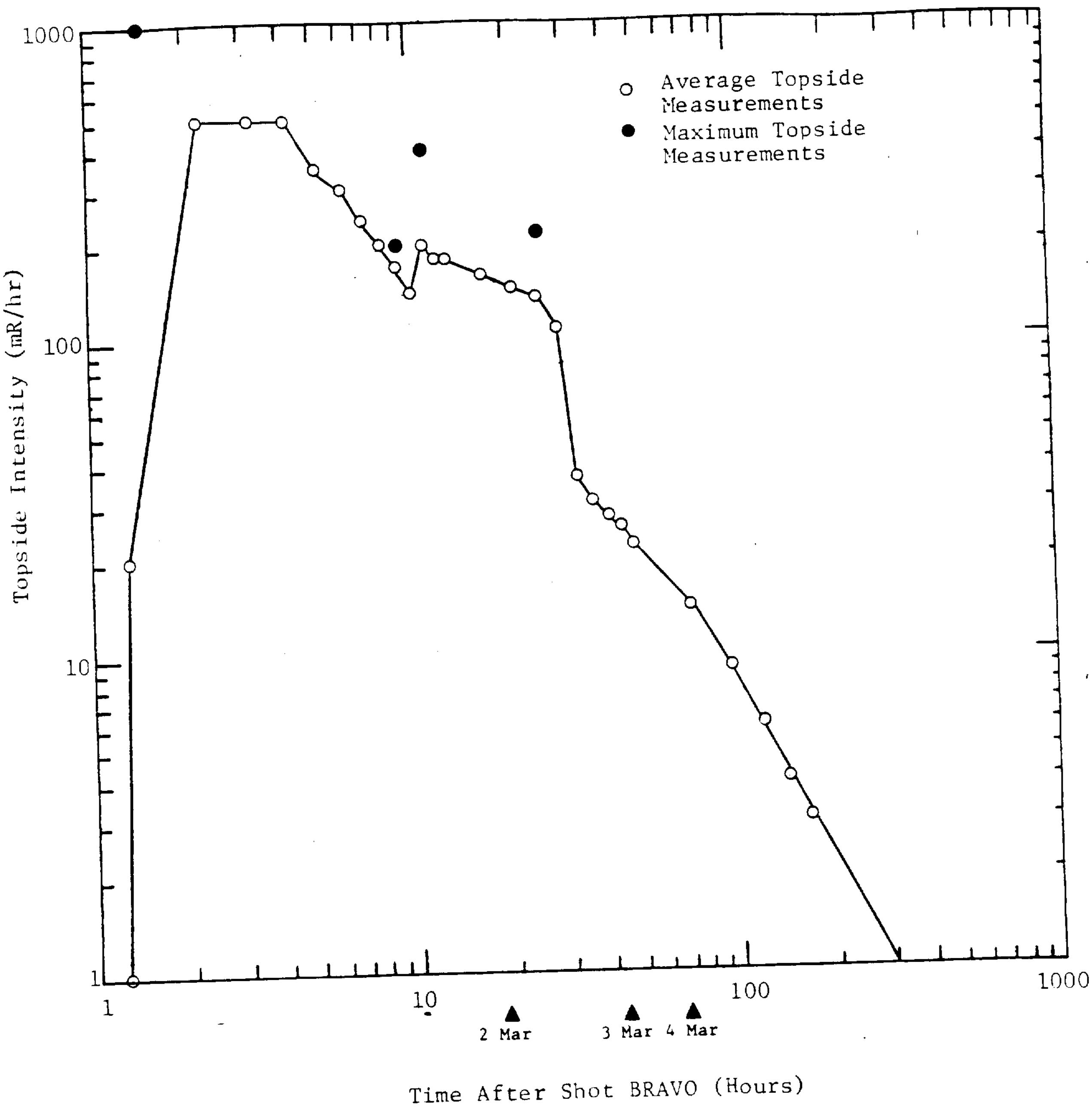

Figure 2-11. USS BAIROKO topside intensity following Shot BRAVO.

efforts on 3-4 March were directed at cleaning up "hot spots"; hence, the decrease in average topside intensities is due mainly to natural radioactive decay.

At the time of Shot ROMEO on 27 March, the BAIROKO was steaming in company with the EPPERSON southeast of Bikini Atoll. At approximately 1400 hours, it returned to Bikini and anchored in the lagoon where it remained until 5 April. At 2000 hours on 28 March, the BAIROKO began receiving secondary fallout from the ROMEO cloud (Reference 10). Average intensities on the flight deck peaked at 25 mR/hr during the early morning hours of 29 March, and the ship's washdown system was turned on intermittently between 0130 and 0400 hours. There is no mention in the BAIROKO's deck log that further efforts were made to decontaminate the ship on 29 March. On 30 March, intensities were down to approximately 10 mR/hour. Figure 2-12 shows the buildup and decay of the Shot ROMEO fallout on the flight deck of the BAIROKO. Also shown is the Shot BRAVO background radiation on the ship and its contribution to the total recorded intensity. The BAIROKO did not receive any more fallout following the four remaining shots in the test series.

In addition to exposure from fallout, the BAIROKO's saltwater piping system became contaminated while at anchor in Bikini Lagoon. By 4 March, "the average intensity in berthing spaces below the hanger deck was less than 2 milliroentgens per hour (gamma only)" and on 8 March, "the saltwater piping systems did not exceed 2 milliroentgens per hour (gamma only)" (Reference 17). This reference also states that "all fresh water samples from the evaporators tested by Task Group 7.1 have shown 1/5000 micro curies per milliliter or less." The ship contamination model developed in Section 2 is used to determine the crew's exposure due to ship contamination. Specific dates and times in and out of the lagoon, along with corresponding integrated intensities, are detailed below.

	Time at Bikini Lagoon		Integrated Intensity (mR)	
Month	In	Out	In	Out
March	03/0834-12/1720		108.3	
		12/1720-13/0720		1.9
	13/0720-26/2034		49.7	
		26/2034-27/1400		0.8
April	27/1400-05/1226		16.2	

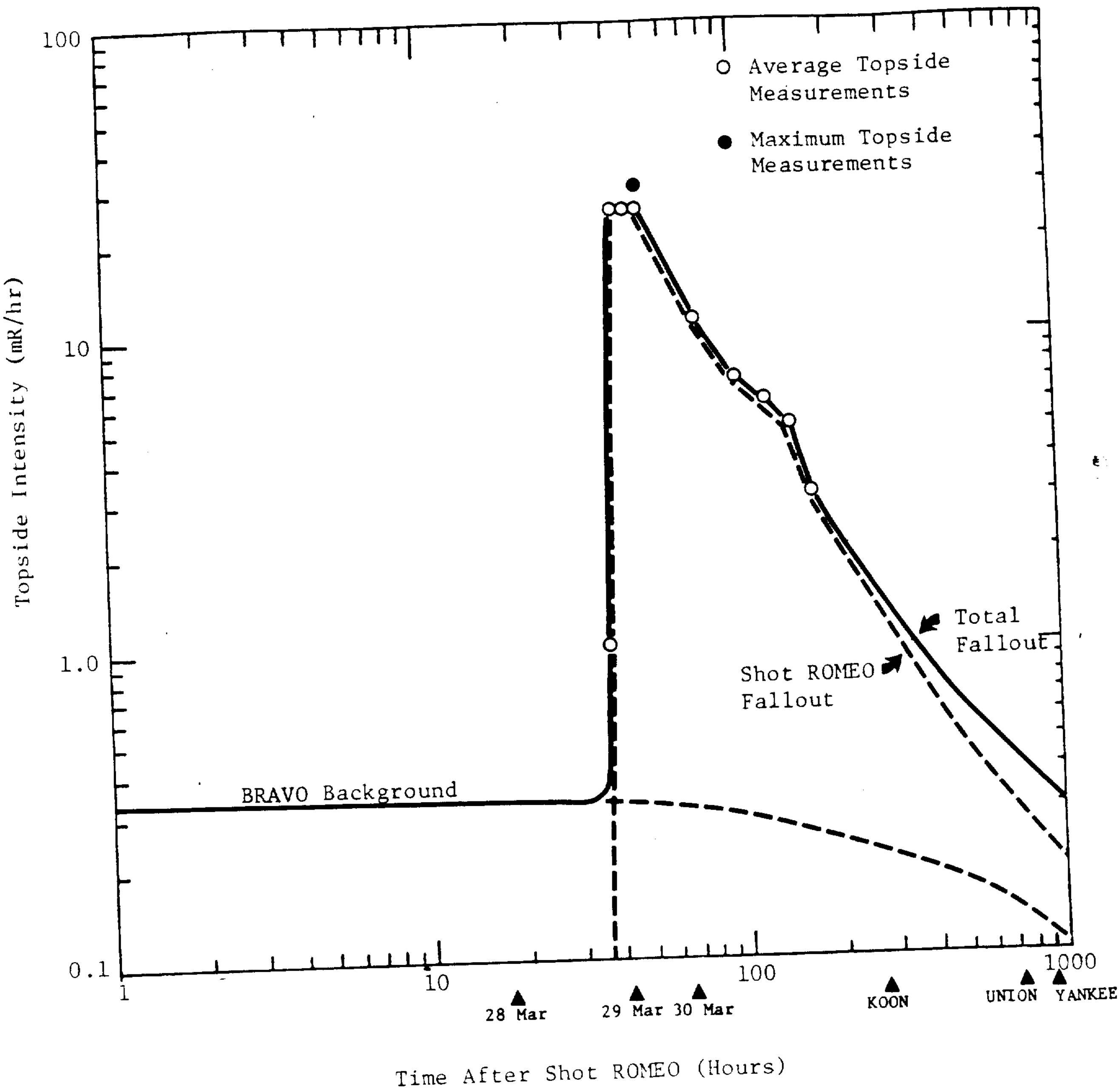

Figure 2-12. USS BAIROKO topside intensity following Shot ROMEO.

	Time at Bikini Lagoon		Integrated Intensity (mR)	
Month	In	Out	In	Out
April		05/1226-07/1028		1.4
	07/1028-15/1317		10.0	
		15/1317-16/1824		0.7
	16/1824-20/0953		3.5	
		20/0953-20/1427		0.1
	20/1427-25/1853		4.5	
		25/1853-26/1535		0.4
May	26/1535-04/1555		43.8	
		04/1555-05/1643		4.8
	05/1643-05/1942		0.7	
		05/1942-06/0709		1.9
	06/0709-12/2227		174.2	
		12/2227-14/1132		7.8
	14/1132-15/1701		7.9	
		15/1701-31/2400		32.4

Table 2-4 is a compilation of the daily contributions to integrated intensity on the BAIROKO due to fallout (topside) and ship contamination (below). The daily integrated intensities calculated from the ship contamination model on 4 and 8 March are consistent with those observed below in Reference 17, i.e., less than 2 mR/hour.

Table 2-4. Daily integrated intensity, USS BAIROKO.

March	Integrated Intensity (mR) Topside	(Below)	April	Integrated Intensity (mR) Topside	(Below)	May	Integrated Intensity (mR) Topside	(Below)
1 (BRAVO)	3943.4		1	137.3	(1.8)	1	8.6	(7.8)
2	2150.7		2	107.6	(1.7)	2	8.4	(14.1)
3	487.5		3	69.6	(1.7)	3	8.1	(11.7)
4	306.4	(13.2)	4	56.8	(1.6)	4	7.9	(5.2)
5	195.2	(22.8)	5	47.5	(0.8)	5 (YANKEE)	7.7	(6.4)
6	130.9	(17.5)	6	40.6	(0.7)	6	7.5	(30.5)
7	94.2	(14.1)	7 (KOON)	35.3	(0.9)	7	7.3	(49.6)
8	71.3	(11.7)	8	31.1	(1.4)	8	7.1	(31.7)
9	56.0	(9.9)	9	27.6	(1.3)	9	7.0	(22.8)
10	45.2	(8.6)	10	24.9	(1.3)	10	6.8	(17.5)
11	37.3	(7.5)	11	22.6	(1.3)	11	6.7	(14.1)
12	31.3	(3.9)	12	20.5	(1.2)	12	6.5	(8.0)
13	26.7	(5.3)	13	18.9	(1.2)	13	6.4	(5.0)
14	23.1	(5.4)	14	17.4	(1.2)	14 (NECTAR)	6.3	(5.7)
15	20.1	(4.9)	15	16.2	(0.7)	15	6.1	(7.0)
16	17.8	(4.5)	16	15.2	(0.6)	16	6.0	(3.3)
17	15.8	(4.2)	17	14.5	(1.0)	17	5.9	(3.0)
18	14.1	(3.9)	18	13.8	(1.0)	18	5.7	(2.7)
19	12.7	(3.6)	19	13.2	(1.0)	19	5.6	(2.5)
20	11.5	(3.4)	20	12.6	(0.5)	20	5.5	(2.3)
21	10.7	(3.2)	21	12.1	(1.0)	21	5.4	(2.1)
22	10.1	(3.0)	22	11.6	(0.9)	22	5.3	(1.9)
23	9.6	(2.8)	23	11.3	(0.9)	23	5.2	(1.8)
24	9.1	(2.6)	24	10.8	(0.9)	24	5.1	(1.7)
25	8.6	(2.5)	25	10.4	(0.6)	25	5.0	(1.6)
26	8.2	(1.6)	26 (UNION)	10.0	(0.9)	26	4.9	(1.5)
27 (ROMEO)	7.8	(1.5)	27	9.8	(0.8)	27	4.9	(1.4)
28	35.2	(2.2)	28	9.4	(0.8)	28	4.7	(1.3)
29	492.1	(2.1)	29	9.2	(0.8)	29	4.7	(1.3)
30	244.5	(2.0)	30	8.9	(0.8)	30	4.6	(1.2)
31	163.8	(1.9)				31	4.6	(1.1)

2.2.5 USS BELLE GROVE (LSD-2)

At the time of Shot BRAVO, the BELLE GROVE was slightly farther east of GZ than were the BAIROKO, ESTES, and PHILIP. When it received word that these other ships were receiving fallout shortly after 0800 hours, it steamed in a southerly direction and avoided being contaminated by the early-time fallout (Reference 10). At noon on shot day, the BELLE GROVE began receiving fallout. Material Condition ABLE was set at 1245 hours, and 7 minutes later the ship's washdown system was activated (Reference 8). Even with the washdown system on, topside intensities rose to approximately 30 mR/hr before it was turned off and the ship opened up at 1537 hours. Intensities continued to rise onboard the ship throughout the day, and by 2012 hours when the ship was closed up and the washdown system turned on again, topside intensities averaged 300 mR/hr (Reference 10). The washdown system was turned off at 2115 hours and, when Material Condition BAKER was set at 2223 hours, intensities had been reduced to approximately 100 mR/hr. Figure 2-13 depicts the average topside intensities on the BELLE GROVE following Shot BRAVO. It appears that some efforts were made to decontaminate the ship between 1600 (H+33) and 2000 hours (H+37) on 2 March when intensities were reduced to 20 mR/hr.

The only other detonation in the CASTLE series that resulted in contamination of the BELLE GROVE was Shot ROMEO. On 27 March, the BELLE GROVE reentered Bikini Lagoon at approximately 1300 hours. During the early evening of 28 March, while still at anchor, the ship began receiving a relatively light fallout. At 2000 hours, topside intensities were 4 mR/hr and increasing (Reference 10). Material Condition ABLE was set throughout the ship at 2200 hours and, at midnight, average topside intensities were 20 mR/hr. From Figure 2-14 it appears that light fallout continued to contaminate the ship until approximately 0800 hours, 29 March (H+50). Although the sharp decline in intensity after the peak is reached (Figure 2-14) suggests that decontamination was initiated, no mention is made in the deck log of any attempt to decontaminate the ship following Shot ROMEO.

The BELLE GROVE entered Bikini Lagoon fifteen times between 2 March and the end of May. Specific periods of time in and out of the lagoon, as well as the

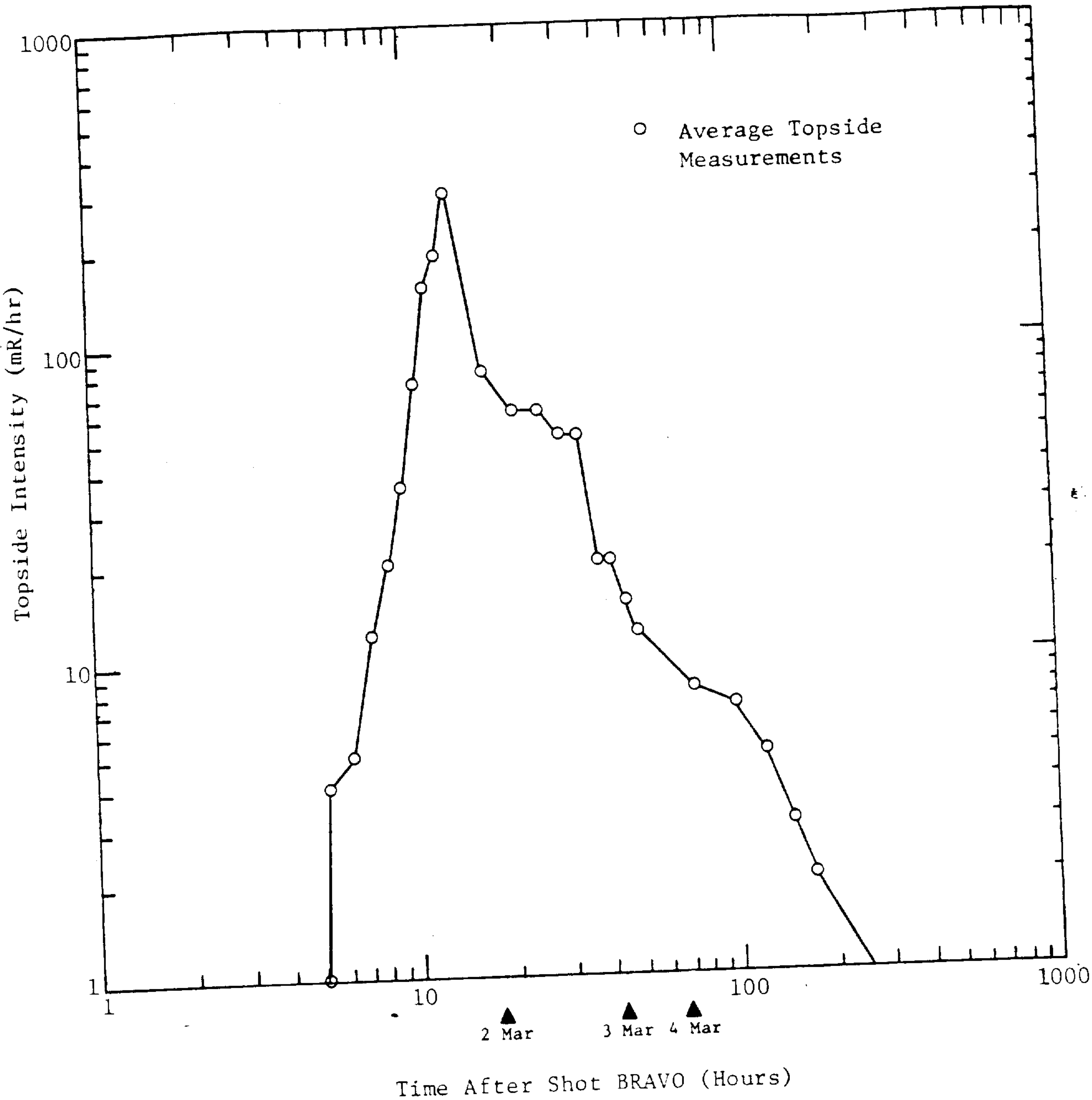

Figure 2-13. USS BELLE GROVE topside intensity following Shot BRAVO.

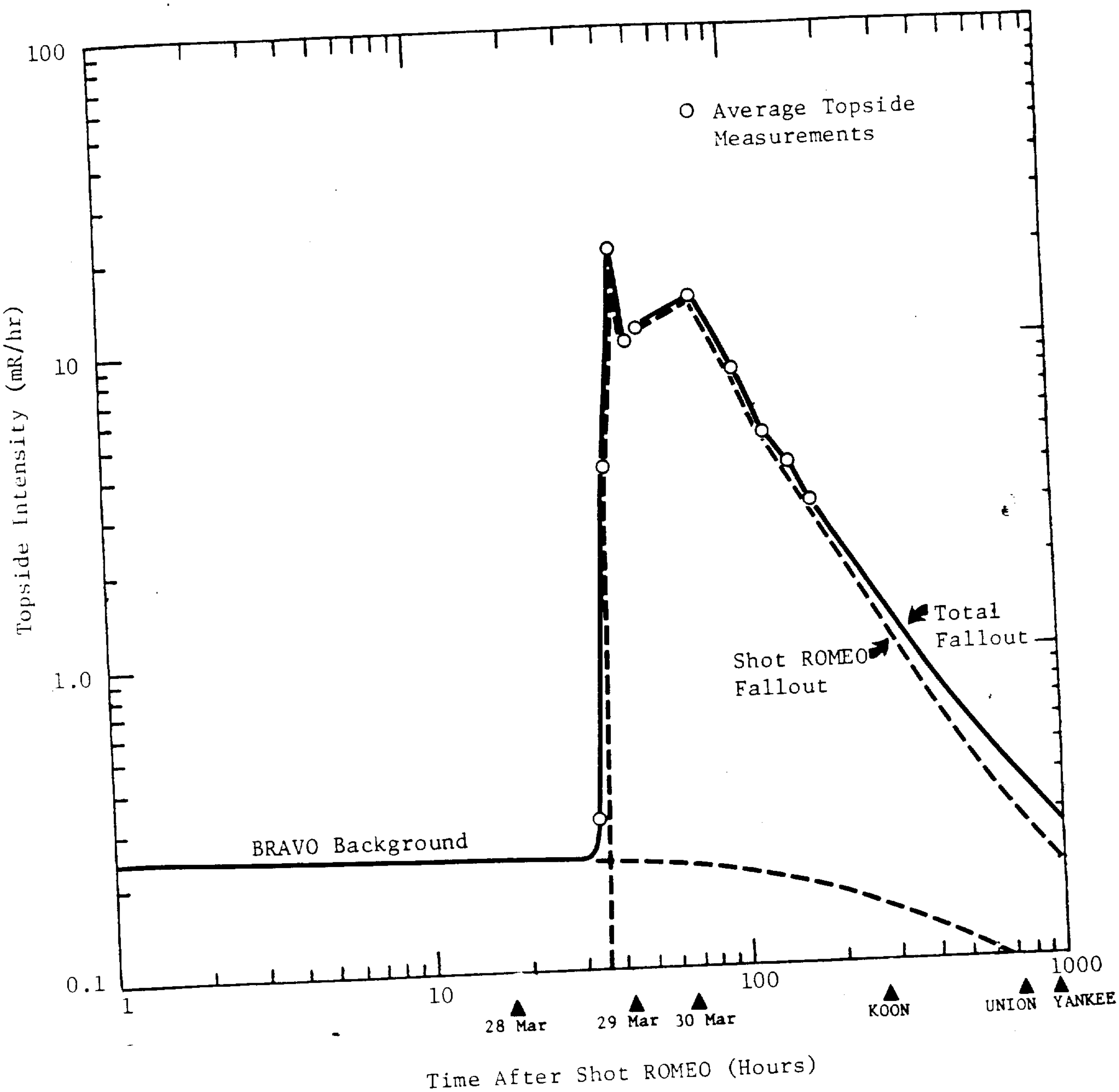

Figure 2-14. USS BELLE GROVE topside intensity following Shot ROMEO.

corresponding integrated intensities determined from the ship contamination model, are given below.

Month	Time at Bikini Lagoon In	Time at Bikini Lagoon Out	Integrated Intensity (mR) In	Integrated Intensity (mR) Out
March	02/0730-06/1826	06/1826-08/0843	67.6	17.6
	08/0843-12/1830	12/1830-13/0630	55.5	2.4
	13/0630-14/0654	14/0654-14/1711	6.8	1.8
	14/1711-26/2000	26/2000-27/1300	62.7	1.1
	27/1300-29/1803	29/1803-31/1606	6.3	2.8
April	31/1606-05/1348	05/1348-07/1050	11.9	2.1
	07/1050-07/1450	07/1450-10/1024	0.2	1.7
	10/1024-13/1224	13/1224-13/1810	5.1	0.2
	13/1810-15/1427	15/1427-16/1859	2.7	1.0
	16/1859-25/1937	25/1937-26/1656	12.7	0.6
	26/1656-29/1727	29/1727-01/1007	3.4	1.0
May	01/1007-04/1645	04/1645-05/1648	53.0	7.0
	05/1648-05/2013	05/2013-06/0743	1.5	3.4
	06/0743-08/1715	08/1715-10/0443	142.1	27.9
	10/0443-10/0857	10/0857-31/2400	2.7	55.0

The daily contribution to the free-field integrated intensity on the BELLE GROVE from fallout (topside) and ship contamination (below) are shown in Table 2-5.

Table 2-5. Daily integrated intensity, USS BELLE GROVE.

March	Integrated Intensity (mR) Topside	(Below)	April	Integrated Intensity (mR) Topside	(Below)	May	Integrated Intensity (mR) Topside	(Below)
1 (BRAVO)	1275.6		1	118.0	(2.8)	1	7.9	(10.2)
2	1145.5		2	88.5	(2.6)	2	7.7	(18.5)
3	284.2		3	69.5	(2.5)	3	7.5	(17.5)
4	188.1	(19.8)	4	56.5	(2.4)	4	7.3	(8.7)
5	155.5	(34.2)	5	47.1	(1.5)	5 (YANKEE)	7.1	(7.5)
6	107.7	(19.9)	6	40.0	(1.1)	6	6.9	(46.4)
7	66.7	(10.6)	7 (KOON)	34.6	(0.8)	7	6.7	(74.0)
8	46.3	(13.4)	8	30.3	(0.6)	8	6.6	(35.8)
9	36.8	(13.6)	9	26.9	(0.6)	9	6.4	(16.2)
10	30.0	(12.9)	10	24.1	(1.1)	10	6.2	(9.3)
11	25.0	(11.3)	11	21.7	(1.9)	11	6.1	(6.1)
12	21.2	(6.3)	12	19.7	(1.8)	12	6.0	(5.0)
13	18.3	(7.2)	13	18.0	(1.0)	13	5.8	(4.3)
14	15.9	(4.6)	14	16.6	(1.7)	14 (NECTAR)	5.7	(3.7)
15	14.0	(8.0)	15	15.3	(0.8)	15	5.6	(3.2)
16	12.4	(6.8)	16	14.4	(1.1)	16	5.5	(2.9)
17	11.1	(6.3)	17	13.7	(1.6)	17	5.3	(2.6)
18	10.0	(5.8)	18	13.0	(1.5)	18	5.2	(2.3)
19	9.0	(5.4)	19	12.4	(1.5)	19	5.1	(2.1)
20	8.2	(5.1)	20	11.9	(1.5)	20	5.0	(2.0)
21	7.7	(4.7)	21	11.3	(1.4)	21	5.0	(1.8)
22	7.3	(4.4)	22	10.9	(1.4)	22	4.8	(1.7)
23	6.9	(4.2)	23	10.5	(1.4)	23	4.7	(1.6)
24	6.5	(4.0)	24	10.1	(1.3)	24	4.6	(1.4)
25	6.2	(3.8)	25	9.7	(0.9)	25	4.6	(1.4)
26	5.9	(2.9)	26 (UNION)	9.4	(0.7)	26	4.5	(1.3)
27 (ROMEO)	5.6	(2.9)	27	9.0	(1.3)	27	4.4	(1.2)
28	48.5	(2.4)	28	8.8	(1.2)	28	4.3	(1.1)
29	291.7	(2.3)	29	8.4	(0.7)	29	4.2	(1.1)
30	284.9	(1.5)	30	8.2	(0.6)	30	4.2	(1.0)
31	175.7	(1.4)				31	4.1	(0.7)

2.2.6 USS CURTISS (AV-4)

The CURTISS was in its assigned operating area southeast of the Shot BRAVO GZ when it began to receive fallout at approximately 0830 hours, 1 March. Average topside intensities increased to 8 mR/hr at 0900 hours before they began to subside (Reference 10). It appears the CURTISS must have been at the extreme southern boundary of the "early-time" Shot BRAVO fallout pattern since those ships to the north of the CURTISS, the BAIROKO, ESTES, and PHILIP, received fallout of much greater intensity and duration at approximately the same time.

Average topside intensities on the CURTISS had decayed to 2 mR/hr by noon, but at 1300 hours, the ship encountered another "wave" of the Shot BRAVO fallout. At 1323 hours, Material Condition ABLE was set throughout the ship (Reference 8). The ship's washdown system was activated intermittently between 1330 and 1700 hours, and average topside intensities reached 55 mR/hr before they began to decline. At approximately 1800 hours, the CURTISS was directed to proceed to Enewetak in company with the AINSWORTH, arriving there at 0730 hours, 2 March. Further attempts to decontaminate the ship during the night of 1 March are not documented. Figure 2-15 depicts the reconstructed radiation environment on the CURTISS resulting from Shot BRAVO fallout. The steep decay rate between H+25 and H+33 (0800-1600 hours, 2 March) indicates that some effort was probably made to decontaminate the CURTISS while anchored at Enewetak--probably flushing the weather decks with high pressure water from fire hoses. After this time, reduced intensities are primarily the result of natural radioactive decay and weathering.

Shot BRAVO appears to be the only detonation that resulted in significant fallout onboard the CURTISS during its participation in Operation CASTLE. It is quite possible the CURTISS received some contamination from the ROMEO cloud as it steamed between Enewetak and Bikini during the evening of 28 March and early morning of 29 March. There is much evidence that the secondary fallout from Shot ROMEO that fell on the ships at Bikini at approximately 2400 hours, 28 March, also hit Enewetak 24-36 hours later. This potential source of contamination was not documented onboard the CURTISS and is not considered in reconstructing the topside radiation environment.

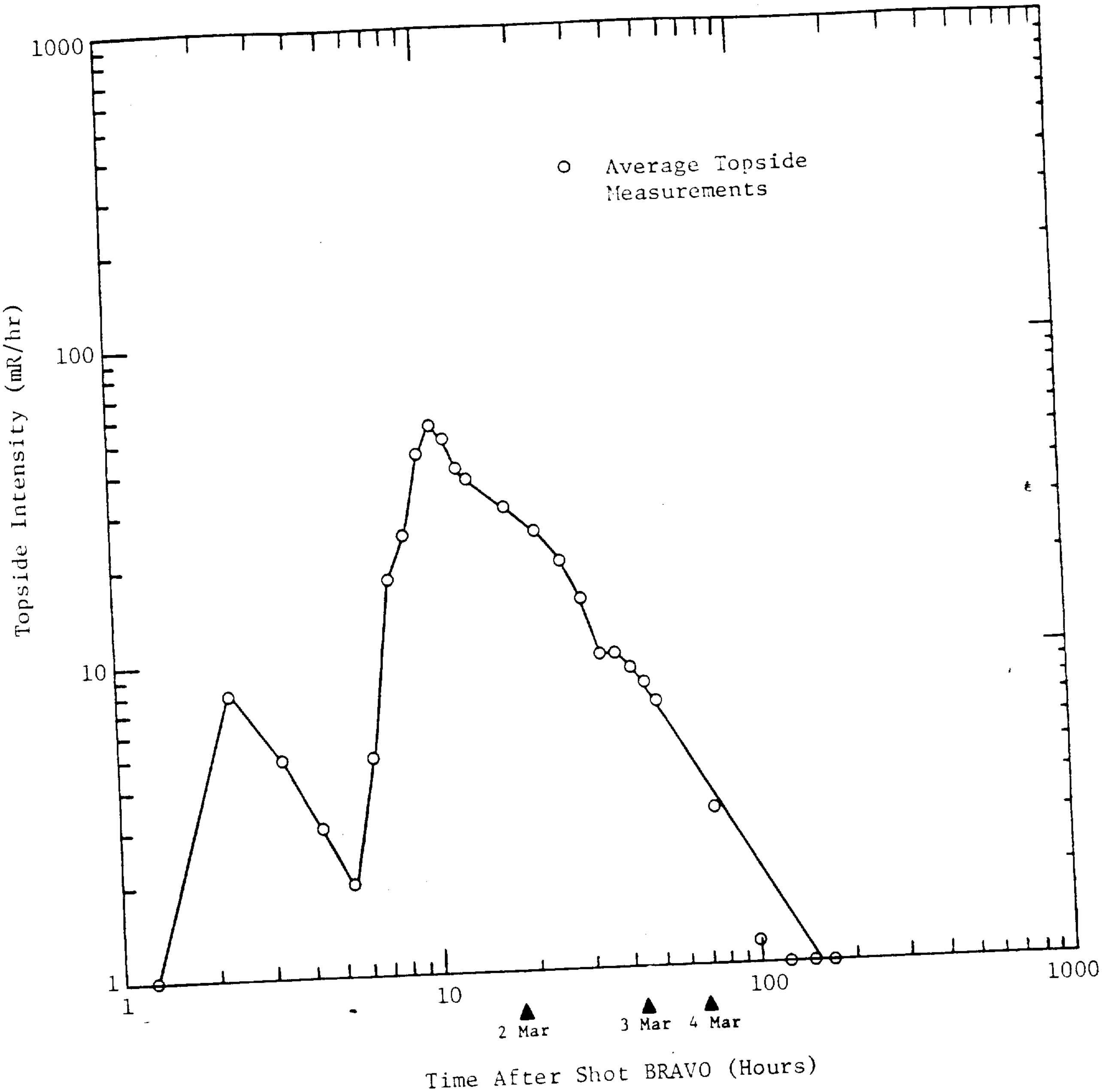

Figure 2-15. USS CURTISS topside intensity following Shot BRAVO.

