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ANALYSIS OF RADIATION EXPOSURE FOR NAVAL PERSONNEL AT OPERATION GREENHOUSE

Science Applications, Inc.
P.O. Box 1303
McLean, Virginia 22102

30 July 1982

Technical Report

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The radiological environments are reconstructed for seven ships and the residence islands of Enewetak Atoll that received fallout during Operation GREENHOUSE (April-May 1951) as a result of Shots DOG, EASY, and ITEM. From the reconstructed operations and radiological environments, equivalent personnel film badge doses are calculated and compared with actual film badge data available for six of the ships. Considering the increased time spent topside by badged personnel as opposed to an average crewmember, correlation between calculations and dosimetry is good.

20. ABSTRACT (Continued)

Average shipboard doses range from a low of 0.13 rem for the crew of the USNS LT. ROEERT CRAIG to a high of 1.14 rem for the crew of the USNS SGT. CHARLES E. MOWER. Average doses on the residence islands of Enewetak Atoll range from 2.57 rem to 3.10 rem.

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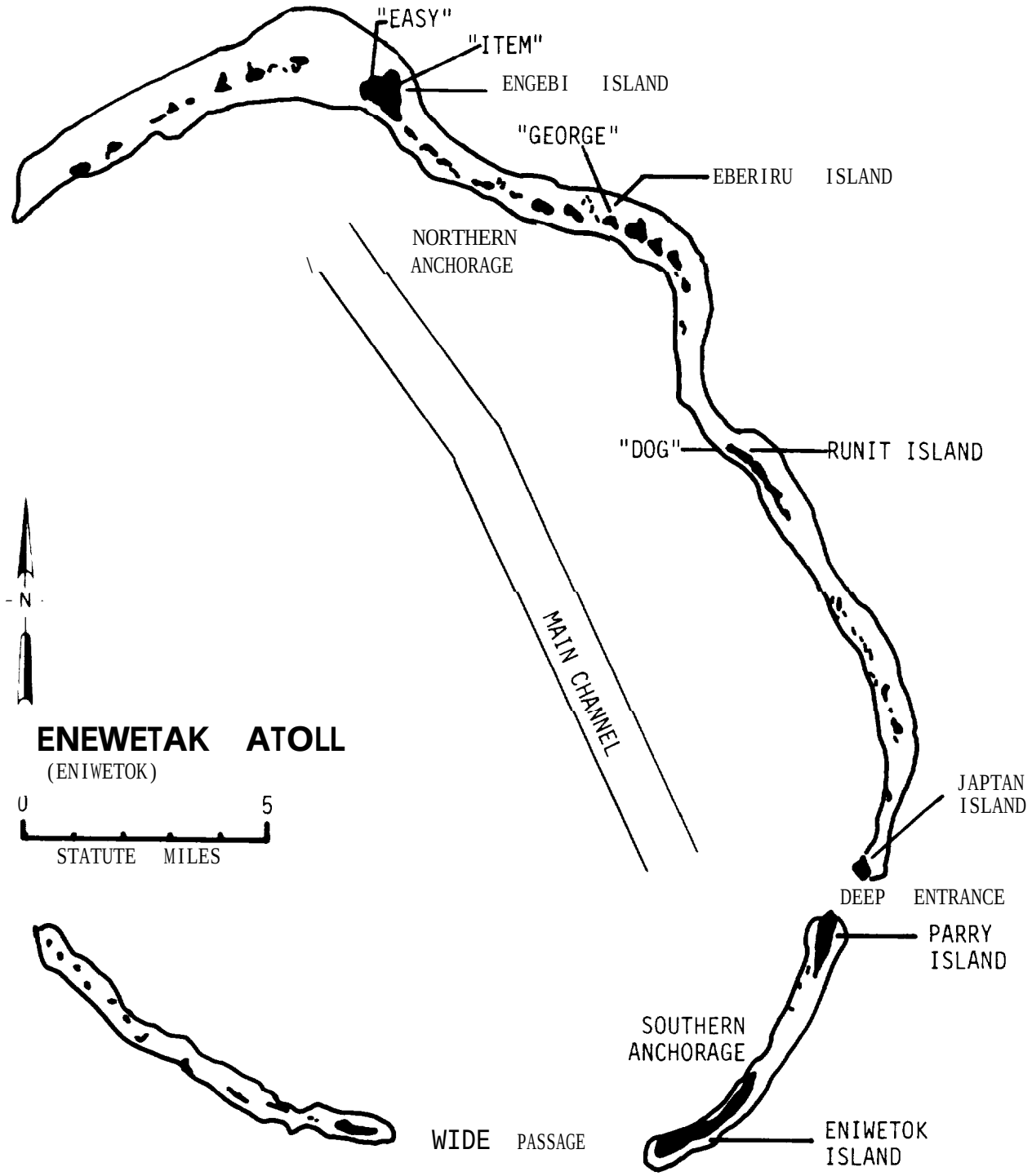
Section 1
INTRODUCTION

Operation GREENHOUSE was a series of four atmospheric nuclear tests conducted by the United States at Enewetak (formerly Eniwetok) Atoll in the Pacific Ocean in 1951. Civilian and military personnel participated both on land and at sea. Radiological safety procedures included the issuance of film badges to selected shipboard personnel that were to be worn from D-Day to D-plus-seven days. In addition, all boatpool personnel and aircrews that were operating on D-Day to D-plus-seven days were issued film badges. In the absence of film badge data, personnel doses were estimated. The doses assigned in 1951 on the basis of these estimates are contained in medical records for most naval personnel, but are of uncertain quality because no documentation has been located that describes how the doses were estimated. Consequently, where film badge coverage is incomplete, it is necessary to reconstruct the radiation dose. This report contains a description of the methodology and the results of the reconstruction of radiation doses received by test participants aboard seven Naval vessels assigned to support the operation. Because some of the task group personnel were assigned to the residence islands of Enewetak Atoll (Enewetak, Parry, and Japtan Islands), the radiation environments on these islands are also reconstructed. As for other nearby atolls, Bikini Atoll, to the east, was not inhabited during operation GREENHOUSE; Kwajalein Atoll, to the southeast, experienced no fallout from any of the detonations.

1.1 BACKGROUND

Operation GREENHOUSE was a series of atmospheric nuclear tests performed by the United States in April and May of 1951 at Enewetak Atoll in the Pacific Ocean. Of five shots authorized, four were conducted: DOG, EASY, GEORGE, and ITEM (References 1, 2). Shot data are shown in Table 1- 1. The locations of the shots are depicted in Figure 1- 1.

By the direction of the Joint Chiefs of Staff, Joint Task Force Three was formed 1 November 1949 for the purpose of conducting tests of atomic weapons. This task



Source: References 1, 2

Figure 1-1. Operation GREENHOUSE Shot Locations

force was commanded by **Lt.** Gen. Edmond R. Quesada, USAF. The organization of JTF-3 is shown in Figure l-2 (Reference 1).

Table 1- 1. Operation GREENHOUSE Shot Data

	DOG	EASY	GEORGE	ITEM
DATE	8 April 1951	21 April 1951	9 May 1951	25 May 1951
TIME (Local)*	0634	0627	0930	0617
ISLAND (SITE)	RUNIT (YVONNE)	ENGEBI (JANET)	EBERIRU (RUBY)	ENGEBI (JANET)
HEIGHT OF BURST	300 ft.	300 ft.	200 ft.	200 ft.
TYPE	TOWER	TOWER	TOWER	TOWER
PLACEMENT	CORAL	CORAL	CORAL	CORAL
YIELD	**	47 KT	**	**

*Local time was 12 hours behind GMT. Source: Reference 2
**Yield is classified.

1.2 NAVAL OPERATIONS

Military responsibility for the Enewetak area was assigned to Commander JTF-3 on 1 February 1951, operating directly under the Joint Chiefs of Staff. The Enewetak area was defined as the area centered on Enewetak Atoll and bounded by north latitudes 10^{o}-15' and 12^{o}-45' and east longitudes 160^{o}-35' and 163^{o}-55'. Due to the entry of the Chinese Communists into the Korean conflict, the President had declared a state of General Emergency. Military assumptions for the conduct of the operations were:

a) War with the USSR and her satellites may begin before or during the conduct of the tests.

b) The USSR will attempt to obtain information of the conduct of the tests and the effectiveness of the atomic weapons by all or any means, including the use of submarines and aircraft.

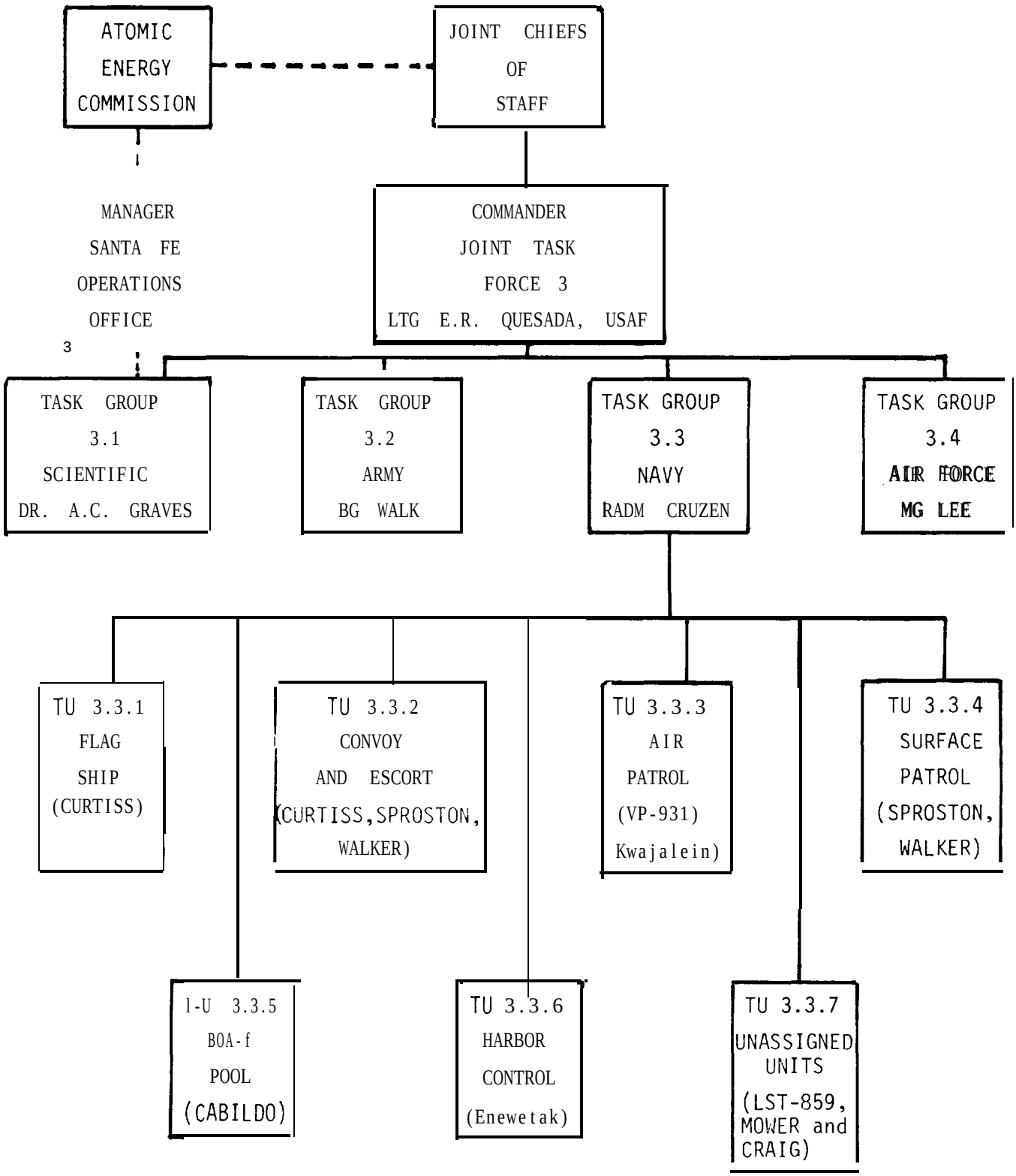


Figure l-2. Joint Task Force Three Organization

In order to deny information to unauthorized personnel concerning the conduct of the tests, and to support and assist in the tests, Task Group 3.3 was formed and specifically directed to:

(a) Deny entry into the Enewetak area to unauthorized vessels by conducting air and surface surveillance patrols to ensure early detection.

(b) Exercise control of all authorized vessels upon their entry into the Enewetak area, during the operational phase; provide harbor entrance control and, in coordination with TG 3.2, control harbor facilities at the Enewetak Atoll.

(c) Transport experimental weapons together with assembly personnel of TG 3.1 and provide necessary shipboard assembly facilities.

(d) Maintain and operate a boat pool to augment intra-atoll water transportation of personnel and cargo.

(e) Assist in: establishment and support of weather stations; maintenance of Naval aircraft; search and rescue operations.

The task group consisted of five Naval vessels, two USNS transports, an air unit for antisubmarine warfare, and a shore-based harbor control unit. The seven surface ships and their crew sizes were:

Ship	Crew Size
uss CABILDO (LSD- 16)	378
USS CURTISS (AV-4)	638
USS LST-859	113
USNS SGT. CHARLES E. MOWER (TAP-186)	29
USS SPROSTON (DDE-577)	283
USS WALKER (DDE-517)	317
USNS LT. ROBERT CRAIG (TAK-252)	12

Personnel aboard these units totaled 1770 officers and men. The boat pool consisted of an additional 213 personnel who were embarked in CABILDO, while the harbor control unit and other land-based units consisted of 467 personnel assigned to the residence islands of Enewetak. The air unit was assigned to Kwajalein and had a total strength of approximately 400 personnel. The total Naval participants at GREENHOUSE was approximately 3000 and are summarized below:

Shipboard Personnel	1770
Boat Pool (on CABILDO)	213
VP-931 (Air Unit at Kwajalein)	386
Shore-Based Personnel (at Enewetak)	467
Total	2836

The reconstructions and dose calculations in this report apply only to the ship's crews and to personnel assigned to the residence islands of Enewetak Atoll. The movements of boat pool personnel and aircrews of VP-931 cannot be followed in sufficient detail to permit a dose reconstruction for these personnel; however, personnel in these units were badged when their missions took them to areas where radiation was likely to be encountered. Personnel on Kwajalein were not exposed to fallout from any of the detonations.

A basic operation plan described the general administration arrangements of the task group and discussed the general concepts of operation and those operations common to all shots. The operation plan assigned the following specific responsibilities to Task Group 3.3 units:

(a) Receive, transport, and safeguard experimental weapons. Provide shipboard assembly facilities. Base at Enewetak. (CURTISS)

(b) Convoy and Escort Unit proceed in convoy in accordance with separate instructions. (CURTISS, SPROSTON, WALKER)

(c) Surface Patrol Unit conduct surface search and antisubmarine patrol within the Enewetak Area. Base at Enewetak. (SPROSTON, WALKER)

(d) **Boat** Pool Unit control and provide transportation within Enewetak Lagoon. Coordinate scheduling and employment of small craft with TG 3.1. Base at Enewetak. (CABILDO)

(e) Unassigned units assist as directed in support of operations, including establishing and resupply of outlying stations, POL support and personnel housing afloat at Enewetak (LST-859, SGT. C. E. MOWER, LT. R. CRAIG).

Operation orders (Reference 3) were prepared by Commander Task Group 3.3 for each shot. Detailed plans were drawn to control the movements and activities of all personnel, not only to support the task force in its mission, but also to provide for safety of personnel. A rigid schedule of all ship and boat movements was kept and rosters of personnel were maintained for each boat. The liberty boats could **take** parties to Enewetak Island only. For each shot, each unit had pre-assigned tasks that were duly checked off by the operation center, in some cases on a minute-by-minute basis.

1.3 METHODOLOGY

The procedures developed in previous **dose** reconstruction efforts have been adapted to both shipboard and island radiological environments at Operation GREENHOUSE. Figure 1-3 depicts the steps taken in calculating personnel **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** Naval operations and to characterize the radiation environment. Individual ship deck logs serve as an authoritative **source** of ship position and activity. It is assumed that the units of Task Group 3.3 adhered to the operation plans as promulgated by Commander Task Group 3.3, which serve as guides to ship activities. References 4, **5, and 6** comprise the official reports of the tests. Each unit prepared radiological contamination **and** decontamination reports for each test. These reports are available for each vessel (Reference 7), although not necessarily for every shot. Supporting documents and reports prepared **by the** Naval Radiological Defense Laboratory (References 8,9,10,11) also contain data pertinent to this **dose** reconstruction.

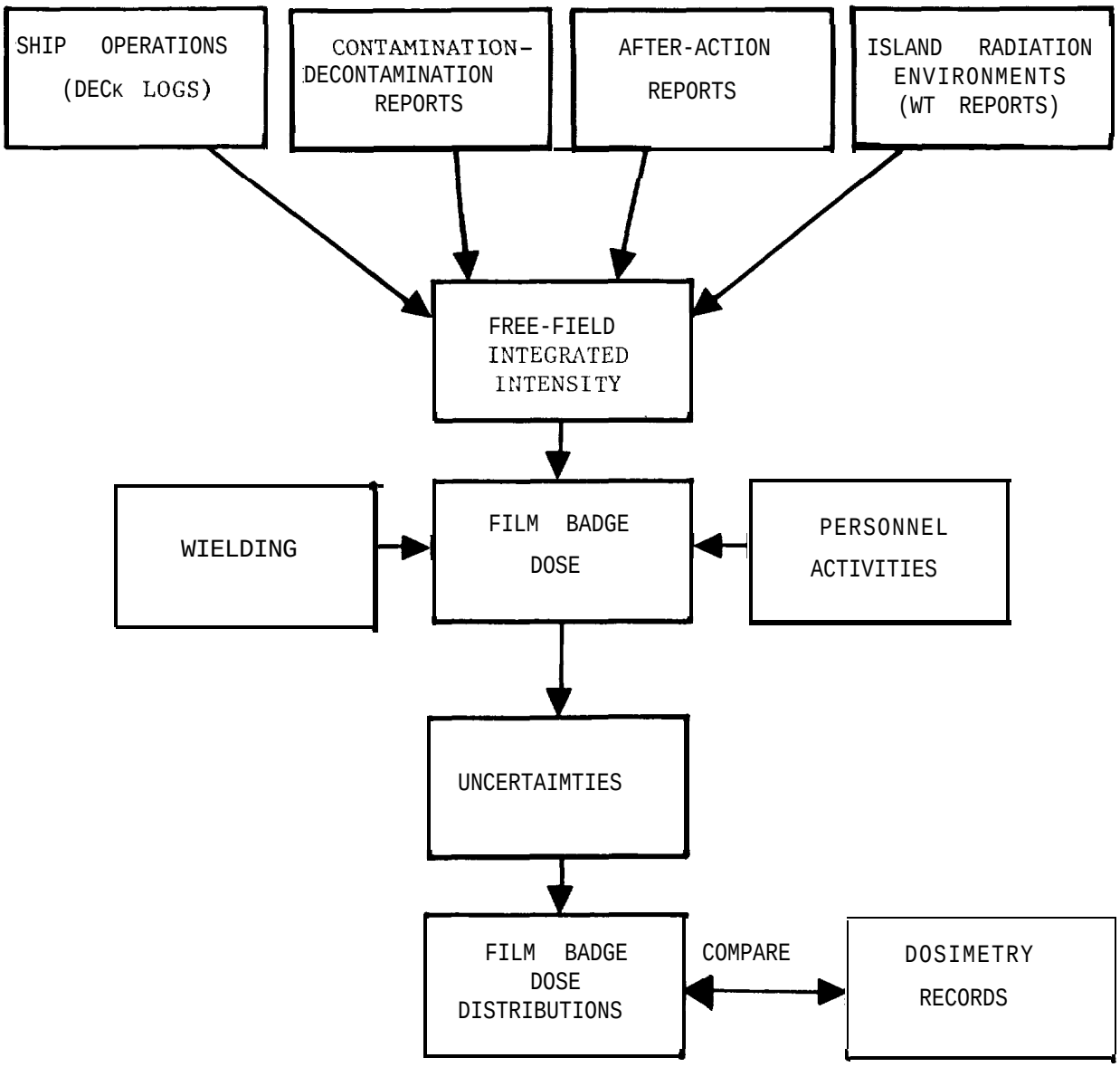


Figure 1-3. Operation GREENHOUSE Dose Reconstruction Methodology

Radiological data are used to reconstruct the time-dependent radiation environments on the residence islands of Enewetak Atoll and on each of the seven ships at Operation GREENHOUSE. 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 free-field intensity as a function of time. For interpolation between shipboard readings, the intensity is assumed to be a power law function of time after burst. At times following the last reported shipboard survey, decay rates determined from nearby island survey data are utilized. Despite significant differences in decay rate between ship and shore due to washdown, decontamination, and weathering, the late-time decay, mostly from insoluble particles adhering to shipdeck or soil, is taken to be the same. Specific data regarding the development of intensity curves for the ships and islands 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 other cases, readings were taken at many predetermined positions on the ship's exposed surfaces. These readings, taken three feet above the surface, are judged to provide an unbiased representation of 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; this matter is considered in the uncertainty analysis (Section 4).

The analysis of radiation exposure to the crew also requires estimation of radiation intensities below deck and the apportionment of crew activities with time below and on deck. A ship-shielding factor is defined as the ratio of intensity below to the mean intensity topside. This factor, determined for each type of ship in Section 2.9, is approximately 0.1 and is nearly constant over the usual crew locations within a ship. Thus, the radiation dose to the crew is dominated by the topside exposure. 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 on-deck 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 of 0.7 is used to account for body shielding by the badge wearer (Reference 12). To facilitate the calculation, the daily fractional topside duration rather than the specified intervals is used on the third and subsequent days after burst, when the slackening decay rate lessens the need for more 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 until the monthly dose drops below 30 mrem; subsequent dose accrual is negligible compared to that previously accrued. An uncertainty analysis of the dose calculations is provided in Section 4. In Section 5, the available dosimetry records are analyzed, and their comparability to the calculated doses is assessed.

Section 2
SHIP OPERATIONS AND RADIATION ENVIRONMENTS

This section describes the operations of each of the seven ships that participated at Operation GREENHOUSE. A complete description of each ship's movements during April and May 1951 while at Enewetak Atoll is obtained from deck logs. Crew activities and other anti-contamination measures are also found in deck logs. Shipboard radiological data have been extracted from after-action reports and Material Contamination-Decontamination Reports, 'or inferred from nearby island data as detailed in Reference 6. These data have been used to derive shot-specific, ship-specific radiation intensity curves, which represent the average topside, free-field radiation environment resulting from each detonation where a ship encountered fallout. Similar radiation environments are reconstructed for the residence islands of Enewetak Atoll. These environments are then time-integrated to determine the daily integrated free-field intensities on each of the ships and islands.

Task Group 3.3 (Reference 1) procedures anticipated that ships would operate in a potentially radioactive environment. Personnel doses were to be limited to 0.1 R/day, thus access to areas where intensities were greater than 12.5 mR/hr (for an assumed eight-hour workday) was controlled. General operating procedures required that each ship be brought to a maximum state of readiness at 30 minutes prior to each shot, with anchored ships at "short stay" and steam at the throttle. This allowed the ship to get underway in a minimum amount of time to maneuver clear of radiological fallout. All ships were alerted by Commander Task Group 3.3 at the occurrence of the first fallout. All unnecessary personnel were cleared from the weather decks, while outside ports, doors, and hatches were closed and the ventilation systems reduced to the minimum. Anti-contamination measures were placed into effect. From the onset of significant fallout, continuous washdown was maintained over all weather decks to minimize the adherence of the fallout particles to the ship's surfaces (References 4, 5). This proved to be an extremely effective technique and resulted in reducing the onboard radiation environment to levels of approximately half those found on the islands in close proximity to the ships. Decontamination procedures that were carried out after fallout had ceased, such as scrubbing the bulkheads and weather decks with a

mixture of lye, soap and water, did not appear to be very effective, except in isolated cases. These attempts to decontaminate usually resulted in a further 10 to 20 percent reduction in the shipboard intensities (Reference 7).

With the exception of the SPROSTON, WALKER, and CRAIG, the units of Task Group 3.3 spent most of their time in Enewetak Lagoon. At the time of each detonation, they were anchored near Parry or Enewetak Islands in the southern anchorage area some IO-20 miles from the shot locations. The surface patrol vessels, SPROSTON and WALKER, conducted surface and anti-submarine patrols in the vicinity of Enewetak Atoll, sweeping with radar and sonar. Patrol areas were specified for each shot, and standard search procedures were employed (References 4, 5). The CRAIG was at Enewetak for five days in April, staying only long enough to unload cargo before proceeding to Guam.

2.1 USS CABILDO (LSD-16)

When Shot DOG was detonated on 8 April, the USS CABILDO (LSD-16) was moored to a telephone buoy in berth **N-2,** approximately 1700 yards west of Enewetak Island and 12 miles south of Shot DOG ground zero (GZ) (see Figure 2-l). A radiological survey made at 0830 hours (H+1.9) detected no contamination. At 1014 hours fallout was (apparently) detected because the ventilation systems were closed and washdown of the weather decks begun. At 1015 hours all hands, except those specifically excepted, were ordered below decks. By 1100 hours the maximum intensity reading was 40 mR/hr and the average intensity was about 25 mR/hr.

At 1300 hours decontamination operations were initiated and a radiological survey of the ship was made. The maximum intensity observed was 26 mR/hr; the average reading on the foredeck was 13.7 mR/hr (Reference 7). Reference 5 indicates an average of 20 mR/hr. The latter value is used for dose reconstruction. Decontamination was accomplished by flushing with high pressure salt water while scrubbing the decks with brushes. Application of these measures continued for two days during which additional radiological surveys were made at the following times:

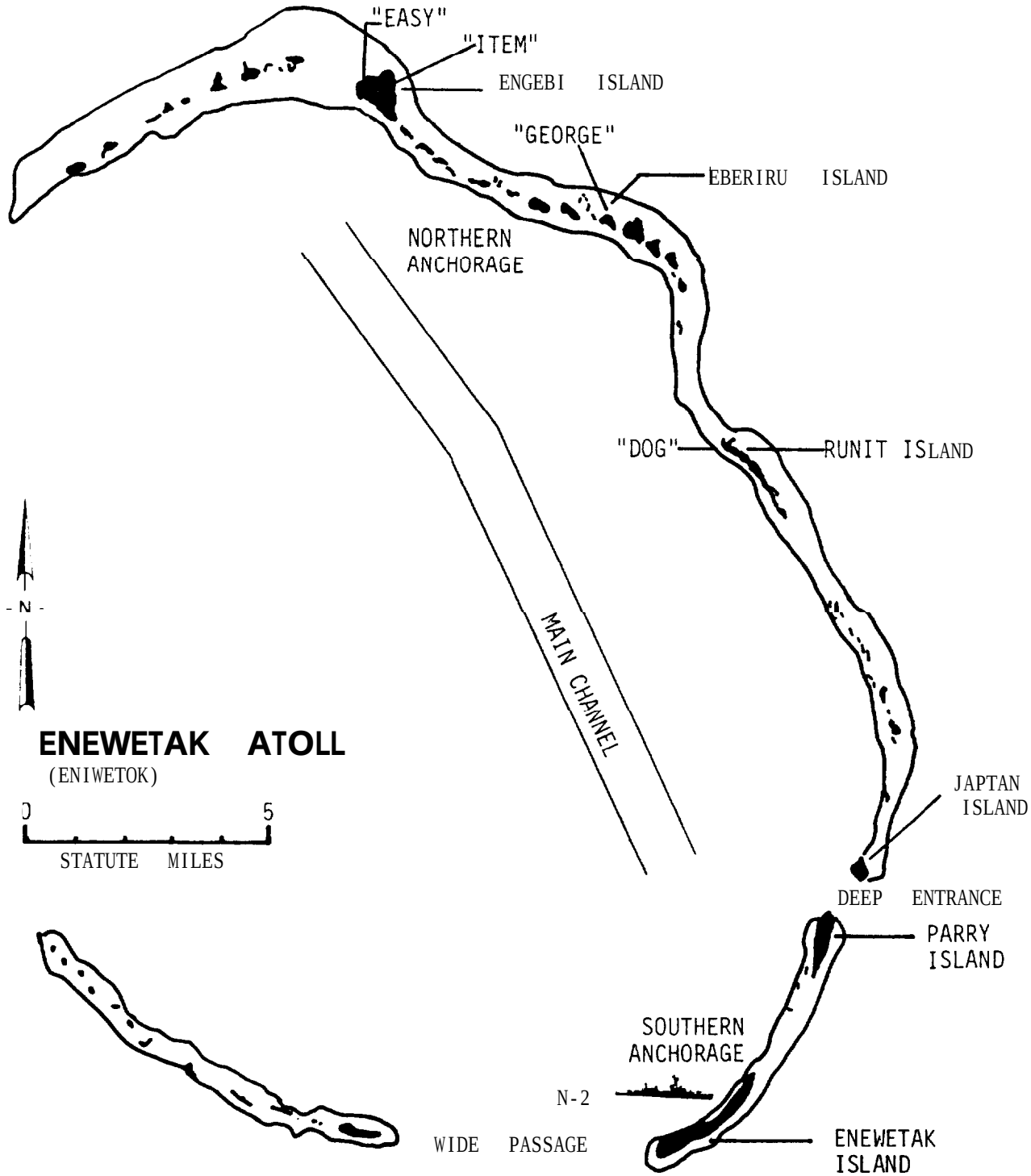


Figure 2-l. LJSS CABILDO Anchorage Area - Operation GREENHOUSE

0400 hours, 9 April; 1030 hours, 9 April; 1500 hours, 9 April; 1000 hours, 10 April. By 1500 hours, 9 April, the average intensity had been reduced to 3.4 mR/hr, with a maximum intensity of 10 mR/hr. By 20 April, the day before Shot EASY, the average intensity was about 0.15 mR/hr, with a maximum intensity of 0.3 mR/hr (see Figure 2-2).

Shot EASY was detonated on 21 April on Engebi Island, approximately 19 miles north of the CABILDO (Figure 2-1). The deck log of the CABILDO makes no mention of fallout occurring after Shot EASY and radiological surveys at 0727 hours and 1230 hours on shot day detected no fallout. However, on Enewetak Island (1700 yards east of the CABILDO) and on Parry Island (four miles northeast of the CABILDO), a small amount of fallout did occur during the night of 21 April and the early morning of 22 April. It is assumed that fallout from Shot EASY began at 2230 hours, 21 April (H+ 16 hours), and that the peak intensity occurred at about 0630 hours, 22 April (H+24 hours). The maximum intensity of this fallout on Parry Island was reported as two to three times the residual radiation from Shot DOG, which had been recently measured to be 0.5 mR/hr. Because radiological surveys made after deposition of the Shot EASY fallout measured the combined intensities of the residual radiation from both Shots DOG and EASY, the intensity due solely to Shot EASY was between 0.5 mR/hr (two tirnes background, minus the Shot DOG contribution) and 1.5 mR/hr (three times the background). Three survey readings for Parry Island are: 0.8 mR/hr at 0900 hours, 23 April, 0.6 mR/hr on 24 April, and 0.6 mR/hr on 25 April. Because the measured intensities were the same on all residence islands, the fallout was sufficiently uniform as to be considered the same on the nearby ships. A survey was made aboard the CABILDO at 1530 hours, 9 May (GEORGE day), the average intensity of which (0.12 mR/hr) was due to the combined residual radiation from Shots DOG and EASY (Shot GEORGE caused no fallout aboard the CABILDO). The survey data are shown in Figure 2 -3. Also shown are the net intensities ascribed to Shot EASY, derived by subtracting the calculated intensity of the residual radiation due to Shot DOG from the observed data. The data are fitted by a power law. The resultant fit indicates that Shot EASY fallout decayed as $t^{-1.1}$, and that the intensity at 0630 hours, 22 April (the assumed peak) was 1.0 mR/hr, which is within the range of peak intensities reported.

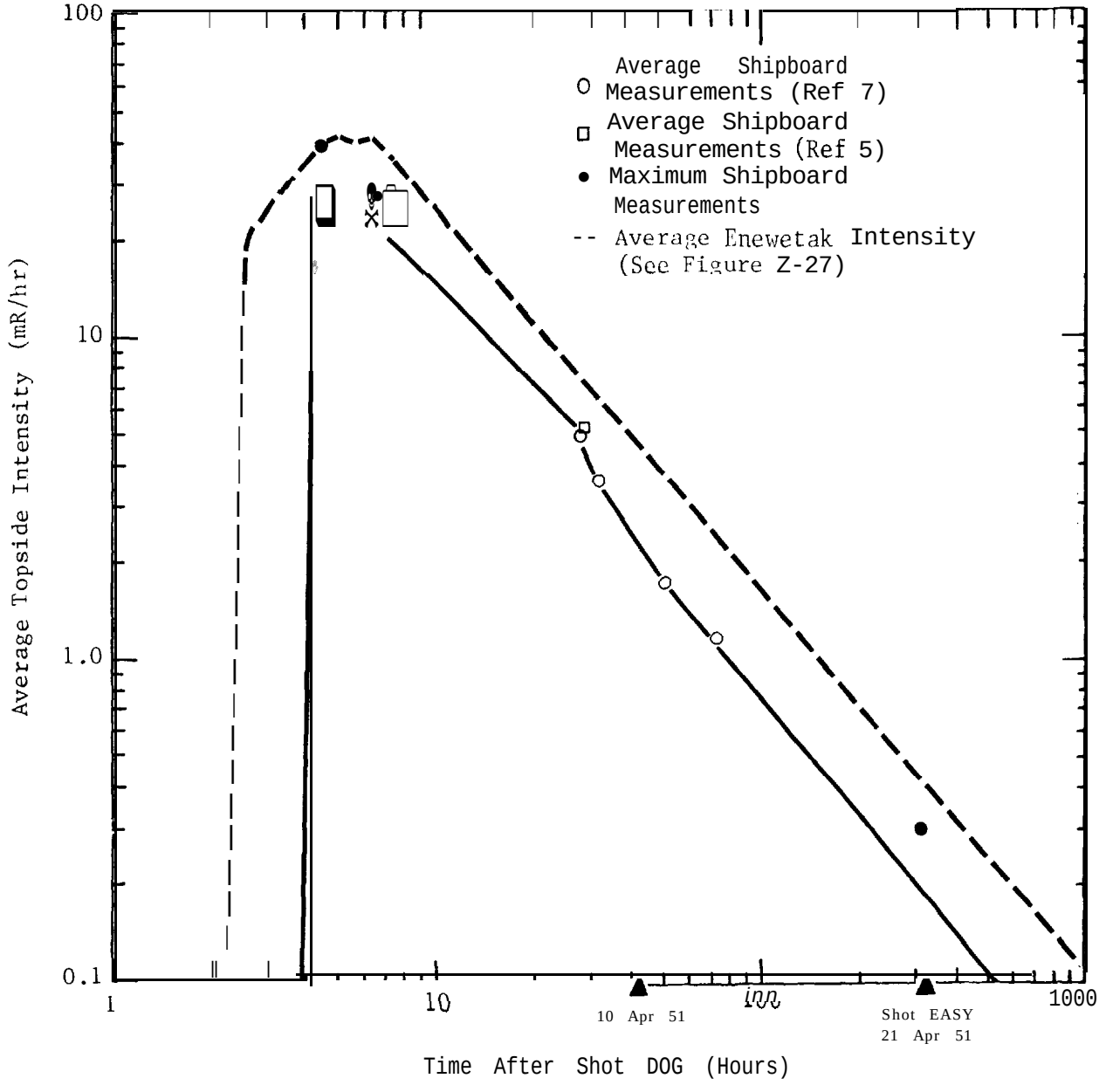


Figure 2-2. USS CABILDO (LSD-16) Ship Intensity Following Shot DOG

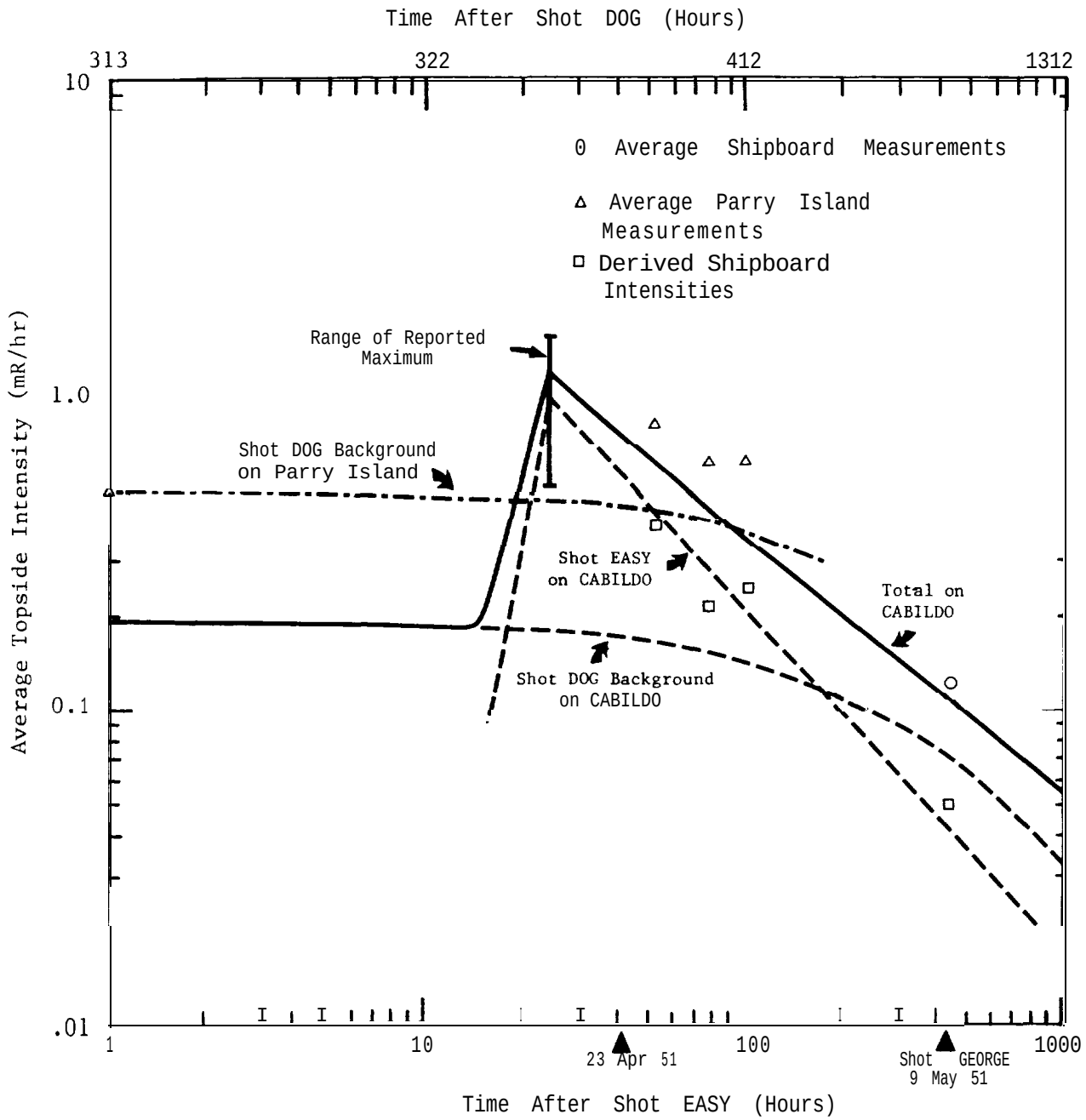


Figure 2-3. USS CABILDO (LSD-16) Ship Intensity Following Shot EASY

The CABILDO remained at anchor in berth N-2 until 0801 hours, 25 April, when it got underway to berth P-3 for fuel. It remained in berth P-3 until 0703 hours, 26 April, when it got underway for berth N-2, anchoring there at 0718 hours, 26 Apt-il.

Shot GEORGE was observed by the crew of the CABILDO from a distance of 16 miles south of GZ. No fallout from this shot occurred on board the CABILDO.

The detonation of Shot ITEM on 25 May was observed by the crew of the CABILDO from a distance of approximately 20 miles south of GZ (Figure 2-l). At 1028 hours (H+4.2) the ventilation system was shut down, washdown of the weather decks was initiated, and all personnel were ordered below decks. At 1045 hours the intensity was 4-6 mR/hr. A radiological survey made at 1130 hours indicated 2-26 mR/hr, with an average intensity of about 12 mR/hr. At 1230 hours decontamination operations were initiated. Although decontamination operations continued, the ventilation system was again started and personnel were permitted topside at 1245 hours. A radiological survey made at 1400 hours showed 2-23 mR/hr, with an average intensity of about 7.3 mR/hr.