As mentioned previously in Section 2.2, the CURTISS entered the contaminated water in the lagoon fifteen times between 5 March and the end of May. Based on the ship contamination model, a profile of the average intensity below deck due to the contaminated water was reconstructed and presented in Figure 2-2. This intensity profile is time-integrated for each period in and out of the lagoon; results are detailed below.

	Time at Bikini Lagoon		Integrated Intensity (mR)	
Month	In	Out	In	Out
March	05/0745-12/1712	12/1712-13/1112	122.0	3.6
	13/1112-14/1122	14/1122-15/0705	6.5	3.3
	15/0705-21/1430	21/1430-21/1540	36.3	0.1
	21/1540-21/1728	21/1728-21/1912	0.2	0.1
	21/1912-26/1956	26/1956-27/1500	18.9	1.4
	27/1500-27/2000	27/2000-29/0730	0.4	1.5
	29/0730-05/1300	05/1300-07/1332	18.5	2.3
April	07/1332-07/1948	07/1948-09/0745	0.3	1.0
	09/0745-13/0908	13/0908-13/1753	7.1	0.3
	13/1753-15/1342	15/1342-15/1820	2.7	0.2
	15/1820-25/1931	25/1931-26/1653	14.4	0.6
	26/1653-01/0732	01/0732-01/1211	5.3	0.1
May	01/1211-04/1616	04/1616-05/1653	50.8	7.1
	05/1653-05/1920	05/1920-06/0702	0.8	2.4
	06/0702-06/1905	06/1905-31/2400	13.2	72.6

The daily contributions to the integrated intensity on the CURTISS from fallout (topside) and ship contamination (below) are presented in Table 2-6. Following Shot

Table 2-6. Daily integrated intensity, USS CURTISS.

March	Integrated Intensity (mR) Topside(Below)		April	Integrated Intensity (mR) Topside(Below)		May	Integrated Intensity (mR) Topside(Below)	
1 (BRAVO)	400.3		1	1.9	(2.7)	1	0.9	(9.5)
2	395.0		2	1.9	(2.6)	2	0.9	(17.2)
3	146.7		3	1.8	(2.5)	3	0.8	(17.5)
4	76.3		4	1.7	(2.4)	4	0.8	(10.8)
5	47.8	(14.7)	5	1.7	(1.2)	5 (YANKEE)	0.8	(5.8)
6	33.2	(25.1)	6	1.6	(1.1)	6	0.8	(23.3)
7	24.6	(21.1)	7 (KOON)	1.6	(1.0)	7	0.8	(13.3)
8	19.0	(17.5)	8	1.5	(0.9)	8	0.8	(8.5)
9	15.3	(14.9)	9	1.5	(1.3)	9	0.7	(6.1)
10	12.6	(12.9)	10	1.4	(1.9)	10	0.7	(4.7)
11	10.5	(11.3)	11	1.4	(1.9)	11	0.7	(3.8)
12	9.0	(7.3)	12	1.4	(1.8)	12	0.7	(3.1)
13	7.8	(3.4)	13	1.3	(1.0)	13	0.7	(2.7)
14	6.8	(7.3)	14	1.3	(1.7)	14 (NECTAR)	0.7	(2.3)
15	6.0	(5.5)	15	1.2	(1.2)	15	0.7	(2.0)
16	5.3	(6.7)	16	1.2	(1.6)	16	0.7	(1.8)
17	4.8	(6.3)	17	1.2	(1.6)	17	0.7	(1.6)
18	4.3	(5.8)	18	1.2	(1.5)	18	0.6	(1.5)
19	3.9	(5.4)	19	1.1	(1.5)	19	0.6	(1.3)
20	3.6	(5.1)	20	1.1	(1.5)	20	0.6	(1.2)
21	3.3	(2.8)	21	1.1	(1.4)	21	0.6	(1.1)
22	3.1	(4.0)	22	1.0	(1.4)	22	0.6	(1.0)
23	2.9	(4.2)	23	1.0	(1.4)	23	0.6	(1.0)
24	2.8	(4.0)	24	1.0	(1.3)	24	0.6	(0.9)
25	2.6	(3.8)	25	1.0	(0.9)	25	0.6	(0.8)
26	2.5	(2.8)	26 (UNION)	1.0	(0.9)	26	0.6	(0.8)
27 (ROMEO)	2.4	(1.4)	27	0.9	(1.1)	27	0.6	(0.8)
28	2.3	(1.0)	28	0.9	(1.2)	28	0.6	(0.7)
29	2.2	(2.1)	29	0.9	(1.2)	29	0.6	(0.7)
30	2.1	(2.9)	30	0.9	(1.2)	30	0.5	(0.6)
31	2.0	(2.8)				31	0.5	(0.5)

BRAVO, the maximum intensity below deck on any ship due to contaminated saltwater systems was measured on the exterior of an auxilary condenser on the CURTISS (Reference 10). This reading was 30 mR/hr, but Reference 10 states that "the average intensity in the engineering spaces where this condenser was located was only about 2 milliroentgens per hour" (48 mR/day). The ship contamination model predicts an average intensity below of 25 mR/day for the CURTISS (Table 2-6, March 6) which is consistent with a maximum reading of 48 mR/day. It was calculated (Reference 6) that engineering spaces in the vicinity of saltwater piping systems would have intensities approximately 1.5 times the average below deck intensity; hence, the measured maximum on the CURTISS appears to support the ship contamination model.

2.2.7 USS EPPERSON (DDE-719)

During the late afternoon and evening of 1 March, the EPPERSON was patrolling the waters off Wide Passage and Deep Entrance, Enewetak Atoll. Fallout from Shot BRAVO hit the residence islands between 1745 and 2300 hours. It is assumed the EPPERSON received the same fallout (see Section 2.2.1 and Figure 2-3).

Following Shot ROMEO on 27 March, the EPPERSON reentered Bikini Lagoon at 1400 hours prior to returning to patrol duties that took it in a counter-clockwise direction around Bikini Atoll. The ship began receiving very light fallout as it departed the lagoon at 1600 hours. By 1900 hours, when it was approximately 20 miles north of Bikini, intensities suddenly rose to 25 mR/hr (Reference 10). The ship's washdown system was activated at 1933 hours (Reference 8) and, when it was turned off 17 minutes later, topside intensities had been reduced to 10 mR/hr (see Figure 2-16). Intensities continued to decrease until approximately 0400 hours on 28 March when they began to increase once more, rising to 15 mR/hr at 0800 hours when the ship was northwest of the atoll. No mention is made of any efforts to decontaminate the ship on 28 March. The ship continued around the atoll and reentered the lagoon at approximately 2000 hours. At 0650 hours, 29 March, the EPPERSON departed on another patrol assignment and immediately encountered more fallout. The washdown system was activated from 0708 to 0735 hours. Average topside intensities were 8 mR/hr at 0800 hours (H+50), and a steady decline was noted thereafter (see Figure 2-16).

When Shot NECTAR was detonated on 14 May, the EPPERSON was in the vicinity of Ujelang Atoll to evacuate the natives if it became necessary. At approximately 1300 hours, when it became clear that evacuation would not be necessary, the ship was directed to return to Enewetak, arriving there at approximately 1820 hours. Fallout on the residence islands of Enewetak began at 1830 hours, 14 May; hence, the crew of the EPPERSON would have encountered the same fallout (see Section 2.2.1 and Figure 2-5). No significant fallout was encountered by this ship following Shots KOON, UNION, and YANKEE.

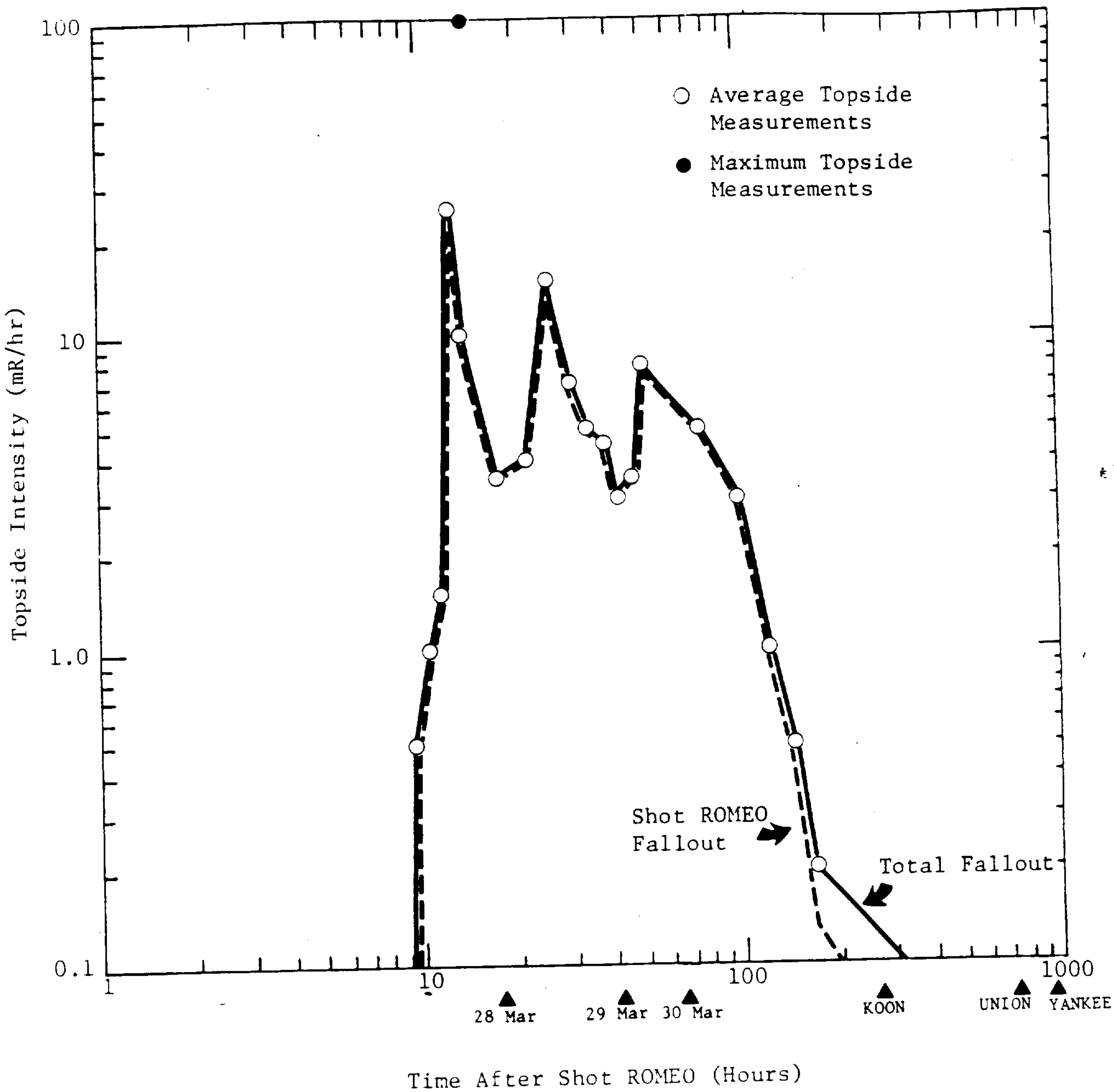

Figure 2-16. USS EPPERSON topside intensity following Shot ROMEO.

The EPPERSON entered Bikini Lagoon fifteen times between 3 March and the end of May. Specific periods of time in and out of the lagoon, as well as the corresponding integrated intensities determined from the ship contamination model, are given below.

	Time at Bikini Lagoon		Integrated Intensity (mR)	
Month	In	Out	In	Out
March	03/1656-03/2040	03/2040-08/0840	0.0	0.0
	08/0840-08/1045	08/1045-09/0959	0.2	1.8
	09/0959-09/2017	09/2017-11/1700	4.3	14.8
	11/1700-12/0849	12/0849-15/1250	9.5	29.2
	15/1250-17/1105	17/1105-18/1316	32.2	9.8
	18/1316-19/1120	19/1120-21/1340	11.1	15.1
	21/1340-21/1705	21/1705-21/2200	1.0	0.8
	21/2200-23/1124	23/1124-24/1258	15.3	6.5
	24/1258-26/0851	26/0851-27/1404	17.5	6.2
	27/1404-27/1557	27/1557-28/2008	0.4	3.1
	28/2008-29/0907	29/0907-29/1914	2.3	1.3
	29/1914-30/1054	30/1054-01/1412	3.1	6.8
April	01/1412-05/0837	05/0837-08/0852	25.4	9.8
	08/0852-08/1234	08/1234-09/0847	0.5	1.5
April/May	09/0847-09/2146	09/2146-31/2400	1.6	58.1

The daily contributions to the free-field integrated intensity on the EPPERSON from fallout (topside) and ship contamination (below) are shown in Table 2-7.

Table 2-7. Daily integrated intensity, USS EPPERSON.

March	Integrated Intensity (mR) Topside	(Below)	April	Integrated Intensity (mR) Topside	(Below)	May	Integrated Intensity (mR) Topside	(Below)
1 (BRAVO)	47.4		1	21.5	(4.5)	1	1.1	(1.1)
2	153.5		2	10.2	(7.0)	2	1.1	(1.1)
3	85.3		3	4.9	(7.3)	3	1.1	(1.1)
4	48.9		4	4.0	(7.0)	4	1.1	(1.0)
5	32.4		5	3.6	(3.6)	5 (YANKEE)	0.9	(1.0)
6	23.5		6	3.2	(3.3)	6	0.9	(1.0)
7	18.0		7 (KOON)	2.9	(3.1)	7	0.9	(1.0)
8	14.4	(1.8)	8	2.6	(1.7)	8	0.9	(1.0)
9	11.8	(8.3)	9	2.5	(2.8)	9	0.9	(0.9)
10	10.0	(7.9)	10	2.3	(1.9)	10	0.9	(0.9)
11	8.5	(7.1)	11	2.2	(1.9)	11	0.9	(0.9)
12	7.4	(14.9)	12	2.1	(1.8)	12	0.9	(0.9)
13	6.5	(9.3)	13	1.9	(1.7)	13	0.9	(0.9)
14	5.8	(8.5)	14	1.8	(1.7)	14 (NECTAR)	7.3	(0.9)
15	5.2	(11.0)	15	1.8	(1.6)	15	25.9	(0.9)
16	4.7	(19.8)	16	1.6	(1.6)	16	14.8	(0.8)
17	4.3	(10.9)	17	1.6	(1.6)	17	8.8	(0.8)
18	3.9	(6.4)	18	1.6	(1.5)	18	6.1	(0.8)
19	3.6	(13.2)	19	1.5	(1.5)	19	4.7	(0.8)
20	3.3	(7.1)	20	1.4	(1.4)	20	3.8	(0.8)
21	3.0	(4.8)	21	1.4	(1.4)	21	3.2	(0.8)
22	2.9	(11.9)	22	1.4	(1.4)	22	2.8	(0.8)
23	2.7	(7.3)	23	1.4	(1.3)	23	2.4	(0.7)
24	2.6	(7.5)	24	1.3	(1.3)	24	2.2	(0.7)
25	2.4	(10.5)	25	1.2	(1.3)	25	1.9	(0.7)
26	2.3	(5.7)	26 (UNION)	1.2	(1.2)	26	1.7	(0.7)
27 (ROMEO)	52.2	(2.9)	27	1.2	(1.2)	27	1.6	(0.7)
28	147.6	(2.6)	28	1.2	(1.2)	28	1.5	(0.7)
29	142.2	(4.1)	29	1.1	(1.2)	29	1.4	(0.7)
30	109.2	(4.8)	30	1.1	(1.1)	30	1.3	(0.7)
31	57.5	(3.1)				31	1.2	(0.7)

2.2.8 USS ESTES (AGC-12)

At the time of Shot BRAVO, the ESTES was operating in its assigned area east-southeast of GZ, somewhat further north than the BAIROKO, PHILIP, and CURTISS, the three other ships that received early fallout from the BRAVO cloud. Heavy fallout began on the ESTES shortly after 0800 hours and Condition PURPLE II (Atomic Attack imminent, one half of crew at battle stations) was set at 0830 hours (Reference 8). The washdown system was probably turned on at this time and remained on until approximately 1130 hours, which made it difficult to obtain reliable intensity measurements (recorded intensities for 0900, 1000, and 1100 hours are estimated intensities). A survey at 1125 hours indicated that conditions were worsening since Condition PURPLE III (Atomic Attack imminent, one third of crew at battle stations) was set at this time. By noon, topside intensities had leveled off at approximately 100 mR/hr (Reference 10). At 1400 hours, they began to increase again as the ship encountered more fallout. Topside intensities increased to 140 mR/hr at 1600 hours before they leveled off at 120 mR/hr for the next twelve hours. At approximately 1800 hours, the ESTES was directed to proceed to Enewetak Atoll. While enroute, the washdown system was activated intermittently but did not prove to be very effective in removing the fallout particles from the topside surfaces. Upon arriving at Enewetak at approximately 0800 hours on 2 March (H+25), decontamination with fire hoses was probably undertaken for the remainder of the day. This is evidenced by the steep decay rate in Figure 2-17 between H+25 and H+35. After departing Enewetak at 1900 hours (H+36), it appears that natural radioactive decay was primarily responsible for reducing the topside intensities.

Following Shot ROMEO on 27 March, the ESTES reentered Bikini Lagoon at approximately 1300 hours. With the exception of a two-hour sortie to sea on 28 March, it remained in the lagoon through 5 April. During the night of 28-29 March, the ESTES encountered fallout similar to that experienced on the other ships anchored in the lagoon. Average topside intensities reached a maximum of 12 mR/hr, but it appears that measures to reduce the contamination were not required. Figure 2-18 depicts the topside intensities on the ESTES resulting from Shot ROMEO fallout. No other fallout was encountered by the ESTES during Operation CASTLE.

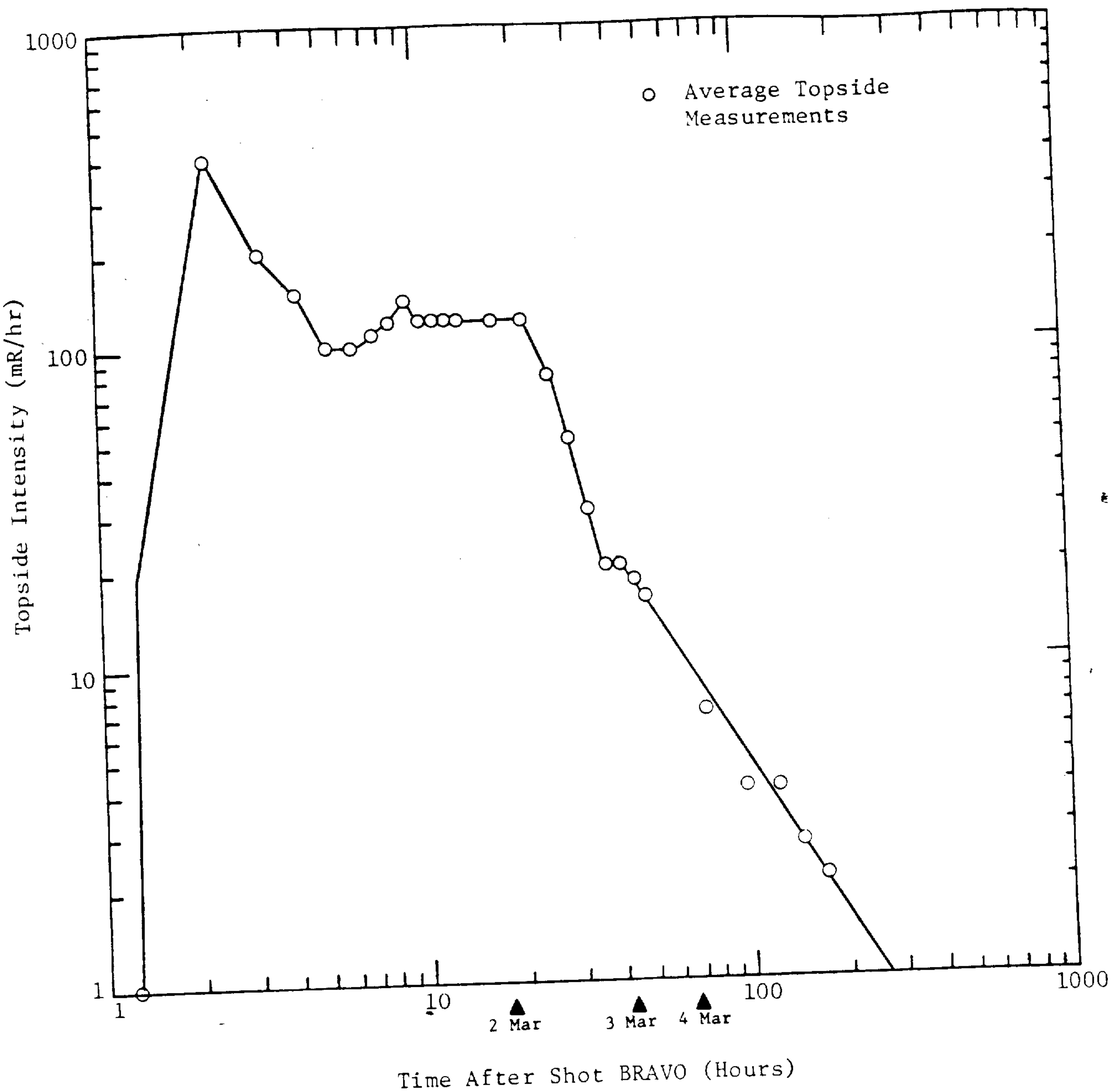

Figure 2-17. USS ESTES topside intensity following Shot BRAVO.

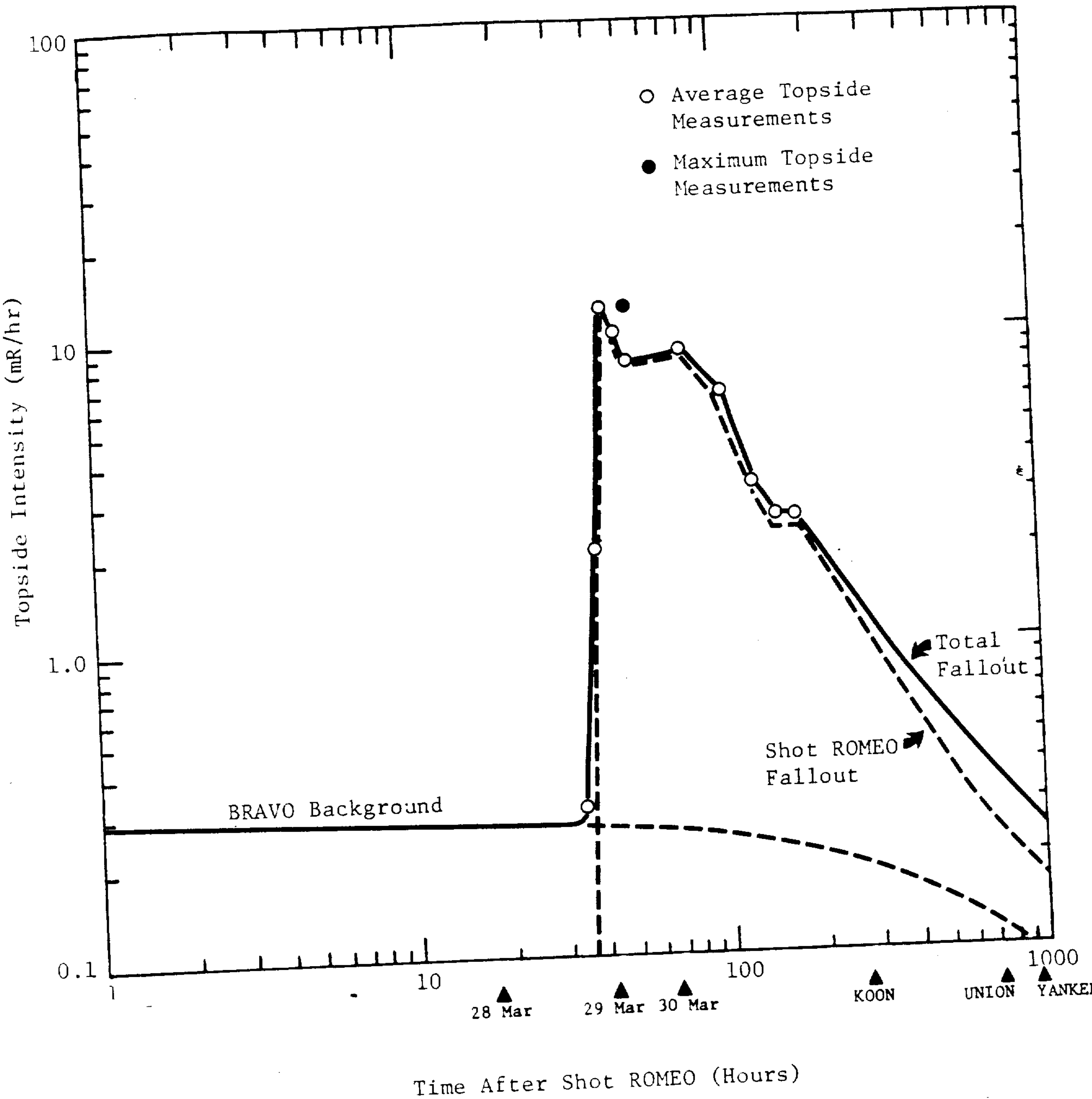

Figure 2-18. USS ESTES topside intensity following Shot ROMEO.

The ESTES entered Bikini Lagoon eleven times between 3 March and the end of May. Specific periods of time in and out of the lagoon, as well as the corresponding integrated intensities determined from the ship contamination model, are given below.

	Time at Bikini Lagoon		Integrated Intensity (mR)	
Month	In	Out	In	Out
March	03/0814-11/1027		191.7	
		11/1027-11/1700		2.1
	11/1700-12/1725		10.3	
		12/1725-13/0650		3.5
	13/0650-13/2347		5.6	
		13/2347-14/1236		2.5
	14/1236-26/2039		82.3	
		26/2039-27/1325		1.6
April	27/1325-05/1227		31.6	
		05/1227-07/1101		2.8
	07/1101-12/1858		13.1	
		12/1858-13/1616		1.0
	13/1616-15/1335		3.6	
		15/1335-16/1912		1.3
	16/1912-25/2228		16.6	
		25/2228-26/1552		0.6
	26/1552-26/1952		0.2	
May		26/1952-04/0941		3.3
	04/0941-04/2049		1.2	
		04/2049-05/1709		2.6
	05/1709-05/1934		1.0	
		05/1934-31/2400		12.1

The daily contributions to the free-field integrated intensity on the ESTES from fallout (topside) and ship contamination (below) are shown in Table 2-8.

Table 2-8. Daily integrated intensity, USS ESTES.

March	Integrated Intensity (mR) Topside(Below)		April	Integrated Intensity (mR) Topside(Below)		May	Integrated Intensity (mR) Topside(Below)	
1 (BRAVO)	2132.8		1	75.2	(3.5)	1	7.2	(0.4)
2	1460.2		2	60.4	(3.4)	2	7.0	(0.4)
3	324.7		3	57.3	(3.2)	3	6.8	(0.4)
4	175.0	(25.6)	4	47.3	(3.1)	4	6.6	(1.7)
5	112.4	(44.1)	5	39.7	(1.8)	5 (YANKEE)	6.4	(6.1)
6	79.5	(33.9)	6	33.9	(1.4)	6	6.3	(2.8)
7	59.9	(27.3)	7 (KOON)	29.5	(2.0)	7	6.2	(1.4)
8	47.0	(22.6)	8	25.9	(2.6)	8	6.0	(0.9)
9	38.1	(19.2)	9	23.1	(2.6)	9	5.9	(0.6)
10	31.7	(16.6)	10	20.8	(2.5)	10	5.6	(0.5)
11	26.8	(7.4)	11	18.9	(2.4)	11	5.6	(0.4)
12	23.1	(9.8)	12	17.2	(1.5)	12	5.5	(0.3)
13	20.1	(6.6)	13	15.8	(1.4)	13	5.3	(0.3)
14	17.7	(7.9)	14	14.6	(2.3)	14 (NECTAR)	5.2	(0.2)
15	15.8	(9.0)	15	13.6	(1.0)	15	5.1	(0.2)
16	14.1	(8.8)	16	12.7	(1.5)	16	5.0	(0.2)
17	12.7	(8.1)	17	12.1	(2.0)	17	4.9	(0.2)
18	11.6	(7.5)	18	11.5	(2.0)	18	4.8	(0.1)
19	10.6	(7.0)	19	11.0	(1.9)	19	4.7	(0.1)
20	9.7	(6.5)	20	10.6	(1.9)	20	4.6	(0.1)
21	9.1	(6.1)	21	10.2	(1.8)	21	4.5	(0.1)
22	8.6	(5.7)	22	9.7	(1.8)	22	4.4	(0.1)
23	8.1	(5.4)	23	9.3	(1.8)	23	4.4	(0.1)
24	7.7	(5.1)	24	9.1	(1.7)	24	4.2	(0.1)
25	7.3	(4.8)	25	8.7	(1.2)	25	4.2	(0.1)
26	7.0	(3.1)	26 (UNION)	8.5	(0.9)	26	4.1	(0.1)
27 (ROMEO)	6.7	(3.2)	27	8.1	(0.5)	27	4.1	(0.1)
28	29.5	(4.3)	28	7.9	(0.5)	28	4.0	(0.1)
29	209.2	(4.0)	29	7.6	(0.4)	29	3.9	(0.1)
30	189.6	(3.8)	30	7.5	(0.4)	30	3.8	(0.1)
31	132.2	(3.6)				31	3.8	(0.0)

2.2.9 USNS FRED C. AINSWORTH (TAP-181)

At the time of Shot BRAVO, the AINSWORTH was about 5-10 miles southeast of the CURTISS and did not encounter the early fallout as did the CURTISS, PHILIP, BAIROKO, and ESTES, all of which were north of the AINSWORTH's position. At 1300 hours, the ship began receiving fallout and, by 1700 hours, average topside intensities had reached 22 mR/hr (Reference 10). Although not explictly stated in the deck log, there is an indication that the ship utilized its washdown system shortly after the fallout started and also intermittently between 1600 hours, 1 March and 0800 hours, 2 March. Figure 2-19 depicts the average topside intensity following Shot BRAVO. The leveling off at 20 mR/hr for a 12-hour period is indicative of either using the washdown system while fallout is still being encountered or cloud "shine". The latter is unlikely since the AINSWORTH was in company with the CURTISS enroute to Enewetak during this time period and a similar phenonemon was not seen to occur on that ship (see Section 2.2.6). It is also noted from Figure 2-19 that decontamination with fire hoses may have been attempted between 1200 and 2000 hours on 2 March (H+29 to H+37), in order to reduce intensity levels to 10 mR/hr.

Following Shot ROMEO on 27 March, the AINSWORTH, with many of the other TG 7.3 ships, reentered Bikini Lagoon at approximately 1300 hours. During the evening of 28 March and early morning of 29 March, the AINSWORTH encountered secondary fallout from the ROMEO cloud (Reference 10). Topside intensities peaked at 24 mR/hr at midnight but did not begin to decline significantly until approximately 0800 hours, 29 March (H+50). The deck log makes no mention of efforts to decontaminate the ship on 29 March. The AINSWORTH remained in the lagoon until 5 April when it got underway in preparation for Shot KOON on 7 April. Figure 2-20 depicts the average intensities resulting from Shot ROMEO fallout. No other shot in the test series resulted in fallout on the AINSWORTH.