At 1620 hours, 25 May, fallout was again detected aboard the CABILDO and all hands wet-e ordered below decks. A radiological survey made at 1630 hours showed 4-130 mR/hr, with an average intensity of 40 mR/hr. Another radiological survey made at 1900 hours showed 4-135 mR/hr, with an average intensity of 33 mR/hr. At 2130 hours another survey showed intensities of 4-75 mR/hr, with an average of 27 mR/hr. The decontamination operations begun at 1230 hours were sustained throughout the remainder of the day (25 May) and through most of the following day.

At 0415 hours, 26 May, a radiological survey indicated intensities of 4-50 mR/hr, with an average of about 20 mR/hr. Three more surveys were made that day, the last one, at 1700 hours, indicated intensities of l-22 mR/hr, with an average intensity of about 7 mR/hr. At that time only four of the 81 selected survey locations had an intensity greater than 12.5 mR/hr. Whether or not decontamination was continued, radioactive decay would have reduced these intensities to 12.5 mR/hr or less within 24 hours.

The CABILDO remained moored in berth N-2 until 1740 hours, 30 May, when it got underway for Pearl Harbor.

The free-field radiation intensities onboard the CABILDO resulting from Shots DOG, EASY and ITEM are plotted in Figures 2-2, 2-3, and 2-4, respectively. They represent the average topside radiation environment resulting from each detonation where fallout occurred onboard the ship. When available, both average and maximum values of intensity are plotted as a function of time after burst. Because of the CABILDO's proximity to Enewetak Island, the average Enewetak Island intensity data (Section 2.8) are plotted to demonstrate the effectiveness of the anti-contamination procedures carried out onboard the CABILDO after Shots DOG and ITEM (Figures 2-2 and 2-4). Table 2-1 is a summary of the radiological data for the CABILDO. These data are used to calculate the daily integrated free-field intensities onboard the CABILDO through 31 May that are presented in Table 2-2.

2.2 USS CURTISS (AV-4)

On 8 April, when Shot DOG was detonated, the USS CURTISS was moored to a telephone buoy in berth B-l, approximately 1500 yards west of Parry Island and nine miles south of Shot DOG GZ (see Figure 2-5). At 0825 hours (H+1.8), the Rad-Safe Officer onboard the CURTISS reported contamination levels between 1 and 4 mR/hr. At that tirne, all ventilation systems were closed and the weather decks were washed down. At 1010 hours, a resurvey of the ship led to a reported average radiation intensity of 35-40 mR/hr; maximum intensity levels had reached 100 mR/hr.

Fallout again started falling on the CURTISS at 1200 hours and continued for appr oxi matel y one hour. At 1300 hours, a rad-safe survey indicated average readings of 16 mR/hr with a maximum reading of 57.5 mR/hr. Decontamination, consisting of continuously washing down the weather decks and scrubbing with a mixture of lye, water, and soap, began at 1300 hours and continued for the next 24 hours. At 1130 hours, 9 April, a rad-safe survey indicated that all areas of the CURTISS had radiation levels at or below 12.5 mR/hr, except for an isolated area of 25 mR/hr.

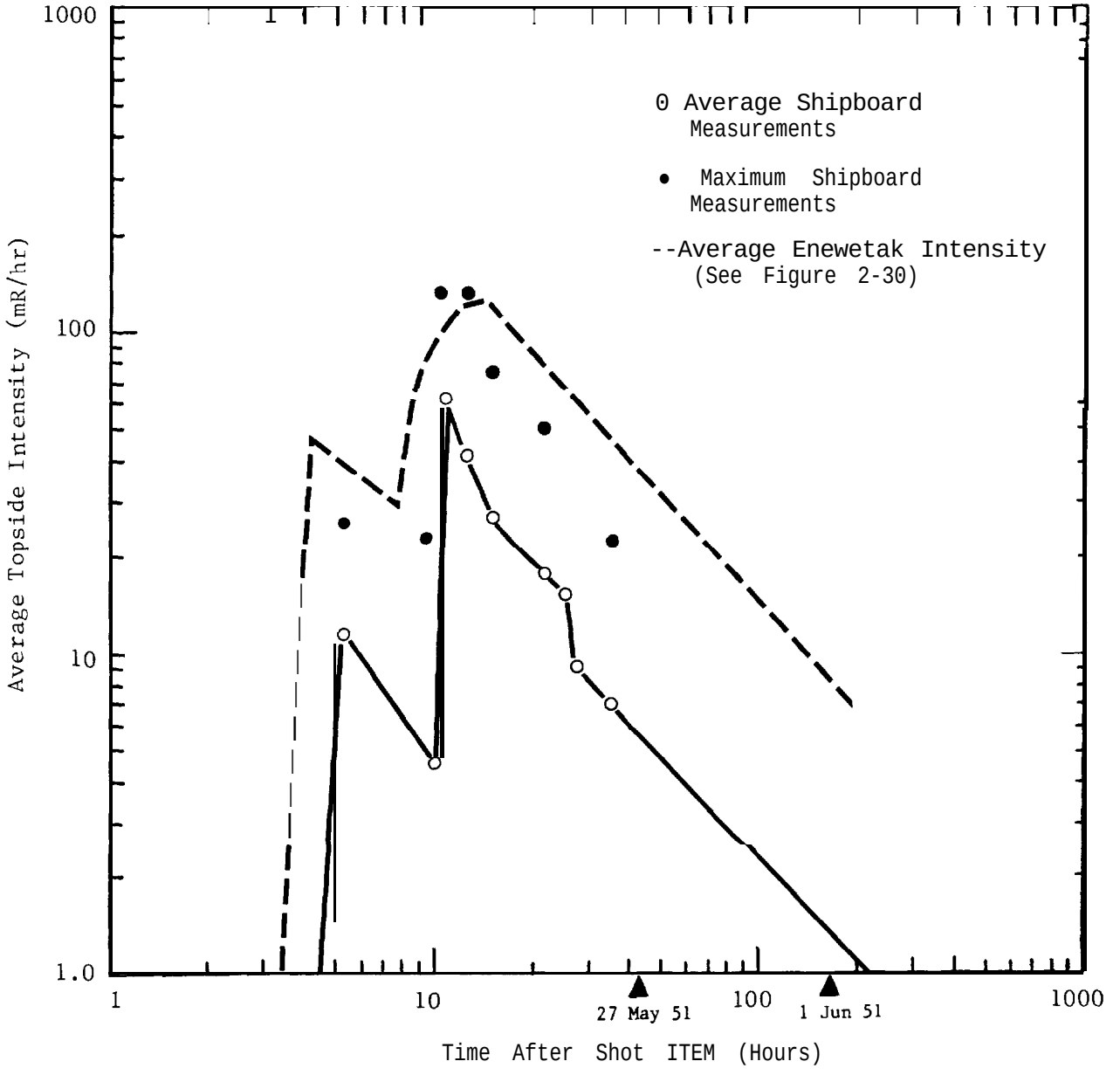


Figure 2-4. USS CABILDO (LSD-16) Ship Intensity Following Shot ITEM

TABLE 2-1. USS CABILDO Average Radiation Intensity Data

Date and Time	Time After Shot (hr)	Intensity (mR/hr)
	Shot DOG	
8 April, 1014	3.7	.01
8 April, 1 100	4.4	25
8 April, 1300	6.6	20
9 April, 0400	21.4	5.8
9 April, 1030	27.9	4.7
9 April, 1500	32.4	3.4
10 April, 1000	51.4	1.7
11 April, 0900	74.4	1.1
(Enewetak Island survey data indicate decay as $t^{-1.2}$ thereafter)		
	Shot EASY (inferred)	
21 April, 2230	16.0	0.1
22 April, 0630	24.0	1.0
(Decay assumed to be as $t^{-1.1}$ thereafter)		
	Shot ITEM	
25 May, 1028	4.2	.01
25 May, 1130	5.2	11.5
25 May, 1630	10.2	4.6
25 May, 1723	11.1	58.6
25 May, 2130	15.2	26.0
26 May, 0730	25.2	15.1
26 May, 0930	27.2	9.1
26 May, 1700	34.7	7.2
(Enewetak Island survey data indicate decay as $t^{-1.1}$ thereafter)		

Table 2-2. Daily Integrated Free-Field Intensity, USS CABILDO

DATE	DOG	EASY	GEORGE	ITEM
8 April 1951	180.1 mR			
9 '	105.4			
10	40.6			
II	26.0			
12	18.0			
13	13.9			
14	11.3			
15	9.4			
16	8.0			
17	7.0			
18	6.1			
19	5.6			
20	5.0			
21	4.6	0.2 mR		
22	4.1	15.4		
23	3.9	9.8		
24	3.6	6.5		
25	3.3	4.8		
26	3.1	3.8		
27	2.9	3.1		
28	2.7	2.6		
29	2.6	2.3		
30	2.4	2.0		
1 May	2.3	1.8		
2	2.1	1.6		
3	2.1	1.5		
4	2.0	1.4		
5	1.9	1.3		
6	1.9	1.2		
7	1.7	1.1		
8	1.7	1.0		
9	1.6	1.0	0	
10	1.6	0.9	0	
II	1.6	0.9	0	
12	1.4	0.8	0	
13	1.4	0.8	0	
14	1.3	0.7	0	
15	1.3	0.7	0	
16	1.3	0.7	0	
17	1.3	0.6	0	
18	1.1	0.6	0	
19	1.1	0.6	0	
20	1.1	0.6	0	
21	1.1	0.5	0	
22	1.0	0.5	0	
23	1.0	0.5	0	
24	1.0	0.5	0	
25	1.0	0.5	0	315.7 mR
26	1.0	0.5	0	257.4
27	1.0	0.4	0	108.6
28	0.9	0.4	0	71.4
29	0.9	0.4	0	52.9
30	0.9	0.4	0	41.7
31	0.9	0.4	0	34.4
June	19	9	0	330
July	13	5	0	106
August	9	4	0	61

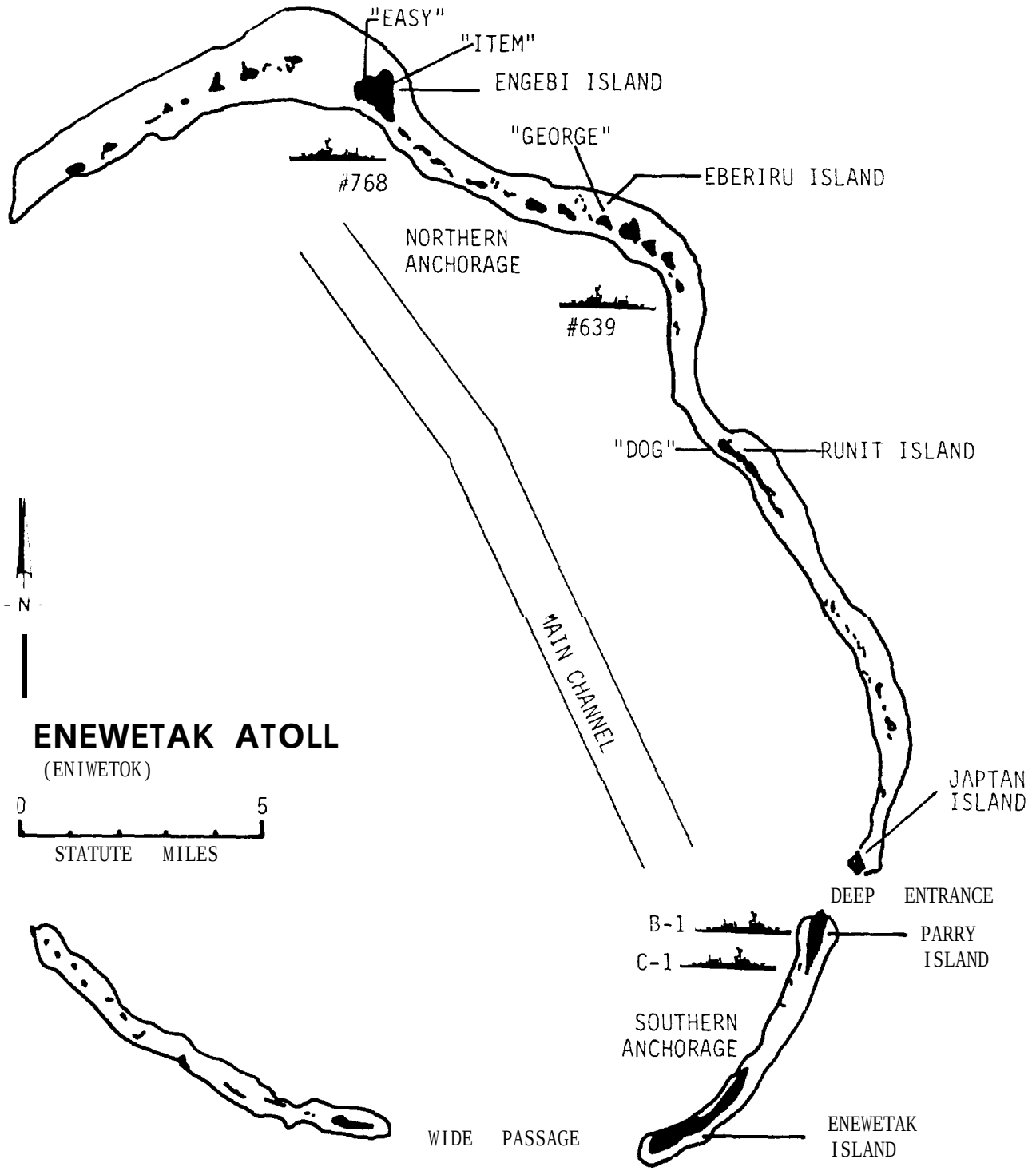


Figure 2-5. USS CURTISS Anchorage Areas - Operation GREENHOUSE

In the early afternoon of 9 April, the CURTISS got underway from berth B-l enroute to berth 768 off Engebi Island, arriving there at 1602 hours (Figure Z-5). It remained there until 1410 hours, 20 April, when it returned to berth B-l off Parry Island, where the crew observed Shot EASY the following day.

Shot EASY was detonated on Engebi Island, approximately 16 miles north of the CURTISS. There is no mention of fallout occurring aboard the CURTISS in its deck log, nor have any Material Contamination-Decontamination Reports been found that would indicate shipboard contamination from Shot EASY. On Parry Island, only 1500 yards east of the CURTISS berth, however, a small amount of fallout did occur during the night of 21 April and the early morning of 22 April. It was determined insignificant, amounting only to 2 or 3 times the Shot DOG residual radiation. It is likely that this same fallout occurred aboard the CURTISS and either went undetected or was deemed too insignificant to report. Since Shot EASY fallout on Parry and Enewetak Islands was identical, the CURTISS probably received the same fallout that occurred onboard the CABILDO and the other ships anchored in the southern anchorage area (see Section 2.1).

The CURTISS remained at anchor in berth B-l until 23 April, when it got underway to take on fuel. On 24 April, it shifted berths and moored to a telephone buoy near berth 639, approximately 2500 yards south of Eberiru Island, the shot island for Shot GEORGE scheduled for 9 May (Figure 2-5). The CURTISS remained there until 8 May when it got underway to shift berths. At 1607 hours, 8 May, the CURTISS was anchored in berth C-l, approximately 1500 yards off Parry Island, where it remained for Shot GEORGE on the following day.

Shot GEORGE was observed by the crew from a distance of 12% miles south of GZ. No fallout occurred on the CURTISS as a result of Shot GEORGE. The ship remained in the vicinity of Parry Island until 16 May, when it got underway for the northern anchorage area off Engebi Island. It remained moored to a telephone buoy in berth 768 off Engebi until 24 May, when it returned to berth B-i off Parry Island, to remain for Shot ITEM on 25 May.

The crew observed Shot ITEM from a position approximately 16 miles south of ground zero, At 0940 hours (H+3.4), fallout was detected on the CURTISS and by 1030 hours, average radiation intensities had reached approximately 6.5 mR/hr with a maximum reported intensity of 25 mR/hr. Decontamination, effected at this time, consisted of continuously flushing the weather decks with salt water. By 1230 hours, decontamination of the ship was halted. At this time intensities had been reduced to an average of 1.6 mR/hr.

At 1530 hours, 25 May, fallout was again experienced aboard the CURTISS. Average intensities reached 25-30 mR/hr, with maximum (probably isolated) intensities of 70 mR/hr reported. Fallout continued until approximately 1930 hours, with average radiation levels remaining at approximately 30 mR/hr. It was not until noon on 26 May that the residual contamination on the weather surfaces of the ship was reduced to acceptable levels of 12.5 mR/hr or less. The CURTISS remained moored in berth B-l until 1528 hours, 27 May, when it departed Enewetak Atoll for Pearl Harbor.

The free-field radiation intensities onboard the CURTISS resulting from Shots DOG, EASY and ITEM are plotted in Figures 2-6, 2-7, and 2-8, respectively. They represent the average topside radiation environment resulting from each detonation where fallout occurred onboard the ship. When available, both average and maximum values of intensity are plotted as a function of time after burst. Since the CURTISS was always anchored near Parry Island when fallout occurred, the average Parry Island intensity data have also been plotted to demonstrate the effectiveness of the anti-contamination procedures carried out onboard the CURTISS after Shots DOG and ITEM (Figure 2-6 and 2-S). Table 2-3 is a summary of the radiological data used to reconstruct the ship intensity curves for the CURTISS. The curves are time-integrated to determine the daily integrated free-fieid intensities on the ship through 31 May, presented in Table 2-4.

2.3 USS LST-859

The USS LST-859 was anchored in berth C-2, approximately 2000 yards west of Parry Island, when Shot DOG was detonated (see Figure 2-9). From this vantage point,

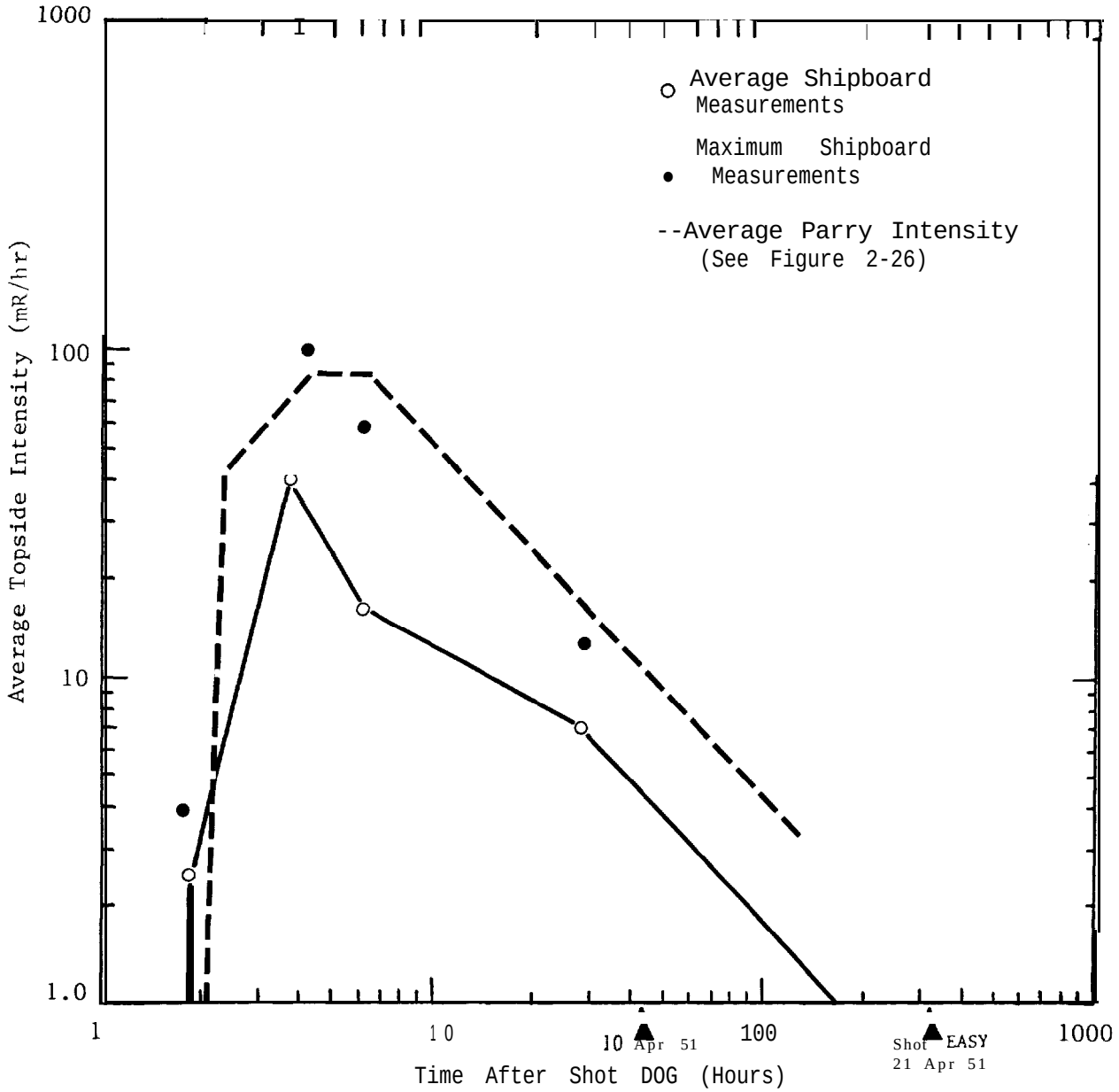


Figure 2-6'. USS CURTISS (AV-4) Ship Intensity Following Shot DOG

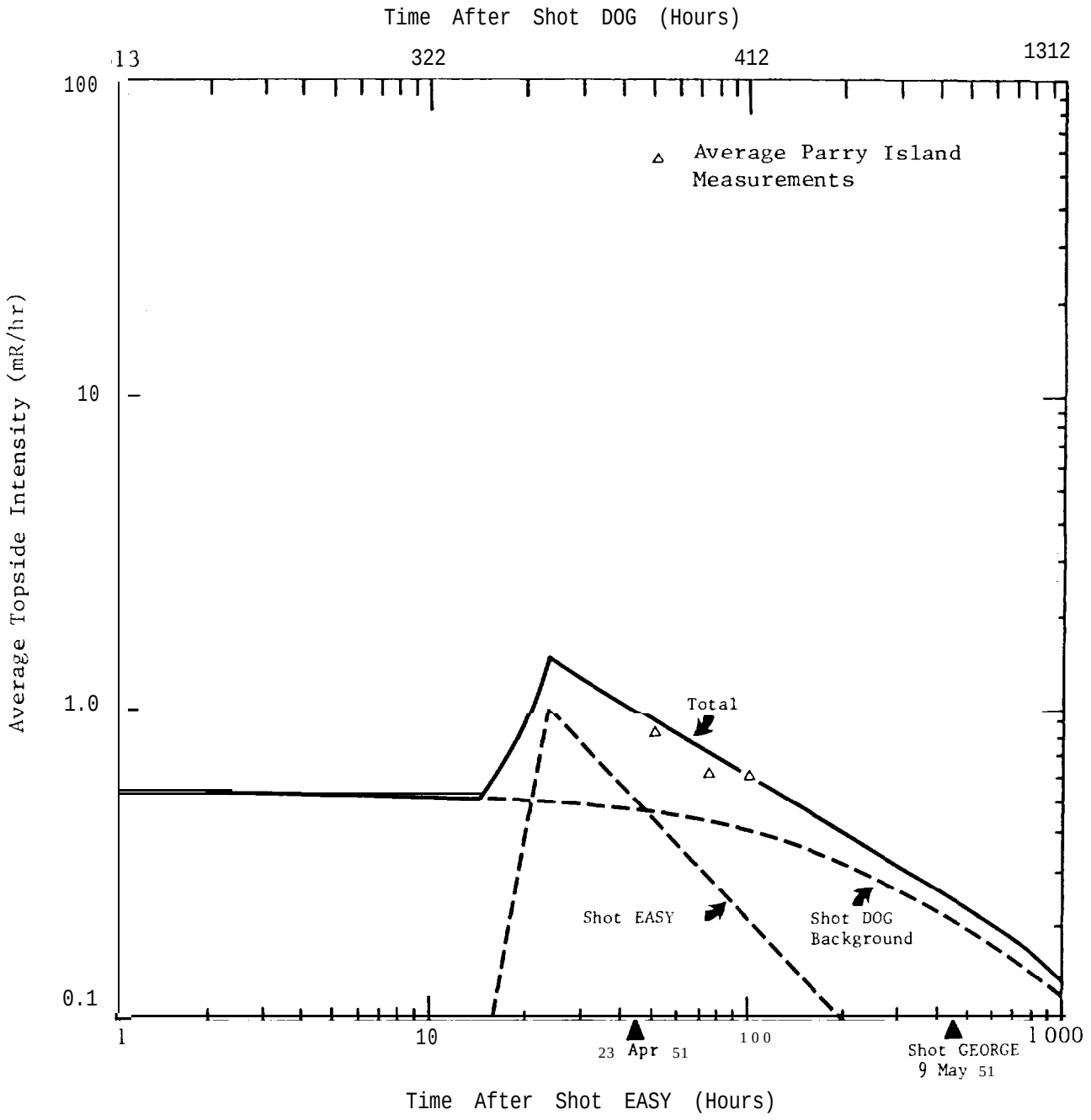


Figure 2-7. USS CUKTISS (AV-4) Ship Intensity Following Shot EASY

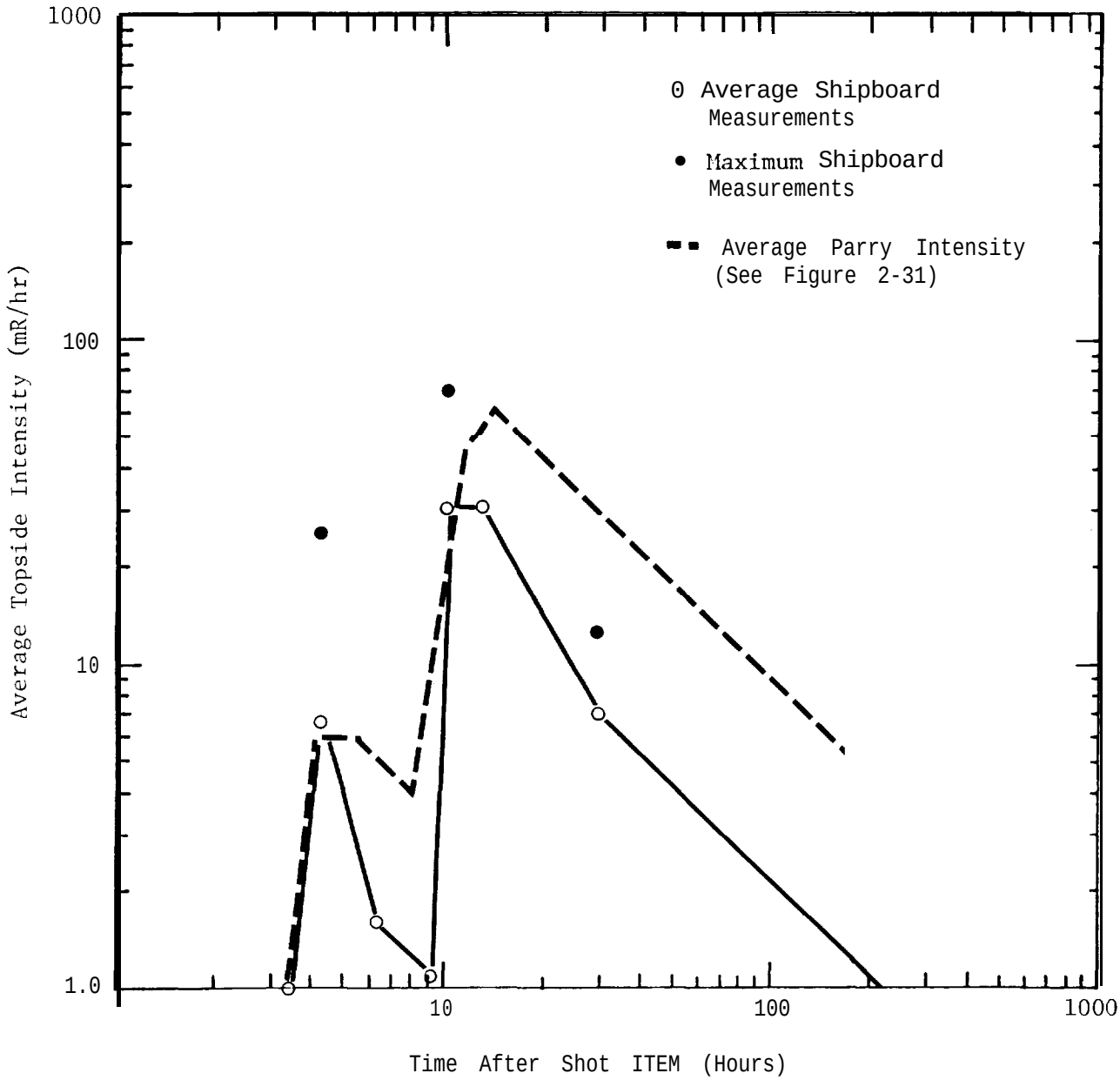


Figure 2-8. USS CURTISS (AV-4) Ship Intensity Following Shot ITEM

TABLE 2-3. USS CURTISS Average Radiation Intensity Data

Date and Time	Time After Shot (hr)	Intensity (mR/hr)
	Shot DOG	
8 April, 0825	1.8	2.5
8 April, 1010	3.6	40.0
8 April, 1300	6.4	16.0
9 April, 1130	29.0	7.0
(Parry Island decay rate as $t^{-1.083}$ assumed thereafter)		
	Shot EASY (inferred)	
21 April, 2230	16.0	**0.1**
22 April, 0630	24.0	1.0
(Decay assumed to be as $t^{-1.1}$ thereafter)		
	Shot ITEM	
25 May, 0940	3.4	**1.0**
25 May, 1030	4.2	6.5
25 May, 1230	6.2	1.6
25 May, 1530	9.2	1.1
25 May, 1630	10.2	30.0
25 May, 1930	13.2	30.0
26 May, 1130	29.0	7.0
(Parry Island decay rate as $t^{-.986}$ assumed thereafter)		

Table 2-4. Daily Integrated Free-Field Intensity, USS CURTISS

DATE	DOG	EASY	GEORGE	ITEM
8 April 1951	227.9 mR			
9	163.9			
10	88.4			
11	58.6			
12	43.6			
13	34.6			
14	28.6			
15	24.3			
16	21.1			
17	18.6			
18	16.7			
19	15.0			
20	13.7			
21	12.6	0.2 mR		
22	11.6	15.4		
23	10.9	9.8		
24	10.1	6.5		
25	9.4	4.8		
26	8.9	3.8		
27	8.4	3.1		
28	8.0	2.6		
29	7.6	2.3		
30	7.1	2.0		
1 May	6.9	1.8		
2	6.6	1.6		
3	6.3	1.5		
4	6.0	1.4		
5	5.7	1.3		
6	5.6	1.2		
7	5.3	1.1		
8	5. 1	1.0		
9	5.0	1.0	0	
10	4.9	0.9	0	
11	4.6	0.9	0	
12	4.4	0.8	0	
13	4.3	0.8	0	
14	4.3	0.7	0	
15	4.1	0.7	0	
16	4.0	0.7	0	
17	3.9	0.6	0	
18	3.7	0.6	0	
19	3.7	0.6	0	
20	3.6	0.6	0	
21	3.4	0.5	0	
22	3.4	0.5	0	
23	3.3	0.5	0	
24	3.3	0.5	0	
25	3. 1	0.5	0	215.3 mR
26	3. 1	0.5	0	198.1
27	3.0	0.4	0	93.1
28	3.0	0.4	0	64.1
29	2.9	0.4	0	49.0
30	2.9	0.4	0	39.7
31	2.9	0.4	0	33.4
June	64	9	0	357
July	44	6	0	131
August	33	4	0	81
September	26	3	0	57

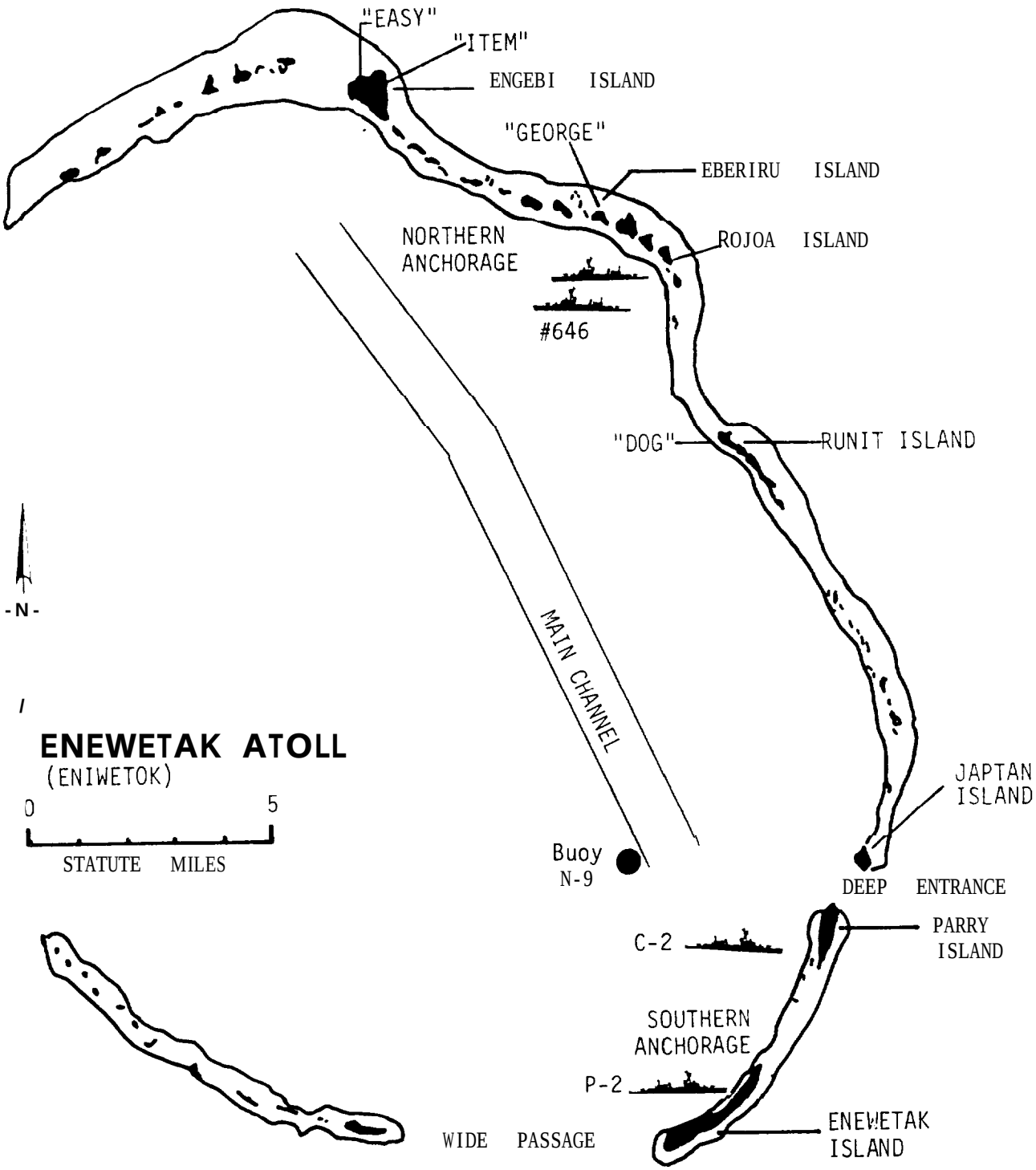


Figure 2-9. USS LST-859 Anchorage Areas - Operation GREENHOUSE

the crew observed the detonation on Runit Island, approximately 9 miles to the north. At 0735 hours, LST-859 got underway enroute to its assigned anchorage off Rojoa Island in the northern portion of the lagoon, taking a station 2500 yards astern of the MOWER. LCM-20, a Task Group 3.3 escort boat, preceded the MOWER and the LST-859 during their passage north. At 0835 hours (H+2.0), LCM-20 reported contamination levels of 10-25 mR/hr at a position 1000 yards north of buoy N-V in the ship channel (Figure 2-V). At that time, the LST-859 and MOWER were ordered to lie to. At 0842 hours they were ordered to resume their passage to the northern anchorage area. At 0835 hours, average readings aboard the LST-859 were 25 mR/hr, with a maximum reading of 100 mR/hr. Decontamination was begun at 0845 hours.

Although it is not explicitly stated, it appears that moderate fallout activity continued as they steamed north. At approximately 0945 hours, when the LST-859 was 3.7 miles west of ground zero, it encountered heavy fallout. An attempt to maneuver free of the fallout area resulted in exposing the ship for a longer period of time than if it had proceeded directly to its assigned berth. By 1100 hours, the LST-859 was reporting an average intensity aboard ship of 76 mR/hr, with a maximum reading of 380 mR/hr. It was not until 1146 hours that the LST finally anchored in its assigned berth, 2100 yards west of Rojoa Island, (Figure 2-V). Decontamination continued both below and above decks, and by 1630 hours, average intensity levels on the weather decks had been reduced to approximately 4 mR/hr, with isolated areas of 10 mR/hr. By 1757 hours, 9 April, all weather deck intensities had been reduced below 4.5 mR/hr.

The LST-859 remained anchored in the area off Rojoa until 1649 hours, 20 April, when it got underway to shift berths. At 1820 hours, it was anchored in berth C-2 off Parry Island, where it remained for Shot EASY on the following day (Figure 2-V).

Shot EASY was detonated approximately 16 miles north of the LST-859. There is no mention of fallout occurring onboard the ship as a result of Shot EASY, but on Parry Island, only 2000 yards east, a small amount of fallout did occur during the night of 21 April and the early morning of 22 April. It was determined insignificant, amounting only to 2 or 3 times the Shot DOG residual radiation (Reference 6). It is not unreasonable to expect that the same fallout occurred aboard the LST-859 and

either went undetected or was deemed too insignificant to report. With the assumption that the ship did receive this fallout, the average peak intensity onboard would have been approximately 1.5 mR/hr.

At 0620 hours, 22 April, the LST-859 got underway to its assigned anchorage off Rojoa Island, where it anchored at 0802 hours the same day. Because of the presence of underwater telephone cables in this area, it shifted anchorages to berth 646, 2500 yards southwest of Rojoa, on 24 April (Figure 2-9). It remained in the northern anchorage area until 1735 hours, 8 May, when it returned to the southern anchorage area. At 2002 hours, 8 May, it dropped anchor in berth P-2, approximately 900 yards north of Enewetak Island.

Shot GEORGE was detonated on Eberiru Island, approximately 16 miles north of berth P-2, where the crew observed the detonation. No fallout occurred onboard the LST-859 as a result of Shot GEORGE. It remained in berth P-2 until 10 May, when it shifted berths to B-2, off Parry Island. On 13 May, the LST-859 departed Enewetak enroute to the Caroline Islands, where it arrived on 15 May. It returned to Enewetak on 21 May and remained off Enewetak Island until 23 May, when it got underway enroute to Kwajalein via Bikini Atoll. No fallout was reported onboard the ship following Shot ITEM.

The free-field radiation intensities onboard the LST-859 resulting from Shots DOG and EASY are depicted in Figures 2-10 and 2- 11, respectively. They represent the average topside radiation environment resulting from each detonation where fallout occurred onboard ship. Both average and maximum values of intensity are plotted with time after burst. Table 2-5 is a summary of the radiological data used to derive the ship intensity curves. Daily integrated free-field intensities onboard the LST-859 are presented in Table 2-6.