The AINSWORTH entered Bikini Lagoon ten times between 5 March and the end of May. Specific periods of time in and out of the lagoon, as well as the corresponding integrated intensities determined from the ship contamination model, are as follows:

	Time at Bikini Lagoon		Integrated Intensity (mR)	
Month	In	Out	In	Out
March	05/0830-21/1733	21/1733-22/0748	182.6	1.4
	22/0748-26/2011	26/2011-27/1317	17.1	1.2
April	27/1317-05/1310	05/1310-07/1135	24.5	2.2
	07/1135-10/1918	10/1918-12/0900	6.3	1.5
	12/0900-15/1409	15/1409-16/1930	5.2	1.0
	16/1930-25/1835	25/1835-26/1650	12.6	0.6
	26/1650-27/2103	27/2103-29/1200	1.2	1.0
May	29/1200-04/1621	04/1621-05/1838	62.6	7.6
	05/1838-05/2000	05/2000-06/0712	0.2	1.1
	06/0712-11/1919	11/1919-31/2400	238.8	78.5

The daily contributions to the free-field integrated intensity on the AINSWORTH from fallout (topside) and ship contamination (below) are shown in Table 2-9.

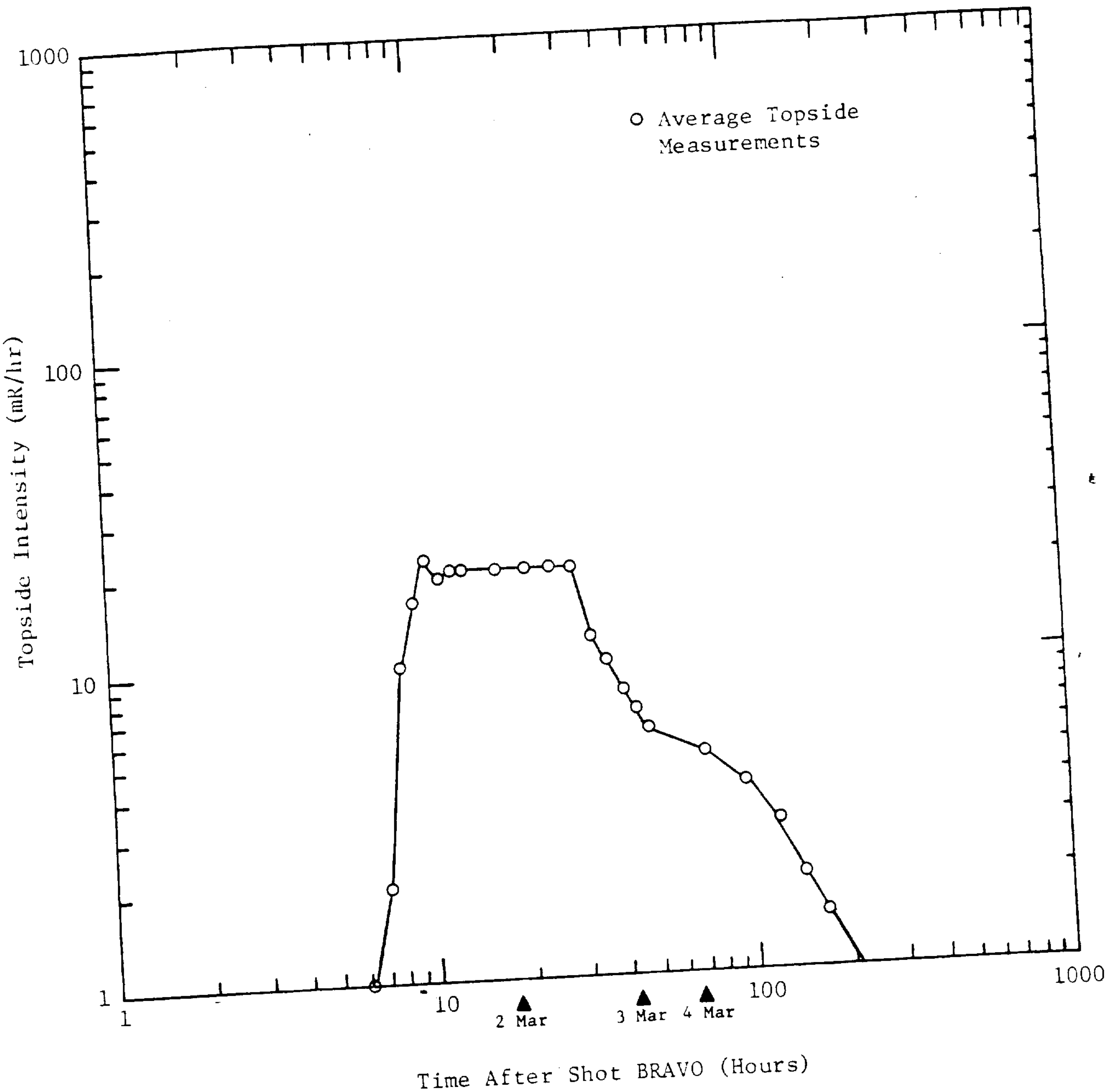

Figure 2-19. USNS FRED C. AINSWORTH topside intensity following Shot BRAVO.

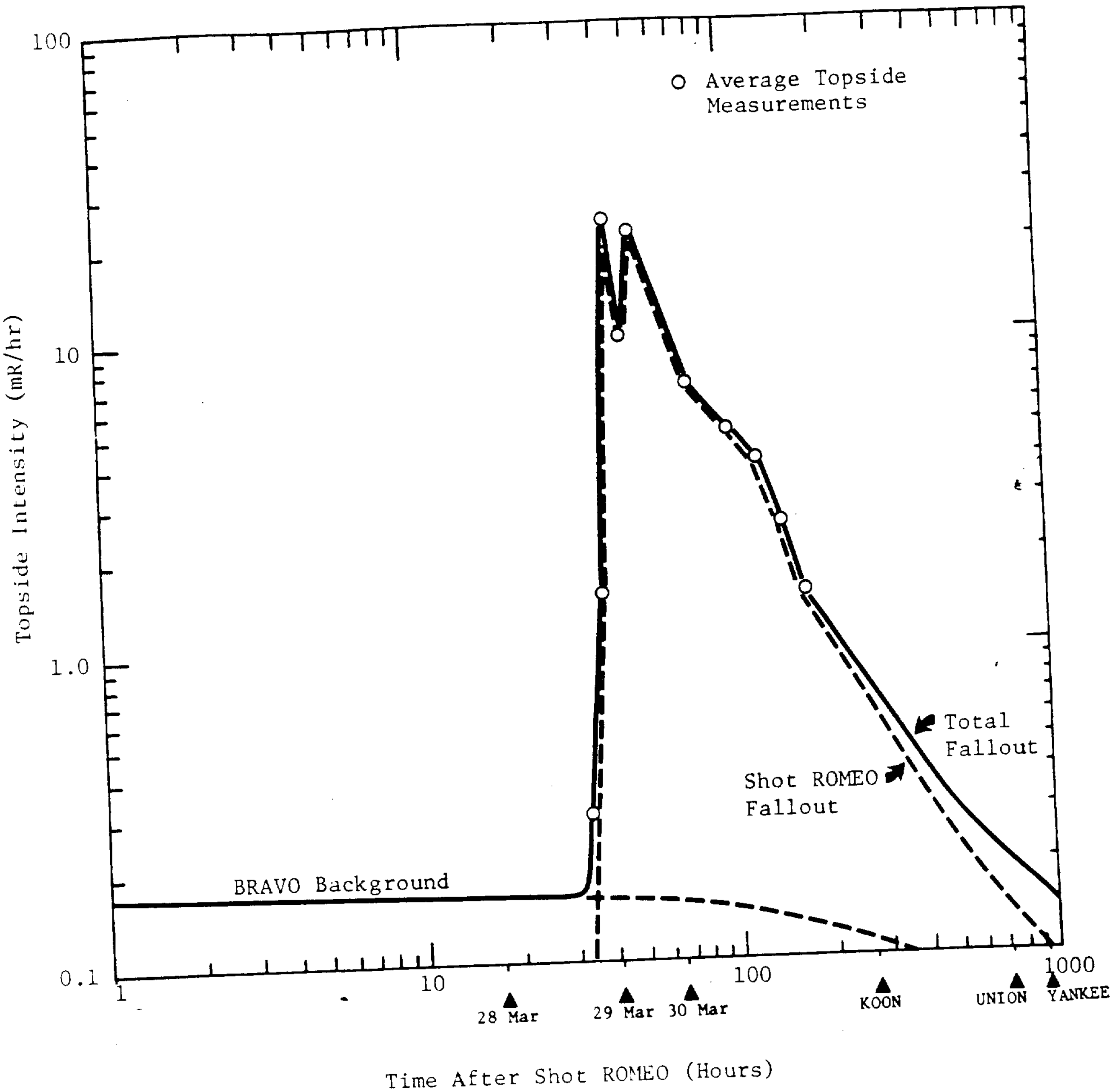

Figure 2-20. USNS FRED C. AINSWORTH topside intensity following Shot ROMEO.

Table 2-9. Daily integrated intensity, USNS FRED C. AINSWORTH.

March	Integrated Intensity (mR) Topside	(Below)	April	Integrated Intensity (mR) Topside	(Below)	May	Integrated Intensity (mR) Topside	(Below)
1 (BRAVO)	178.2		1	87.0	(2.7)	1	4.4	(12.8)
2	381.9		2	54.6	(2.6)	2	4.3	(22.2)
3	145.0		3	34.8	(2.5)	3	4.1	(18.6)
4	114.0		4	28.5	(2.4)	4	4.0	(11.2)
5	89.6	(14.5)	5	23.8	(1.2)	5 (YANKEE)	3.9	(4.7)
6	63.7	(24.2)	6	20.4	(1.1)	6	3.9	(46.0)
7	46.3	(21.1)	7 (KOON)	17.7	(1.3)	7	3.7	(73.0)
8	35.3	(17.5)	8	15.6	(2.5)	8	3.6	(47.6)
9	27.9	(14.9)	9	13.9	(2.0)	9	3.6	(34.2)
10	22.7	(12.9)	10	12.5	(1.4)	10	3.5	(26.3)
11	18.8	(11.3)	11	11.4	(0.9)	11	3.3	(16.5)
12	15.9	(10.0)	12	10.3	(1.2)	12	3.3	(8.8)
13	13.6	(9.0)	13	9.6	(2.0)	13	3.2	(7.4)
14	11.8	(8.1)	14	8.8	(1.7)	14 (NECTAR)	3.2	(6.4)
15	10.4	(7.4)	15	8.1	(1.1)	15	3.1	(5.7)
16	9.2	(6.8)	16	7.7	(0.7)	16	3.0	(5.0)
17	8.2	(6.3)	17	7.3	(1.6)	17	2.9	(4.5)
18	7.3	(5.8)	18	7.0	(1.5)	18	2.9	(4.1)
19	6.6	(5.4)	19	6.6	(1.5)	19	2.9	(3.7)
20	6.0	(5.1)	20	6.4	(1.5)	20	2.8	(3.4)
21	5.6	(3.2)	21	6.1	(1.4)	21	2.8	(3.1)
22	5.3	(3.7)	22	5.9	(1.4)	22	2.6	(2.9)
23	5.0	(4.0)	23	5.7	(1.4)	23	2.6	(2.7)
24	4.7	(4.0)	24	5.5	(1.3)	24	2.6	(2.5)
25	4.5	(3.8)	25	5.3	(0.8)	25	2.5	(2.4)
26	4.3	(2.0)	26 (UNION)	5.1	(0.7)	26	2.5	(2.2)
27 (ROMEO)	4.1	(2.7)	27	4.9	(0.9)	27	2.5	(2.1)
28	38.0	(3.3)	28	4.8	(0.7)	28	2.5	(2.0)
29	354.2	(3.1)	29	4.6	(0.9)	29	2.3	(1.9)
30	163.3	(2.9)	30	4.5	(1.1)	30	2.3	(1.8)
31	114.8	(2.8)				31	2.3	(1.3)

2.2.10 USS GYPSY (ARSD-1)

At the time of Shot BRAVO, the GYPSY was in its assigned area east-southeast of Bikini (see Figure 2-1). Being much farther south than the BAIROKO, PHILIP, and ESTES, the GYPSY did not receive the early fallout that these ships did. Intensities began to rise on the deck of the GYPSY at approximately 1400 hours and peaked at 1800 hours when a shipboard survey indicated average intensities of 250 mR/hr (Reference 10). The GYPSY's deck log makes no mention of the washdown system being turned on; however, a rapid decrease in average topside intensities to 150 mR/hr by 2000 hours (Figure 2-21) suggests some efforts were made to decontaminate the ship, probably with fire hoses. Figure 2-21 also indicates that further efforts to decontaminate the ship were made between 0800-1200 hours on 2 March (H+25 to H+29) when average intensities were reduced to 45 mR/hr. The GYPSY reentered Bikini Lagoon at approximately 1300 hours on 2 March, and the following day the crew began to wash down (decontaminate) the LCUs and other small craft that had been left in the lagoon for Shot BRAVO. Topside intensities did not decay as rapidly on the GYPSY as on the other ships in the lagoon. It was surmised at the time (Reference 10) that the reason for this was that the ship's weather decks were quite rusty, which appeared to hold the radioactive particles. Also, the ship was used extensively to recover contaminated chains and mooring gear from the bottom of the lagoon. Except for two brief periods out of the lagoon on 12 and 19 March, the GYPSY remained in the lagoon conducting salvage operations until it got underway for Kwajalein on 26 March.

The GYPSY arrived at Kwajalein on 27 March, but on 30-31 March when that atoll received fallout from Shot ROMEO (see Section 2.2.2), the ship was conducting aircraft recovery operations at Ailinglapalap Atoll. It returned to Kwajalein on 2 April and on 9 April it departed for Pearl Harbor. The GYPSY did not return to the PPG during Operation CASTLE; hence, Shot BRAVO was the only detonation that resulted in fallout on this ship.

The GYPSY remained in Bikini Lagoon almost continuously from 2-26 March, departing only twice for brief periods. The ship contamination model described

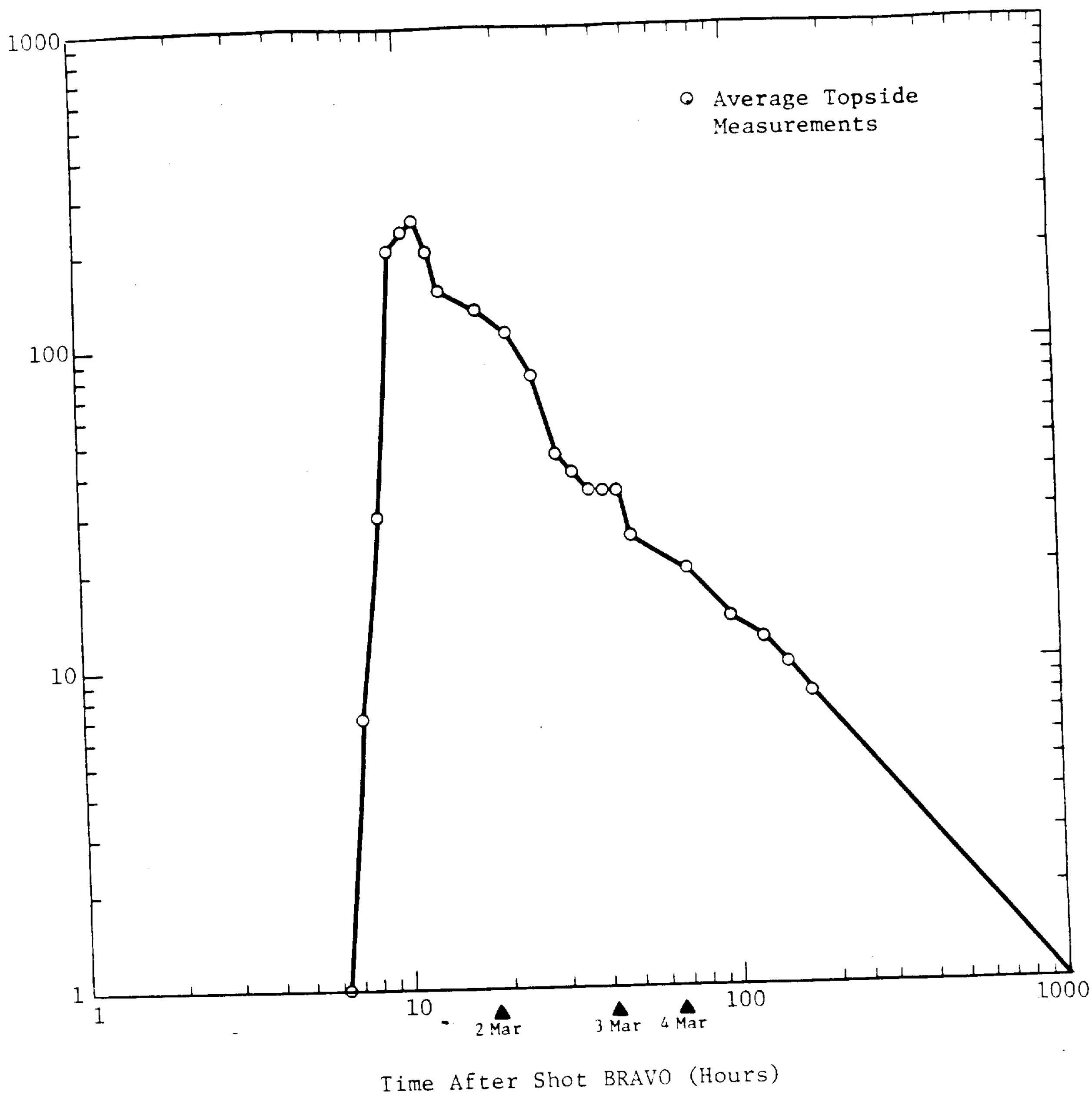

Figure 2-21. USS GYPSY topside intensity following Shot BRAVO.

previously is used to estimate the crew's exposure due to radioactive lagoon water. Specific periods in and out of the lagoon, and the corresponding integrated intensities for each period, are detailed below.

	Time at Bikini Lagoon		Integrated Intensity (mR)	
Month	In	Out	In	Out
March	02/1303-12/1812		414.1	
		12/1812-13/0635		16.5
	13/0635-19/1750		101.0	
		19/1750-19/2115		8.3
	19/2115-26/1256		63.4	
		26/1256-31/2400		22.9
April		01/0000-30/2400		66.7
May		01/0000-31/2400		34.3

The daily contributions to the free-field integrated intensities on the GYPSY from fallout (topside) and ship contamination (below) are shown in Table 2-10.

Table 2-10. Daily integrated intensity, USS GYPSY.

March	Integrated Intensity (mR) Topside	(Below)	April	Integrated Intensity (mR) Topside	(Below)	May	Integrated Intensity (mR) Topside	(Below)
1 (BRAVO)	1519.8		1	34.3	(3.4)	1	15.3	(1.4)
2	1554.4		2	33.0	(3.3)	2	15.0	(1.4)
3	624.2		3	31.8	(3.2)	3	14.7	(1.4)
4	442.5	(50.3)	4	30.7	(3.1)	4	14.4	(1.4)
5	334.5	(86.9)	5	29.7	(2.9)	5 (YANKEE)	14.2	(1.3)
6	294.5	(66.8)	6	28.7	(2.8)	6	13.9	(1.3)
7	238.3	(53.7)	7 (KOON)	27.8	(2.7)	7	13.7	(1.3)
8	199.1	(44.5)	8	26.9	(2.6)	8	13.4	(1.3)
9	170.4	(37.8)	9	26.1	(2.6)	9	13.2	(1.2)
10	148.4	(32.7)	10	25.3	(2.5)	10	13.0	(1.2)
11	131.1	(28.7)	11	24.6	(2.4)	11	12.7	(1.2)
12	117.2	(19.1)	12	23.9	(2.3)	12	12.5	(1.2)
13	105.8	(16.9)	13	23.2	(2.3)	13	12.3	(1.1)
14	96.2	(20.7)	14	22.6	(2.2)	14 (NECTAR)	12.1	(1.1)
15	88.2	(18.9)	15	22.0	(2.1)	15	11.9	(1.1)
16	81.2	(17.3)	16	21.4	(2.1)	16	11.8	(1.1)
17	75.3	(16.0)	17	20.9	(2.0)	17	11.6	(1.1)
18	70.0	(14.8)	18	20.4	(2.0)	18	11.4	(1.0)
19	65.5	(9.7)	19	19.9	(1.9)	19	11.2	(1.0)
20	61.4	(12.5)	20	19.4	(1.9)	20	11.1	(1.0)
21	57.8	(12.0)	21	18.9	(1.8)	21	10.9	(1.0)
22	54.5	(11.3)	22	18.5	(1.8)	22	10.7	(1.0)
23	51.6	(10.7)	23	18.1	(1.7)	23	10.6	(1.0)
24	48.9	(10.1)	24	17.7	(1.7)	24	10.4	(1.0)
25	46.5	(9.5)	25	17.3	(1.6)	25	10.3	(0.9)
26	44.3	(5.7)	26	16.9	(1.6)	26	10.1	(0.9)
27 (ROMEO)	42.3	(4.3)	27	16.6	(1.6)	27	10.0	(0.9)
28	40.4	(4.1)	28	16.2	(1.5)	28	9.9	(0.9)
29	38.7	(3.9)	29	15.9	(1.5)	29	9.7	(0.9)
30	37.1	(3.7)	30	15.6	(1.5)	30	9.6	(0.9)
31	35.7	(3.6)				31	9.5	(0.9)

2.2.11 USS LST-551

At the time of shot BRAVO, LST-551 was operating in an area 30 miles west of Enewetak. At approximately 1000 hours, the ship entered Enewetak Lagoon where it remained anchored/beached off Parry Island until 3 March, when it left for Bikini. It is assumed that while beached at Parry, the LST-551 received the same fallout as the residence islands of Enewetak between 1745 and 2300 hours on 1 March (Section 2.2.1 and Figure 2-3).

Shortly after Shot ROMEO was detonated on 27 March, LST-551, which had been beached on Parry Island (Enewetak), got underway for Bikini. At approximately 1500 hours, the ship began receiving a relatively light fallout which peaked at 1900 hours with average topside intensities approaching 3 mR/hr. There is no mention in the deck log of efforts to decontaminate the ship, but by 0800 hours on 28 March, when it arrived at Bikini, intensities were only 0.3 mR/hr (Reference 10). During the night of 28 March and early morning of 29 March, LST-551 was beached on Eneman Island at Bikini when it received more fallout. At 0315 hours on 29 March, Material Condition ABLE was set throughout the ship and the deck log states that it "took rad-safe measures". Intensities at this time were approximately 25 mR/hr. From the deck log, it appears that crew routines during the day of 29 March were not altered by the presence of this contamination. Figure 2-22 depicts the reconstructed radiation environment onboard the LST-551 resulting from Shot ROMEO fallout.

The only other radioactive fallout received by the LST-551 while at Operation CASTLE was following Shot NECTAR on 14 May. Although shipboard radiological data was not obtained to document the NECTAR fallout, it is assumed that while anchored in Enewetak Lagoon on 14 May, the LST-551 received the same fallout as was experienced on the residence islands during the same time period (See Section 2.2.1 and Figure 2-5).

The LST-551 made eight trips to Bikini from Enewetak during Operation CASTLE. Specific time periods in and out of the lagoon and integrated intensities for each period as determined from the ship contamination model are as follows:

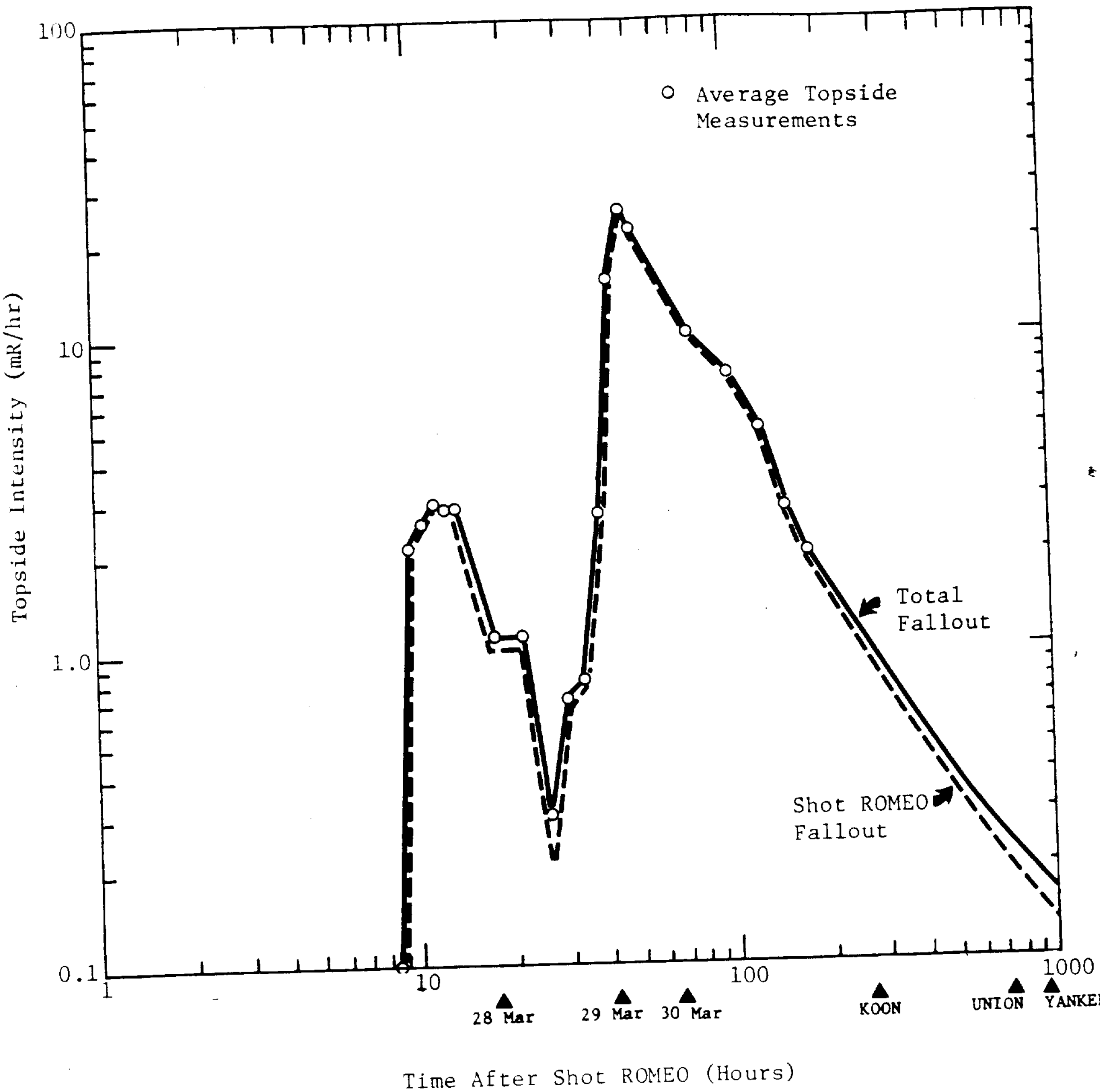

Figure 2-22. USS LST-551 topside intensity following Shot ROMEO.

	Time at Bikini Lagoon		Integrated Intensity (mR)	
Month	In	Out	In	Out
March	04/1200-09/1014		241.6	
		09/1014-11/1228		30.6
	11/1228-12/0952		15.1	
		12/0952-14/1600		21.3
	14/1600-16/1405		26.7	
		16/1405-21/1020		30.2
	21/1020-23/1641		19.5	
		23/1641-28/0720		18.6
	28/0720-29/1452		7.4	
April		29/1452-03/1457		15.1
	03/1457-05/1148		8.5	
		05/1148-17/1626		25.4
	17/1626-19/1822		6.1	
		19/1822-27/1350		11.6
	27/1350-30/1233		7.0	
April/May		30/1233-31/2400		30.0

Table 2-11 summarizes the daily contributions to the total integrated intensity on the LST-551 due to fallout (topside) and ship contamination (below).

2.2.12 USS LST-762

On 1 March, the LST-762 was anchored off Parry Island, Enewetak Atoll, and probably received fallout from Shot BRAVO. Although shipboard radiological data was not obtained or documented on the LST-762 following Shot BRAVO, it is assumed that it received the same fallout as experienced on the residence islands of Enewetak during the evening of 1 March (see Section 2.2.1 and Figure 2-3).

During the period 27-30 March, LST-762 was again anchored off Enewetak when Shot ROMEO fallout occurred on the atoll. Again, no radiological survey data on the LST-762 was recorded, but it is assumed that the ship received the same fallout (see Section 2.2.1 and Figure 2-4).

On 27 April, the LST-762 got underway from Enewetak enroute to Pearl Harbor. On 4 May, LST-975 rendezvoused with LST-762 and took it in tow for the remainder of its trip to Pearl. Two days later, on 6 May, both ships began receiving fallout from

Table 2-11. Daily integrated intensity, USS LST-551.

March	Integrated Intensity (mR) Topside	(Below)	April	Integrated Intensity (mR) Topside	(Below)	May	Integrated Intensity (mR) Topside	(Below)
1 (BRAVO)	47.4		1	104.6	(2.9)	1	4.9	(1.2)
2	153.5		2	61.7	(2.8)	2	4.7	(1.2)
3	85.3		3	46.4	(3.3)	3	4.6	(1.2)
4	48.9	(30.0)	4	37.5	(5.0)	4	4.5	(1.2)
5	32.4	(65.8)	5	31.1	(3.1)	5 (YANKEE)	4.3	(1.1)
6	23.5	(56.9)	6	26.3	(2.4)	6	4.2	(1.1)
7	18.0	(45.8)	7 (KOON)	22.6	(2.3)	7	4.1	(1.1)
8	14.4	(38.0)	8	19.7	(2.3)	8	4.0	(1.1)
9	11.8	(18.7)	9	17.4	(2.2)	9	3.9	(1.0)
10	10.0	(13.9)	10	15.4	(2.1)	10	3.8	(1.0)
11	8.5	(12.1)	11	13.9	(2.0)	11	3.7	(1.0)
12	7.4	(14.9)	12	12.6	(2.0)	12	3.6	(1.0)
13	6.5	(9.2)	13	11.4	(1.9)	13	3.6	(1.0)
14	5.8	(11.3)	14	10.5	(1.9)	14 (NECTAR)	9.9	(1.0)
15	5.2	(14.0)	15	9.7	(1.8)	15	28.4	(0.9)
16	4.7	(9.7)	16	9.0	(1.8)	16	17.2	(0.9)
17	4.3	(6.8)	17	8.5	(2.2)	17	11.2	(0.9)
18	3.9	(6.3)	18	8.1	(3.0)	18	8.4	(0.9)
19	3.6	(5.9)	19	7.7	(2.4)	19	7.0	(0.9)
20	3.3	(5.5)	20	7.3	(1.6)	20	6.0	(0.9)
21	3.0	(9.6)	21	7.0	(1.5)	21	5.4	(0.9)
22	2.9	(9.0)	22	6.8	(1.5)	22	4.9	(0.8)
23	2.7	(6.4)	23	6.5	(1.5)	23	4.5	(0.8)
24	2.6	(4.3)	24	6.2	(1.4)	24	4.2	(0.8)
25	2.4	(4.1)	25	6.0	(1.4)	25	3.9	(0.8)
26	2.3	(3.9)	26 (UNION)	5.8	(1.4)	26	3.7	(0.8)
27 (ROMEO)	19.5	(3.7)	27	5.6	(1.7)	27	3.6	(0.8)
28	46.9	(4.1)	28	5.4	(2.5)	28	3.4	(0.8)
29	433.2	(5.6)	29	5.1	(2.6)	29	3.3	(0.8)
30	229.6	(3.2)	30	5.0	(1.6)	30	3.2	(0.7)
31	163.8	(3.1)				31	3.0	(0.7)

Shot YANKEE, which had been detonated on 5 May (Reference 10). At 1330 hours, average topside intensities had reached 20 mR/hr and the ship's washdown system was turned on (Reference 8). With the washdown system still activated, intensities increased to 40 mR/hr by 1730 hours when the fallout apparently ceased. The LST-975, which did not have a washdown system (Reference 10), reported shipboard intensities approximately twice those on the LST-762 (see Section 2.2.14). The washing down continued on 6 May and, by 0930 hours on 7 May, when decontamination was terminated, intensities had been reduced to 5 mR/hr. On 8 May, a rad-safe survey on the ship indicated average topside intensities were 3 mR/hr. Figure 2-23 depicts the reconstructed radiation environment onboard the LST-762 resulting from Shots BRAVO, ROMEO, and YANKEE, the only three shots in the series resulting in fallout onboard this ship.