2.4 USNS SGT. CHARLES E. MOWER (TAP-186)

The USNS SGT. CHARLES E. MOWER was anchored in berth C-l, approximately 1500 yards west of Parry Island (see Figure 2-12) when Shot DOG was detonated. The

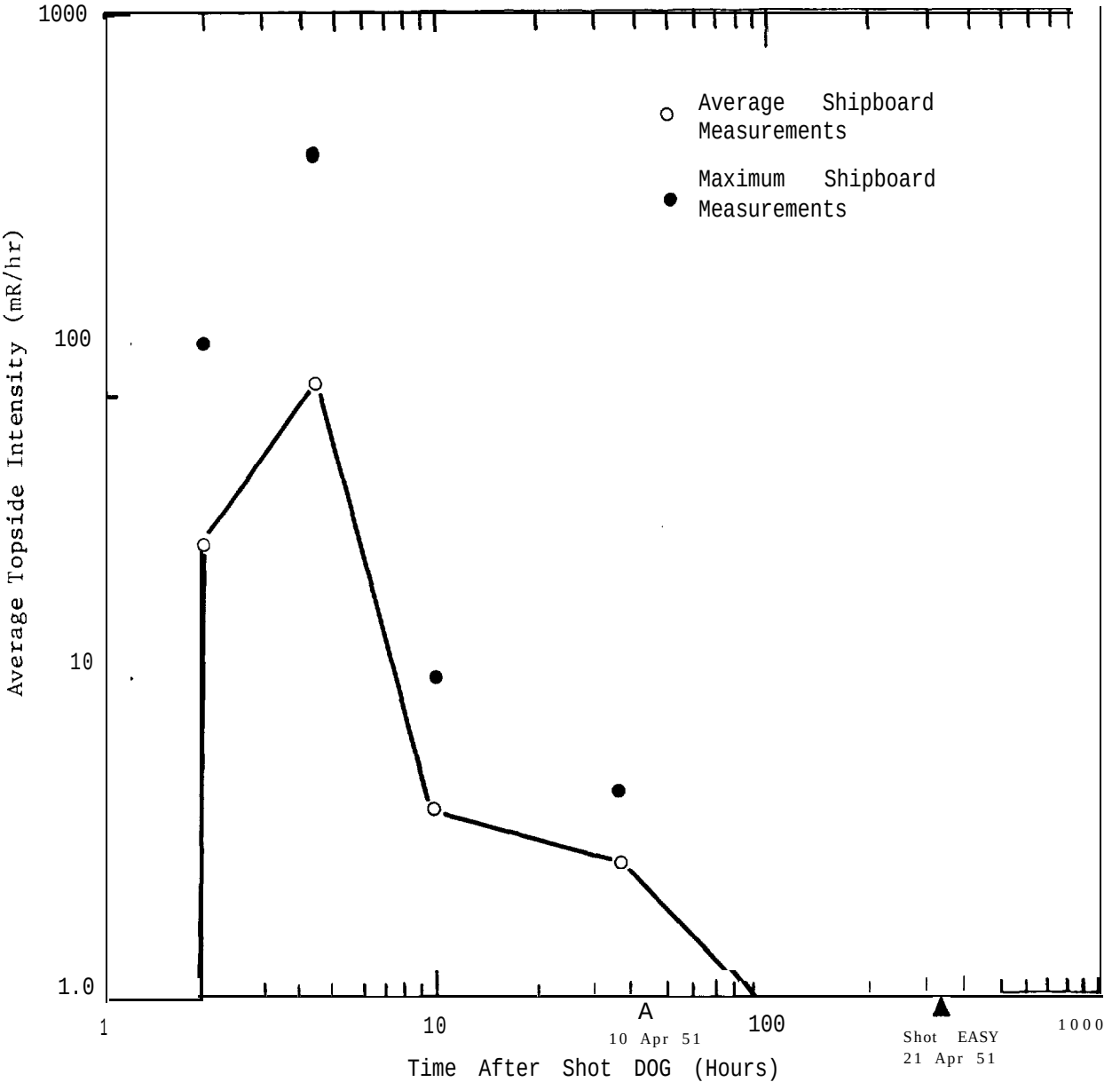


Figure 2-10. USS LST-859 Ship Intensity Following Shot DOC

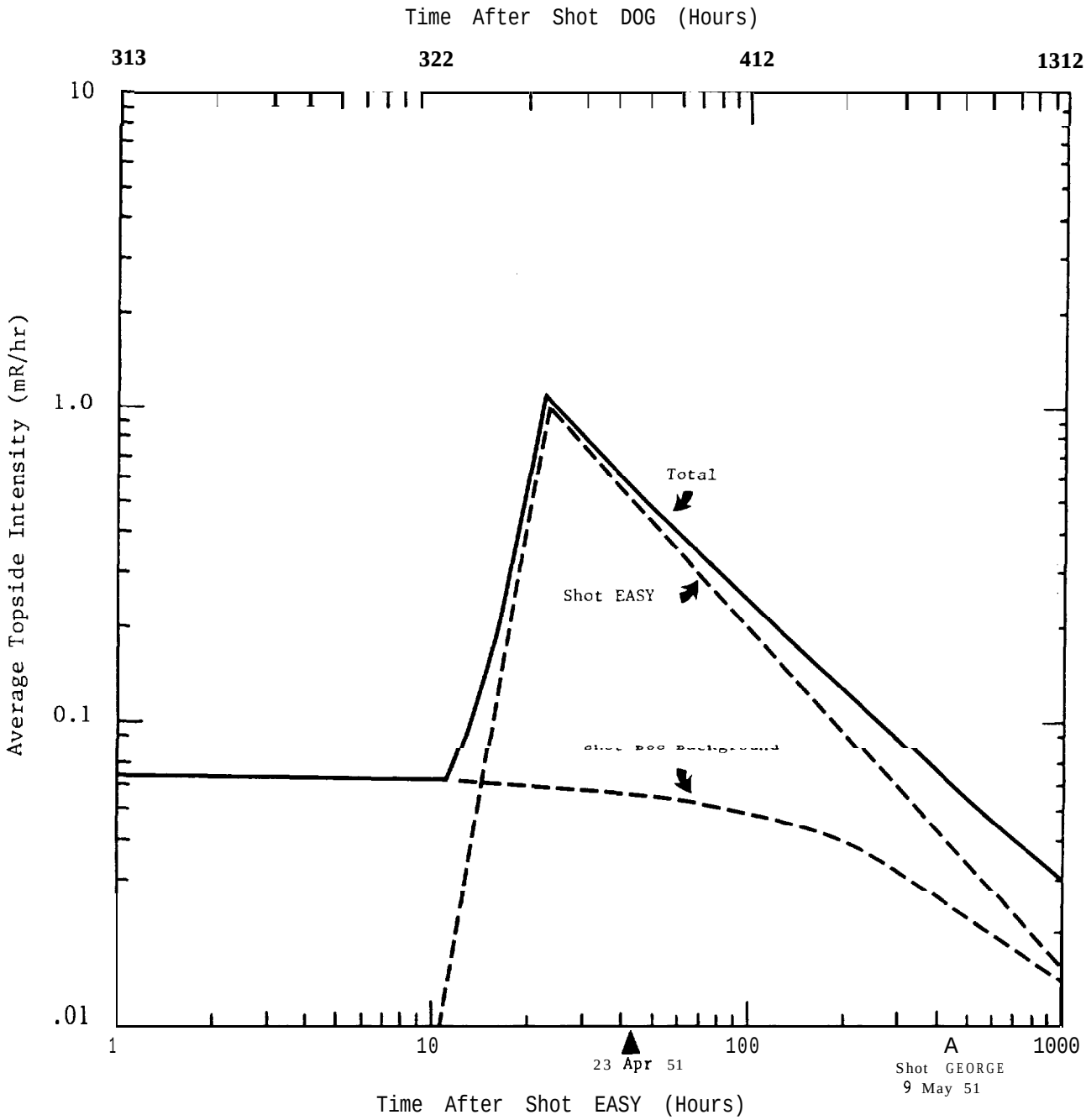


Figure 2-11. USS LST-859 Ship Intensity Following Shot EASY

TABLE 2-5. USS LST-859 Average Radiation Intensity Data

Date and Time	Time After Shot (hr)	Intensity (mR/hr)
	Shot DOG	
8 April, 0835	2.0	25.0
8 April, 1100	4.4	75.6
8 April, 1630	9.9	3.9
9 April, 1757	35.4	2.8
(Parry Island decay rate as $t^{-1.083}$ assumed thereafter)		
	Shot EASY (inferred)	
21 April, 2230	16.0	0.1
22 April, 0630	24.0	1.0
(Decay assumed to be as $t^{-1.1}$ thereafter)		

NOTE: LST-859 was enroute to Bikini at the time of Shot ITEM.

Table 2-6. Daily Integrated Free-Field Intensity, USS LST-859

DATE	DOG	EASY	G E O R G E ITEM*
8 April 1951	255.4 mR		
9	69.1		
10	43.1		
11	28.5		
12	21.3		
13	16.9		
14	13.9		
15	11.9		
16	10.3		
17	9.1		
18	8.1		
19	7.3		
20	6.7		
21	6.1	0.2 mR	
22	5.7	15.4	
23	5.3	9.8	
24	4.9	6.5	
25	4.6	4.8	
26	4.3	3.8	
27	4.1	3.1	
28	3.9	2.6	
29	3.7	2.3	
30	3.4	2.0	
I May	3.3	1.8	
2	3.1	1.6	
3	3.0	1.5	
4	2.9	1.4	
5	2.9	1.3	
6	2.7	1.2	
7	2.6	1.1	
8	2.6	1.0	
9	2.4	1.0	0
10	2.3	0.9	0
II	2.3	0.9	0
12	2.1	0.8	0
13	2.1	0.8	0
14	2.0	0.7	0
15	2.0	0.7	0
16	2.0	0.7	0
17	1.9	0.6	0
18	1.9	0.6	0
19	1.9	0.6	0
20	1.7	0.6	0
21	1.7	0.5	0
22	1.7	0.5	0
23	1.6	0.5	0
24	1.6	0.5	0
25	1.6	0.5	0
26	1.6	0.5	0
27	1.4	0.4	0
28	1.4	0.4	0
29	I.4	0.4	0
30	1.4	0.4	0
31	1.4	0.4	0

*LST-859 was enroute to Bikini at the time of Shot ITEM.

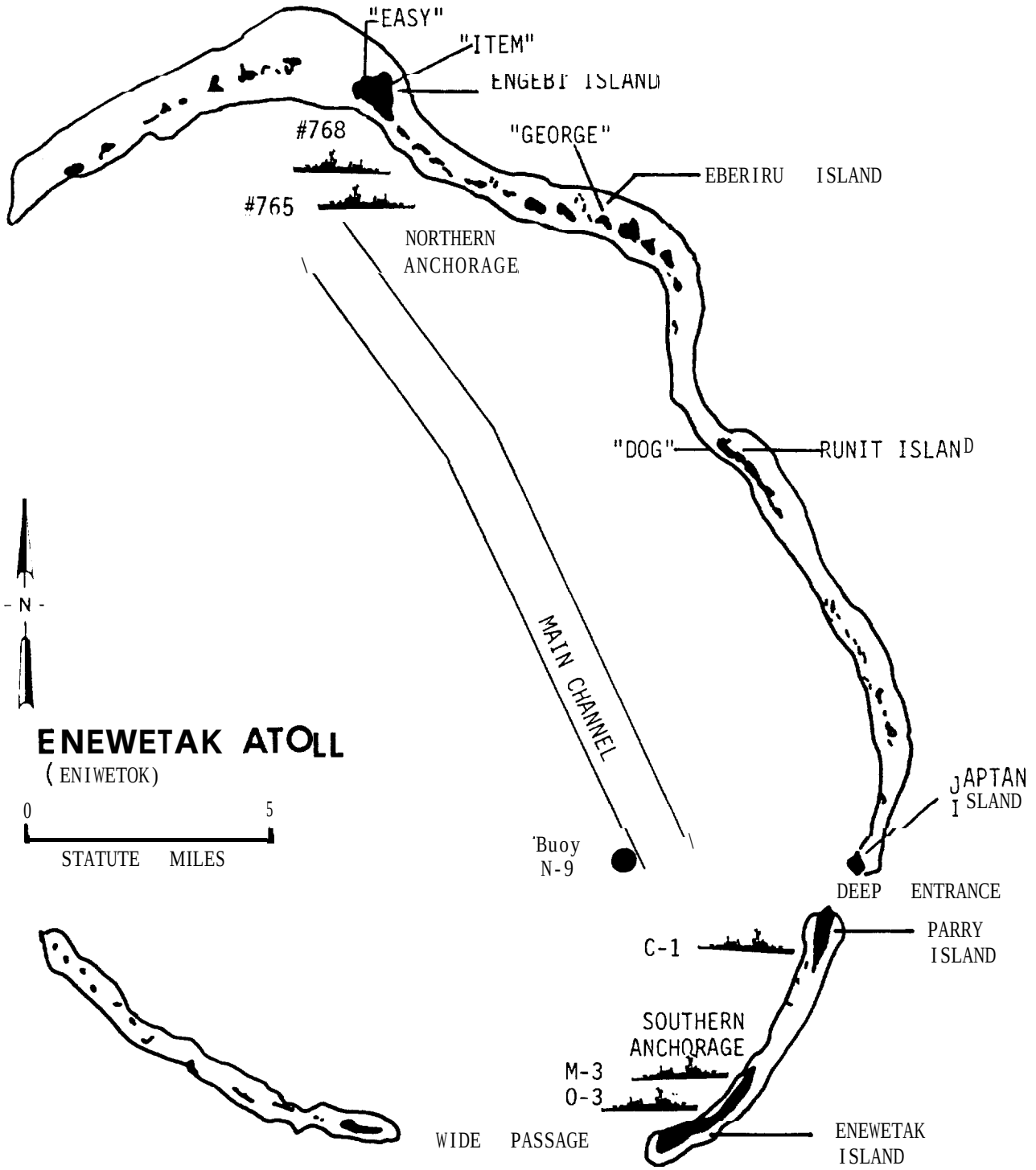


Figure 2-12. USNS SGT. CHARLES E. MOWER Anchorage Areas - Operation GREENHOUSE

crew observed the explosion on Runit Island, approximately 9 miles north of their anchorage off Parry. At 0737 hours the MOWER weighed anchor and got underway for berth 765 in the northern anchorage area off Engebi Island. LCM-20, a Task Group 3.3 escort boat, preceded the MOWER and the LST-859. At 0835 hours (H+2), the LCM-20 reported contamination levels of 10-25 mR/hr at a position 1000 yards north of buoy N-Y in the ship channel (Figure 2-12), and both the MOWER and LST-859 were ordered to lie to. At 0842 hours, the MOWER was ordered to resume passage to its assigned anchorage off Engebi and it steamed up the channel at a speed of approximately 10 knots. At 0858 hours, when a rad-safe survey was initiated, average intensities onboard the MOWER were 15 mR/hr, with maximum readings of 20 mR/hr. At 0937 hours, when the MOWER was approximately 3.7 miles west of ground zero, it encountered heavy fallout. Rather than trying to avoid the fallout area as did the LST-859, the MOWER proceeded directly toward its assigned berth. A rad-safe survey at 0940 hours indicated average intensity levels aboard the MOWER of approximately 40 mR/hr, with isolated readings as high as 110 mR/hr. Decontamination was begun at 09 45 hours.

By 1037 hours, the MOWER had passed through the fallout area and was anchored in berth 765 off Engebi (Figure 2-12). Decontamination of the ship continued, and by 1215 hours, average levels had been reduced to 20 mR/hr. It was not until approximately 1000 hours, 9 April, that contamination levels were reduced to approximately 2 mR/hr, with isolated areas as high as 4.1 mR/hr.

The MOWER remained anchored off Engebi until 20 April, when it returned to berth C-l in the southern anchorage area off Parry Island, from which the crew would observe Shot EASY on the following day.

Shot EASY was detonated on Engebi, approximately 16 miles north of the MOWER. There is no mention of fallout occurring onboard the MOWER as a result of Shot EASY, but on Parry Island, only 1500 yards east, a small amount of fallout did occur during the night of 21 April and the early morning of 22 April. It is likely that this same fallout occurred aboard the MOWER, but either went undetected or was deemed too insignificant to report. With the assumption that the MOWER did receive

this fallout, the average peak intensity onboard would have been approximately 1.5 mR/hr.

Except for being refueled on 22 April, the MOWER remained in berth C-l until 23 April, when it got underway for berth 768 off Engebi. It remained moored off Engebi until 1716 hours, 8 May, when it returned to the southern anchorage area and anchored in berth M-3, approximately 2500 yards west of the northern tip of Enewetak Island (see Figure 2-12). Here, the crew would observe Shot GEORGE on the following day.

Shot GEORGE was detonated on Eberiru Island approximately 15 miles north of the MOWER. No fallout occurred onboard as a result of this shot. On 10 May, it returned to berth 765 off Engebi, where it remained until 24 May. At 1400 hours, 24 May, the MOWER got underway for berth O-3 in the southern anchorage area, where, at 1605 hours, it anchored 2000 yards off Enewetak Island in close proximity to the USS CABILDO (LSD-16).

On 25 May, the crew observed Shot ITEM, which was approximately 20 miles north of the MOWER (see Figure 2-12). Although shipboard rad-safe surveys and Material Contamination-Decontamination Reports are not available, a reasonable representation of the radiation environment aboard the ship can be inferred from the USS CABILDO, only 700 yards to the northeast.

Fallout from Shot ITEM was deposited on the ships anchored off Enewetak during two periods; these were between 1030 (H+4.2) and 1230 hours and between 1630 and 1830 hours. Average intensities onboard the CABILDO reached approximately 12 mR/hr during the first period and approximately 60 mR/hr during the second (see Figure 2-4). During each fallout period, the weather decks on the CABILDO were being continuously flushed with salt water. It is known that the crew of the MOWER followed this procedure during the Shot DOG fallout, and it is probable that they effected these same procedures during the Shot ITEM fallout. Thus, it is reasonable to infer that average radiation intensities onboard the MOWER would be nearly the same as those measured on the CABILDO, at least until the time the fallout stopped. After

the fallout had ceased, all of the ships' crews normally began decontamination procedures to reduce the shipboard radiation intensities. Shipboard intensities, plotted in Figure 2-4, indicate that decontamination was quite successful on the CABILDO in the first 20 hours after the fallout had stopped. The crew of the MOWER probably followed a similar routine, but, because no contamination-decontamination report from the MOWER is available to confirm this, it is assumed that they did not effect any further decontamination procedures. This assumption tends to high-side the subsequent dose calculations for the MOWER crew. The inferred ship intensity curve for the [MOWER resulting from Shot ITEM fallout is therefore that of the CABILDO (Figure 2-4), except that, after fallout ceased, only radioactive decay acted to reduce shipboard intensities. Island data are used to arrive at a $t^{-1.1}$ decay rate.

The free-field radiation intensities onboard the USS MOWER resulting from Shots DOG and EASY are depicted in Figures 2-13 and 2-14, respectively. They represent the average topside radiation environment resulting from each detonation where fallout occurred onboard ship. When available, both average and maximum values of intensity are plotted with time after burst. Table 2-7 is a summary of the radiological data used to derive ship intensity curves for the MOWER. These data are used to calculate the daily integrated free-field intensities onboard the MOWER found in Table 2-8.

2.5 USS SPROSTON (DDE-577)

The crew of the USS SPROSTON (DDE-577) observed Shot DOG while patrolling the waters 30 miles north of the Runit Island ground zero (see Figure 2-15). It continued patrolling in this area until 0740 hours (H+1.1), when it proceeded toward DOG ground zero. At 0940, the SPROSTON passed Runit Island 2000 yards abeam before heading off on an easterly course to investigate a surface contact. Although it passed close to DOG GZ, the SPROSTON did not encounter any radioactive fallout at this time, although the WALKER had received large particle fallout about two hours earlier some 15 nautical miles east of GZ. Apparently, deposition was complete in this area by the time the SPROSTON arrived. After identifying the surface contact as the

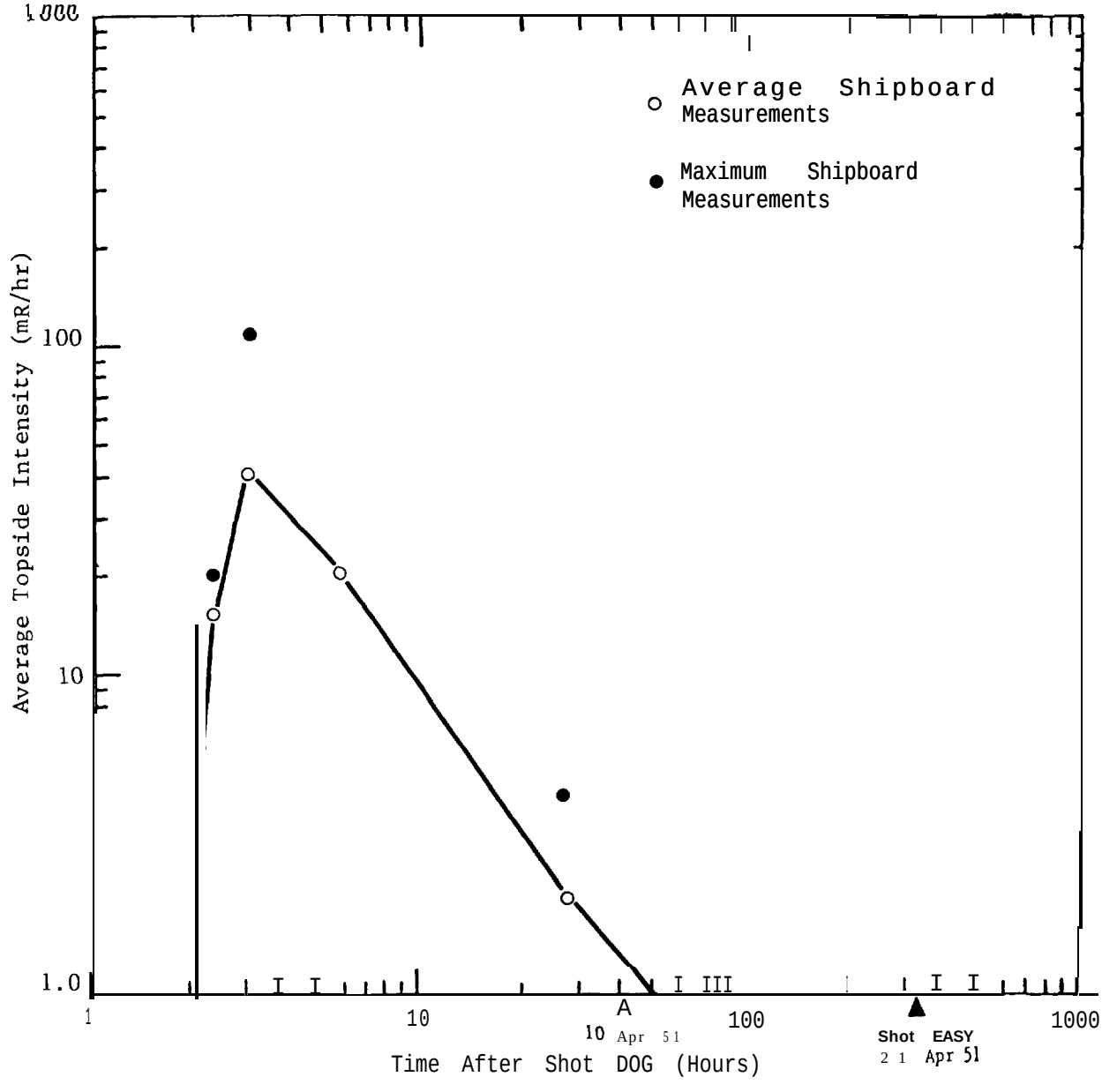


Figure 2-13. USNS SGT. CHARLES E. MOWER (TAP-186) Ship Intensity Following Shot DOG

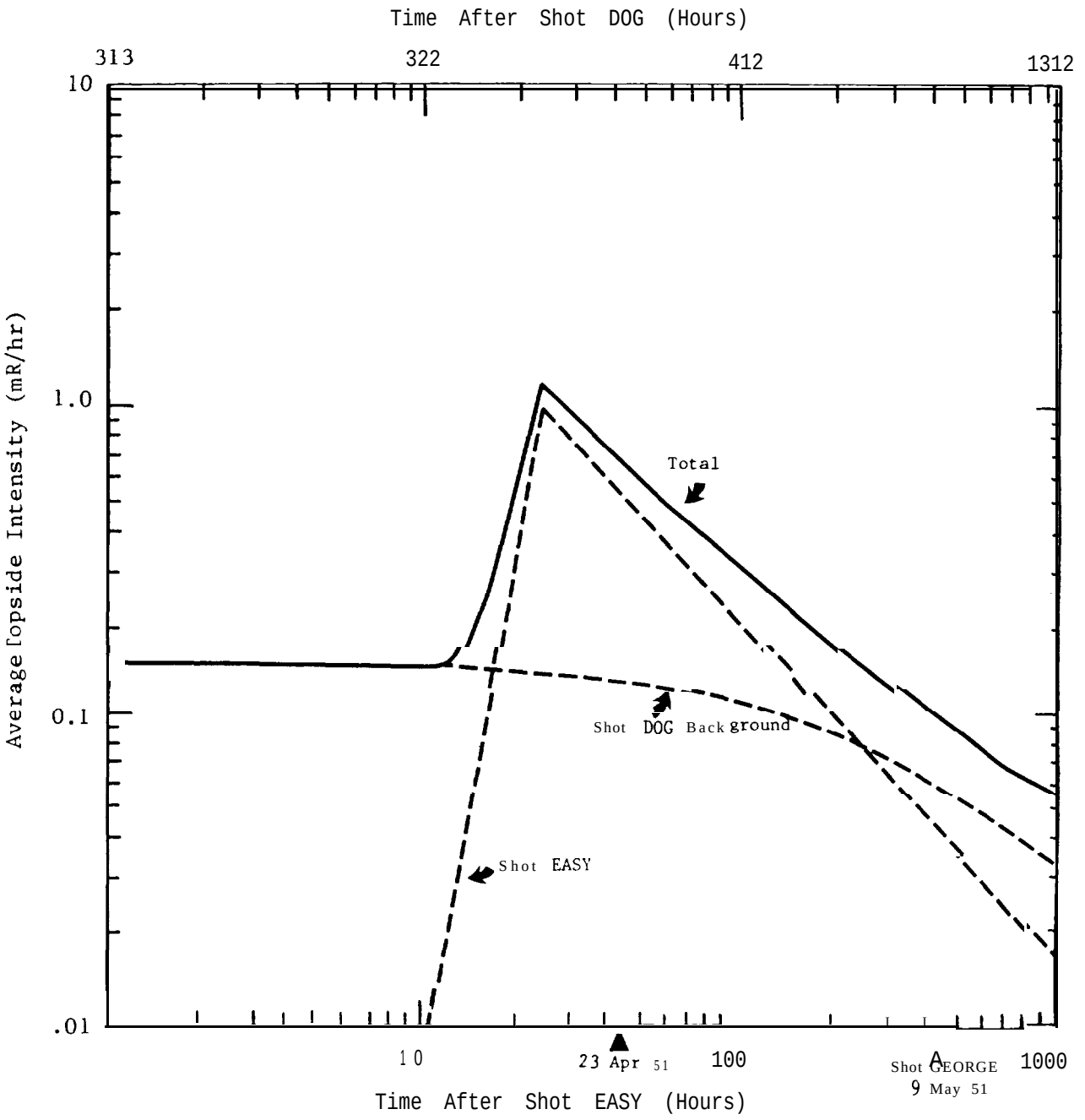


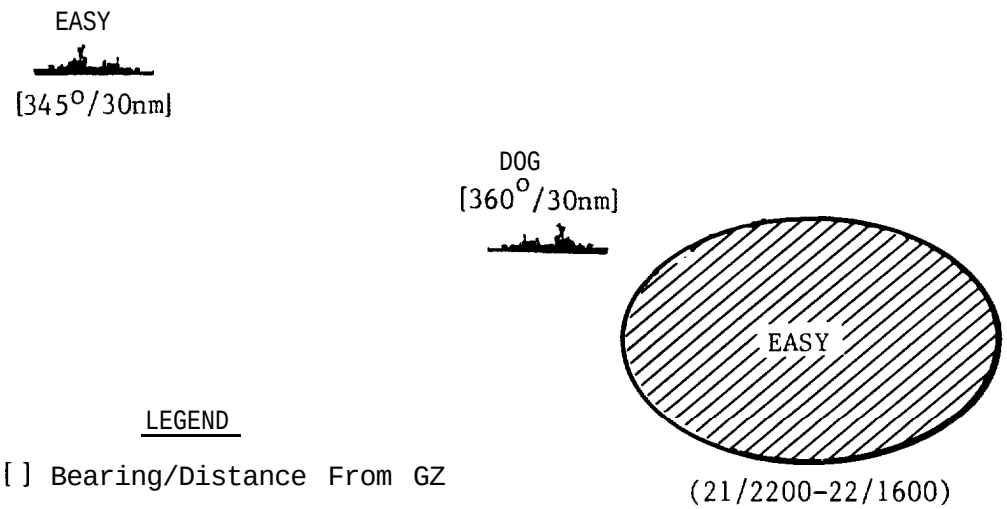
Figure 2-14. USNS SGT. CHARLES E. MOWER (TAP-186) Ship Intensity Following Shot EASY

TABLE 2-7. USNS SGT. CHARLES E. MOWER Average Radiation Intensity Data

Date and Time	Time After Shot (hr)	Intensity (mR/hr)
	Shot DOG	
8 April, 0858	2.4	15.0
8 April, 0940	3.1	38.4
8 April, 1215	5.7	20.0
9 April, 1000	27.4	2.0
(Parry Island decay rate as $t^{-1.083}$ assumed thereafter)		
	Shot EASY (inferred)	
21 April, 2230	16.0	0.1
22 April, 0630	24.0	1.0
(Decay asssumed to be as $t^{-1.1}$ thereafter)		
	Shot ITEM	
25 May, 1028	4.2	.01
25 May, 1130	5.2	11.5
25 May, 1630	10.2	4.6
25 May, 1723	11.1	58.6
(Enewetak Island decay rate as $t^{-1.1}$ assumed thereafter)		

Table 2-8. Daily Integrated Free-Field Intensity, USNS SGT. CHARLES E. MOWER

DATE	DOG	EASY	G E O R G E	ITEM
8 April 1951	188.1 mR			
9	50.3			
10	24.0			
11	15.9			
12	11.9			
13	9.3			
14	7.7			
15	6.6			
16	5.7			
17	5.0			
18	4.6			
19	4.1			
20	3.7			
21	3.4	0.2 mR		
22	3.1	15.4		
23	2.9	9.8		
24	2.7	6.5		
25	2.6	4.8		
26	2.4	3.8		
27	2.3	3.1		
28	2.1	2.6		
29	2.0	2.3		
30	2.0	2.0		
I May	1.9	1.8		
2	1.7	1.6		
3	1.7	1.5		
4	1.6	1.4		
5	1.6	1.3		
6	1.4	1.2		
7	1.4	1.1		
8	1.4	1.0		
9	1.3	1.0	0	
10	1.3	0.9	0	
II	1.3	0.9	0	
12	1.3	0.8	0	
13	1.1	0.8	0	
14	1.1	0.7	0	
15	1.1	0.7	0	
16	1.1	0.7	0	
17	1.0	0.6	0	
18	1.0	0.6	0	
19	1.0	0.6	0	
20	1.0	0.6	0	
21	1.0	0.5	0	
22	0.9	0.5	0	
23	0.9	0.5	0	
24	0.9	0.5	0	
25	0.9	0.5	0	353.1 mR
26	0.9	0.5	0	508.0
27	0.9	0.4	0	251.7
28	0.9	0.4	0	165.6
29	0.9	0.4	0	122.6
30	0.7	0.4	0	96.9
31	0.7	0.4	0	79.7
June	20	10	0	764
July	13	7	0	244
August	10	4	0	143
September	9	3	0	97
October	7	3	0	77



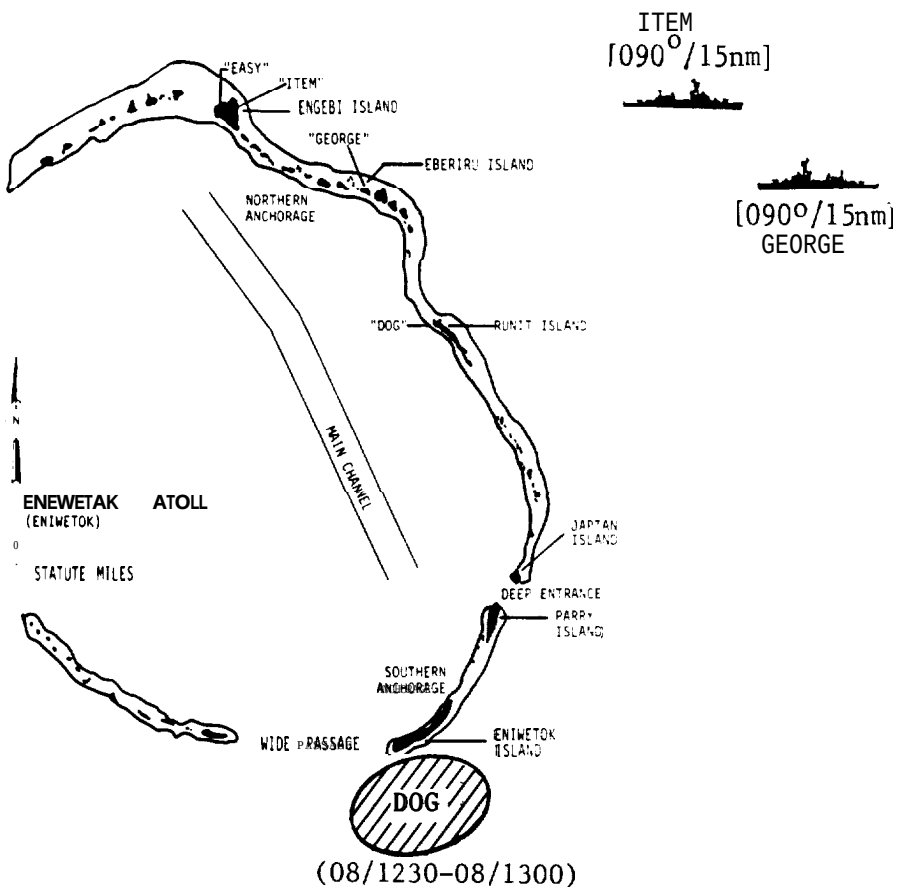


Figure 2-15. USS SPRINGFIELD Pre-Shot Positions and Fallout Areas

LT. ROBERT CRAIG, at 1142 hours, the SPROSTON took a southwesterly course, where it intercepted the 500-fathom contour off Enewetak Island at approximately 1230 hours (see Figure 2-16). It then continued along the 500-fathom contour in a clockwise direction around the atoll and, at 1300 hours, Wide Passage (South Channel) was observed abeam to starboard. It continued patrolling the atoll in this manner until approximately 1950 hours, when it reversed direction and began to patrol in a counterclockwise direction.

Between 1230 and 1300 hours, as the SPROSTON was heading in a westerly direction along the 500-fathom contour off Enewetak, it began to encounter the second period of fallout from the DOG cloud that was passing over the southwestern portion of the lagoon. Personnel decontamination was effected at about 1300 hours (H+6½); average radiation intensities onboard the SPROSTON, presumably obtained at a similar time, were approximately 5 mR/hr, with maximum readings of 10 mR/hr. The SPROSTON was now heading toward an area of heavier fallout (see Figure 2-16), and it is probable that it encountered contamination levels greater than 10 mR/hr before the fallout ended shortly after 1300 hours. To be conservative, it is assumed the ship had proceeded to a point almost due south of Igurin Island (See Figure 2-16), before the fallout ceased, hence, it received fallout similar to that which occurred on Parry Island between 1200 and 1300 hours. Much heavier fallout had occurred to the west of this point, but deposition was complete by the time the ship reached this area. Figure 2-17 depicts the fallout which occurred on Parry during the two periods of DOG fallout. Fallout occurring between 0830 and 1100 is subtracted from the total intensity curve to arrive at the 1200 to 1300 fallout intensity onboard the SPROSTON.

Shipboard decontamination was not begun until approximately 1600 hours, 8 April. It consisted of washing down the bulkheads with soap and water and cleaning the deck areas at a rate of four square feet per minute with a stream of high velocity water. About 2% hours were required to reduce the intensities to “normal” (Reference 7).

The crew of the SPROSTON observed Shot EASY from approximately 30 miles north-northwest (bearing 3450T) of the Engebi Island ground zero (see Figure 2-l 5).