The LST-762 sortied to Bikini Lagoon only four times during operation CASTLE. The ship contamination model is used to determine the crew exposure due to contaminated lagoon water. Specific periods of time in and out of the lagoon, as well as the corresponding integrated intensities, are given below.

	Time at Bikini Lagoon		Integrated Intensity (mR)	
Month	In	Out	In	Out
March	03/1412-04/1930		12.1	
		04/1930-07/1410		42.8
	07/1410-10/0819		84.7	
		10/0819-13/1206		38.3
	13/1206-14/1307		15.0	
April		14/1307-08/1015		108.3
	08/1015-11/1242		12.3	
		11/1242-31/2400		60.5

The daily contributions to the free-field integrated intensity on the LST-762 from fallout (topside) and ship contamination (below) are shown in Table 2-12.

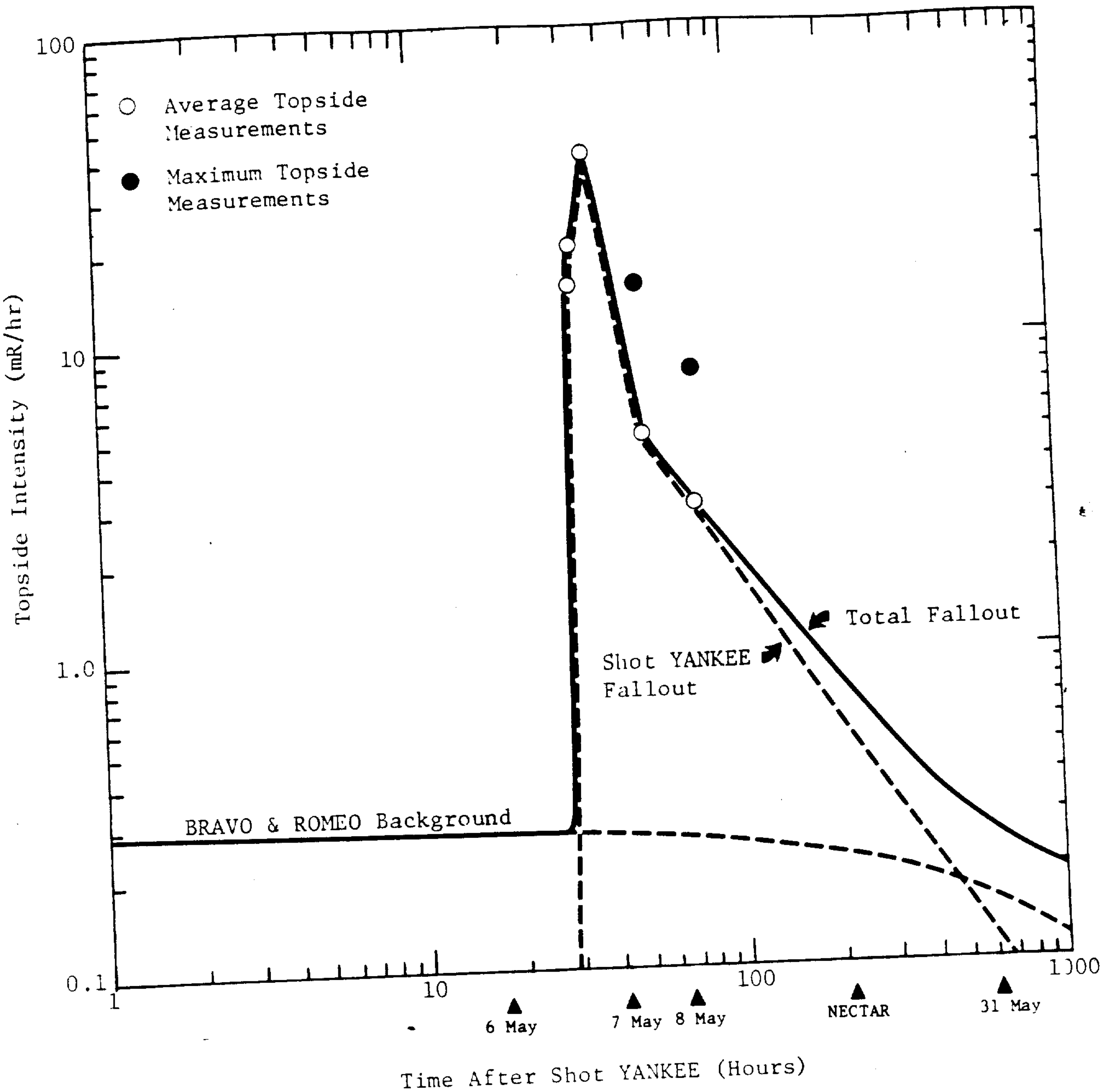

Figure 2-23. USS LST-762 topside intensity following Shot YANKEE.

Table 2-12. Daily integrated intensity, USS LST-762.

March	Integrated Intensity (mR) Topside	(Below)	April	Integrated Intensity (mR) Topside	(Below)	May	Integrated Intensity (mR) Topside	(Below)
1 (BRAVO)	47.4		1	101.7	(2.9)	1	7.6	(1.2)
2	153.5		2	78.4	(2.8)	2	7.3	(1.2)
3	85.3		3	63.0	(2.7)	3	7.1	(1.2)
4	48.9	(21.9)	4	52.0	(2.6)	4	6.9	(1.2)
5	32.4	(16.7)	5	44.1	(2.5)	5 (YANKEE)	6.6	(1.1)
6	23.5	(12.8)	6	37.9	(2.4)	6	298.3	(1.1)
7	18.0	(18.3)	7 (KOON)	33.1	(2.3)	7	145.7	(1.1)
8	14.4	(35.5)	8	29.2	(2.9)	8	66.6	(1.1)
9	11.8	(32.2)	9	26.1	(4.2)	9	46.1	(1.0)
10	10.0	(15.0)	10	23.5	(4.2)	10	35.0	(1.0)
11	8.5	(12.2)	11	21.3	(2.5)	11	28.1	(1.0)
12	7.4	(10.9)	12	19.5	(2.0)	12	23.5	(1.0)
13	6.5	(7.2)	13	17.8	(1.9)	13	20.1	(1.0)
14	5.8	(16.4)	14	16.5	(1.9)	14 (NECTAR)	17.6	(1.0)
15	5.2	(8.0)	15	15.3	(1.8)	15	15.7	(0.9)
16	4.7	(7.4)	16	14.3	(1.8)	16	14.2	(0.9)
17	4.3	(6.8)	17	13.5	(1.7)	17	13.0	(0.9)
18	3.9	(6.3)	18	12.9	(1.7)	18	12.0	(0.9)
19	3.6	(5.9)	19	12.2	(1.6)	19	11.2	(0.9)
20	3.3	(5.5)	20	11.6	(1.6)	20	10.4	(0.9)
21	3.0	(5.1)	21	11.1	(1.5)	21	9.8	(0.9)
22	2.9	(4.8)	22	10.6	(1.5)	22	9.4	(0.8)
23	2.7	(4.5)	23	10.2	(1.5)	23	8.9	(0.8)
24	2.6	(4.3)	24	9.7	(1.4)	24	8.4	(0.8)
25	2.4	(4.1)	25	9.4	(1.4)	25	7.9	(0.8)
26	2.3	(3.9)	26 (UNION)	9.0	(1.4)	26	7.7	(0.8)
27 (ROMEO)	14.5	(3.7)	27	8.7	(1.3)	27	7.4	(0.8)
28	43.1	(3.5)	28	8.4	(1.3)	28	7.2	(0.8)
29	67.2	(3.3)	29	8.1	(1.3)	29	7.0	(0.8)
30	180.0	(3.2)	30	7.8	(1.3)	30	6.8	(0.7)
31	139.7	(3.1)				31	6.6	(0.7)

2.2.13 USS LST-825

Although not part of the task group, LST-825 was operating in the Pacific Proving Ground prior to Shot BRAVO. The ship departed Bikini on 27 February and arrived at Enewetak the following morning. It remained anchored in the lagoon until approximately 0830 hours on 2 March when it got underway enroute to Japan. It is assumed that the LST-825 received the same fallout as the residence islands of Enewetak following Shot BRAVO (see Section 2.2.1 and Figure 2-3). Table 2-13 is a tabulation of the daily integrated intensities topside on the LST-825 as inferred from the island data. Since this ship did not enter Bikini Lagoon, there is no contribution due to ship contamination.

2.2.14 USS LST-975

On 28 April, while steaming from Japan to Pearl Harbor, the LST-975 was requested to rendezvous with the LST-762 at 11° N, 175° 35' E, and to take it in tow to Pearl Harbor. The rendezvous was accomplished on 4 May (See section 2.2.12). On 6 May, while the LST-975 was towing LST-762, both ships encountered fallout from Shot YANKEE. By 1330 hours, intensities averaged 20 mR/hr on the weather surfaces and, at 1505 hours, General Quarters was called. The crew secured from General Quarters at 1556 hours (Reference 8), and fire hoses were used in an attempt to reduce the shipboard intensities. At approximately 1730 hours when the fallout stopped, average intensities were as high as 96 mR/hr. By 0930 hours the next day, topside intensities had been reduced to 10 mR/hr; a subsequent survey on 8 May showed a further decrease to 7 mR/hr (Reference 10). Figure 2-24 depicts the reconstructed radiation environment onboard the LST-975; Table 2-14 details the daily topside integrated intensities through 31 May resulting from Shot YANKEE fallout. Ship contamination from Bikini Lagoon is not an issue.

Table 2-13. Daily integrated intensity, USS LST-825.

March	Integrated Intensity (mR)	April	Integrated Intensity (mR)	May	Integrated Intensity (mR)
1 (BRAVO)	47.4	1	1.8	1	0.8
2	153.5	2	1.7	2	0.8
3	85.3	3	1.7	3	0.8
4	48.9	4	1.6	4	0.8
5	32.4	5	1.6	5 (YANKEE)	0.7
6	23.5	6	1.5	6	0.7
7	18.0	7 (KOON)	1.5	7	0.7
8	14.4	8	1.4	8	0.7
9	11.8	9	1.4	9	0.7
10	10.0	10	1.3	10	0.7
11	8.5	11	1.3	11	0.7
12	7.4	12	1.3	12	0.7
13	6.5	13	1.2	13	0.7
14	5.8	14	1.2	14 (NECTAR)	0.6
15	5.2	15	1.2	15	0.6
16	4.7	16	1.1	16	0.6
17	4.3	17	1.1	17	0.6
18	3.9	18	1.1	18	0.6
19	3.6	19	1.0	19	0.6
20	3.3	20	1.0	20	0.6
21	3.0	21	1.0	21	0.6
22	2.9	22	1.0	22	0.6
23	2.7	23	1.0	23	0.6
24	2.6	24	0.9	24	0.6
25	2.4	25	0.9	25	0.5
26	2.3	26 (UNION)	0.9	26	0.5
27 (ROMEO)	2.2	27	0.9	27	0.5
28	2.1	28	0.9	28	0.5
29	2.0	29	0.8	29	0.5
30	2.0	30	0.8	30	0.5
31	1.9			31	0.5

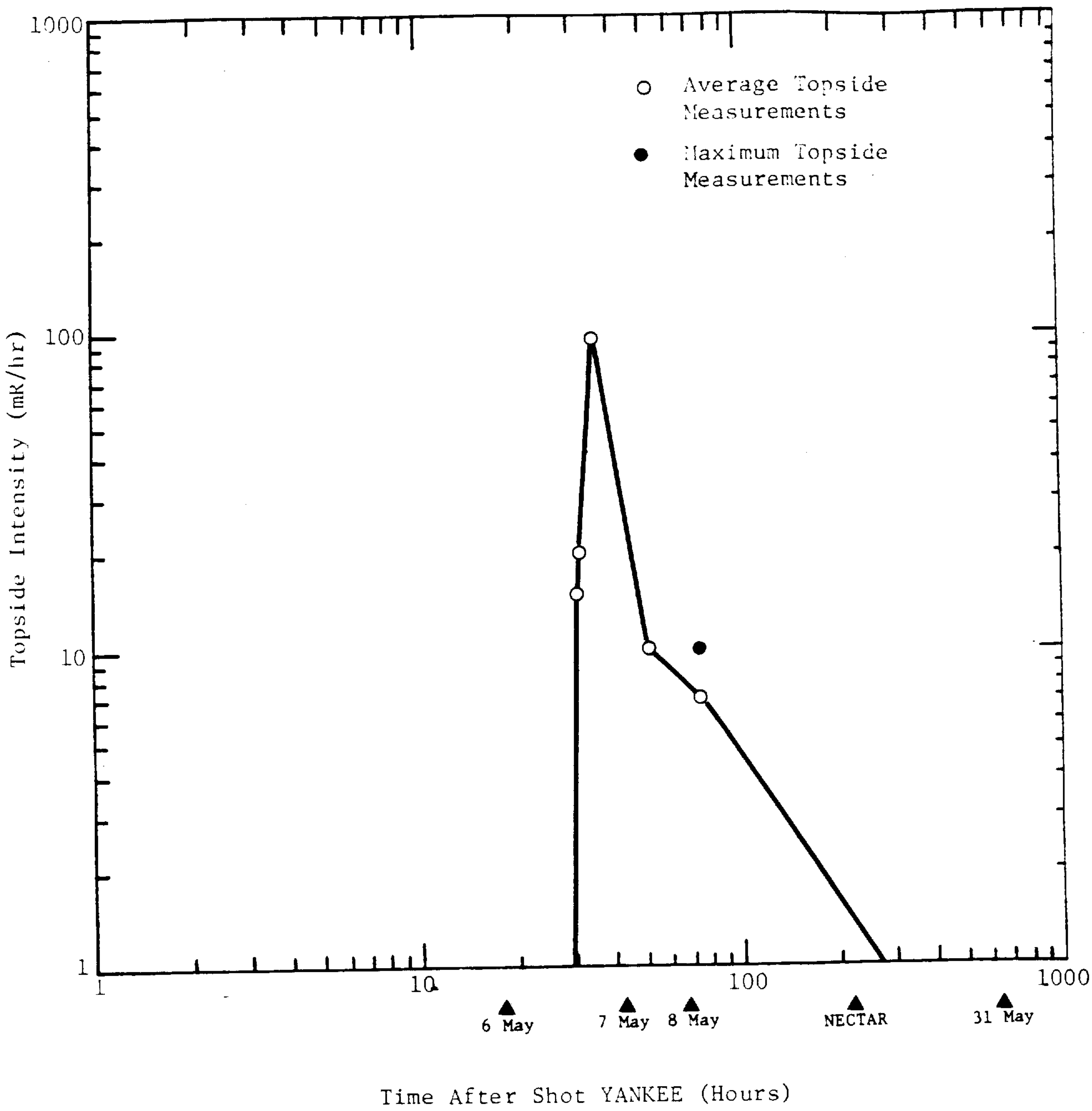

Figure 2-24. USS LST-975 topside intensity following Shot YANKEE.

Table 2-14. Daily integrated intensity, USS LST-975.

March	Integrated Intensity (mR)	April	Integrated Intensity (mR)	May	Integrated Intensity (mR)
1 (BRAVO)		1		1	
2		2		2	
3		3		3	
4		4		4	
5		5		5 (YANKEE)	0
6		6		6	611.2
7		7 (KOON)		7	322.6
8		8		8	154.1
9		9		9	102.5
10		10		10	74.4
11		11		11	57.2
12		12		12	45.7
13		13		13	37.6
14		14		14 (NECTAR)	31.7
15		15		15	27.1
16		16		16	23.6
17		17		17	20.7
18		18		18	18.4
19		19		19	16.5
20		20		20	14.9
21		21		21	13.6
22		22		22	12.4
23		23		23	11.4
24		24		24	10.5
25		25		25	9.8
26		26 (UNION)		26	9.3
27 (ROMEO)		27		27	8.8
28		28		28	8.3
29		29		29	7.9
30		30		30	7.5
31				31	7.2

2.2.15 USS NICHOLAS (DDE-449)

On 1 March, the NICHOLAS was approximately 300 miles south of Enewetak Atoll when Shot BRAVO was detonated and did not arrive at Bikini until 4 March. The NICHOLAS encountered no fallout following Shot BRAVO.

Following Shot ROMEO, the NICHOLAS reentered Bikini Lagoon at approximately 1700 hours. At 2000 hours, the ship departed Bikini in company with the CURTISS enroute to Enewetak, arriving there at 0800 hours, 28 March. The ship departed the evening of 29 March to patrol the waters east and southeast of the atoll, and returned at approximately noon on 30 March. Two waves of fallout occurred on Enewetak following Shot ROMEO (see Section 2.2.1)--the first during the evening of 27 March and the second on 29-30 March (see Figure 2-4). It is assumed that the NICHOLAS encountered the second wave of fallout while it was in the vicinity of Enewetak. Figure 2-25 depicts the radiation environment as inferred from the Enewetak data.

Approximately 7 hours after Shot UNION was detonated on 26 April, the NICHOLAS, while on patrol 90 miles west southwest of Bikini, encountered fallout from the UNION cloud. Material Condition ABLE was set at 1313 hours, and the washdown system was turned on (Reference 8). Intensity levels peaked at 1417 hours with average intensities of 37 mR/hr being recorded; a maximum intensity of 110 mR/hr was also reported at this time (Reference 8). Washdown continued until 1429 hours and Material Condition BAKER was set at 1440 hours. Figure 2-26 depicts the reconstructed radiation environment following Shot UNION. Radioactive decay after 1417 hours (H+8) is assumed to follow the Bikini decay rates (Section 2.2).

Following Shot NECTAR on 14 May, the NICHOLAS was on patrol in the vicinity of Enewetak Atoll. It entered the lagoon to refuel at approximately 1600 hours and resumed patrol at approximately 2200 hours. The time in the lagoon corresponds to the time when Enewetak received minor fallout from Shot NECTAR (see Section 2.2.1 and Figure 2-5) and it is assumed the NICHOLAS received this fallout.

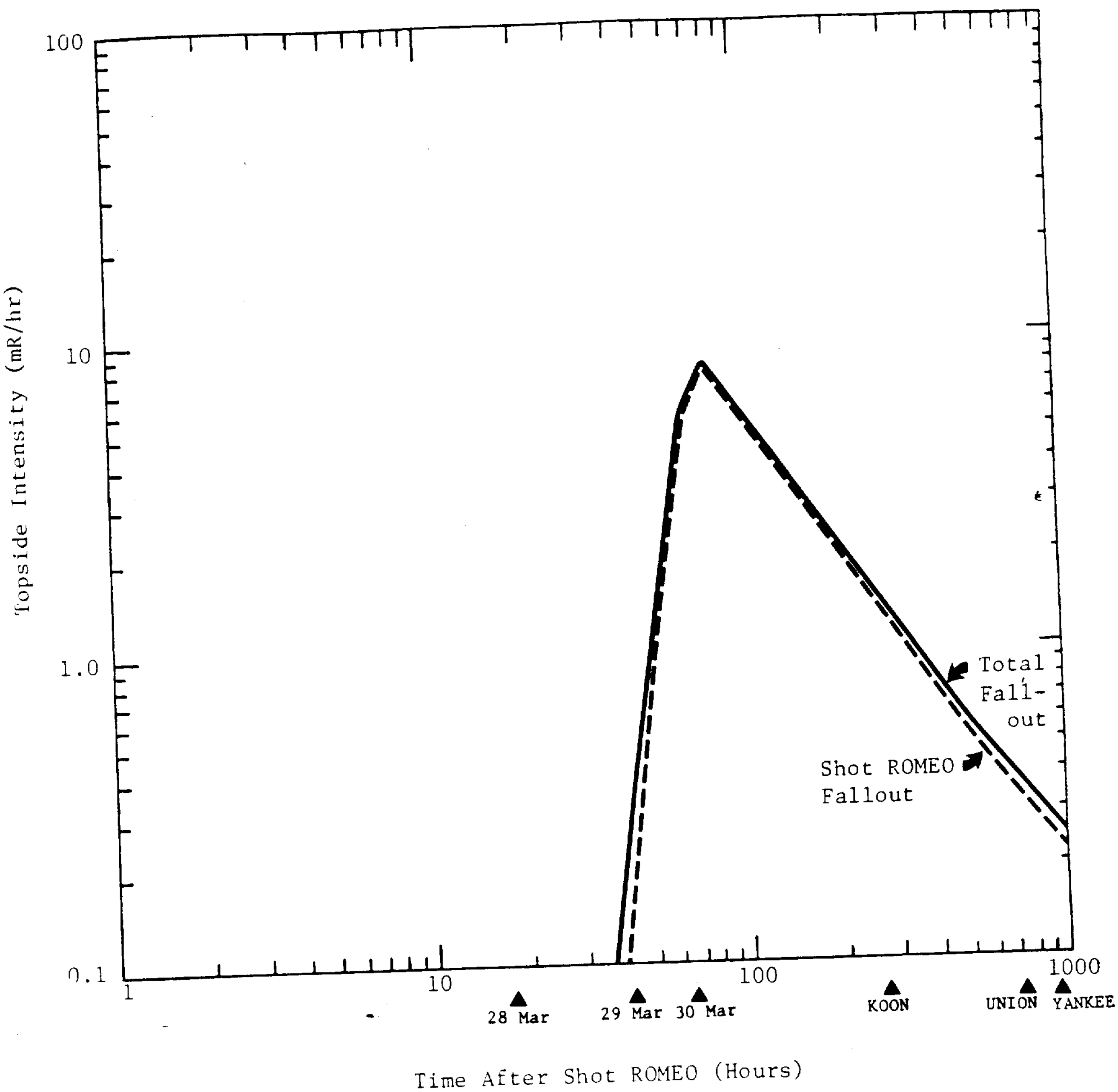

Figure 2-25. USS NICHOLAS topside intensity following Shot ROMEO.

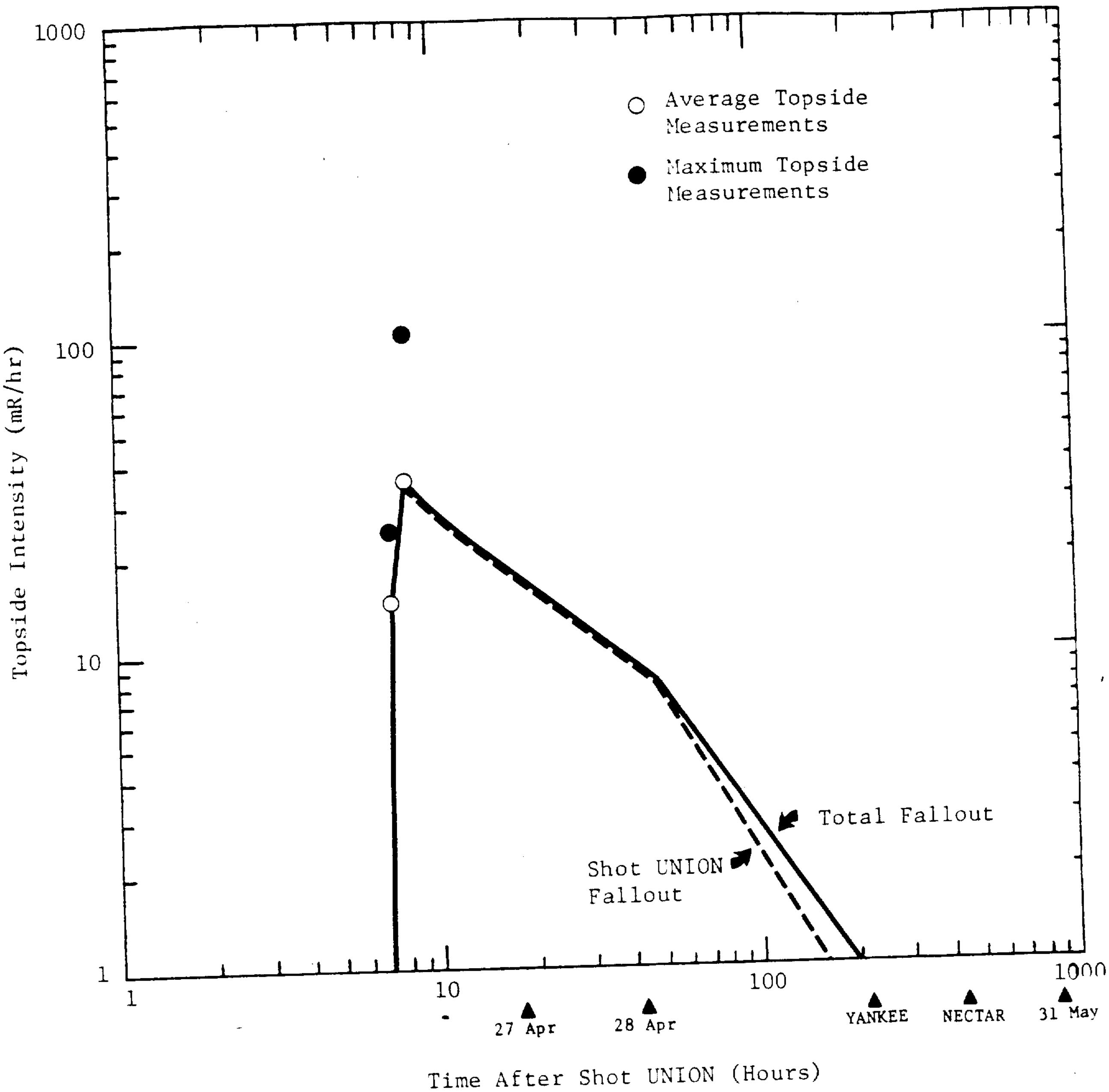

Figure 2-26. USS NICHOLAS topside intensity following Shot UNION.

The NICHOLAS entered Bikini Lagoon fifteen times between 4 March and the end of May. Specific periods of time in and out of the lagoon, as well as the corresponding integrated intensities determined from the ship contamination model, are given below.

	Time at Bikini Lagoon		Integrated Intensity (mR)	
Month	In	Out	In	Out
March	04/0810-05/1935	05/1935-07/1735	106.2	74.6
	07/1735-07/2356	07/2356-11/0900	9.1	47.0
	11/0900-11/1241	11/1241-24/0800	2.0	51.4
	24/0800-25/1909	25/1909-27/1701	12.0	9.9
	27/1701-27/1956	27/1956-01/0718	0.6	11.1
April	01/0718-03/1107	03/1107-05/1018	13.8	7.0
	05/1018-05/1217	05/1217-07/1850	0.3	4.0
	07/1850-11/1029	11/1029-13/1747	19.4	6.2
	13/1747-14/0720	14/0720-14/1558	1.8	0.7
	14/1558-14/1703	14/1703-17/1332	0.1	2.9
	17/1332-17/1637	17/1637-19/0919	0.2	1.2
	19/0919-20/0937	20/0937-20/1352	2.5	0.4
	20/1352-21/0752	21/0752-23/1016	2.2	3.8
	23/1016-25/1541	25/1541-26/1759	7.5	2.1
April/May	26/1759-27/1353	27/1353-31/2400	2.1	41.6

The daily contributions to the free-field integrated intensity on the NICHOLAS from fallout (topside) and ship contamination (below) are shown in Table 2-15.

Table 2-15. Daily integrated intensity, USS NICHOLAS.

March	Integrated Intensity (mR) Topside	(Below)	April	Integrated Intensity (mR) Topside	(Below)	May	Integrated Intensity (mR) Topside	(Below)
1 (BRAVO)	0		1	96.5	(5.1)	1	42.1	(1.5)
2	0		2	74.1	(7.4)	2	32.5	(1.5)
3	0		3	59.2	(4.3)	3	26.3	(1.5)
4	0	(56.0)	4	48.7	(3.5)	4	22.0	(1.4)
5	0	(71.8)	5	41.0	(1.8)	5 (YANKEE)	18.8	(1.4)
6	0	(38.3)	6	35.1	(2.0)	6	16.5	(1.4)
7	0	(28.7)	7 (KOON)	30.5	(2.9)	7	14.7	(1.3)
8	0	(15.9)	8	26.9	(5.2)	8	13.2	(1.3)
9	0	(13.5)	9	23.9	(5.9)	9	12.1	(1.3)
10	0	(11.7)	10	21.4	(5.7)	10	11.1	(1.3)
11	0	(8.0)	11	19.3	(3.2)	11	10.3	(1.2)
12	0	(6.0)	12	17.6	(2.7)	12	9.6	(1.2)
13	0	(5.4)	13	16.1	(2.7)	13	8.9	(1.2)
14	0	(4.9)	14	14.8	(1.7)	14 (NECTAR)	14.9	(1.2)
15	0	(4.4)	15	13.6	(1.0)	15	33.1	(1.2)
16	0	(4.1)	16	12.8	(1.0)	16	21.6	(1.1)
17	0	(3.8)	17	12.1	(0.6)	17	15.3	(1.1)
18	0	(3.5)	18	11.4	(1.0)	18	12.3	(1.1)
19	0	(3.2)	19	10.9	(2.1)	19	10.7	(1.1)
20	0	(3.0)	20	10.3	(2.9)	20	9.5	(1.1)
21	0	(2.8)	21	9.8	(1.0)	21	8.7	(1.1)
22	0	(2.7)	22	9.4	(2.2)	22	8.2	(1.0)
23	0	(2.5)	23	9.0	(3.4)	23	7.6	(1.0)
27	0	(5.1)	24	8.6	(3.5)	24	7.2	(1.0)
25	0	(9.6)	25	8.2	(2.4)	25	6.8	(1.0)
26	0	(5.2)	26 (UNION)	267.6	(1.9)	26	6.6	(1.0)
27 (ROMEO)	0	(4.0)	27	302.9	(2.5)	27	6.3	(1.0)
28	0.4	(2.6)	28	167.4	(1.6)	28	6.1	(0.9)
29	48.9	(2.5)	29	90.8	(1.6)	29	5.9	(0.9)
30	170.9	(2.4)	30	58.6	(1.5)	30	5.6	(0.9)
31	133.1	(2.3)				31	5.4	(0.9)

2.2.16 USS PHILIP (DDE-498)

The PHILIP was providing plane guard for the BAIROKO when the two ships encountered Shot BRAVO fallout at approximately 0800 hours, 1 March. Intensities rose rapidly and by 0900 hours, average topside intensities had reached 750 mR/hr (Reference 10). Although not stated in the deck log, the washdown system was probably activated at this time and all unnecessary personnel were ordered below. At approximately 1000 hours, when the fallout had ceased, decontamination efforts probably paralleled those being carried out onboard the BAIROKO, i.e., fire hoses were broken out and the weather decks flushed with high pressure water (see Section 2.2.4). This assumption is supported by the relatively rapid reduction in topside intensities between 0900 and 1200 hours (H+2.3 to H+5.3) as evidenced in Figure 2-27. Another period of fallout was encountered by the PHILIP between 1600 hours and midnight, 1 March, when intensities increased to approximately 200 - 250 mR/hr before they began to decrease. Figure 2-27 depicts the BRAVO fallout on the PHILIP. It does not appear that attempts to decontaminate after 2400 hours, 1 March (H+17), were very successful; the rate of reduction in topside intensities is not much greater than would be expected from natural decay alone.

During the early morning of 27 March, the PHILIP was on patrol east of Enewetak Atoll and, at approximately 1030 hours, it joined company with the LST-551 enroute to Bikini. While steaming in formation, both ships encountered minor fallout from Shot ROMEO at approximately 1500 hours; average intensities of approximately 3 mR/hr were recorded on both ships (See Section 2.2.11). At approximately midnight on 28 March, while on patrol south and southeast of Bikini, the PHILIP encountered the same secondary fallout from the ROMEO cloud as that received by the ships anchored in the lagoon. Shipboard intensities reached a maximum of approximately 20 mR/hr at 0400 hours on 29 March (Reference 10). Figure 2-28 depicts the reconstructed radiation environment on the PHILIP following Shot ROMEO. It is almost identical to the environment onboard the LST-551 (Figure 2-22). Shots BRAVO and ROMEO were the only two detonations that resulted in the ship receiving significant fallout.