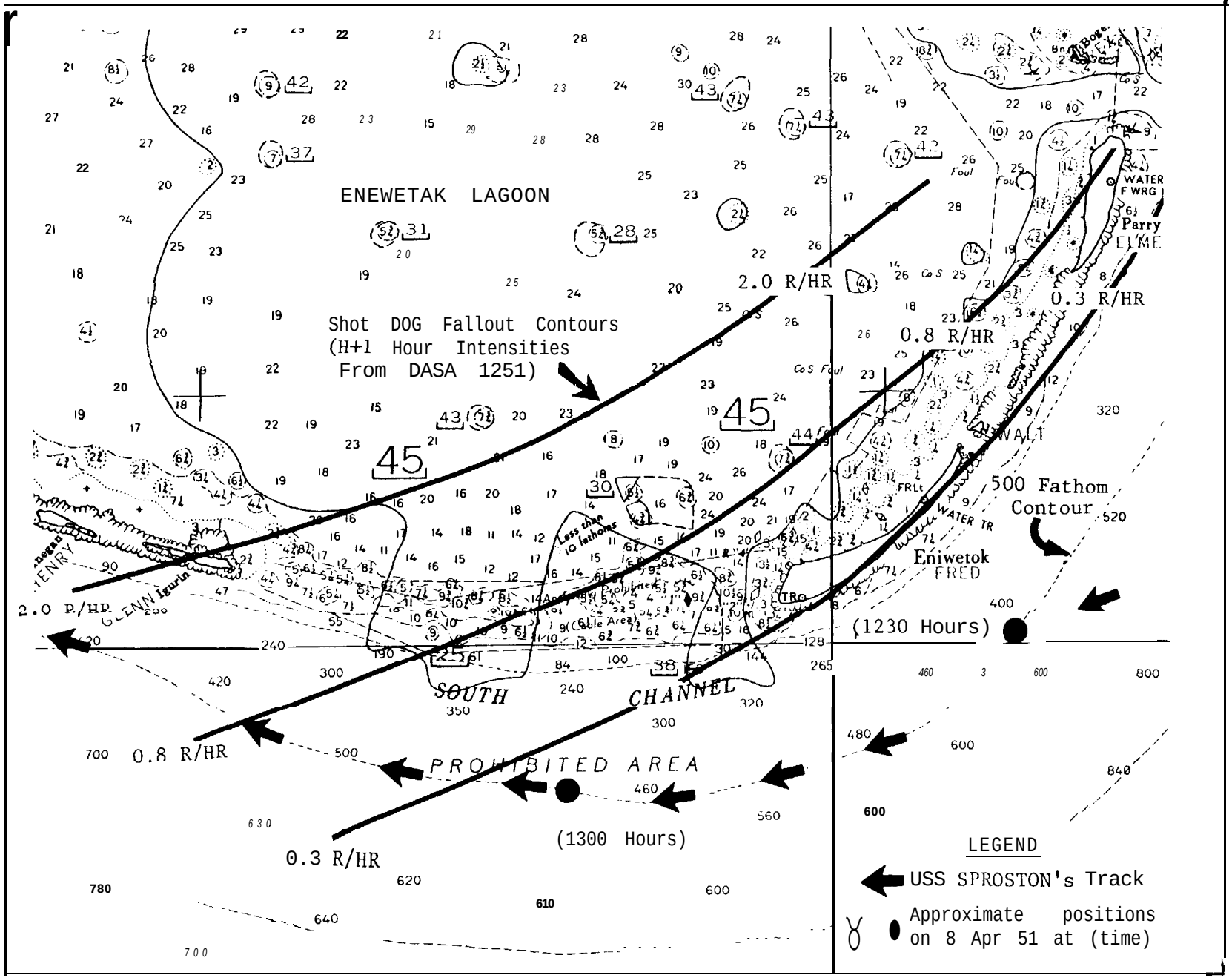


Figure 2-16. USS SPROSTON Patrol Positions - 8 April 1951

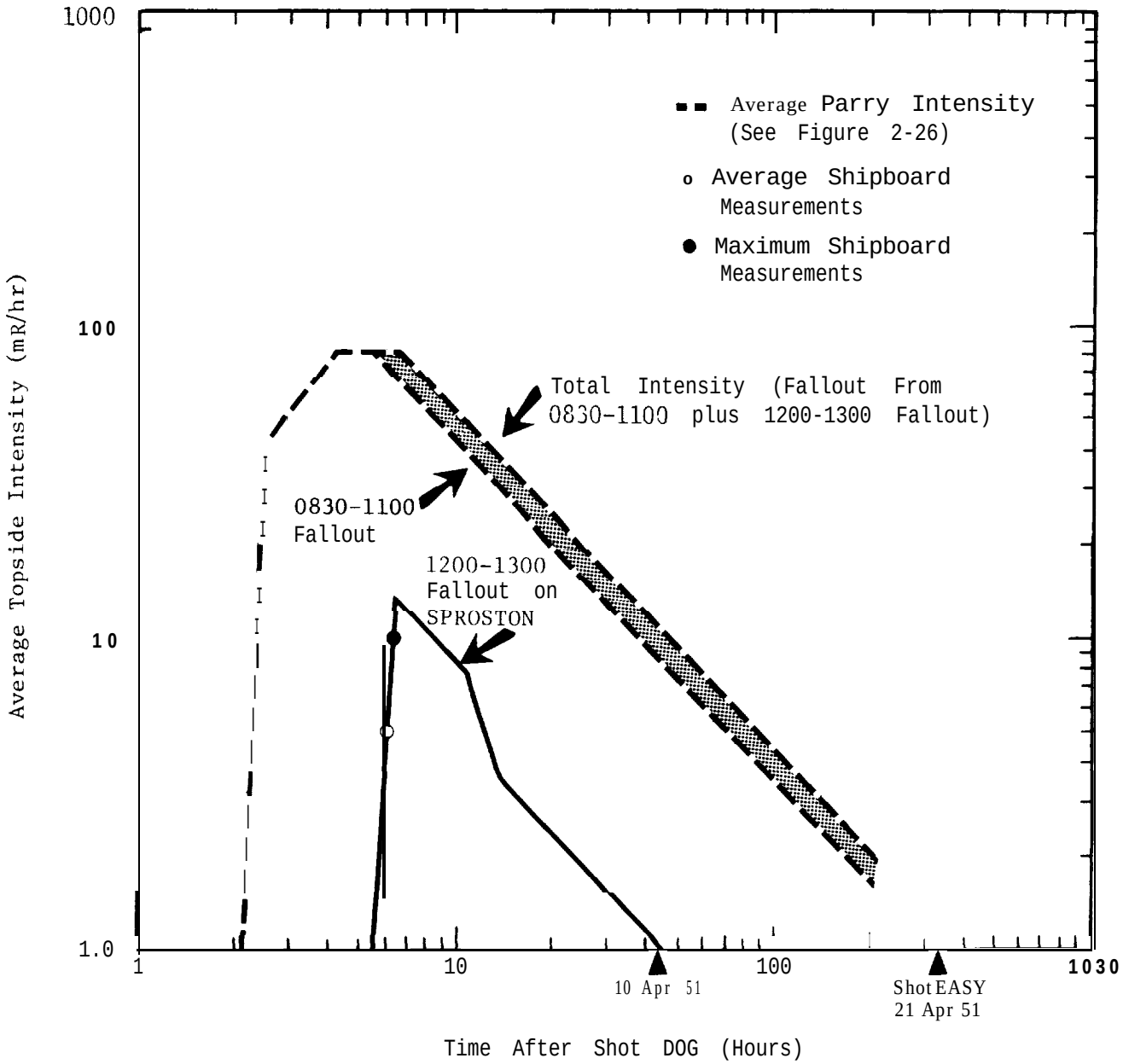


Figure 2-17. USS SPROSTON (DDE-577) Ship Intensity Following Shot DOG

After the detonation, the SPROSTON proceeded toward GZ but approached no closer than approximately 15 miles. At 0715 hours it began patrolling the area to the north and northeast of Engebi Island. At approximately 1300 hours, it took a southwesterly course to begin patrolling an area 10-20 miles east-northeast of Engebi. It continued patrolling this area until 1849 hours, when it headed south and began patrolling an area to the east of Engebi at 1935 hours. (Shortly after the SPROSTON arrived in this area, the WALKER, which had been patrolling these waters since H-hour, departed on a clockwise patrol of Enewetak Atoll). SPROSTON remained in an area approximately 15 miles east of GZ until 1952 hours when it took a northeasterly course.

While it was on this course (045°T), radiation levels aboard the SPROSTON began to rise and decontamination was begun at 2200 hours, 21 April (H+15.5). According to the 21 April 1951 Material Contamination-Decontamination Report, all deck surfaces were sprayed with a stream of high velocity water. It further states that these procedures had virtually no effect on reducing the onboard contamination levels. The shipboard radiological survey that accompanies the report shows that the exposed surfaces of the ship read virtually the same (15 mR/hr) throughout the ship. It further states that: "It is our opinion that the radiation stayed above us, thus is the reason we did not reduce the intensity by decontamination, but withdrawing from the area reduced the readings more effectively. Once out of the area our readings dropped to normal." From this same report, intensity levels were not reduced to normal until 18 hours after decontamination began, or 1600 hours, 22 April. This was about the time they departed the area northeast of Engebi Island and began a counterclockwise patrol around the atoll. It appears that, al though decontamination was periodically attempted during this 18-hour period, "cloud shine" was keeping the intensity relatively constant at 15 mR/hr on all the weather decks.

On 9 May, the SPROSTON was 15 miles east of the Shot GEORGE GZ on Eberiru Island (see Figure 2- 15). After the shot, it took a southwesterly course and, by 1043 hours, it was conducting a barrier patrol off Wide Passage (South Channel). At no time on GEORGE day, or during subsequent days, was the SPROSTON exposed to any fallout from the shot.

Again, during the early morning hours of 25 May, 1951, the SPROSTON took a position 15 miles east of Engebi Island where Shot ITEM was detonated (see Figure 2-15). After a short rendezvous with the WALKER at approximately 0840 hours, the SPROSTON began an independent patrol off the atoll. At this time, an onboard gamma intensity meter was indicating radiation levels of 0.03 mR/hr due to the residual contamination from Shot DOG. The 25 May deck log does not yield enough navigational data to reconstruct the ship's movements for the remainder of the day, but a memorandum on USS SPROSTON letterhead indicates that the ship did encounter minor fallout between approximately 1900 and 2300 hours. The fallout appears to have occurred in two closely-spaced periods, the first at 1915 hours (H+13) with a maximum intensity of 0.5 mR/hr and the second at 2300 hours with a maximum intensity of 4 mR/hr. The 25 May Material Contamination-Decontamination Report shows that no decontamination was effected onboard the ship during this fallout, probably because of the relatively low intensities. By 0600 hours, 26 May, the onboard intensity had decreased to 0.2 mR/hr when readings were discontinued and the instrurnent secured. This rapid rate of decrease in shipboard intensities is an indication that the SPROSTON was again receiving cloud "shine", in addition to a very small amount of fallout.

The SPROSTON continued patrolling the waters around the atoll until 1254 hours, 26 May, when it entered the lagoon to take on fuel. After refueling was completed at 1540 hours, it anchored in berth L-3, approximately 2500 yards west of Enewetak Island. It remained there until 1450 hours, 27 May, when it departed enroute to Pearl Harbor.

The free-field radiation intensities plotted in Figures 2-17, 2-18, and 2-19, represent the average topside environment resulting from each detonation where fallout occurred onboard the ship. When available, both average and maximum values of intensity are plotted as a function of time after burst. Table 2-9 is a summary of the shipboard intensities derived from the radiological data. Daily integrated free-field intensities as determined from the radiological data are presented in Table 2-10.

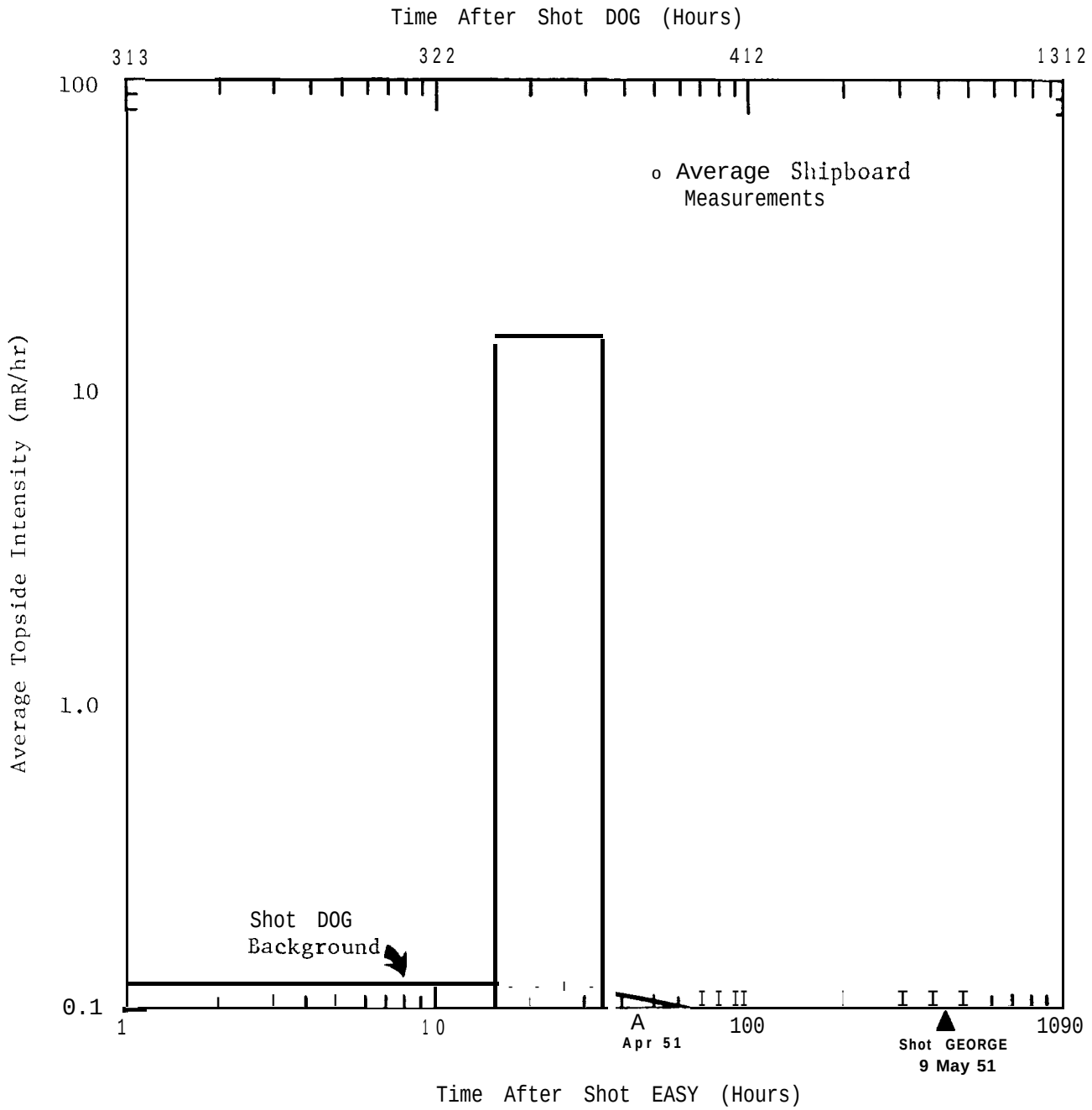


Figure 2-18. USS SPROSTON (DDE-577) Ship Intensity Following Shot EASY

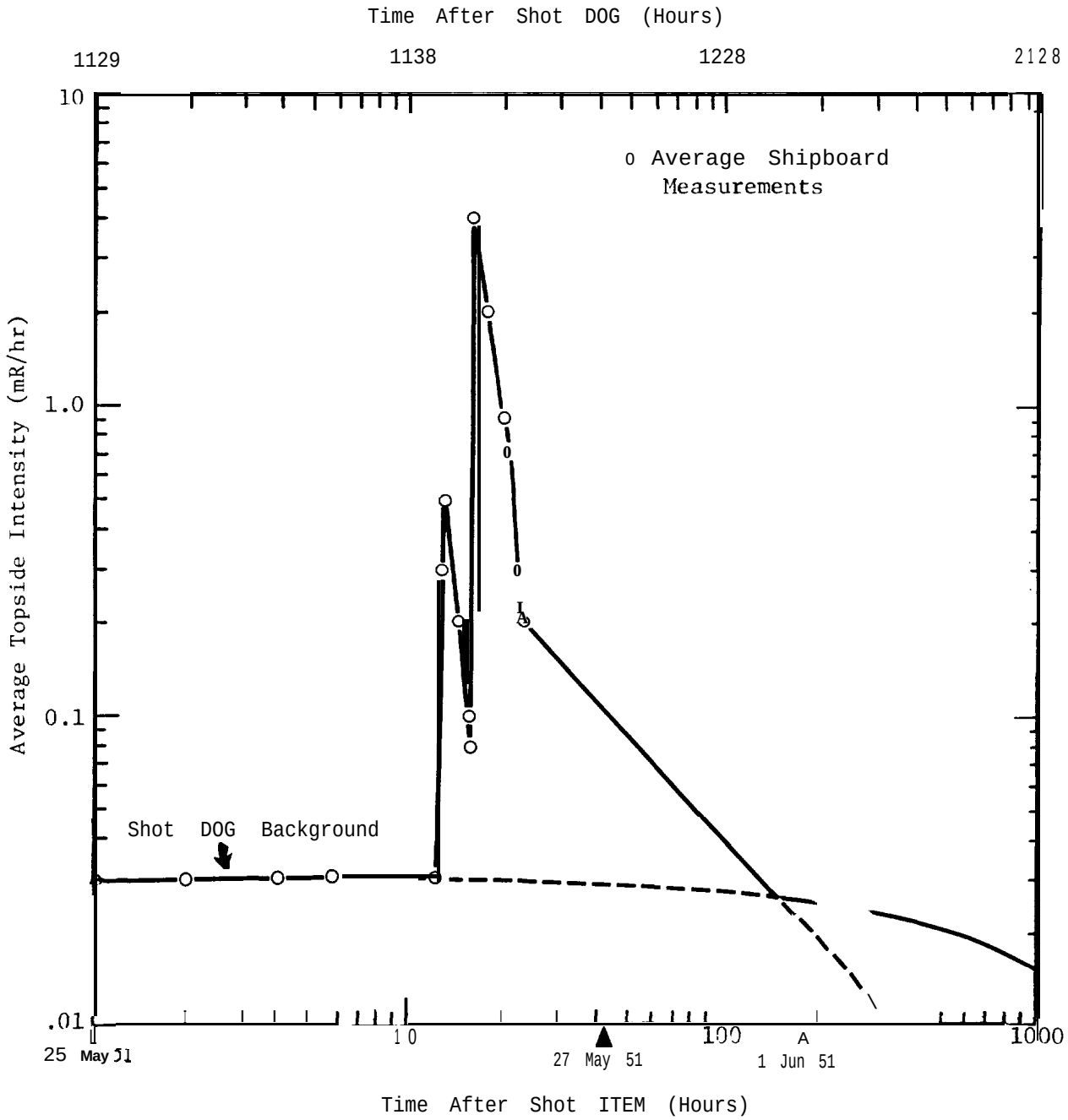


Figure 2-19. USS SPROSTON (DDE-577) Ship Intensity Following Shot ITEM

TABLE 2-9. USS SPROSTON Average Radiation Intensity Data

Date and Time	Time After Shot (hr)	Intensity (mR/hr)
	Shot DOG	
8 April, 1200	5.4	1.0
8 April, 1300	6.4	13.7
8 April, 1700	10.4	8.1
8 April, 2000	13.4	3.7
(Parry Island decay rate as $t^{-1.083}$ assumed thereafter)		
	Shot EASY (inferred)	
21 April, 2200	15.5	15.0
22 April, 1600	33.5	15.0
22 April, 1630	34.0	.11
(Decay assumed to be as $t^{-1.083}$ thereafter)		
	Shot ITEM	
25 May, 0717	1.0	.03
25 May, 1900	12.7	.03
25 May, 1930	13.2	0.3
25 May, 1935	13.3	0.5
25 May, 2200	15.7	0.1
25 May, 2230	16.2	.08
25 May, 2300	16.7	4.0
26 May, 0400	21.7	0.7
26 May, 0600	23.7	0.2
(Decay assumed to be as $t^{-1.1}$ thereafter)		

Table 2-10. Daily Integrated Free-Field Intensity, USS SPROSTON

DATE	DOG	EASY	GEORGE	ITEM
8 April 51	80.9 mR			
9	40.1			
10	20.0			
11	13.3			
12	9.9			
13	7.9			
14	6.4			
15	5.6			
16	4.7			
17	4.3			
18	3.7			
19	3.4			
20	3.1			
21	2.9	30.0 mR		
22	2.6	240.0		
23	2.4	0		
24	2.3	0		
25	2.1	0		
26	2.0	0		
27	1.9	0		
28	1.7	0		
29	1.7	0		
30	1.6	0		
I May	1.6	0		
2	1.4	0		
3	I.4	0		
4	1.3	0		
5	1.3	0		
6	1.3	0		
7	1.1	0		
8	1.1	0		
9	1.1	0		
10	1.1	0		
II	1.0	0	0	
12	1.0	0	0	
13	1.0	0	0	
14	1.0	0	0	
15	1.0	0	0	
16	1.0	0	0	
17	0.9	0	0	
18	0.9	0	0	
19	0.9	0	0	
20	0.9	0	0	
21	0.7	0	0	
22	0.7	0	0	
23	0.7	0	0	
24	0.7	0	0	
25	0.7	0	0	6.0 mR
26	0.7	0	0	8.6
27	0.7	0	0	2.0
28	0.7	0	0	1.3
29	0.7	0	0	1.0
30	0.7	0	0	0.7
31	0.6	0	0	0.7
TOTAL				

2.6 USS WALKER (DDE-517)

The crew of the USS WALKER (DDE-517) observed Shot DOG from an area 15 miles east of Runit Island (see Figure 2-20). Immediately after the detonation, the WALKER began a security patrol in an area 15-20 miles east of Runit and, at approximately 0745 hours (H+1.2), the ship began to receive some minor fallout from the Shot DOG radioactive cloud. Average shipboard intensities reached approximately 6 mR/hr before decontamination was begun at 0830 hours. The Material Contamination-Decontamination Report states that only 5 minutes were spent decontaminating an eight-by-ten foot area on the 01 deck. Although not explicitly stated, fallout continued while the crew was trying to decontaminate the ship because by 1010 hours, average levels had reached 10 mR/hr. There is no mention of any further efforts to decontaminate the ship after the Shot DOG fallout had ceased, probably because levels were below the maximum permissible intensity of 12.5 mR/hr set for the ships participating in Operation GREENHOUSE.

The crew observed Shot EASY from an area 15 miles east-northeast (bearing 070oT) of ground zero (Figure 2-20). After the shot it began to patrol the waters 10-15 miles east of Engebi. At 1130 hours (H+5), the WALKER was approximately 15 miles east of GZ when a gamma intensity meter onboard began to indicate increased levels of contamination. Average radiation levels reached 4-5 mR/hr with a maximum of 6 mR/hr being reported at 1300 hours, 21 April. No decontamination procedures were effected by the crew after Shot EASY and by noon the following day, natural radioactive decay (using nearby island decay rate according to $t^{-1.1}$) had reduced the radiation levels onboard the WALKER to less than 1 mR/hr.

On 9 May 1951, the WALKER was 30 miles north (bearing 356°T) of Eberiru Island when Shot GEORGE was detonated (Figure 2-20). Immediately after the shot, it steamed on a southerly course and allegedly arrived off Wide Passage (South Channel) at 1130 hours. At no tirne on 9 May, or during subsequent days, was the crew of the WALKER exposed to any radioactive fallout from Shot GEORGE.