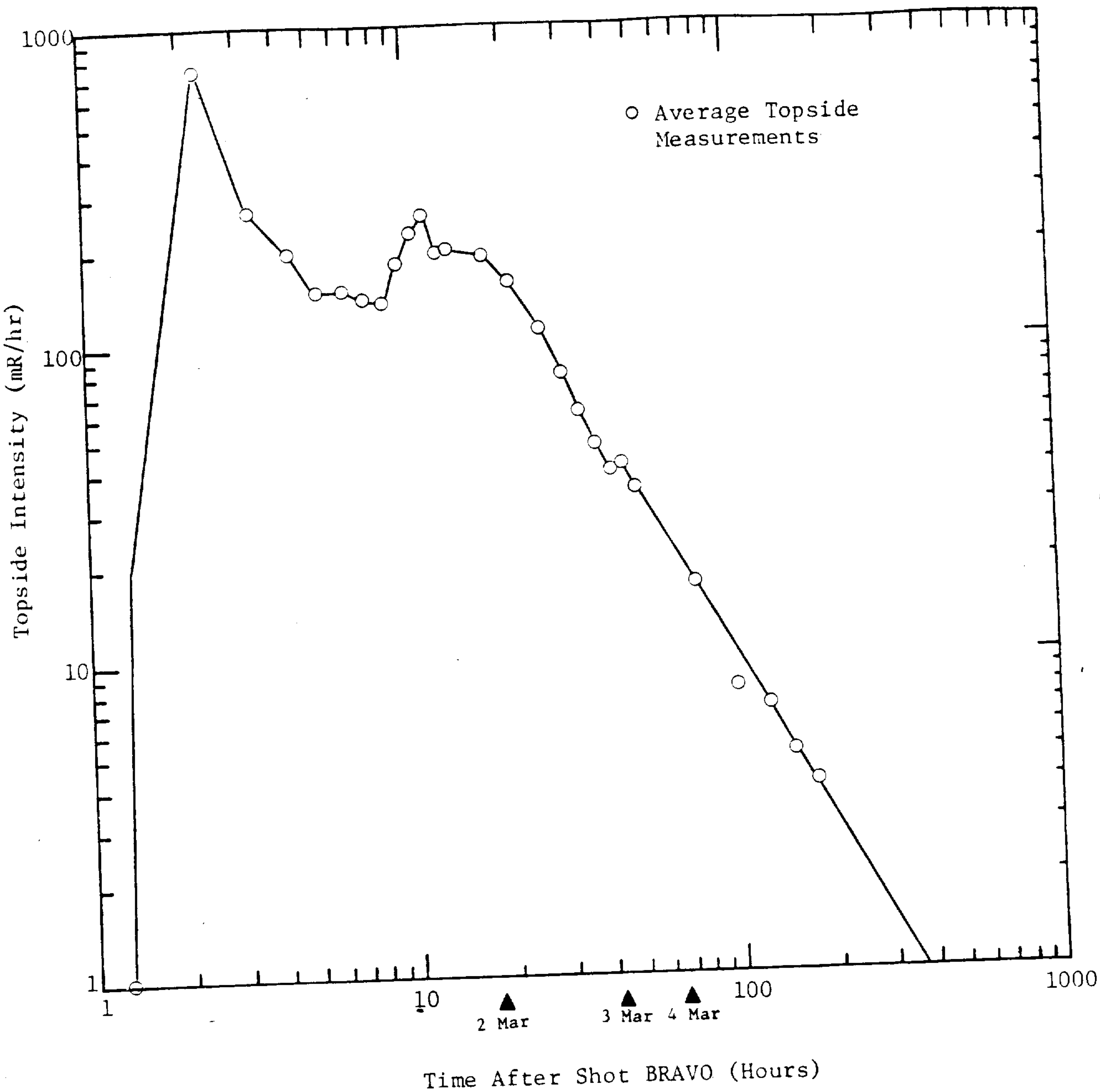

Figure 2-27. USS PHILIP topside intensity following Shot BRAVO.

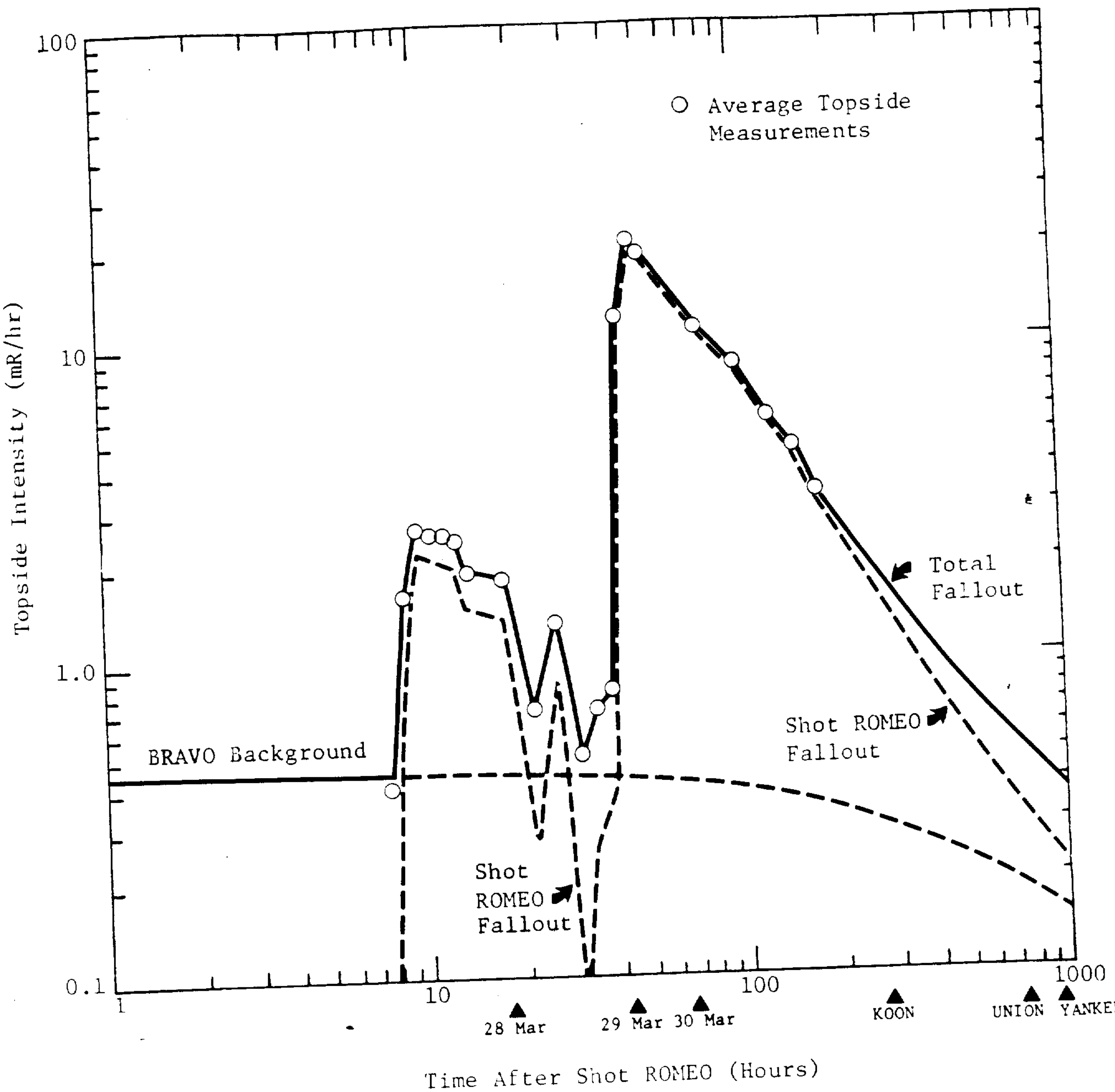

Figure 2-28. USS PHILIP topside intensity following Shot ROMEO.

The PHILIP entered Bikini Lagoon fifteen times between 2 March and the end of May. Specific periods of time in and out of the lagoon, as well as the corresponding integrated intensities determined from the ship contamination model, are given below.

	Time at Bikini Lagoon		Integrated Intensity (mR)	
Month	In	Out	In	Out
March	02/1910-02/2145	02/2145-05/0738	0.0	0.0
	05/0738-06/1800	06/1800-07/0857	43.6	39.2
	07/0857-07/1955	07/1955-09/0726	17.6	28.0
	09/0726-09/2018	09/2018-11/0800	12.1	19.5
	11/0800-11/2027	11/2027-28/1305	8.7	94.5
	28/1305-28/1414	28/1414-30/1127	0.2	3.1
	30/1127-31/1901	31/1901-10/1500	7.5	33.6
April	10/1500-13/1605	13/1605-14/0742	15.2	1.8
	14/0742-14/2000	14/2000-25/0933	1.5	17.0
	25/0933-25/1029	25/1029-27/1600	0.1	1.6
	27/1600-27/1905	27/1905-29/0940	0.1	6.2
May	29/0940-01/1006	01/1006-01/1254	1.0	0.7
	01/1254-04/1236	04/1236-06/0758	140.8	35.7
	06/0758-14/0745	14/0745-14/1201	807.1	3.5
	14/1201-15/0735	15/0735-31/2400	20.5	133.2

The daily contributions to the free-field integrated intensity on the PHILIP from fallout (topside) and ship contamination (below) are shown in Table 2-16.

Table 2-16. Daily integrated intensity, USS PHILIP.

March	Integrated Intensity (mR) Topside	(Below)	April	Integrated Intensity (mR) Topside	(Below)	May	Integrated Intensity (mR) Topside	(Below)
1 (BRAVO)	3287.2		1	134.1	(3.9)	1	10.4	(22.2)
2	2240.0		2	101.4	(3.8)	2	10.1	(57.3)
3	736.2		3	80.2	(3.6)	3	9.9	(51.1)
4	381.0		4	65.7	(3.5)	4	9.6	(27.9)
5	234.3	(40.0)	5	55.2	(3.4)	5 (YANKEE)	9.3	(18.8)
6	160.2	(39.8)	6	47.3	(3.3)	6	9.2	(134.9)
7	117.3	(29.9)	7 (KOON)	41.2	(3.1)	7	8.9	(200.0)
8	90.0	(18.2)	8	36.4	(3.0)	8	8.7	(138.8)
9	71.5	(18.8)	9	32.5	(2.9)	9	8.5	(99.7)
10	58.3	(12.7)	10	29.3	(3.0)	10	8.3	(76.6)
11	48.6	(13.8)	11	26.6	(5.8)	11	8.1	(61.6)
12	41.2	(9.7)	12	24.4	(5.3)	12	7.9	(51.4)
13	35.4	(8.7)	13	22.4	(3.8)	13	7.7	(43.4)
14	30.8	(7.9)	14	20.8	(2.3)	14 (NECTAR)	7.6	(23.9)
15	27.1	(7.2)	15	19.3	(1.8)	15	7.4	(16.5)
16	24.0	(6.6)	16	18.2	(1.7)	16	7.3	(13.1)
17	21.5	(6.1)	17	17.3	(1.7)	17	7.2	(11.8)
18	19.3	(5.6)	18	16.6	(1.7)	18	7.0	(10.7)
19	17.5	(5.2)	19	15.9	(1.6)	19	6.9	(9.7)
20	15.9	(4.9)	20	15.1	(1.6)	20	6.7	(8.9)
21	14.7	(4.6)	21	14.6	(1.5)	21	6.6	(8.2)
22	13.9	(4.3)	22	14.0	(1.5)	22	6.4	(7.6)
23	13.2	(4.1)	23	13.5	(1.5)	23	6.4	(7.1)
24	12.5	(3.8)	24	13.0	(1.4)	24	6.3	(6.6)
25	11.9	(3.6)	25	12.6	(0.6)	25	6.1	(6.2)
26	11.3	(3.5)	26 (UNION)	12.2	(0.7)	26	6.0	(5.8)
27 (ROMEO)	26.1	(3.3)	27	11.8	(0.7)	27	6.0	(5.5)
28	31.5	(2.2)	28	11.4	(0.5)	28	5.8	(5.2)
29	393.3	(1.6)	29	11.1	(2.0)	29	5.7	(4.9)
30	253.2	(2.8)	30	10.8	(3.0)	30	5.7	(4.7)
31	189.3	(7.0)				31	5.5	(3.4)

2.2.17 USS RENSHAW (DDE-499)

On 1 March, when Shot BRAVO was detonated, the RENSHAW was on patrol approximately midway between Enewetak and Bikini Atolls. At about 2100 hours, the ship steamed toward Enewetak where fallout from Shot BRAVO was already descending (See Section 2.2.1). Although not documented, it is probable that the portion of the cloud responsible for the Enewetak fallout passed over the RENSHAW sometime during the evening of 1 March, exposing the crew to levels of radioactive fallout comparable to those documented on Enewetak. Since shipboard intensity levels are not documented, it is assumed the RENSHAW received the same fallout as Enewetak following Shot BRAVO. (See Figure 2-3).

On 27 March, the RENSHAW was on patrol when Shot ROMEO was detonated and it did not return to Bikini until approximately 1500 hours, 28 March. It remained anchored in the lagoon until 31 March when it resumed patrol duties. At 2000 hours, 28 March, the ship began receiving secondary fallout from Shot ROMEO and by 2400 hours, average topside intensities were 20 mR/hr (Reference 10). The deck log for 28-29 March does not specify if decontamination of the ship was undertaken, but at 0800 hours on 29 March when the crew was mustered, average intensities were less than 10 mR/hr. Figure 2-29 depicts the average topside intensity onboard the RENSHAW resulting from the Shot ROMEO fallout.

Following Shot NECTAR on 14 May, the RENSHAW briefly returned to Enewetak Lagoon at approximately 0800 hours and again at approximately 1730 hours. At 2200 hours, it departed Enewetak enroute to Pearl Harbor. While in the lagoon between 1730 and 2200 hours, the ship probably received the same fallout as the residence islands of Enewetak during this same period (See Section 2.2.1 and Figure 2-5). The three other shots in the CASTLE series did not result in fallout on the RENSHAW.

The RENSHAW entered Bikini Lagoon eighteen times between 8 March and the end of May. Specific periods of time in and out of the lagoon, as well as the corresponding integrated intensities determined from the ship contamination model, are given below.

Month	Time at Bikini Lagoon In	Time at Bikini Lagoon Out	Integrated Intensity (mR) In	Integrated Intensity (mR) Out
March	08/0738-08/1935	08/1935-10/0714	5.6	15.1
	10/0714-10/1952	10/1952-12/0726	8.4	15.3
	12/0726-12/1058	12/1058-13/1212	1.6	6.0
	13/1212-14/0041	14/0041-14/1321	5.4	3.9
	14/1321-15/1100	15/1100-16/1225	12.5	10.4
	16/1225-18/1122	18/1122-20/1322	31.1	16.8
	20/1322-21/1349	21/1349-22/1850	10.9	8.2
	22/1850-24/1018	24/1018-26/1126	17.2	11.4
	26/1126-26/1445	26/1445-28/1459	0.7	5.6
	28/1459-31/0642	31/0642-31/1742	20.4	1.9
	31/1742-31/1900	31/1900-15/0733	0.2	24.2
April	15/0733-15/0906	15/0906-16/2227	0.1	1.2
	16/2227-17/1133	17/1133-18/2105	1.0	2.0
	18/2105-18/2135	18/2135-28/0752	0.0	6.1
	28/0752-28/2000	28/2000-01/0945	0.7	2.6
May	01/0945-01/1226	01/1226-01/1628	0.4	0.6
	01/1628-02/1315	02/1315-06/0847	25.3	75.9
	06/0847-07/1958	07/1958-31/2400	243.2	443.7

The daily contributions to the free-field integrated intensity on the RENSHAW from fallout (topside) and ship contamination (below) are shown in Table 2-17.

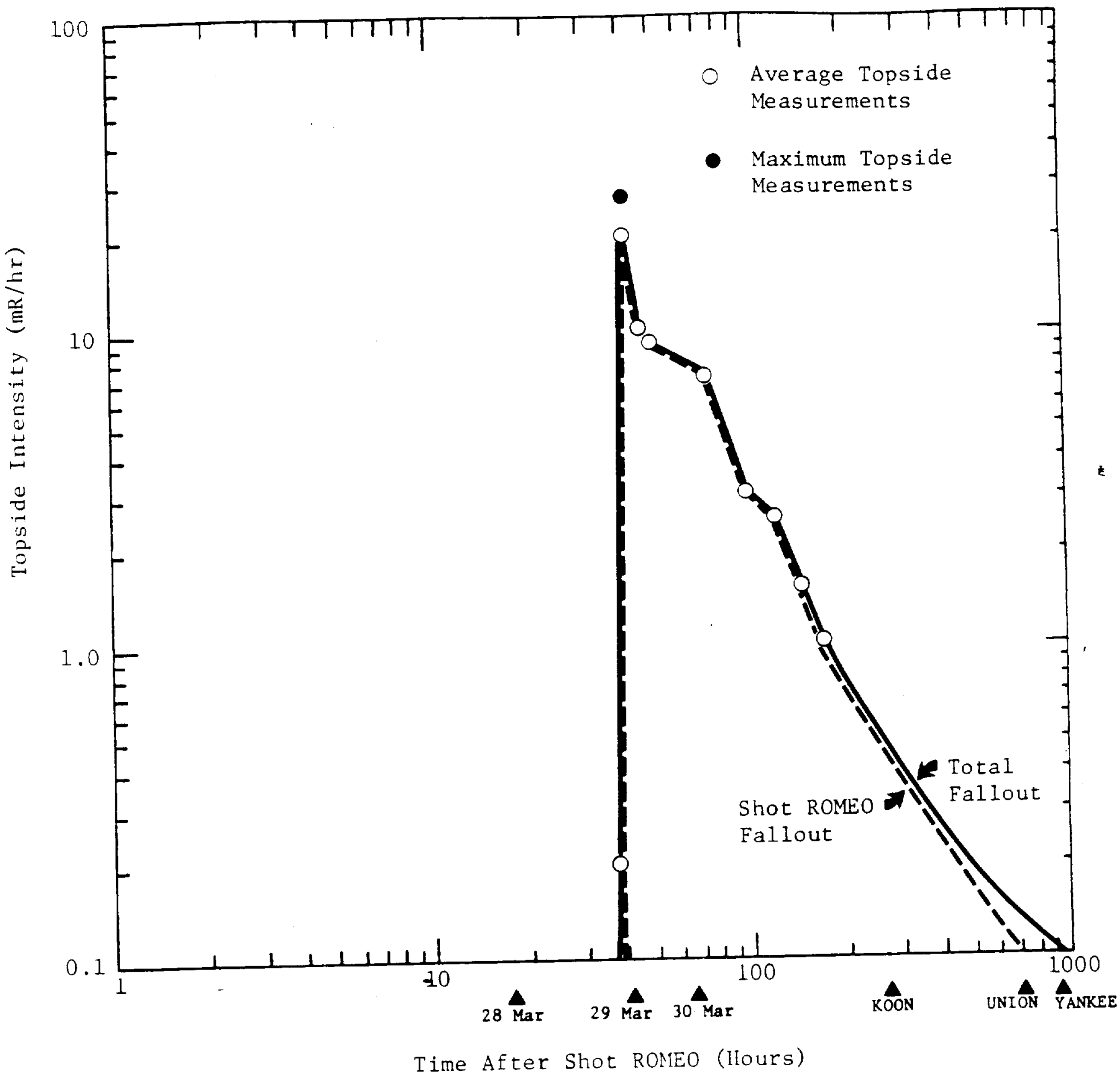

Figure 2-29. USS RENSHAW topside intensity following Shot ROMEO.

Table 2-17. Daily integrated intensity, USS RENSHAW.

March	Integrated Intensity (mR) Topside	(Below)	April	Integrated Intensity (mR) Topside	(Below)	May	Integrated Intensity (mR) Topside	(Below)
1 (BRAVO)	47.4		1	54.0	(2.1)	1	2.8	(11.1)
2	153.5		2	33.4	(2.0)	2	2.7	(33.2)
3	85.3		3	23.2	(1.9)	3	2.6	(21.8)
4	48.9		4	18.9	(1.8)	4	2.6	(18.5)
5	32.4		5	15.8	(1.8)	5 (YANKEE)	2.4	(16.0)
6	23.5		6	13.4	(1.7)	6	2.4	(131.6)
7	18.0		7 (KOON)	11.7	(1.7)	7	2.3	(153.1)
8	14.4	(10.8)	8	10.2	(1.6)	8	2.3	(69.4)
9	11.8	(9.8)	9	9.1	(1.5)	9	2.2	(49.8)
10	10.0	(13.6)	10	8.1	(1.5)	10	2.2	(38.3)
11	8.5	(10.1)	11	7.4	(1.4)	11	2.2	(30.8)
12	7.4	(6.7)	12	6.8	(1.4)	12	2.1	(25.6)
13	6.5	(6.7)	13	6.1	(1.4)	13	2.1	(21.7)
14	5.8	(7.9)	14	5.7	(1.3)	14 (NECTAR)	8.4	(18.8)
15	5.2	(16.6)	15	5.3	(0.8)	15	27.0	(16.5)
16	4.7	(12.3)	16	4.9	(0.5)	16	15.9	(14.6)
17	4.3	(17.8)	17	4.7	(1.7)	17	9.8	(13.1)
18	3.9	(10.1)	18	4.5	(1.6)	18	7.1	(11.9)
19	3.6	(7.9)	19	4.2	(0.7)	19	5.7	(10.8)
20	3.3	(6.0)	20	4.1	(0.7)	20	4.8	(9.9)
21	3.0	(11.9)	21	3.9	(0.7)	21	4.1	(9.2)
22	2.9	(6.7)	22	3.8	(0.7)	22	3.7	(8.5)
23	2.7	(12.0)	23	3.7	(0.6)	23	3.3	(7.9)
24	2.6	(6.7)	24	3.5	(0.6)	24	3.0	(7.4)
25	2.4	(5.5)	25	3.3	(0.6)	25	2.8	(6.9)
26	2.3	(3.7)	26 (UNION)	3.2	(0.6)	26	2.6	(6.5)
27 (ROMEO)	2.2	(2.8)	27	3.2	(0.6)	27	2.5	(6.1)
28	17.8	(5.0)	28	3.1	(1.3)	28	2.4	(5.8)
29	226.9	(7.7)	29	2.9	(1.0)	29	2.3	(5.5)
30	141.9	(8.6)	30	2.8	(1.0)	30	2.2	(5.2)
31	71.8	(3.1)				31	2.0	(3.7)

2.2.18 USS SIOUX (ATF-75)

On 1 March, while operating in an area southeast of Bikini, the SIOUX began receiving fallout at approximately 1300 hours (Reference 10). The washdown system was turned on at 1413 hours and used intermittently until 2000 hours, when it appeared that the fallout had ceased. Average intensities had reached 50 mR/hr, but by 2000 hours, they were reduced to 15 mR/hr. At approximately 2300 hours, fallout was again encountered and the washdown system was turned on at 2345 hours. Average intensities on deck rose to 40 mR/hr at 2400 hours. The washdown system was used intermittently until approximately 0200 hours on 2 March, when it became apparent that the fallout had ended (Reference 8). By the time the crew was mustered at 0800 hours (H+25), average topside intensities had been reduced to 12 mR/hr. Figure 2-30 depicts the radiation environment on the SIOUX resulting from Shot BRAVO fallout.

When Shot ROMEO was detonated on 27 March, the SIOUX was again in an area southeast of Bikini. After the detonation, the ship proceeded to the north of Bikini to search for Project 2.5 buoys. At 2400 hours on 27 March, when it was approximately 50 miles northeast of Bikini, the SIOUX began receiving secondary fallout. The buildup was gradual, peaking at 30 mR/hr at 2000 hours on 28 March, when the ship was north of Bikini (and heading southeast). This was probably the same fallout that occurred onboard the ships anchored in the lagoon approximately four hours later. The ship continued toward Bikini, and at 0300 hours when it was off Enyu Island, it was ordered to proceed to Enewetak. At 0800 hours, while enroute to Enewetak, intensity levels again rose to 30 mR/hr (Reference 10), probably from the same portion of the ROMEO cloud that the ship had encountered north of Bikini 12 hours earlier, and that passed over Bikini Lagoon between midnight and 0400 hours. Figure 2-31 depicts the average topside intensities resulting from ROMEO fallout.

The SIOUX was in Enewetak Lagoon on 14 May when that atoll received fallout from Shot NECTAR. Although the SIOUX departed at approximately 1900 hours (fallout had started at 1830 hours), it is assumed the ship received the same fallout as the residence islands (See Section 2.2.1 and Figure 2-5).

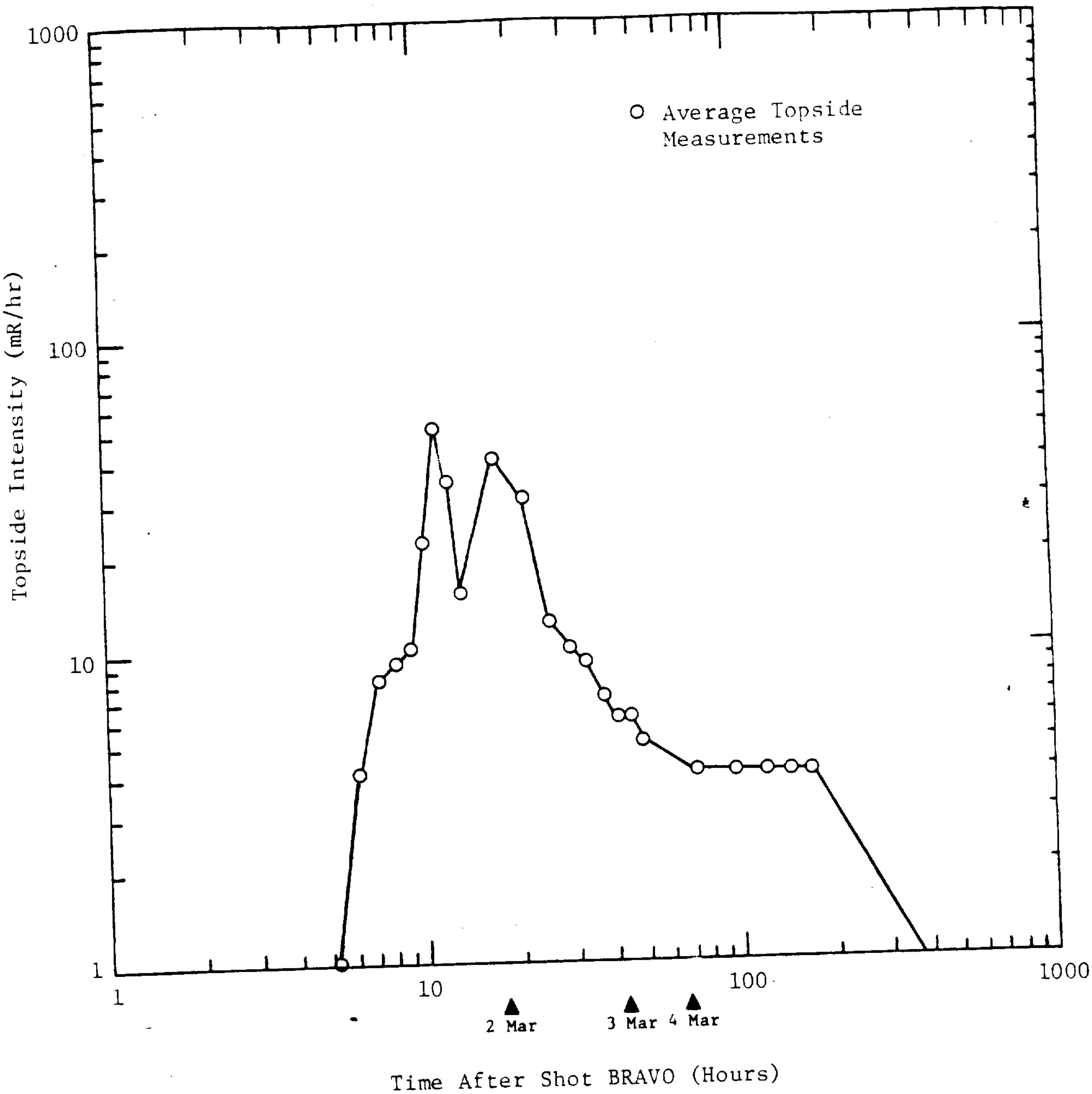

Figure 2-30. USS SIOUX topside intensity following Shot BRAVO.

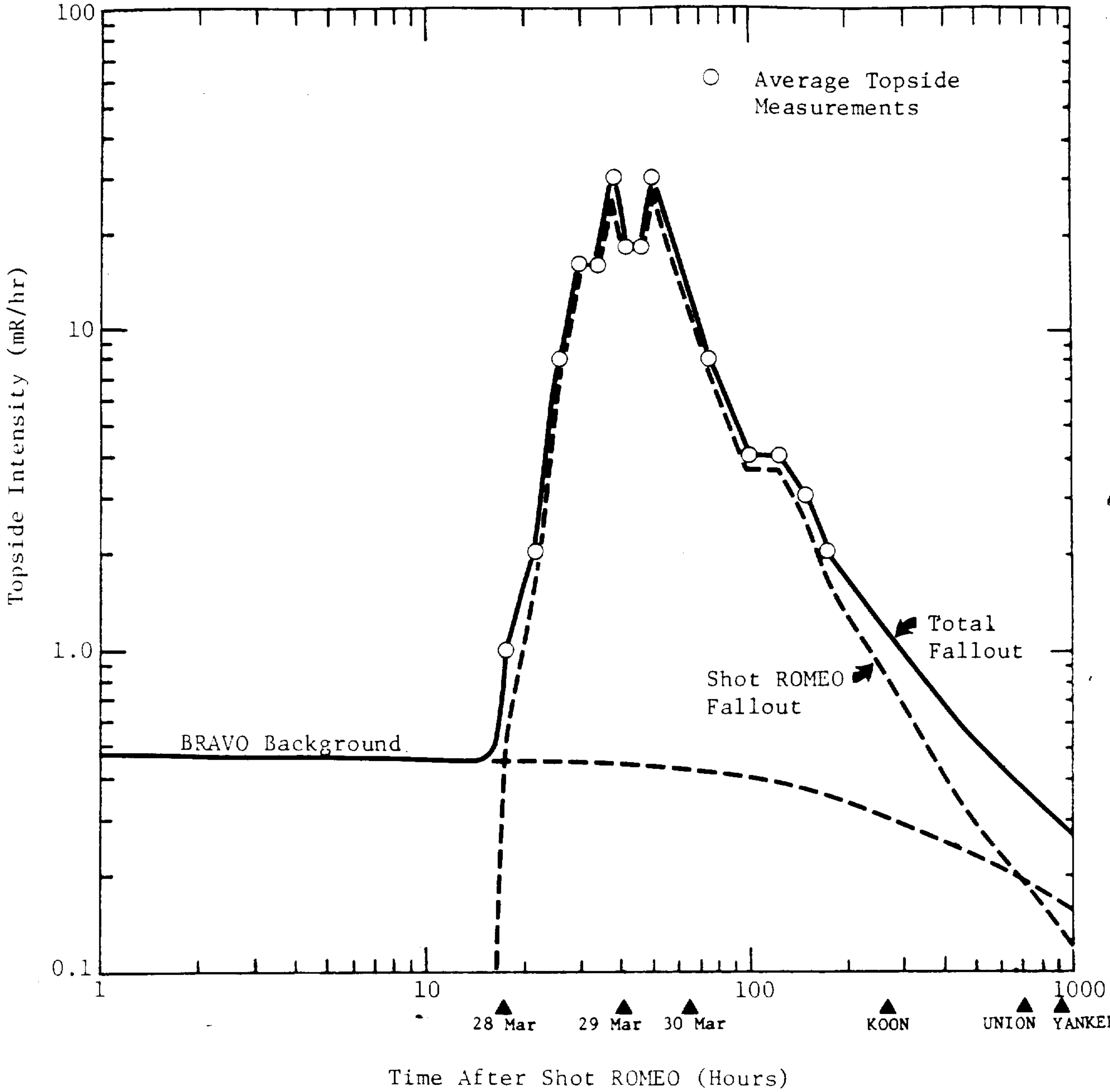

Figure 2-31. USS SIOUX topside intensity following Shot ROMEO.

In addition to receiving fallout while at Bikini and Enewetak, the SIOUX was utilized to "map out" the over-water extent of the fallout following Shots YANKEE and NECTAR. While aiding in this experiment (Project 2.7), the SIOUX was required to steam through water contaminated by fallout and take periodic water samples and sea surface intensity readings. The ship's path through contaminated water and water intensity readings are well documented for a five day period following Shot YANKEE (Reference 13) and it is possible to reconstuct the radiation environment to which the crew was exposed while participating in this experiment. Similar documentation is not as complete following Shot NECTAR since the USS MOLALA (ATF-106) served as the primary water sampling platform during this experiment. The few intensity readings obtained from the SIOUX indicate the ship was in water much less contaminated than it was after Shot YANKEE (Reference 13). The resultant crew exposure would thus be much less.

Figure 2-32 depicts the reconstructed radiation intensity of the water through which the SIOUX steamed following Shot YANKEE. Several simultaneous measurements made on the deck of the ship indicated deck level (topside) intensities due to "shine" from the contaminated water were approximately 40 percent of the measured water intensities.

Prior to its Project 2.7 activities during May, the SIOUX was in and out of Bikini Lagoon on nine occasions between 6 March and 17 April. Integrated intensities due to hull contamination while in the lagoon have been determined from the ship contamination model. These are detailed below for each period in and out of the lagoon.

	Time at Bikini Lagoon		Integrated Intensity (mR)	
Month	In	Out	In	Out
March	06/1726-09/1316		110.6	
		09/1316-11/2102		38.7
	11/2102-12/0456		5.1	
		12/0456-13/0810		9.5
	13/0810-19/0910		102.4	
		19/0910-21/1926		15.8
	21/1926-22/1908		8.5	
		22/1908-26/0141		16.7

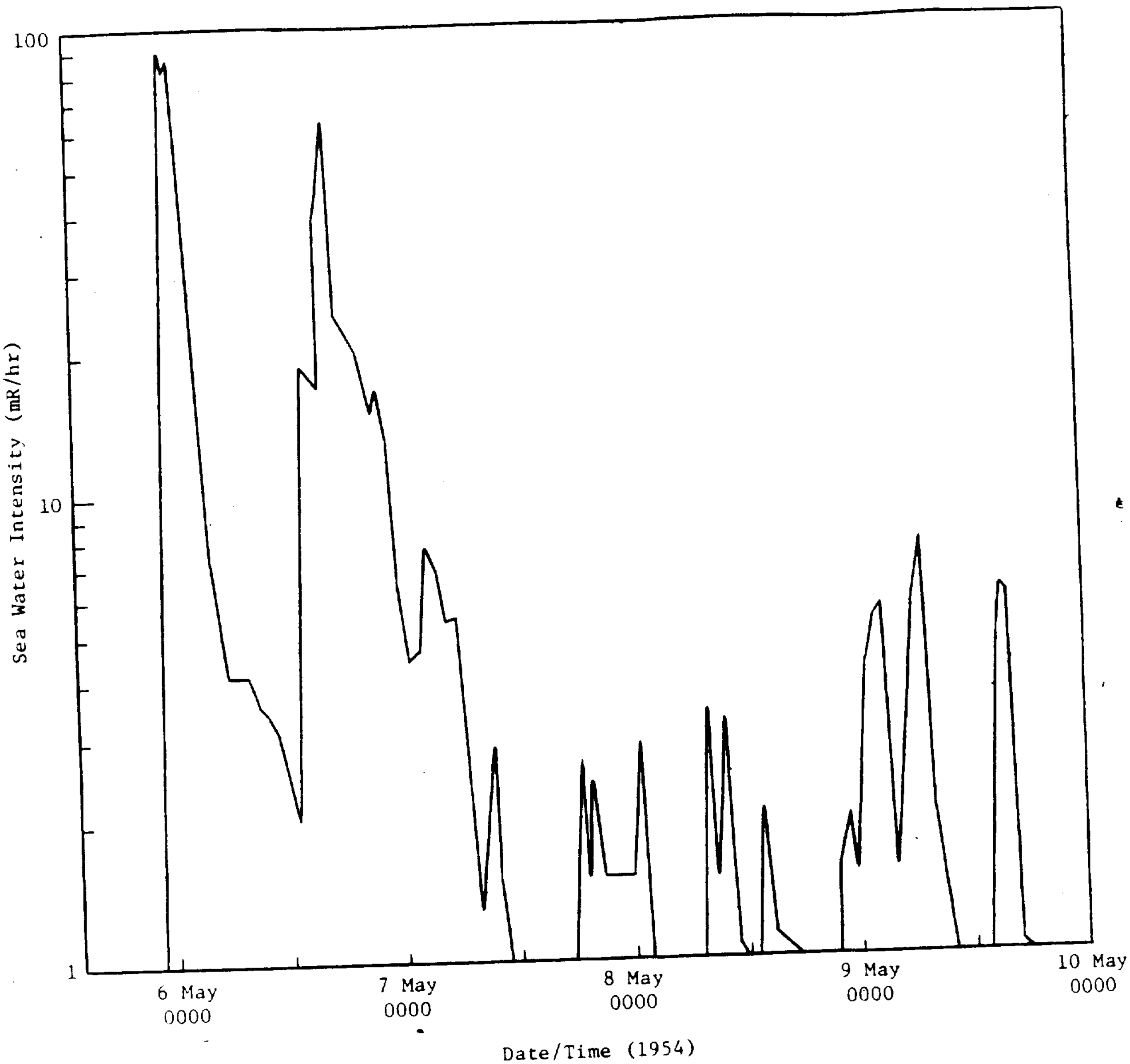

Figure 2-32. Sea water intensity measured from the USS SIOUX following Shot YANKEE.

	Time at Bikini Lagoon		Integrated Intensity (mR)	
Month	In	Out	In	Out
March	26/0141-26/1013		1.9	
April		26/1013-04/0900		22.5
	04/0900-05/1054		4.5	
		05/1054-07/1320		6.0
	07/1320-09/1854		10.5	
		09/1854-13/1425		9.2
	13/1425-14/1824		4.1	
		14/1824-17/1735		6.2
	17/1735-17/1920		0.2	
April/May		17/1920-05/2300		16.0
		*05/2300-31/2400		1125.9

*Off-site contamination

Table 2-18 summarizes the daily contribution to the free-field integrated intensity on the SIOUX due to fallout (topside) and ship contamination (below) from 1 March to 31 May. The tabulated topside values for 5-9 May include the topside contribution from "shine" while steaming in the contaminated water following Shot YANKEE.

Table 2-18. Daily integrated intensity, USS SIOUX.

March	Integrated Intensity (mR) Topside	(Below)	April	Integrated Intensity (mR) Topside	(Below)	May	Integrated Intensity (mR) Topside	(Below)
1 (BRAVO)	244.3		1	90.5	(2.3)	1	7.5	(0.8)
2	355.3		2	66.7	(2.2)	2	7.4	(0.8)
3	119.0		3	47.1	(2.1)	3	7.2	(0.7)
4	96.8		4	38.8	(3.2)	4	7.0	(0.7)
5	96.0		5	33.0	(3.9)	5 (YANKEE)	25.2	(0.7)
6	96.0	(9.0)	6	28.8	(2.8)	6	194.0	(422.1)
7	96.0	(46.3)	7 (KOON)	25.4	(3.6)	7	34.3	(218.0)
8	91.0	(44.5)	8	22.7	(5.0)	8	20.8	(133.4)
9	73.6	(24.3)	9	20.6	(3.8)	9	31.4	(93.6)
10	60.1	(16.4)	10	18.8	(2.5)	10	6.0	(43.1)
11	50.7	(11.4)	11	17.3	(2.4)	11	6.0	(26.8)
12	42.5	(10.0)	12	16.0	(2.3)	12	5.8	(22.3)
13	36.5	(16.1)	13	14.8	(1.8)	13	5.7	(18.9)
14	31.8	(20.0)	14	13.9	(4.1)	14 (NECTAR)	12.1	(16.4)
15	28.0	(18.9)	15	13.1	(2.1)	15	30.6	(14.4)
16	24.8	(17.3)	16	12.5	(2.1)	16	19.4	(12.8)
17	22.2	(16.0)	17	11.9	(1.6)	17	13.4	(11.4)
18	20.0	(14.8)	18	11.4	(1.1)	18	10.5	(10.4)
19	18.1	(7.6)	19	11.0	(1.0)	19	9.0	(9.4)
20	16.5	(6.4)	20	10.5	(1.0)	20	8.0	(8.7)
21	15.3	(6.2)	21	10.2	(1.0)	21	7.3	(8.0)
22	14.4	(8.2)	22	9.9	(0.9)	22	6.8	(7.4)
23	13.6	(5.3)	23	9.5	(0.9)	23	6.3	(6.9)
24	12.9	(5.0)	24	9.2	(0.9)	24	6.1	(6.4)
25	12.3	(3.8)	25	8.9	(0.9)	25	5.8	(6.0)
26	11.7	(4.5)	26 (UNION)	8.7	(0.9)	26	5.6	(5.7)
27 (ROMEO)	12.3	(2.9)	27	8.4	(0.8)	27	5.4	(5.3)
28	316.8	(2.7)	28	8.2	(0.8)	28	5.3	(5.0)
29	467.1	(2.6)	29	7.9	(0.8)	29	5.1	(4.8)
30	175.0	(2.5)	30	7.7	(0.8)	30	4.9	(4.5)
31	98.5	(2.4)				31	4.8	(4.3)

SECTION 3
DOSE CALCULATIONS

To determine the dose to personnel, consideration is given to the time spent topside (outside) and below decks (inside) and the radiation protection afforded by a ship or building. The daily, free-field integrated intensities (topside and below) from Section 2 are adjusted to account for crew activities, either documented or assumed. The daily exposures (mR) are then converted to film badge equivalence (mrem). Results are presented as a daily cumulative dose to personnel through 31 May 1954, when the CASTLE roll-up phase was nearly complete.

3.1 PERSONNEL ACTIVITIES

An estimate of personnel movements is critical in determining a film badge dose, especially during fallout deposition and at early times when intensities are relatively high and intensity levels are changing through decontamination. As inferred from deck logs and after-action reports, normal crew activities were somewhat altered during the day that Shot BRAVO fallout occurred. By the following day (2 March) normal crew duties were generally resumed. Because intensity levels were still relatively high on some of the ships, it is necessary to account for specific periods of time on deck in order to calculate personnel doses. Shot ROMEO fallout, on the other hand, peaked at approximately 0001-0400 hours, 29 March, on nearly all of the ships anchored in Bikini Lagoon. Rad-safe measures, such as turning on the ship's washdown system, were generally accomplished at a time when virtually all of the crew was already below deck. By the time crews were mustered at approximately 0800, shipboard intensity levels had been reduced to where normal crew duties could be resumed without too many restrictions. Hence, it is not necessary to detail personnel movements onboard the task group ships following Shot ROMEO to estimate their dose.

With the exception of 1-2 March, when actual times topside and below are used, the integrated intensities topside are multiplied by a time-averaged shielding factor to account for the time spent topside (outside) and below (inside) during a typical work day. It is estimated that the crew on each ship was on deck at the following times:

0800-1200, 1330-1700, and 1800-2000 hours. This amounts to 40 percent of the day (9½ hours) topside and 60 percent (14½ hours) below. While below, the crew was offered shielding provided by the ship's structure. In References 3, 4, 5, and 6, it is estimated that ship-shielding factors vary from approximately 0.06 to 0.15, depending on the main deck thickness. A time-averaged shielding factor is computed as 0.4 + 0.6 x ship-shielding factor, where the 0.4 and 0.6 represent the fraction of the day spent above and below the deck, respectively. The time-averaged shielding factors vary from approximately 0.44 to 0.49. An average value of 0.46 (corresponding to a ship-shielding factor of 0.1) is used in this analysis and variations are treated as an uncertainty in Section 4. A similar argument is used to obtain a time-averaged shielding factor of 0.8 for the land-based personnel. This assumes that 60 percent of the day is spent outside and 40 percent inside. While inside, personnel are afforded a protection factor of 2, i.e., a shielding factor of 0.5.

In addition to being exposed to a fraction of the topside (fallout) radiation environment, crew members, while below, were exposed to radiation from the ship's hull and saltwater systems that became contaminated while in the radioactive waters of Bikini Lagoon. Since the typical crew was below for an estimated 14½ hours per day, they received 60 percent of the integrated intensity below due to ship contamination.

3.2 CALCULATED PERSONNEL FILM BADGE DOSES

Film badge doses are calculated by applying the actual exposure conditions to the free-field integrated intensity and converting this to a film badge dose. Conditions of exposure include shielding as well as duration of exposure. When fallout was significant, actual periods topside (outside) and below (inside) are used, such as for the APACHE on 1 March when crew routines were altered due to BRAVO fallout. When fallout was relatively minor and duty routines were not significantly altered, film badge doses are calculated by applying the appropriate time-averaged shielding factor to the free-field integrated intensity and again converting to a film badge dose. The conversion factor has been determined to be 0.7 rem/R (Reference 7). The following sections describe the dose calculations for both island-based and shipboard personnel.

3.2.1 Enewetak Atoll Dose Calculations

Fallout on the residence islands of Enewetak Atoll following Shots BRAVO, ROMEO, and NECTAR was relatively light and daily duty routines would not have been altered. Personnel film badge doses are calculated by multiplying the daily free-field integrated intensities in Table 2-1 by the time-averaged shielding factor for island-based personnel (0.8), and then by 0.7 to convert to an equivalent film badge dose. Cumulative film badge doses through 31 May 1954 are given in Table 3-1.

Table 3-1. Calculated personnel film badge dose, residence islands of Enewetak Atoll.

March	Cumulative Dose (mrem)	April	Cumulative Dose (mrem)	May	Cumulative Dose (mrem)
1 (BRAVO)	27	1	594	1	954
2	113	2	638	2	958
3	160	3	673	3	962
4	188	4	702	4	966
5	206	5	727	5 (YANKEE)	969
6	219	6	748	6	973
7	229	7 (KOON)	767	7	977
8	237	8	783	8	980
9	244	9	798	9	983
10	249	10	811	10	987
11	254	11	823	11	990
12	258	12	834	12	993
13	262	13	844	13	996
14	265	14	853	14 (NECTAR)	1003
15	268	15	861	15	1020
16	271	16	869	16	1030
17	273	17	877	17	1037
18	275	18	884	18	1043
19	277	19	891	19	1048
20	279	20	898	20	1052
21	281	21	904	21	1056
22	282	22	910	22	1060
23	284	23	915	23	1063
24	285	24	921	24	1066
25	287	25	926	25	1069
26	288	26 (UNION)	931	26	1072
27 (ROMEO)	296	27	936	27	1075
28	320	28	941	28	1078
29	358	29	945	29	1080
30	459	30	950	30	1083
31	537			31	1085

3.2.2 Kwajalein Atoll Dose Calculations

Fallout on Kwajalein Atoll following Shots BRAVO, ROMEO, and YANKEE was relatively light and daily duty routines would not have been altered. Personnel film badge doses are calculated by multiplying the daily free-field integrated intensities in Table 2-2 by the time-averaged shielding factor for island-based personnel (0.8), and then by 0.7 to convert to an equivalent film badge dose. Cumulative film badge doses through 31 May 1954 are given in Table 3-2.

Table 3-2. Calculated personnel film badge dose, Kwajalein Atoll.

March	Cumulative Dose (mrem)	April	Cumulative Dose (mrem)	May	Cumulative Dose (mrem)
1 (BRAVO)	0	1	98	1	273
2	4	2	120	2	275
3	16	3	137	3	277
4	23	4	151	4	279
5	27	5	164	5 (YANKEE)	281
6	31	6	174	6	284
7	33	7 (KOON)	183	7	287
8	35	8	191	8	290
9	37	9	198	9	292
10	38	10	205	10	295
11	39	11	210	11	297
12	40	12	216	12	298
13	41	13	221	13	300
14	42	14	225	14 (NECTAR)	302
15	43	15	229	15	303
16	44	16	233	16	305
17	44	17	237	17	306
18	45	18	240	18	308
19	45	19	243	19	309
20	46	20	247	20	310
21	46	21	250	21	312
22	47	22	252	22	313
23	47	23	255	23	314
24	47	24	258	24	315
25	48	25	260	25	317
26	48	26 (UNION)	263	26	318
27 (ROMEO)	48	27	265	27	319
28	49	28	267	28	320
29	49	29	269	29	321
30	50	30	271	30	322
31	70			31	323

3.2.3 USS APACHE Dose Calculations

The crew activity time-lines depicting periods spent above and below deck on 1-2 March are shown in Figure 3-1. Also shown is the average topside intensity during this time period. For 1 March, periods during which the ship's washdown system was turned on are annotated as obtained from the APACHE's deck log. It is assumed that when the washdown system was on, all personnel were below. Other time periods above or below deck for eating, working, and sleeping are also annotated. On 2 March, a "typical" work day is resumed, i.e., 9½ hours on deck and 14½ hours below.

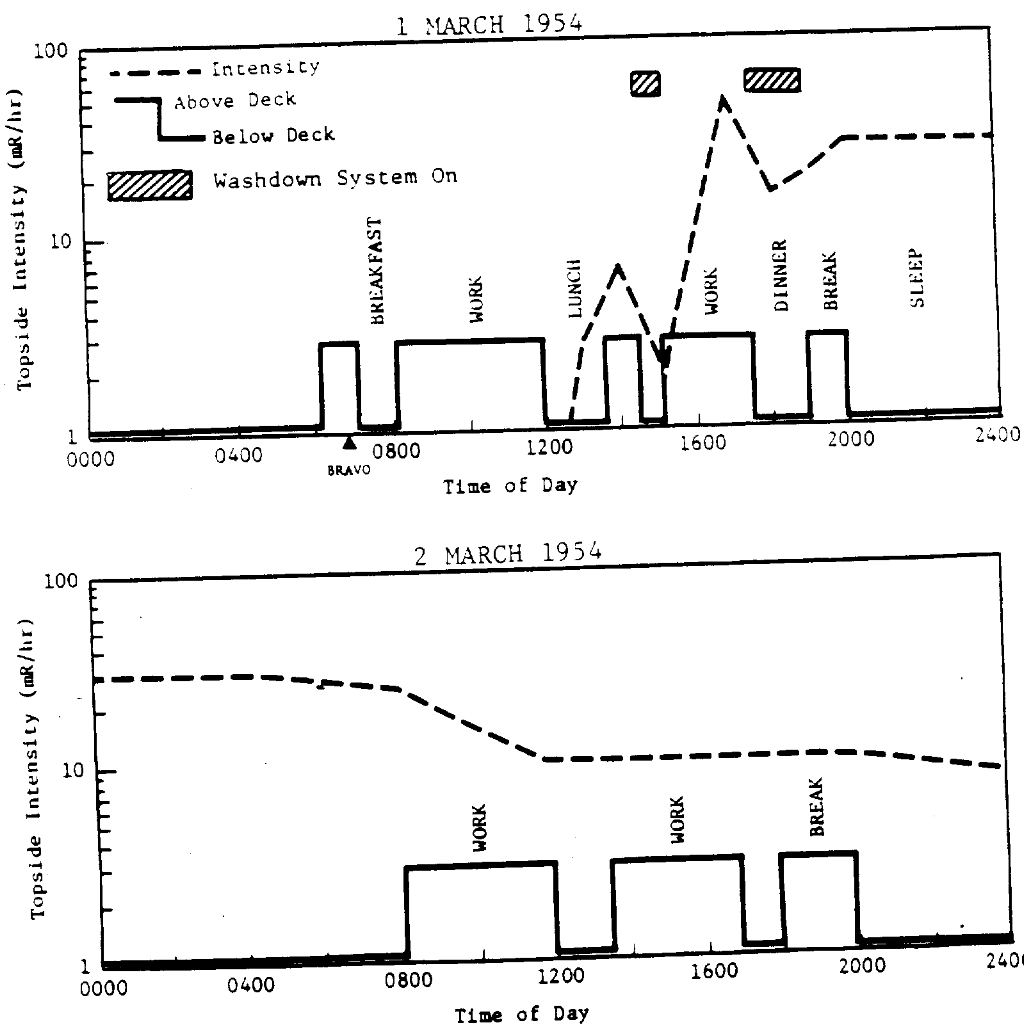

Figure 3-1. Crew activity time-line for the USS APACHE, 1-2 March 1954.

Dose calculations for personnel onboard the APACHE on 1-2 March are detailed below. Time periods below deck are indicated by an asterisk (*). After 2 March, the daily film badge dose is calculated by multiplying the integrated intensity topside (Table 2-3) by the time-averaged shielding factor (0.46); the integrated intensity below is multiplied by the fraction of the day spent below deck (0.6). Contributions from each source are summed and converted to a film badge dose. Cumulative film badge doses for the APACHE's crew through 31 May 1954 are given in Table 3-3.

Day	Time Period	Integrated Intensity (mR)	x	Ship Shielding Factor	=	Adjusted Exposure (mR)
1 March	0000-0600*	0				0
	0600-0700	0				0
	0700-0800*	0				0
	0800-1200	0				0
	1200-1330*	1.5		0.1		0.2
	1330-1430	5.0		1.0		5.0
	1430-1500*	3.7		0.1		0.4
	1500-1730	51.0		1.0		51.0
	1730-1900*	29.0		0.1		2.9
	1900-2000	24.7		1.0		24.7
	2000-2400*	120.0		0.1		12.0
		234.9 (Table 2-3)				96.2

1 March film badge dose = (96.2 mR) (0.7) = 67.3 mrem (Table 3-3)

Day	Time Period	Integrated Intensity (mR)	x	Ship Shielding Factor	=	Adjusted Exposure (mR)
2 March	0000-0800*	229.4		0.1		22.9
	0800-1200	64.8		1.0		64.8
	1200-1330*	15.0		0.1		1.5
	1330-1700	35.0		1.0		35.0
	1700-1800*	10.0		0.1		1.0
	1800-2000	20.0		1.0		20.0
	2000-2400*	35.8		0.1		3.6
		410.0 (Table 2-3)				148.8 mR

2 March film badge dose = (148.8 mR) (0.7) = 104.2 mrem
Cumulative film badge dose through 2 March = 172 mrem (Table 3-3)

Table 3-3. Calculated personnel film badge dose, USS APACHE.

March	Cumulative Dose (mrem)	April	Cumulative Dose (mrem)	May	Cumulative Dose (mrem)
1 (BRAVO)	67	1	887	1	1128
2	172	2	918	2	1131
3	214	3	943	3	1134
4	237	4	964	4	1136
5	252	5	980	5 (YANKEE)	1139
6	264	6	994	6	1142
7	291	7 (KOON)	1006	7	1170
8	316	8	1016	8	1220
9	332	9	1026	9	1259
10	343	10	1034	10	1289
11	353	11	1042	11	1314
12	360	12	1049	12	1334
13	370	13	1055	13	1349
14	380	14	1062	14 (NECTAR)	1358
15	390	15	1067	15	1366
16	399	16	1072	16	1373
17	408	17	1077	17	1379
18	416	18	1082	18	1385
19	420	19	1086	19	1391
20	424	20	1091	20	1396
21	427	21	1095	21	1400
22	433	22	1099	22	1405
23	436	23	1102	23	1409
24	439	24	1106	24	1413
25	443	25	1109	25	1417
26	446	26 (UNION)	1113	26	1421
27 (ROMEO)	451	27	1116	27	1424
28	573	28	1119	28	1428
29	709	29	1122	29	1431
30	785	30	1125	30	1434
31	843			31	1436

3.2.4 USS BAIROKO Dose Calculations

Dose calculations for the BAIROKO on 1-2 March 1954 are detailed below. For 1 March, separate calculations are presented for the average crew and for crewmen involved in shipboard decontamination. For 2 March, it is assumed the "average" crew and "deck" crew had equal opportunity for exposure. Time periods below deck are indicated by an asterisk(*). After 2 March, the daily film badge dose is calculated by multiplying the integrated intensity topside (Table 2-4) by the time-averaged shielding factor (0.46); the integrated intensity below is multiplied by the fraction of the day spent below deck (0.6). Contributions from each source are summed and converted to a film badge dose. Cumulative film badge doses through 31 May 1954 are given in Table 3-4.

Day	Time Period	Integrated Intensity (mR)	x	Ship Shielding Factor	=	Adjusted Exposure (mR)
		Average Crew				
1 March	0000-0600*	0				0
	0600-0800	0				0
	0800-1300*	1901.9		0.1		190.2
	1300-1700	825.7		1.0		825.7
	1700-2400*	1215.8		0.1		121.6
		3943.4 (Table 2-4)				1137.5

1 March film badge dose = (1138 mR) (0.7 mrem/mR) = 797 mrem (Table 3-4)

Day	Time Period	Integrated Intensity (mR)	x	Ship Shielding Factor	=	Adjusted Exposure (mR)
		Decon/Deck Crew				
1 March	0000-0600*	0				0
	0600-0800	0				0
	0800-1000*	660.3		0.1		66.0
	1000-1200	917.9		1.0		917.9
	1200-1300*	323.6		0.1		32.4
	1300-1900	1184.1		1.0		1184.1
	1900-2400*	857.5		0.1		85.8
		3943.4 (Table 2-4)				2286.2

1 March film badge dose = (2286 mR) (0.7 mrem/mR) = 1600 mrem

Day	Time Period	Integrated Intensity (mR)	x	Ship Shielding Factor	=	Adjusted Exposure (mR)
2 March	0000-0800*	1165.6		0.1		116.6
	0800-1200	480.9		1.0		480.9
	1200-1330*	142.0		0.1		14.2
	1330-1700	152.1		1.0		152.1
	1700-1800*	33.5		0.1		3.4
	1800-2000	62.9		1.0		62.9
	2000-2400*	113.7		0.1		11.4
		2150.7 (Table 2-4)				841.5

2 March film badge dose = (842 mR) (0.7 mR/mrem) = 589 mrem
Cumulative film badge dose through 2 March = 1386 mrem (Table 3-4)

Table 3-4. **Calculated personnel film badge dose, USS BAIROKO.**

March	Cumulative Dose (mrem)	April	Cumulative Dose (mrem)	May	Cumulative Dose (mrem)
1 (BRAVO)	797*	1	2338	1	2585
2	1386	2	2374	2	2594
3	1543	3	2397	3	2601
4	1647	4	2416	4	2606
5	1720	5	2432	5 (YANKEE)	2611
6	1769	6	2445	6	2627
7	1805	7 (KOON)	2457	7	2650
8	1833	8	2467	8	2665
9	1855	9	2477	9	2677
10	1874	10	2485	10	2687
11	1889	11	2493	11	2695
12	1900	12	2500	12	2700
13	1911	13	2507	13	2704
14	1921	14	2513	14 (NECTAR)	2709
15	1930	15	2518	15	2714
16	1937	16	2524	16	2717
17	1944	17	2529	17	2720
18	1950	18	2534	18	2723
19	1956	19	2538	19	2726
20	1961	20	2542	20	2729
21	1966	21	2547	21	2731
22	1970	22	2551	22	2734
23	1975	23	2555	23	2736
24	1979	24	2559	24	2739
25	1982	25	2562	25	2741
26	1986	26 (UNION)	2566	26	2743
27 (ROMEO)	1989	27	2569	27	2745
28	2001	28	2573	28	2747
29	2160	29	2576	29	2750
30	2240	30	2579	30	2751
31	2294			31	2753

*An additional 803 mrem would have been received on 1 March by personnel involved in decontaminating the ship's weather decks.

3.2.5 USS BELLE GROVE Dose Calculations

Dose calculations for the BELLE GROVE on 1-2 March when BRAVO fallout was encountered are detailed below. Time periods below deck are indicated by an asterisk (*). After 2 March, the daily film badge dose is calculated by multiplying the integrated intensity topside (Table 2-5) by the time-averaged shielding factor (0.46); the integrated intensity below is multiplied by the fraction of the day spent below deck (0.6). Contributions from each source are summed and converted to a film badge dose. Cumulative film badge doses through 31 May 1954 are given in Table 3-5.

Day	Time Period	Integrated Intensity (mR)	x	Ship Shielding Factor	=	Adjusted Exposure (mR)
1 March	0000-0600*	0				0
	0600-0830	0				0
	0830-1030*	0				0
	1030-1200	0.5		1.0		0.5
	1200-1530*	39.6		0.1		4.0
	1530-1700	68.5		1.0		68.5
	1700-1800*	108.9		0.1		10.9
	1800-2000	411.0		1.0		411.0
	2000-2400*	647.1		0.1		64.7
		1275.6 (Table 2-5)				559.6

1 March film badge dose = (559.6 mR) (0.7 mrem/mR) = 391.7 mrem (Table 3-5)

Day	Time Period	Integrated Intensity (mR)	x	Ship Shielding Factor	=	Adjusted Exposure (mR)
2 March	0000-0800*	516.7		0.1		51.7
	0800-1200	218.9		1.0		218.9
	1200-1330*	75.0		0.1		7.5
	1330-1700	168.0		1.0		168.0
	1700-1800*	37.7		0.1		3.8
	1800-2000	49.2		1.0		49.2
	2000-2400*	80.0		0.1		8.0
		1145.5 (Table 2-5)				507.1

2 March film badge dose = (507.1 mR) (0.7 mrem/mR) = 355.0 mrem
Cumulative film badge dose through 2 March = 747 mrem (Table 3-5)

Table 3-5. Calculated personnel film badge dose, USS BELLE GROVE.

March	Cumulative Dose (mrem)	April	Cumulative Dose (mrem)	May	Cumulative Dose (mrem)
1 (BRAVO)	392	1	1495	1	1734
2	747	2	1524	2	1744
3	838	3	1548	3	1754
4	907	4	1567	4	1760
5	971	5	1583	5 (YANKEE)	1765
6	1014	6	1596	6	1787
7	1040	7 (KOON)	1607	7	1820
8	1061	8	1617	8	1837
9	1078	9	1626	9	1846
10	1093	10	1635	10	1852
11	1106	11	1642	11	1856
12	1116	12	1649	12	1860
13	1125	13	1656	13	1864
14	1132	14	1662	14 (NECTAR)	1867
15	1140	15	1667	15	1871
16	1146	16	1672	16	1874
17	1153	17	1677	17	1876
18	1158	18	1682	18	1879
19	1163	19	1687	19	1882
20	1168	20	1691	20	1884
21	1173	21	1695	21	1886
22	1177	22	1699	22	1889
23	1181	23	1703	23	1891
24	1185	24	1707	24	1893
25	1188	25	1711	25	1895
26	1191	26 (UNION)	1714	26	1897
27 (ROMEO)	1194	27	1717	27	1899
28	1211	28	1721	28	1901
29	1306	29	1724	29	1903
30	1398	30	1727	30	1904
31	1455			31	1906

3.2.6 USS CURTISS Dose Calculations

Dose calculations for personnel onboard the CURTISS on 1-2 March are detailed below. Time periods below deck are indicated by an asterisk(*). After 2 March, the daily film badge dose is calculated by multiplying the integrated intensity topside (Table 2-6) by the time-averaged shielding factor (0.46); the integrated intensity below is multiplied by the fraction of the day spent below deck (0.6). Contributions from each source are summed and converted to a film badge dose. Cumulative film badge doses through 31 May 1954 are given in Table 3-6.

Day	Time Period	Integrated Intensity (mR)	x	Ship Shielding Factor	=	Adjusted Exposure (mR)
1 March	0000-0600*	0		0.1		0
	0600-1200	12.6		1.0		12.6
	1200-1800*	171.6		0.1		17.2
	1800-2000	83.2		1.0		83.2
	2000-2400*	132.9		0.1		13.3
		400.3 (Table 2-6)				126.3

1 March film badge dose = (126.3 mR) (0.7 mrem/mR) = 88.4 mrem (Table 3-6)

Day	Time Period	Integrated Intensity (mR)	x	Ship Shielding Factor	=	Adjusted Exposure (mR)
2 March	0000-0800*	198.7		0.1		19.9
	0800-1200	69.3		1.0		69.3
	1200-1330*	21.0		0.1		2.1
	1330-1700	38.1		1.0		38.1
	1700-1800*	10.0		0.1		1.0
	1800-2000	20.0		1.0		20.0
	2000-2400*	37.9		0.1		3.8
		395.0 (Table 2-6)				154.2

2 March film badge dose = (154.2 mR) (0.7 mrem/mR) = 107.9 mrem
Cumulative film badge dose through 2 March = 196 mrem (Table 3-6)

Table 3-6. Calculated personnel film badge dose, USS CURTISS.

March	Cumulative Dose (mrem)	April	Cumulative Dose (mrem)	May	Cumulative Dose (mrem)
1 (BRAVO)	88	1	433	1	467
2	196	2	434	2	474
3	244	3	436	3	482
4	268	4	438	4	487
5	290	5	439	5 (YANKEE)	489
6	311	6	440	6	499
7	328	7 (KOON)	441	7	505
8	341	8	441	8	509
9	352	9	443	9	512
10	362	10	444	10	514
11	370	11	445	11	516
12	376	12	446	12	517
13	380	13	447	13	519
14	385	14	448	14 (NECTAR)	520
15	389	15	449	15	521
16	394	16	450	16	522
17	398	17	451	17	523
18	402	18	452	18	524
19	405	19	453	19	524
20	409	20	454	20	525
21	411	21	455	21	526
22	414	22	456	22	526
23	416	23	457	22	527
24	419	24	458	24	527
25	421	25	459	25	528
26	423	26 (UNION)	459	26	529
27 (ROMEO)	425	27	460	27	529
28	426	28	461	28	530
29	427	29	462	29	530
30	429	30	462	30	530
31	431			31	531

3.2.7 USS EPPERSON Dose Calculations

The EPPERSON received relatively light fallout following Shots BRAVO, ROMEO, and NECTAR and crew duty routines were probably not altered by its presence. The daily badge dose is calculated by multiplying the integrated intensity topside (Table 2-7) by the time-averaged shielding factor (0.46); the integrated intensity below is multiplied by the fraction of the day spent below deck (0.6). Contributions from each source are summed and converted to a film badge dose. Cumulative film badge doses through 31 May 1954 are given in Table 3-7.

Table 3-7. Calculated personnel film badge dose, USS EPPERSON.

March	Cumulative Dose (mrem)	April	Cumulative Dose (mrem)	May	Cumulative Dose (mrem)
1 (BRAVO)	15	1	419	1	469
2	65	2	425	2	470
3	92	3	430	3	471
4	108	4	434	4	471
5	118	5	437	5 (YANKEE)	472
6	126	6	439	6	473
7	132	7 (KOON)	441	7	474
8	137	8	443	8	474
9	145	9	445	9	475
10	151	10	446	10	476
11	157	11	448	11	476
12	166	12	449	12	477
13	172	13	451	13	478
14	177	14	452	14 (NECTAR)	480
15	183	15	453	15	489
16	193	16	454	16	494
17	199	17	456	17	497
18	203	18	457	18	500
19	210	19	458	19	501
20	214	20	459	20	503
21	217	21	460	21	504
22	223	22	461	22	506
23	227	23	462	23	507
24	231	24	463	24	508
25	236	25	464	25	509
26	239	26 (UNION)	465	26	509
27 (ROMEO)	257	27	466	27	510
28	306	28	467	28	511
29	353	29	467	29	512
30	390	30	468	30	512
31	410			31	513

3.2.8 USS Dose Calculations

Dose calculations for the ESTES on 1-2 March 1954 are detailed below. For 1 March, separate calculations are presented for the average crew and for crewmen involved in shipboard decontamination. For 2 March, it is assumed the "average" crew and "deck" crew had equal opportunity for exposure. Time periods below deck are indicated by an asterisk(*). After 2 March, the daily film badge dose is calculated by multiplying the integrated intensity topside (Table 2-8) by the time-averaged shielding factor (0.46); the integrated intensity below is multiplied by the fraction of the day spent below deck (0.6). Contributions from each source are summed and converted to a film badge dose. Cumulative film badge doses through 31 May 1954 are given in Table 3-8.

Day	Time Period	Integrated Intensity (mR)	x Ship Shielding Factor	= Adjusted Exposure (mR)
		Average Crew		
1 March	0000-0600*	0		0
	0600-0900	136.6	1.0	136.6
	0900-1100*	455.2	0.1	45.5
	1100-1200	122.4	1.0	122.4
	1200-1400*	203.0	0.1	20.3
	1400-1500	116.0	1.0	116.0
	1500-1700*	259.6	0.1	26.0
	1700-1800	120.0	1.0	120.0
	1800-2000*	240.0	0.1	24.0
	2000-2200	240.0	1.0	240.0
	2200-2400*	240.0	0.1	24.0
		2132.8 (Table 2-8)		874.8

1 March film badge dose = (874.8 mR) (0.7 mrem/mR) = 612.4 mrem (Table 3-8)

Day	Time Period	Integrated Intensity (mR)	x Ship Shielding Factor	= Adjusted Exposure (mR)
		Decon/Deck Crew		
1 March	0000-0600*	0		
	0600-0900	136.6	1.0	136.6
	0900-1100*	455.2	0.1	45.5
	1100-1500	441.4	1.0	441.4
	1500-1700*	259.6	0.1	26.0
	1700-1800	120.0	1.0	120.0
	1800-1900*	120.0	0.1	12.0
	1900-2300	480.0	1.0	480.0
	2300-2400*	120.0	0.1	12.0
		2132.8 (Table 2-8)		1273.5

1 March film badge dose = (1273.5 mR) (0.7 mrem/mR) = 891.5 mR

Day	Time Period	Integrated Intensity (mR)	x Ship Shielding Factor	= Adjusted Exposure (mR)
2 March	0000-0800*	872.3	0.1	87.2
	0800-1200	253.9	1.0	253.9
	1200-1330*	67.2	0.1	6.7
	1330-1700	116.6	1.0	116.6
	1700-1800*	26.0	0.1	2.6
	1800-2000	44.2	1.0	44.2
	2000-2400*	80.0	0.1	8.0
		1460.2 (Table 2-8)		519.2

2 March film badge dose = (519.2 mR) (0.7 mrem/mR) = 363.4 mrem
Cumulative film badge dose through 2 March = 976 mrem (Table 3-8)

Table 3-8. Calculated personnel film badge dose, USS ESTES.

March	Cumulative Dose (mrem)	April	Cumulative Dose (mrem)	May	Cumulative Dose (mrem)
1 (BRAVO)	612*	1	1664	1	1869
2	976	2	1685	2	1872
3	1080	3	1705	3	1874
4	1147	4	1721	4	1877
5	1202	5	1735	5 (YANKEE)	1882
6	1242	6	1746	6	1885
7	1272	7 (KOON)	1757	7	1887
8	1297	8	1766	8	1890
9	1317	9	1775	9	1892
10	1335	10	1782	10	1894
11	1346	11	1790	11	1896
12	1358	12	1796	12	1898
13	1367	13	1801	13	1900
14	1376	14	1807	14 (NECTAR)	1901
15	1385	15	1812	15	1903
16	1393	16	1817	16	1905
17	1401	17	1821	17	1906
18	1408	18	1826	18	1908
19	1414	19	1830	19	1910
20	1420	20	1834	20	1911
21	1425	21	1838	21	1913
22	1430	22	1842	22	1914
23	1435	23	1846	23	1915
24	1440	24	1850	24	1917
25	1444	25	1853	25	1918
26	1448	26 (UNION)	1856	26	1920
27 (ROMEO)	1451	27	1859	27	1921
28	1463	28	1862	28	1922
29	1532	29	1864	29	1924
30	1594	30	1867	30	1925
31	1638			31	1926

* An additional 279 mrem would have been received on 1 March by personnel involved in decontaminating the ship's weather decks.

3.2.9 USNS FRED C. AINSWORTH Dose Calculations

Dose calculations for personnel onboard the AINSWORTH on 1-2 March are detailed below. Time periods below deck are indicated by an asterisk (*). After 2 March, the daily film badge dose is calculated by multiplying the integrated intensity topside (Table 2-9) by the time-averaged shielding factor (0.46); the integrated intensity below is multiplied by the fraction of the day spent below deck (0.6). Contributions from each source are summed and converted to a film badge dose. Cumulative film badge doses through 31 May 1954 are given in Table 3-9.

Day	Time Period	Integrated Intensity (mR)	x	Ship Shieldig Factor	=	Adjusted Exposure (mR)
1 March	0000-0600*	0				0
	0600-1200	0				0
	1200-1330*	0				0
	1330-1700	38.2		1.0		38.2
	1700-1800*	20.5		0.1		2.1
	1800-2000	39.5		1.0		39.5
	2000-2400*	80.0		0.1		8.0
		178.2 (Table 2-9)				87.8

1 March film badge dose = (87.8 mR) (0.7 mrem/mR) = 61.4 mrem (Table 3-9).

Day	Time Period	Integrated Intensity (mR)	x	Ship Shieldig Factor	=	Adjusted Exposure (mR)
2 March	0000-0800*	160.0		0.1		16.0
	0800-1200	80.0		1.0		80.0
	1200-1330*	27.9		0.1		2.8
	1330-1700	47.1		1.0		47.1
	1700-1800*	10.2		0.1		1.0
	1800-2000	20.9		1.0		20.9
	2000-2400*	35.8		0.1		3.6
		381.9 (Table 2-9)				171.4

2 March film badge dose = (171.4 mR) (0.7 mrem/mR) = 120.0 mrem
Cumulative film badg dose through 2 March = 181 mrem (Table 3-9)

Table 3-9. Calculated personnel film badge dose, USNS FRED C. AINSWORTH.

March	Cumulative Dose (mrem)	April	Cumulative Dose (mrem)	May	Cumulative Dose (mrem)
1 (BRAVO)	61	1	738	1	877
2	181	2	757	2	888
3	228	3	769	3	897
4	265	4	779	4	903
5	300	5	787	5 (YANKEE)	906
6	331	6	794	6	927
7	354	7 (KOON)	801	7	959
8	373	8	807	8	980
9	388	9	812	9	995
10	401	10	817	10	1008
11	412	11	821	11	1016
12	421	12	824	12	1020
13	429	13	828	13	1024
14	437	14	832	14 (NECTAR)	1028
15	443	15	835	15	1032
16	449	16	838	16	1035
17	454	17	841	17	1037
18	459	18	844	18	1040
19	463	19	846	19	1043
20	467	20	849	20	1045
21	471	21	852	21	1047
22	474	22	854	22	1049
23	477	23	857	23	1051
24	480	24	859	24	1053
25	483	25	861	25	1055
26	486	26 (UNION)	863	26	1057
27 (ROMEO)	488	27	865	27	1058
28	502	28	867	28	1060
29	617	29	869	29	1062
30	671	30	870	30	1063
31	709			31	1064

3.2.10 USS GYPSY Dose Calculations

Dose calculations for the GYPSY on 1-2 March when BRAVO fallout was encountered are detailed below. Time periods below deck are indicated by an asterisk (*). After 2 March, the daily film badge dose is calculated by multiplying the integrated intensity topside (Table 2-10) by the time-averaged shielding factor (0.46); the integrated intensity below is multiplied by the fraction of the day spent below deck (0.6). Contributions from each source are summed and converted to a film badge dose. Cumulative film badge doses through 31 May 1954 are given in Table 3-10.

Day	Time Period	Integrated Intensity (mR)	x	Ship Shielding Factor	=	Adjusted Exposure (mR)
1 March	0000-0600*	0				0
	0600-1200	0				0
	1200-1330*	0.8		0.1		0.1
	1330-1700	324.5		1.0		324.5
	1700-1800*	240.0		0.1		24.0
	1800-1900	223.7		1.0		223.7
	1900-2400*	730.8		0.1		73.1
		1519.8 (Table 2-10)				645.4

1 March film badge dose = (645.4 mR)(0.7 mrem/mR) = 451.8 mrem (Table 3-10)

Day	Time Period	Integrated Intensity (mR)	x	Ship Shielding Factor	=	Adjusted Exposure (mR)
2 March	0000-0800*	852.6		0.1		85.3
	0800-1200	241.6		1.0		241.6
	1200-1330*	66.0		0.1		6.6
	1330-1700	142.7		1.0		142.7
	1700-1800*	38.5		0.1		3.9
	1800-2000	73.0		1.0		73.0
	2000-2400*	140.0		0.1		14.0
		1554.4(Table 2-10)				567.1

2 March film badge dose = (567.1mR)(0.7 mrem/mR) = 397.0 mrem
Cumulative film badge dose through 2 March = 849 mrem (Table 3-10)

Table 3-10. Calculated personnel film badge dose, USS GYPSY.

March	Cumulative Dose (mrem)	April	Cumulative Dose (mrem)	May	Cumulative Dose (mrem)
1 (BRAVO)	452	1	2361	1	2602
2	849	2	2373	2	2608
3	1050	3	2385	3	2613
4	1213	4	2396	4	2618
5	1357	5	2407	5 (YANKEE)	2623
6	1480	6	2417	6	2628
7	1580	7 (KOON)	2427	7	2633
8	1662	8	2437	8	2638
9	1733	9	2446	9	2643
10	1795	10	2456	10	2648
11	1849	11	2464	11	2652
12	1895	12	2473	12	2657
13	1936	13	2482	13	2661
14	1975	14	2490	14 (NECTAR)	2666
15	2012	15	2498	15	2670
16	2045	16	2505	16	2674
17	2076	17	2513	17	2678
18	2105	18	2520	18	2682
19	2130	19	2528	19	2687
20	2155	20	2535	20	2691
21	2179	21	2542	21	2694
22	2201	22	2548	22	2698
23	2222	23	2555	23	2702
24	2242	24	2561	24	2706
25	2261	25	2567	25	2710
26	2278	26 (UNION)	2574	26	2713
27 (ROMEO)	2293	27	2580	27	2717
28	2308	28	2585	28	2720
29	2322	29	2591	29	2724
30	2336	30	2597	30	2727
31	2349			31	2731

3.2.11 USS LST-551 Dose Calculations

The LST-551 experienced fallout after Shots BRAVO, ROMEO, and NECTAR while participating at Operation CASTLE. All fallout was either light (Shots BRAVO and NECTAR), or came at a time when normal crew routines were not significantly altered by its presence (ROMEO). The daily film badge dose is calculated by multiplying the integrated intensity topside (Table 2-11) by the time-averaged shielding factor (0.46); the integrated intensity below is multiplied by the fraction of the day spent below deck (0.6). Contributions from each source are summed and converted to a film badge dose. Table 3-11 gives the cumulative film badge dose through 31 May 1954.

3.2.12 USS LST-762 Dose Calculations

Most of the fallout that was experienced onboard the LST-762 occurred while the ship was beached on Parry Island, Enewetak Atoll (Shots BRAVO and ROMEO). This fallout was relatively light and normal crew routines were probably not altered by its presence. Although Shot YANKEE fallout necessitated using the ship's washdown system intermittently for a four-hour period during the afternoon of 6 May, intensities were not so high as to seriously restrict crew duties. A "typical" work day has been assumed on 6 May which tends to high-side the dose calculated for that day. The daily film badge dose is calculated by multiplying the integrated intensity topside (Table 2-12) by the time-averaged shielding factor (0.46); the integrated intensity below is multiplied by the fraction of the day spent below deck (0.6). Contributions from each source are summed and converted to a film badge dose. Cumulative film badge doses are given in Table 3-13 thorugh 31 May 1954.

3.2.13 USS LST-825 Dose Calculations

The LST-825 experienced light fallout following Shot BRAVO as it was passing through the PPG enroute to Japan. Crew activities would not have been altered by this contamination. Since the ship's hull and interior saltwater systems did not become contaminated from steaming in radioactive water, personnel film badge doses are calculated by multiplying the integrated free-field intensities in Table 2-13 by the time-averaged shielding factor (0.46), and then by 0.7 to convert to a film badge dose. Cumulative film badge doses through 31 May 1954 are given in Table 3-13.

Table 3-11. Calculated personnel film badge dose, USS LST-551.

March	Cumulative Dose (mrem)	April	Cumulative Dose (mrem)	May	Cumulative Dose (mrem)
1 (BRAVO)	15	1	666	1	835
2	65	2	687	2	837
3	92	3	704	3	839
4	120	4	718	4	841
5	158	5	729	5 (YANKEE)	843
6	190	6	739	6	845
7	215	7 (KOON)	747	7	847
8	236	8	754	8	849
9	247	9	761	9	850
10	256	10	767	10	852
11	264	11	772	11	853
12	274	12	777	12	855
13	280	13	781	13	857
14	287	14	785	14 (NECTAR)	860
15	294	15	789	15	870
16	300	16	793	16	876
17	304	17	797	17	880
18	308	18	800	18	883
19	311	19	804	19	885
20	315	20	807	20	888
21	320	21	810	21	890
22	325	22	813	22	892
23	328	23	815	23	894
24	331	24	818	24	895
25	333	25	821	25	897
26	336	26 (UNION)	823	26	898
27 (ROMEO)	343	27	826	27	900
28	360	28	828	28	901
29	502	29	831	29	903
30	577	30	833	30	904
31	631			31	905

Table 3-12. Calculated personnel film badge dose, USS LST-762.

March	Cumulative Dose (mrem)	April	Cumulative Dose (mrem)	May	Cumulative Dose (mrem)
1 (BRAVO)	15	1	461	1	693
2	65	2	488	2	696
3	92	3	509	3	699
4	117	4	527	4	702
5	134	5	542	5 (YANKEE)	704
6	147	6	555	6	801
7	161	7 (KOON)	567	7	848
8	180	8	578	8	870
9	198	9	588	9	885
10	207	10	597	10	897
11	215	11	605	11	907
12	222	12	612	12	915
13	227	13	619	13	922
14	236	14	625	14 (NECTAR)	928
15	241	15	630	15	933
16	246	16	636	16	938
17	250	17	641	17	943
18	254	18	646	18	947
19	257	19	650	19	951
20	261	20	655	20	955
21	264	21	659	21	958
22	267	22	663	22	961
23	270	23	667	23	965
24	272	24	671	24	968
25	275	25	674	25	971
26	277	26 (UNION)	678	26	973
27 (ROMEO)	283	27	681	27	976
28	299	28	684	28	979
29	322	29	687	29	981
30	381	30	691	30	984
31	427			31	986

Table 3-13. Calculated personnel film badge dose, USS LST-825.

March	Cumulative Dose (mrem)	April	Cumulative Dose (mrem)	May	Cumulative Dose (mrem)
1 (BRAVO)	15	1	169	1	181
2	65	2	170	2	181
3	92	3	171	3	181
4	108	4	171	4	182
5	118	5	172	5 (YANKEE)	182
6	126	6	172	6	182
7	132	7 (KOON)	173	7	182
8	136	8	173	8	182
9	140	9	173	9	183
10	143	10	174	10	183
11	146	11	174	11	183
12	148	12	175	12	183
13	151	13	175	13	184
14	152	14	175	14 (NECTAR)	184
15	154	15	176	15	184
16	156	16	176	16	184
17	157	17	177	17	184
18	158	18	177	18	185
19	159	19	177	19	185
20	160	20	178	20	185
21	161	21	178	21	185
22	162	22	178	22	185
23	163	23	179	23	186
24	164	24	179	24	186
25	165	25	179	25	186
26	166	26 (UNION)	179	26	186
27 (ROMEO)	166	27	180	27	186
28	167	28	180	28	186
29	168	29	180	29	187
30	168	30	181	30	187
31	169			31	187

3.2.14 USS 975 Dose Calculations

Dose calculations for the LST-975 on 6-7 May, when YANKEE fallout was encountered, are detailed below. Time periods below deck are indicated by an asterisk (*). After 7 May, the daily film badge dose is calculated by multiplying the integrated intensities in Table 2-14 by the time-averaged shielding factor (0.46), and then by the film badge conversion factor (0.7). Cumulative film badge doses through 31 May 1954 are given in Table 3-14.

Day	Time Period	Integrated Intensity (mR)	x	Ship Shieldig Factor	=	Adjusted Exposure (mR)
6 May	0000-0600*	0				0
	0600-1200	0				0
	1200-1330*	0				0
	1330-1500	40.0		1.0		40.0
	1500-1600*	43.0		0.1		4.3
	1600-1700	69.0		1.0		69.0
	1700-1800*	90.5		0.1		9.1
	1800-2000	162.2		1.0		162.2
	2000-2400*	206.5		0.1		20.7
		611.2 (Table 2-14)				305.3

6 May film badge dose = (305.3 mR) (0.7 mrem/mR) = 213.7 mrem (Table 3-14)

Day	Time Period	Integrated Intensity (mR)	x	Ship Shieldig Factor	=	Adjusted Exposure (mR)
7 May	0000-0800*	177.5		0.1		17.8
	0800-1200	42.5		1.0		42.5
	1200-1330*	14.0		0.1		1.4
	1330-1700	31.3		1.0		31.3
	1700-1800*	8.6		0.1		0.9
	1800-2000	16.7		1.0		16.7
	2000-2400*	32.0		0.1		3.2
		322.6 (Table 2-14)				113.8

7 May film badge dose = (113.8 mR) (0.7 mrem/mR) = 79.7 mrem
Cumulative film badge dose through 7 May = 293 mrem (Table 3-14)

Table 3-14. Calculated personnel film badge dose, USS LST-975.

March	Cumulative Dose (mrem)	April	Cumulative Dose (mrem)	May	Cumulative Dose (mrem)
1 (BRAVO)		1		1	
2		2		2	
3		3		3	
4		4		4	
5		5		5 (YANKEE)	0
6		6		6	214
7		7 (KOON)		7	293
8		8		8	343
9		9		9	376
10		10		10	400
11		11		11	418
12		12		12	433
13		13		13	445
14		14		14 (NECTAR)	455
15		15		15	464
16		16		16	471
17		17		17	478
18		18		18	484
19		19		19	489
20		20		20	494
21		21		21	499
22		22		22	503
23		23		23	506
24		24		24	510
25		25		25	513
26		26 (UNION)		26	516
27 (ROMEO)		27		27	519
28		28		28	521
29		29		29	524
30		30		30	526
31				31	529

3.2.15 USS NICHOLAS Dose Calculations

Dose calculations for the NICHOLAS on 26-27 April, when UNION fallout was encountered, are detailed below. Time periods below deck are indicated by an asterisk (*). For all other days, the daily film badge dose is calculated by multiplying the integrated intensity topside (Table 2-15) by the time-averaged shielding factor (0.46); the integrated intensity below is multiplied by the fraction of the day spent below deck (0.6). Contributions from each source are summed and converted to a film badge dose. Cumulative film badge doses through 31 May 1954 are given in Table 3-15.

Day	Time Period	Integrated Intensity (mR)	x	Ship Shieldig Factor	=	Adjusted Exposure (mR)
26 April	0000-0600*	0				0
	0600-1200	0				0
	1200-1430*	32.5		0.1		3.3
	1430-1700	78.5		1.0		78.5
	1700-1800*	25.2		0.1		2.5
	1800-2000	50.4		1.0		50.4
	2000-2400*	81.0		0.1		8.1
		267.6 (Table 2-15)				142.8

26 April film badge dose = (142.8 mR) (0.7 mrem/mR) = 100.0 mrem

Day	Time Period	Integrated Intensity (mR)	x	Ship Shieldig Factor	=	Adjusted Exposure (mR)
27 April	0000-0800*	127.2		0.1		12.7
	0800-1200	49.9		1.0		49.9
	1200-1330*	17.6		0.1		1.8
	1330-1700	41.4		1.0		41.4
	1700-1800*	10.3		0.1		1.0
	1800-2000	19.5		1.0		19.5
	2000-2400*	37.0		0.1		3.7
		302.9 (Table 2-15)				130.0

27 April film badge dose = (130.0 mR) (0.7 mrem/mR) = 91 mrem

Table 3-15. Calculated personnel film badge dose, USS NICHOLAS.

March	Cumulative Dose (mrem)	April	Cumulative Dose (mrem)	May	Cumulative Dose (mrem)
1 (BRAVO)	0	1	283	1	799
2	0	2	310	2	810
3	0	3	331	3	819
4	24	4	348	4	827
5	54	5	362	5 (YANKEE)	833
6	70	6	374	6	839
7	82	7 (KOON)	385	7	845
8	88	8	396	8	849
9	94	9	406	9	854
10	99	10	415	10	858
11	102	11	423	11	862
12	105	12	430	12	865
13	107	13	436	13	869
14	109	14	442	14 (NECTAR)	874
15	111	15	446	15	885
16	113	16	451	16	893
17	114	17	455	17	898
18	116	18	459	18	903
19	117	19	464	19	906
20	119	20	468	20	910
21	120	21	472	21	913
22	121	22	476	22	916
23	122	23	480	23	919
24	124	24	484	24	922
25	128	25	488	25	924
26	130	26 (UNION)	589	26	927
27 (ROMEO)	132	27	681	27	929
28	133	28	735	28	932
29	150	29	765	29	934
30	206	30	785	30	936
31	250			31	938

3.2.16 USS PHILIP Dose Calculations

Dose calculations for the PHILIP on 1-2 March 1954 are detailed below. For 1 March, separate calculations are presented for the average crew and for crewmen involved in shipboard decontamination. For 2 March, it is assumed the "average" crew and "deck" crew had equal opportunity for exposure. Time periods below deck are indicated by an asterisk(*). After 2 March, the daily film badge dose is calculated by multiplying the integrated intensity topside (Table 2-16) by the time-averaged shielding factor (0.46); the integrated intensity below is multiplied by the fraction of the day spent below deck (0.6). Contributions from each source are summed and converted to a film badge dose. Cumulative film badge doses through 31 May 1954 are given in Table 3-16.

Day	Time Period	Integrated Intensity (mR)	x Ship Shielding Factor	= Adjusted Exposure (mR)
		Average Crew		
1 March	0000-0600*	0		0
	0600-0900	218.7	1.0	218.7
	0900-1100*	679.0	0.1	67.9
	1100-1200	168.3	1.0	168.3
	1200-1400*	288.4	0.1	28.8
	1400-1500	136.0	1.0	136.0
	1500-1700*	358.4	0.1	35.8
	1700-1800	243.3	1.0	243.3
	1800-2000*	422.3	0.1	42.2
	2000-2200	392.0	1.0	392.0
	2200-2400*	380.8	0.1	38.1
		3287.2 (Table 2-16)		1371.1

1 March film badge dose = (1371. mR) (0.7 mrem/mR) = 959.8 mrem (Table 3-16)

Day	Time Period	Integrated Intensity (mR)	x Ship Shielding Factor	= Adjusted Exposure (mR)
		Decon/Deck Crew		
1 March	0000-0600*	0		0
	0600-0900	218.7	1.0	218.7
	0900-1100*	679.0	0.1	67.9
	1100-1500	592.6	1.0	592.6
	1500-1700*	358.4	0.1	35.8
	1700-1800	243.3	1.0	243.3
	1800-1900*	225.8	0.1	22.6
	1900-2300	730.4	1.0	730.4
	2300-2400*	189.0	0.1	18.9
		3287.2 (Table 2-16)		1980.2

1 March film badge dose = (1980.2 mR) (0.7 mrem/mR) = 1386 mrem

Day	Time Period	Integrated Intensity (mR)	x Ship Shielding Factor	= Adjusted Exposure (mR)
2 March	0000-0800*	1211.4	0.1	121.1
	0800-1200	372.5	1.0	372.5
	1200-1330*	110.8	0.1	11.1
	1330-1700	219.5	1.0	219.5
	1700-1800*	56.9	0.1	5.7
	1800-2000	97.7	1.0	97.7
	2000-2400*	171.2	0.1	17.1
		2240.0 (Table 2-16)		844.7

2 March film badge dose = (844.7 mR) (0.7 mrem/mR) = 591.3 mrem
Cumulative film badge dose through 2 March = 1551 mrem (Table 3-16)

Table 3-16. Calculated personnel film badge dose, USS PHILIP.

March	Cumulative Dose (mrem)	April	Cumulative Dose (mrem)	May	Cumulative Dose (mrem)
1	960*	1	2710	1	3014
2	1551	2	2745	2	3041
3	1788	3	2772	3	3066
4	1911	4	2795	4	3081
5	2003	5	2814	5 (YANKEE)	3091
6	2072	6	2831	6	3151
7	2122	7 (KOON)	2845	7	3238
8	2158	8	2858	8	3299
9	2189	9	2870	9	3344
10	2214	10	2880	10	3378
11	2235	11	2891	11	3407
12	2252	12	2902	12	3431
13	2267	13	2910	13	3452
14	2281	14	2918	14 (NECTAR)	3464
15	2292	15	2925	15	3474
16	2303	16	2932	16	3481
17	2312	17	2938	17	3489
18	2321	18	2944	18	3495
19	2329	19	2950	19	3502
20	2336	20	2955	20	3508
21	2343	21	2961	21	3513
22	2349	22	2966	22	3518
23	2355	23	2971	23	3524
24	2360	24	2975	24	3528
25	2366	25	2980	25	3533
26	2371	26 (UNION)	2984	26	3537
27 (ROMEO)	2381	27	2988	27	3541
28	2392	28	2992	28	3546
29	2519	29	2996	29	3549
30	2602	30	3001	30	3553
31	2666			31	3556

*An additional 426 mrem would have been received on 1 March by personnel involved in decontaminating the ship's weather decks.

3.2.17 USS RENSHAW Dose Calculations

The RENSHAW experienced relatively light fallout following Shots BRAVO, ROMEO, and NECTAR and crew duty routines probably were not altered by its presence. The daily film badge dose is calculated by multiplying the integrated intensity topside (Table 2-17) by the time-averaged shielding factor (0.46); the integrated intensity below is multiplied by the fraction of the day spent below deck (0.6). Contributions from each source are summed and converted to a film badge dose. Cumulative film badge doses through 31 May 1954 are given in Table 3-17.

Table 3-17. Calculated personnel film badge dose, USS RENSHAW.

March	Cumulative Dose (mrem)	April	Cumulative Dose (mrem)	May	Cumulative Dose (mrem)
1 (BRAVO)	15	1	421	1	515
2	65	2	432	2	530
3	92	3	441	3	540
4	108	4	447	4	548
5	118	5	453	5 (YANKEE)	556
6	126	6	458	6	612
7	132	7 (KOON)	463	7	677
8	141	8	467	8	707
9	149	9	470	9	729
10	158	10	474	10	745
11	165	11	476	11	759
12	170	12	479	12	770
13	175	13	482	13	780
14	180	14	484	14 (NECTAR)	791
15	189	15	486	15	806
16	196	16	488	16	818
17	204	17	490	17	826
18	210	18	492	18	834
19	214	19	494	19	840
20	218	20	496	20	846
21	224	21	497	21	851
22	228	22	499	22	856
23	234	23	500	23	860
24	237	24	502	24	864
25	240	25	503	25	868
26	243	26 (UNION)	504	26	871
27 (ROMEO)	245	27	505	27	875
28	252	28	507	28	878
29	329	29	508	29	881
30	378	30	510	30	884
31	402			31	886

3.2.18 USS SIOUX Dose Calculations

Dose calculations for 1-2 March for personnel onboard the SIOUX are detailed below. Time periods below deck are indicated by an asterisk (*). After 2 March, the daily film badge dose is calculated by multiplying the integrated intensity topside (Table 2-18) by the time-averaged shielding factor (0.46); the integrated intensity below is multiplied by the fraction of the day spent below deck (0.6). Contributions from each source are summed and converted to a film badge dose. Cumulative film badge doses through 31 May 1954 are given in Table 3-18.

Day	Time Period	Integrated Intensity (mR)	x	Ship Shielding Factor	=	Adjusted Exposure (mR)
1 March	0000-0600*	0				0
	0600-1200	0				0
	1200-1330*	3.0		0.1		0.3
	1330-1400	5.0		1.0		5.0
	1400-1500*	8.6		0.1		0.9
	1500-1700	24.8		1.0		24.8
	1700-2000*	98.8		0.1		9.9
	2000-2100	17.5		1.0		17.5
	2100-2400*	86.6		0.1		8.7
		244.3 (Table 2-18)				67.1

1 March film badge dose = (67.1 mR) (0.7 mrem/mR) = 47.0 mrem (Table 3-18)

Day	Time Period	Integrated Intensity (mR)	x	Ship Shielding Factor	=	Adjusted Exposure (mR)
2 March	0000-0800*	215.9		0.1		21.6
	0800-1200	43.8		1.0		43.8
	1200-1330*	14.6		0.1		1.5
	1330-1700	31.8		1.0		31.8
	1700-1800*	8.5		0.1		0.9
	1800-2000	14.8		1.0		14.8
	2000-2400*	25.9		0.1		2.6
		355.3 (Table 2-18)				117.0

2 March film badge dose = (117 mR) (0.7 mrem/mR) = 81.9 mrem
Cumulative film badge dose through 2 March = 129 mrem (Table 3-18)

Table 3-18. Calculated personnel film badge dose, USS SIOUX.

March	Cumulative Dose (mrem)	April	Cumulative Dose (mrem)	May	Cumulative Dose (mrem)
1 (BRAVO)	47	1	994	1	1189
2	129	2	1016	2	1192
3	167	3	1032	3	1194
4	198	4	1046	4	1197
5	229	5	1058	5 (YANKEE)	1205
6	264	6	1069	6	1445
7	314	7 (KOON)	1079	7	1548
8	362	8	1088	8	1610
9	396	9	1096	9	1660
10	422	10	1103	10	1680
11	443	11	1110	11	1693
12	461	12	1116	12	1704
13	480	13	1121	13	1714
14	498	14	1128	14 (NECTAR)	1725
15	515	15	1133	15	1741
16	531	16	1138	16	1752
17	544	17	1142	17	1761
18	557	18	1146	18	1769
19	566	19	1150	19	1776
20	574	20	1154	20	1782
21	582	21	1158	21	1788
22	590	22	1161	22	1793
23	596	23	1165	23	1798
24	603	24	1168	24	1803
25	608	25	1171	25	1807
26	614	26 (UNION)	1175	26	1811
27 (ROMEO)	619	27	1178	27	1815
28	722	28	1181	28	1819
29	874	29	1183	29	1823
30	931	30	1186	30	1826
31	964			31	1830

SECTION 4
UNCERTAINTY ANALYSIS

The uncertainty in calculated film badge doses is estimated from the underlying parameters. Not only is the uncertainty in the mean film badge dose determined, but also the distribution in dose about the mean is estimated for typical personnel. The basic uncertainties in the topside environment include radiation intensities on deck, the positions of personnel (hence their exposure) on deck, the time spent on deck, and the shielding from fallout afforded to those below. Uncertainties in the radiation environment below due to ship contamination are dominated by assumed buildup and decay rates of the radioactive material accumulated on the ship's hull and interior salt water systems.

Intensity levels on deck are determined from shipboard radiological survey data, supplemented at late times by decay rates measured on Bikini Atoll. Individual meter readings on deck, where available, are taken as accurate, their inherent error having a negligible influence on the overall uncertainty in dose. Average on-deck intensity as a function of time is taken as accurate; the power law interpolation in time between surveys closely approximates fission product decay at the times after burst considered. Power law fitting is less accurate during fallout deposition and decontamination; however, the influence of this uncertainty is minimized because the typical crew-member was below during these intervals. Overall, error in on-deck intensity is small compared to the uncertainty associated with crew position in the non-uniform radiation environment.

The significant variation in on-deck intensities following fallout deposition focuses attention on the positioning of the crew relative to those intensities. Specific data on crew positioning are lacking; however, the crew size and the variety of duties performed suggest that the crew was, on the average, randomly positioned on deck and therefore randomly exposed to each reported intensity. The uncertainty in dose resulting from these assumptions cannot be directly quantified, except by considering unrealistic extremes. However, an indication is provided by the assumption that, for each interval topside, personnel remained in the same general deck area but were randomly repositioned for each subsequent interval. A distribution around the mean film badge reading is calculated by assuming a random position, corresponding to an intensity reading, each time a crewman comes on deck. The tails of this distribution indicate, in a general way, the possible error of the mean dose if crew positioning were significantly biased toward the extremes of intensity readings. Note: for personnel moving continuously about the deck, their dose approaches the calculated mean.

In order to arrive at dose distributions, it is assumed the reported average intensities used to reconstruct the topside environments in Section 2 were derived from many topside measurements that were normally distributed, and could be characterized by a mean (μ) and standard deviation (σ). For the sixteen ships under consideration, shipboard survey data are not available to substantiate this assumption; however, detailed surveys on the YAG-40 following Shots ROMEO and YANKEE indicate a distribution of topside intensity values that can be approximated by applying a normal distribution to the data. Figure 4-1 summarizes the results of surveys taken onboard the ship on 31 March and 8 May. Each survey consists of 70 topside intensity readings obtained at the same location following each shot (Reference 18). The survey data are depicted by histograms while the smooth curves represent normal distributions fitted to the survey data. From Figure 4-1, it does appear that the topside intensities following fallout deposition can be adequately represented by assuming a normal distribution of values.

The fractional (of mean) standard deviation (μ/σ), a measure of the spread in the intensity data obtained during each survey, is determined to vary between 0.52 (31 March survey) and 0.40 (8 May survey) on the YAG 40. A value of 0.50 is chosen as being applicable to represent the spread in intensity data around the average (mean) values reported for the sixteen ships of interest. The normal distribution around the average intensity is integrated throughout each interval on deck to obtain the corresponding distribution in dose. When the dose distributions from all intervals are combined, the square of the standard deviation of the resultant normal distribution is equal to the sum of the squares of the standard deviations of the contributing distributions. As contributions from more intervals are added, the fractional standard deviation of the combined distribution decreases. Because the calculated dose in

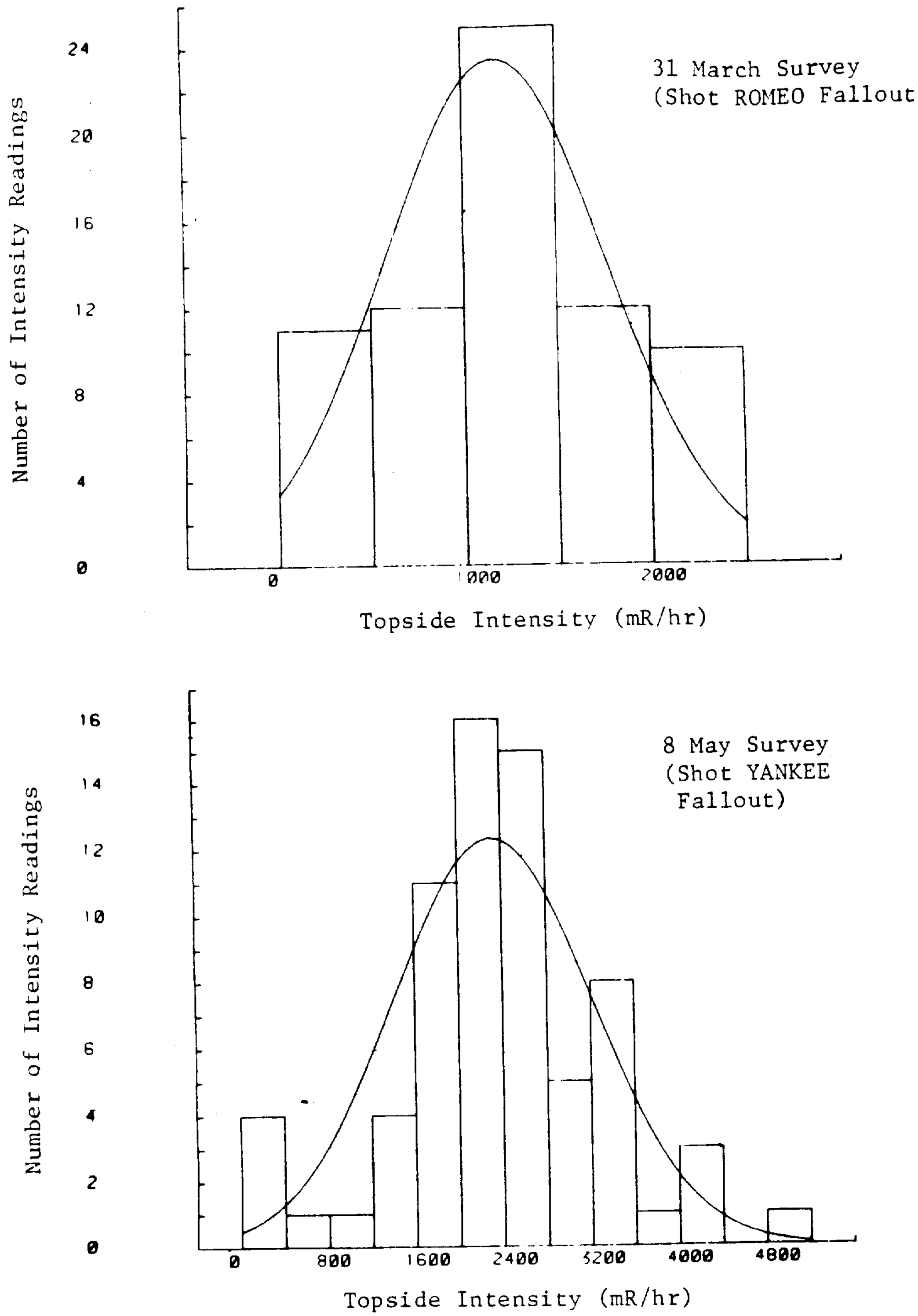

Figure 4-1. Results of radiological surveys onboard the YAG-40 following Shot ROMEO and Shot YANKEE

reality approaches a limit with time, a finite distribution remains around the mean total dose. Distributions for each ship are reported at the 90-percent level, i.e., $\pm 1.65\sigma$ (5th to 95th percentile). Although exposure below deck to fallout makes some contribution to the mean total dose, it is not used in generating a topside dose distribution because its minor contribution involves an averaging of topside readings (for geometrical reasons). Despite the simplified calculation of mean dose starting on the third day after burst, the uncertainty analysis continues to reflect three intervals (taken equal) per day of on-deck exposure at random positions.

The value for the fraction of time spent on deck is estimated to be accurate within a factor of 1.2 with 90-percent confidence. For the typical (non-shot) day, this corresponds to 8 to 11½ hours on deck. The systematic uncertainty in the time on deck is considered to be greater than its random variation from day to day and ship to ship. The uncertainty in mean total dose is reasonably high-sided by treating the uncertainty in time on deck as a systematic error; as such, the factor of 1.2 applies to the on-deck contribution to the mean total dose as well. Not only the means, but also the distributions as discussed above (minus the below-deck contribution) are directly proportional to the time spent on deck. The below-deck contribution introduces a small, ship-dependent perturbation to the factor of 1.2.

The ship-shielding factor reduces the below-deck crew exposure to fallout to a minor contribution to dose, thus any realistic error in that parameter has only a few-percent effect on the total dose. For example, for a typical day (60 percent below deck) and a ship-shielding factor of 0.10, with an error generously assumed to be ± 0.05, the fractional error introduced is $\frac{0.60(0.05)}{0.60(0.10)+0.40(1)} = 0.065$. Such values negligibly increase the uncertainty in dose resulting from uncertainty in time spent topside.

For doses resulting from fallout onboard ships or islands, the calculated dose distribution for typical personnel (except as noted) and the uncertainty in the mean (based on time topside) are as follows. The bounds on each represent the 5th and 95th percentiles.

Shipboard Personnel	Calculated Fallout Dose Distribution	Uncertainty in Mean Fallout Dose
USS APACHE	1.01 ± .12 rem	1.01 ± .20 rem
USS BAIROKO		
(Average Crew)	2.56 ± .58	2.56 ± .51
(Decon Crew)	3.36 ± .92	3.36 ± .67
USS BELLE GROVE	1.67 ± .31	1.67 ± .33
USS CURTISS	0.37 ± .07	0.37 ± .07
USS EPPERSON	0.39 ± .05	0.39 ± .08
USS ESTES		
(Average Crew)	1.76 ± .27	1.76 ± .35
(Decon Crew)	2.04 ± .43	2.04 ± .41
USNS FRED C. AINSWORTH	0.79 ± .10	0.79 ± .16
USS GYPSY	2.43 ± .32	2.43 ± .49
USS LST-551	0.69 ± .09	0.69 ± .14
USS LST-762	0.83 ± .08	0.83 ± .17
USS LST-825	0.19 ± .03	0.19 ± .04
USS LST-975	0.53 ± .12	0.53 ± .11
USS NICHOLAS	0.75 ± .08	0.75 ± .15
USS PHILIP		
(Average Crew)	2.93 ± .44	2.93 ± .59
(Decon Crew)	3.36 ± .67	3.36 ± .67
USS RENSHAW	0.45 ± .05	0.45 ± .09
USS SIOUX	1.19 ± .12	1.19 ± .24
Island Based Personnel		
Enewetak Atoll	1.09 ± .10	1.09 ± .22
Kwajalein Atoll	0.32 ± .03	0.32 ± .06

Intensity levels below are estimated using a ship contamination model that is dependent on radiological decay rates and the rapidity with which hulls accumulate contamination. The decay rate of $t^{-1.3}$ that was used for Operation CROSSROADS is applied in this report, but an estimated uncertainty in the exponent of ±0.2 is also considered. This variation is of the magnitude that thermonuclear devices can exhibit within days after detonation. By influencing the parameter S described in Section 2, the steeper decay rate ($t^{-1.5}$) results in larger contamination doses for all ships. In all cases, the variation in dose with decay rate is within a factor of two. Also as determined for Operation CROSSROADS, saturation of ship hulls occurred within the order of one day. Estimated limits for the time to saturation are 0.5 and 2 days. For all ships, these saturation times influence the contamination dose by less than a factor of 1.5. The combined uncertainty from decay rate and saturation time, approximated as a normal distribution, is shown for each ship below at the estimated 90-percent level.

Ship	Ship Contamination Dose
APACHE	0.43 ± .17 rem
BAIROKO	0.20 ± .09
BELLE GROVE	0.24 ± .12
CURTISS	0.17 ± .10
EPPERSON	0.12 ± .06
ESTES	0.16 ± .07
AINSWORTH	0.27 ± .13
GYPSY	0.31 ± .12
LST-551	0.21 ± .08
LST-762	0.16 ± .07
LST-825	---
LST-975	---
NICHOLAS	0.19 ± .10
PHILIP	0.63 ± .4
RENSHAW	0.44 ± .3
SIOUX	$0.64^{+.6}_{-.4}$

SECTION 5
FILM BADGE DOSIMETRY

At Operation CASTLE, the issuance of film badges to personnel generally followed one of two basic procedures: (1) individual or "mission" badging, where personnel were issued badges when they were expected to enter areas of radioactive contamination other than those encountered onboard the ships; and (2) cohort badging, where a group of individuals performing duties in the same area of a ship would be assigned a dose based on the actual reading of one film badge worn by an individual within the group. Generally, individual badges reflect higher than average doses, whereas cohort badges reflect the average exposure of a group of individuals during a certain time period. The total dose assigned to an individual was obtained by summing the recorded dose on a cohort badge with any individual (mission) badges assigned to that individual during the same period of time covered by the cohort badge.

Sufficient dosimetry data are available for three ships for which dose calculations have been performed that allow meaningful comparisons. On these three ships, the ESTES, PHILIP, and SIOUX, cohort badges were issued for three time periods and provide a continuous record of exposure during the entire operation. Reconstructed doses are compared with dosimetry data obtained during each specific time period and with the total operational exposure of individuals who were badged during all three periods. Not all personnel badged during a specific period wore badges for all three periods, thus the number of doses obtained covering the entire operation is less than the number of personnel badged in any one time period.

Figures 5-1, 5-2, and 5-3 summarize the available dosimetry data from the ESTES, PHILIP, and SIOUX, respectively, as obtained from cohort badges. The dosimetry data for each ship are depicted by a series of four histograms; one for each of the three badged periods and a summary of the total dose received by those personnel who were badged for the entire operation, i.e., for all three periods. For comparison, the calculated mean is also depicted above each histogram. For the total operation summaries, upper and lower bounds for the calculated means are also depicted. For the ESTES and PHILIP, calculated means for the average crew and for those involved with decontamination following Shot BRAVO are both presented.

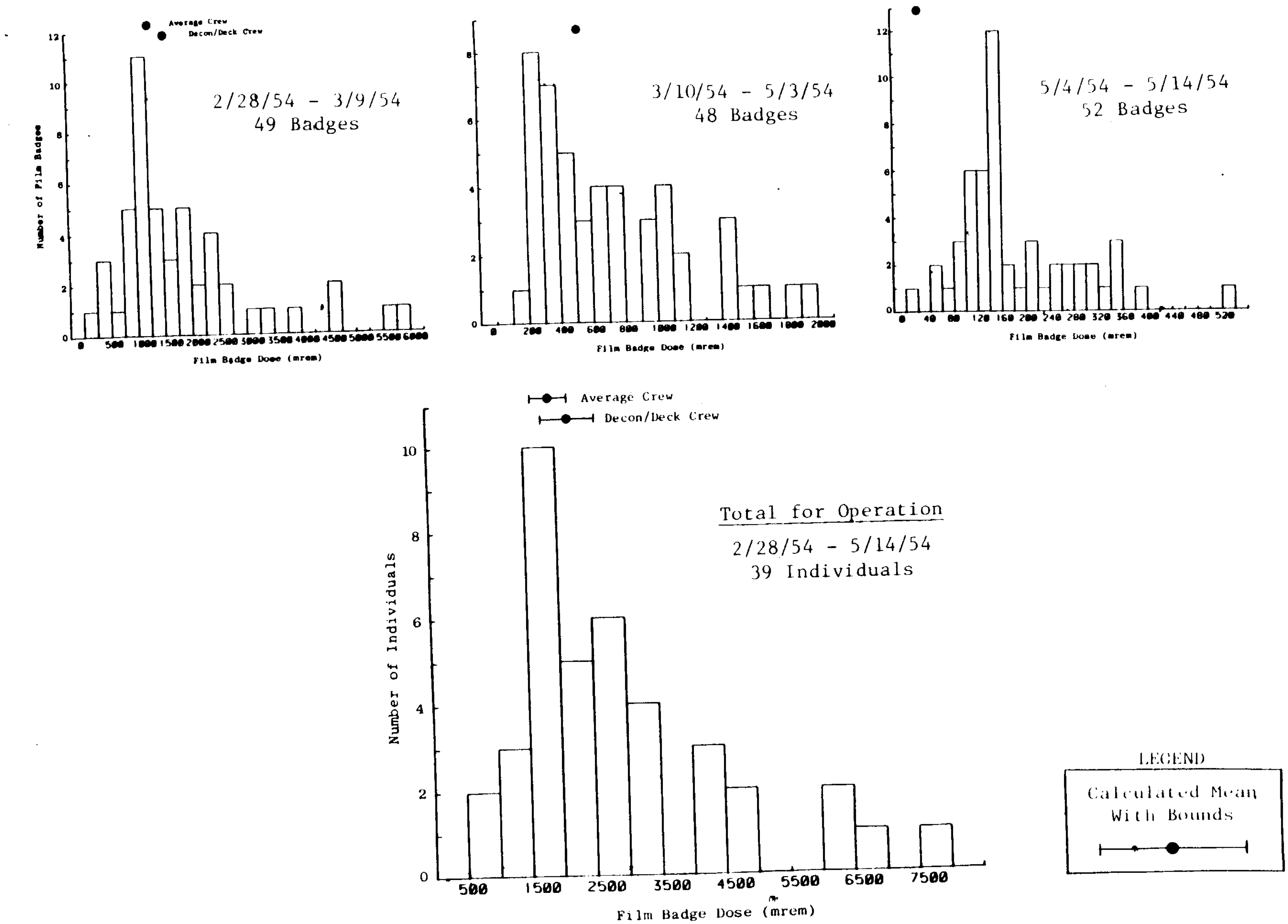

Figure 5-1. USS ESTES - Comparison of dosimetry data with calculated doses.

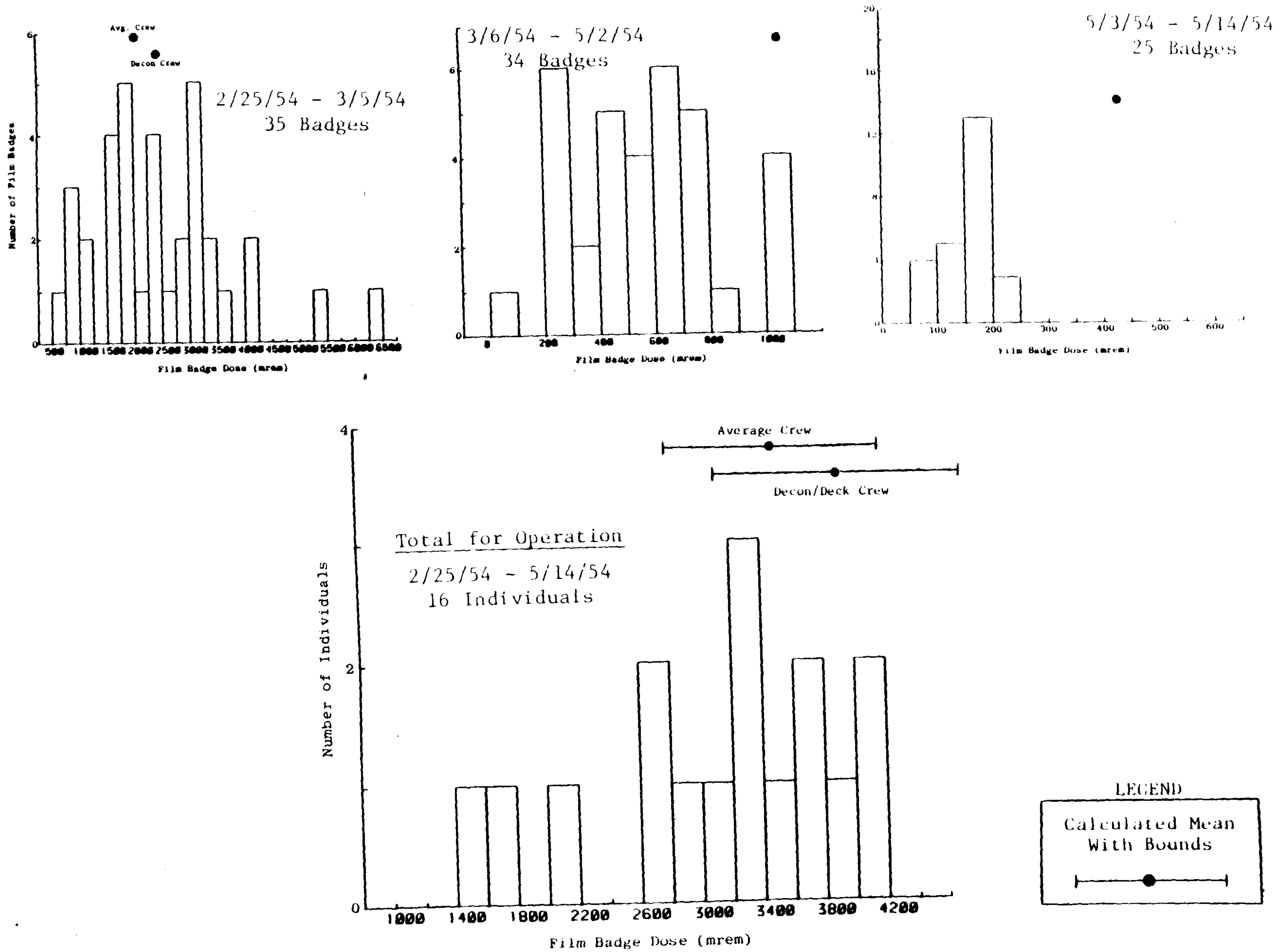

Figure 5-2. USS PHILIP - Comparison of dosimetry data with calculated doses.

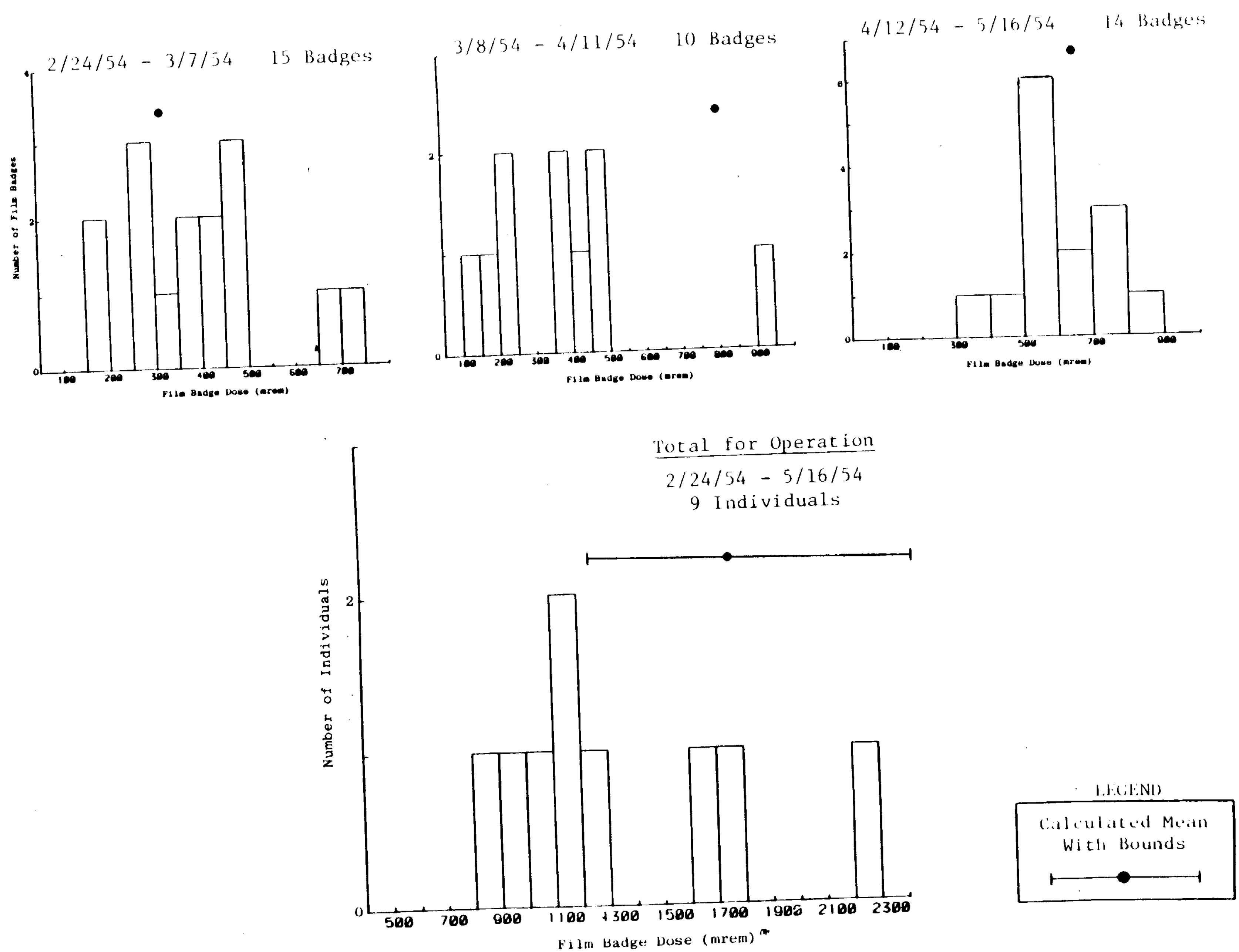

Figure 5-3. USS SIOUX - Comparison of dosimetry data with calculated doses.

The first badged period covers Shot BRAVO fallout only, and agreement between the calculated mean and the mean of the dosimetry data is quite good for each ship. Calculated doses for the average crew for the ESTES, PHILIP, and SIOUX are lower than the mean film badge dose by 28, 19, and 19 percent, respectively. It is interesting to note that the calculated doses for the decontamination crews on the ESTES and PHILIP are quite close to the mean film badge dose, only 13 and 2 percent lower, respectively. The dose contribution from contaminated lagoon water during this period accounts for only 5-8 percent of the total calculated dose for the crew of each ship; hence, calculations based on radiological surveys obtained during and after cessation of the BRAVO fallout appear to adequately describe the crews' exposure.

Fallout from Shot ROMEO was the second largest contributor to the total dose received by the crews of the ESTES, PHILIP, and SIOUX. The second badged period reflects exposures due to Shot ROMEO fallout as well as the residual from Shot BRAVO. Fallout from other shots that occurred during this period did not contribute to the dose on these three ships. The dose contribution due to ship contamination during the second badged period amounts to approximately 16 percent of the total dose received by the crews of each ship. The calculated mean for the ESTES is 24 percent lower than the mean of the dosimetry data; again the agreement is quite good. This is not the case, however, with the PHILIP and the SIOUX; calculated doses are almost twice the mean of the dosimetry data. Because ship contamination during this period accounts for only 16 percent of the calculated dose, the overestimation could be due to assumptions concerning crew activity scenarios during and after the ROMEO fallout. The crews on these two ships may have taken more protective measures during the ROMEO fallout than described in Section 3.1, where it is assumed that normal duty routines were not interrupted by the occurrence of ROMEO fallout. When the crews were mustered at approximately 0800 hours on 29 March, topside intensities on the ESTES were only 8 mR/hr and duty routines were probably not altered. On the PHILIP and SIOUX, however, intensities at that time were 19 and 30 mR/hr, respectively, and it is probable that normal crew routines were somewhat altered to reduce exposures. This change, however likely, is undocumented and thus cannot be used with certainty.

The third badged period terminated the day of Shot NECTAR for the crews of the ESTES and PHILIP, and two days later (16 May) for the crew of the SIOUX. For the crew of the ESTES, dose calculations significantly underestimate the crews' exposure as inferred from the dosimetry data. As for fallout, only residual radiation from Shots BRAVO and ROMEO are considered as contributing to crew exposure; because the ESTES reentered Bikini Lagoon only briefly after Shots UNION and YANKEE, ship contamination did not contribute significantly to the calculated dose. The reasons for the poor agreement between the calculated doses and dosimetry data for the ESTES during this period are not clear, but it should be noted that exposures during this badged period are relatively low and account for only 7 percent of the crews' average operational exposure. For the entire operation, calculated doses are only slightly lower than the mean of the dosimetry data.

Dose calculations for the crew of the PHILIP during the third badged period are significantly higher than inferred from the dosimetry data. Because the PHILIP remained in Bikini Lagoon during most of the badged period (see Section 2.2.16), most of the calculated dose (92 percent) is due to ship contamination, while residual radiation from shots BRAVO and ROMEO is only a minor contributor. Uncertainties in the ship contamination model alone do not account for the overestimation of crew exposure; it is more likely that the contaminated lagoon water from Shot YANKEE took longer to reach the anchorage areas in the southern part of the lagoon than the few hours assumed in the analysis. Again it should be noted that exposures during this badged period are relatively low and account for only 5 percent of the operational dose for the crew of the PHILIP as inferred from the dosimetry data. For the entire operation, calculated doses are slightly higher than the mean of the dosimetry data.

The correlation between calculated doses and dosimetry data for the crew of the SIOUX during the third badged period is excellent. Although Shot NECTAR fallout, along with residual radiation from Shots BRAVO and ROMEO, contributed somewhat to the calculated doses, approximately 80 percent of the calculated dose is due to the ship steaming in contaminated water for five days following Shot YANKEE (see Section 2.2.18). The ship contamination model described in Reference 6 was applied for the full period to calculate the crew's exposure. Results compared favorably with the dosimetry data. For the entire operation, calculated doses for the crew of the SIOUX are approximately 28 percent higher than the mean of the dosimetry data covering all three badged periods.

SECTION 6

CONCLUSIONS AND TOTAL DOSE SUMMARY

For Operation CASTLE, calculated doses and dosimetry data for the crews of three ships are, for the most part, in good agreement. During badged periods when exposures were relatively high and radiation environments were well documented, the dose calculations correlate well with the dosimetry data. For periods when topside intensities were not documented, generally late in the operation when radiation levels were low, agreement between calculated doses and dosimetry is not as good. A ship contamination model is used to estimate crew exposures due to radioactive water contaminating the ships' hulls and saltwater piping systems while in Bikini Lagoon. During the first two badging periods, doses accrued due to ship contamination are masked by the much higher contribution from BRAVO and ROMEO fallout. During the last badge period when fallout was not a significant factor, the SIOUX remained in contaminated water of known intensity for a five-day period. Doses calculated using the model are in excellent agreement with the film badge doses recorded onboard the ship.

Table 6-1 summarizes the calculated dose contributions due to fallout as well as from ship contamination for the sixteen ships considered in this report; Eneweták and Kwajalein Atoll fallout doses are also listed. The total dose (with bounds) is tabulated and, in the absence of dosimetry data, should be used for dose determination. The calculated distribution in dose due to the spatial nonuinformity of topside radiation intensities is not reflected in the mean total dose or its bounds (see Section 4).

Table 6-1. Summary of calculated mean doses.

Shipboard Personnel	Dose (rem) Contribution From Fallout	Dose (rem) Contribution From Ship Contamination	Total Dose (rem)
USS APACHE	1.01 ± .20	0.43 ± .17	1.44 ± .26
USS BAIROKO (Average Crew)	2.56 ± .51	0.20 ± .09	2.75 ± .52
(Decon Crew)	3.36 ± .67		3.56 ± .68
USS BELLE GROVE	1.67 ± .33	0.24 ± .12	1.91 ± .35
USS CURTISS	0.37 ± .07	0.17 ± .10	0.53 ± .12
USS EPPERSON	0.39 ± .08	0.12 ± .06	0.51 ± .10
USS ESTES (Average Crew)	1.76 ± .35	0.16 ± .07	1.93 ± .36
(Decon Crew)	2.04 ± .41		2.20 ± .42
USNS FRED C. AINSWORTH	0.79 ± .16	0.27 ± .13	1.06 ± .21
USS GYPSY	2.43 ± .49	0.31 ± .12	2.73 ± .50
USS LST-551	0.69 ± .14	0.21 ± .08	0.90 ± .16
USS LST-762	0.83 ± .17	0.16 ± .07	0.99 ± .18
USS LST-825	0.19 ± .04	--	0.19 ± .04
USS LST-975	0.53 ± .11	--	0.53 ± .11
USS NICHOLAS	0.75 ± .15	0.19 ± .10	0.94 ± .18
USS PHILIP (Average Crew)	2.93 ± .59	0.63 ± .4	3.56 ± .7
(Decon Crew)	3.36 ± .67		3.98 ± .8
USS RENSHAW	0.45 ± .09	0.44 ± .3	0.89 ± .3
USS SIOUX	1.19 ± .24	$0.64^{+.6}_{-.4}$	$1.83^{+.7}_{-.5}$
Island-Based Personnel			
Enewetak Atoll	1.09 ± .22		1.09 ± .22
Kwajalein Atoll	0.32 ± .06		0.32 ± .06

SECTION 7

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