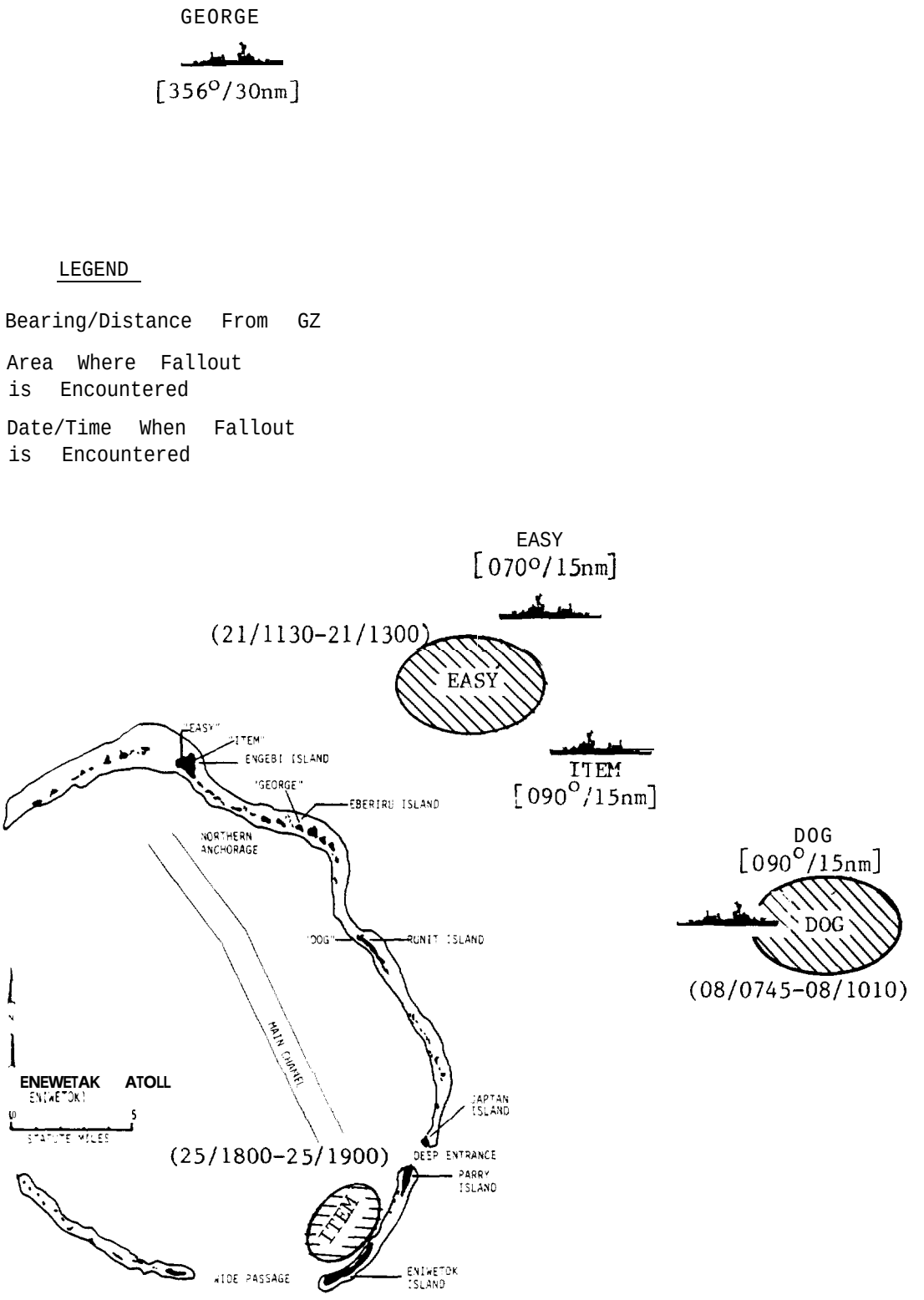


Figure 2-20. USS WALKER Pre-Shot Positions and Fallout Areas

The crew of the WALKER observed Shot ITEM from an area 15 miles east of Engebi Island (Figure 2-20). After the shot, it continued patrolling the waters east of Engebi until 1800 hours when it entered the lagoon through Deep Entrance (East Channel). At 1826 the WALKER was lying to in the vicinity of the USS CABILDO (the CABILDO was anchored in berth N-2 aproximately 1700 yards west of Enewetak Island) to transfer mail and passengers. Two minutes later it got underway and at 1847 hours departed Enewetak Lagoon through Wide Passage (South Channel) where it resumed an irregular counter-clockwise security patrol around the atoll.

Prior to entering the lagoon at 1800 hours (H+11.7), the WALKER had not encountered any fallout from the Shot ITEM radioactive cloud. Bet ween approximately 1600 and 1900 hours a second period of fallout from the ITEM dust cloud did occur on the islands of Enewetak Atoll and, as the WALKER entered the lagoon, it began to encounter this fallout. A radiation survey onboard the ship at 1900 hours (after it had departed the lagoon) noted average intensities of 30 mR/hr "around the bridge deck and on such material as canvas awnings, lines, etc." Decontamination, however, was not begun until 0630 hours the following morning when high pressure salt water was used for 1½ hours. The decontamination was reported as 95 percent effective; it thus reduced intensity levels to approximately 1 mR/hr.

The WALKER continued to patrol the waters around the atoll until 1208 hours, 26 May when it reentered the lagoon to take on fuel. After refueling, it proceeded to berth M-2, approximately 2000 yards off Enewetak Island where it anchored at 1406 hours. It remained in berth M-2 overnight and at 1456 hours, 27 May, the WALKER got underway for Pearl Harbor.

The free-field intensities environment onboard the WALKER resulting from shots DOG, EASY, and ITEM are plotted in Figures 2-21, 2-22 and 2-23, respectively. They represent the average topside radiation environment resulting from each shot where fallout occurred onboard ship. When available, both average and maximum values of intensity are plotted as a function of time after burst. Table 2-l 1 is a summary of the shipboard intensities derived from radiological data; daily integrated free-field intensities on the ship are given in Table 2-12.

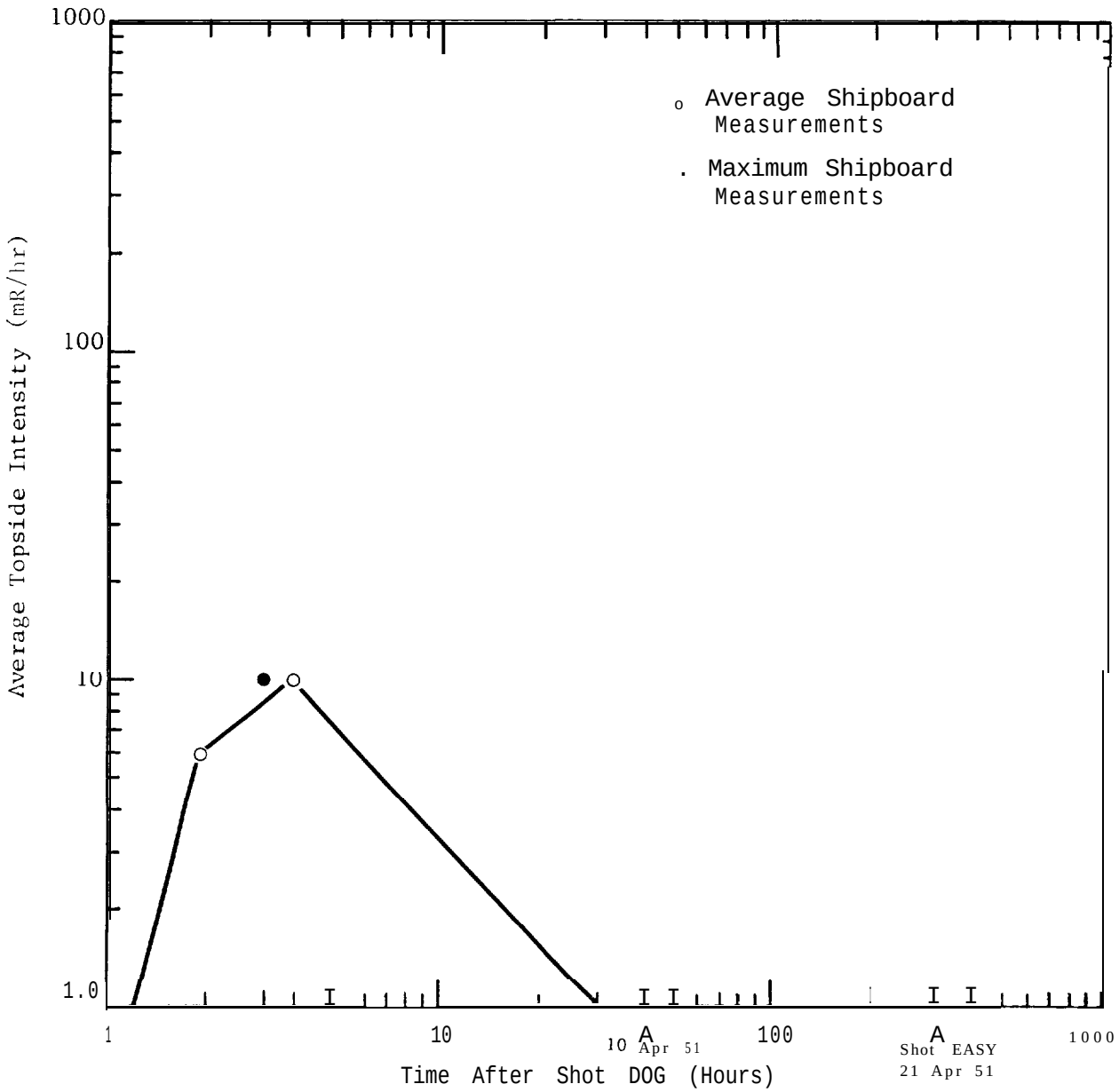


Figure 2-21. USS WALKER (DDE-517) Ship Intensity Following Shot DOG

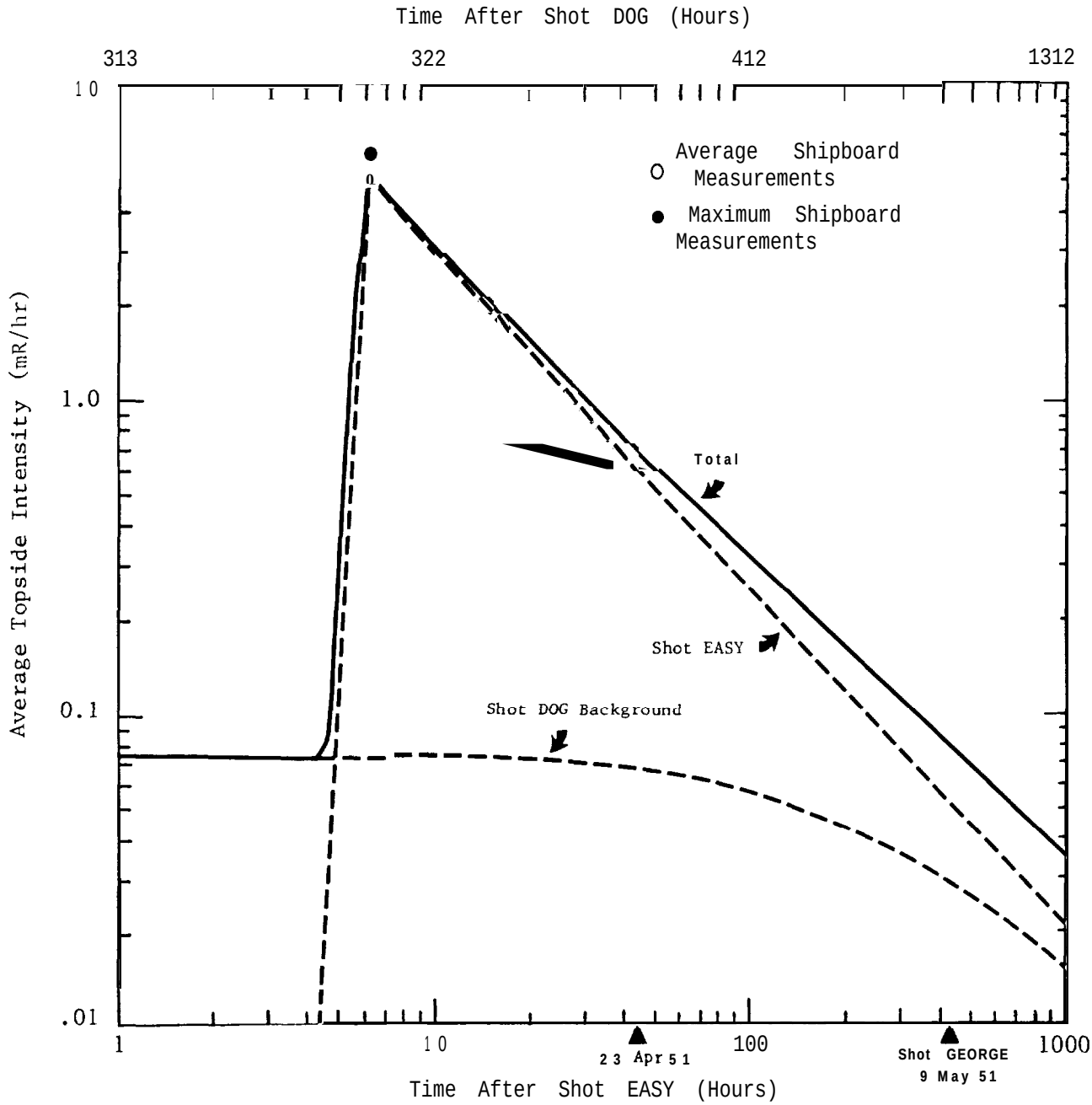


Figure 2-22. USS WALKER (DDE-517) Ship Intensity Following Shot EASY

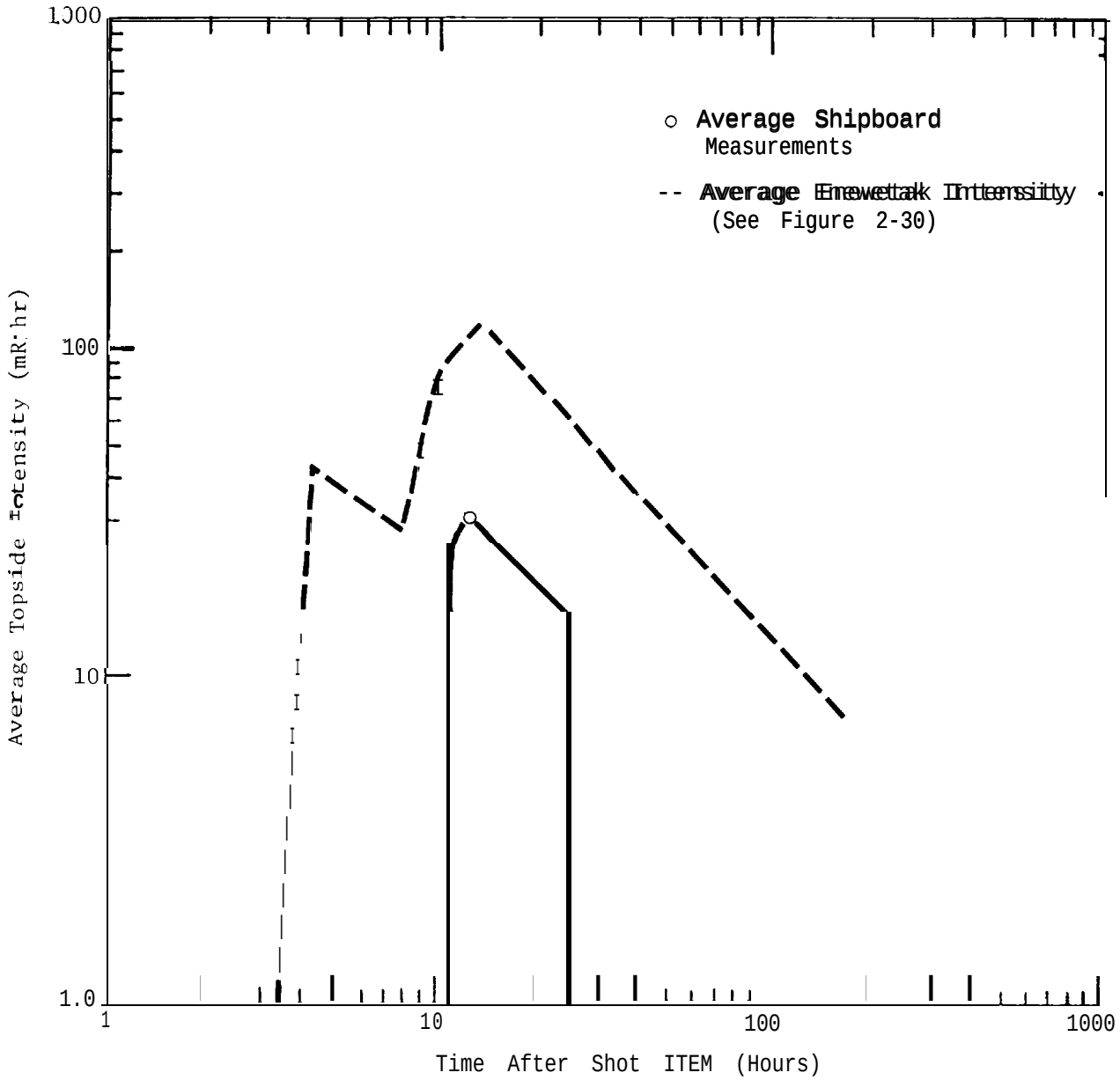


Figure 2-23. USS WALKER (DDE-517) Ship Intensity Following Shot ITEM

TABLE 2-l 1. USS WALKER Average Radiation Intensity Data

Date and Time	Time After Shot (hr)	Intensity (mR/hr)
	Shot DOG	
8 April, 0745	1.2	1.0
8 April, 0830	1.9	6.0
8 April, 1010	3.6	10.0
(Decay assumed to be as $t^{-1.1}$ thereafter)		
	Shot EASY (inferred)	
21 April, 1130	5.0	.07
22 April, 1399	6.5	5.0
(Decay assumed to be as $t^{-1.1}$ thereafter)		
	Shot ITEM	
25 May, 1800	11.7	32.5
26 May, 0630	24.2	15.9 (inferred)
26 May, 0800	25.7	1.0 (inferred)
(Enewetak Island survey data indicate decay as $t^{-1.1}$ thereafter)		

Table 2-12. Daily Integrated Free-Field Intensity, USS WALKER

DATE	DOG	EASY	GEORGE	ITEM
8 April 1951	68.3 mR			
9	25.6			
10	12.6			
11	8.3			
12	6.1			
13	4.9			
14	4.0			
15	3.4			
16	3.0			
17	2.6			
18	2.3			
19	2.1			
20	1.9			
21	1.7	32.6 mR		
22	1.6	24.3		
23	1.4	12.0		
24	1.4	8.0		
25	1.3	5.9		
26	1.3	4.6		
27	1.1	3.9		
28	1.1	3.3		
29	1.0	2.9		
30	1.0	2.4		
1 May	1.0	2.1		
2	0.9	2.0		
3	0.9	1.9		
4	0.9	1.7		
5	0.9	1.6		
6	0.7	1.4		
7	0.7	1.3		
8	0.7	1.3		
9	0.7	1.1	0	
10	0.7	1.1	0	
II	0.6	1.0	0	
12	0.6	1.0	0	
13	0.6	1.0	0	
14	0.6	0.9	0	
15	0.6	0.9	0	
16	0.6	0.9	0	
17	0.6	0.7	0	
18	0.6	0.7	0	
19	0.4	0.7	0	
20	0.4	0.7	0	
21	0.4	0.7	0	
22	0.4	0.7	0	
23	0.4	0.6	0	
24	0.4	0.6	0	
25	0.4	0.6	0	158.0 mR
26	0.4	0.6	0	140.6
27	0.4	0.6	0	11.9
28	0.4	0.6	0	8.1
29	0.4	0.6	0	6.3
30	0.4	0.6	0	5.0
31	0.4	0.4	0	4.3
June	9	10	0	46

2.7 USNS LT. ROBERT CRAIG (TAK-252)

On 8 April, the USNS LT. ROBERT CRAIG was enroute to Enewetak Atoll from Pearl Harbor. At 0634 hours, the crew observed the flash from the Shot DOG detonation approximately 100 miles west-southwest of the ship (bearing 245°T). At 1214 hours, the CRAIG arrived at the entrance to South Channel (Wide Passage), Enewetak Atoll and proceeded to berth C-2, where it anchored at 1420 hours (see Figure 2-24).

Upon arriving at Enewetak, the CRAIG probably encountered the second period of Shot DOG fallout that occurred over the southeastern portion of the lagoon between 1200 and 1300 hours. As it entered the lagoon and during its passage to the anchorage off Parry Island, fallout intensities on the ship would have approximated those occurring on Parry during this same time period (Figure 2-24). Although shipboard contamination levels are not documented, an estimate can be made from island fallout data, after subtracting out the fallout that occurred between 0830 and 1100 hours. Figure 2-25 depicts the Parry fallout data (dashed curves) and shows the intensity contributions from the two periods of Shot DOG fallout. The solid curve is the inferred Shot DOG ship intensity curve for the CRAIG and is obtained by subtracting the 0830-1100 fallout from the total intensity curve. The difference between the two curves is depicted by the shaded region in Figure 2-25. Table 2-13 is a summary of the radiological data for the CRAIG as inferred from the island data.

Table 2-13. USNS LT. ROBERT CRAIG Average Radiation Intensity Data

Date and Time	Time After Shot (hr)	Intensity (mr/hr)
8 April, 1200	5.4	1 .O (inferred)
8 April, 1300	6.4	13.7 (inferred)

(Parry Island decay rate as $t^{-1.083}$ assumed thereafter)

The CRAIG remained anchored in the lagoon discharging cargo until 12 April when it got underway for Guam via Kwajalein. It returned to Enewetak on 30 April, but departed on 6 May, three days prior to Shot GEORGE, enroute to San Francisco via Kwajalein and Pearl Harbor.

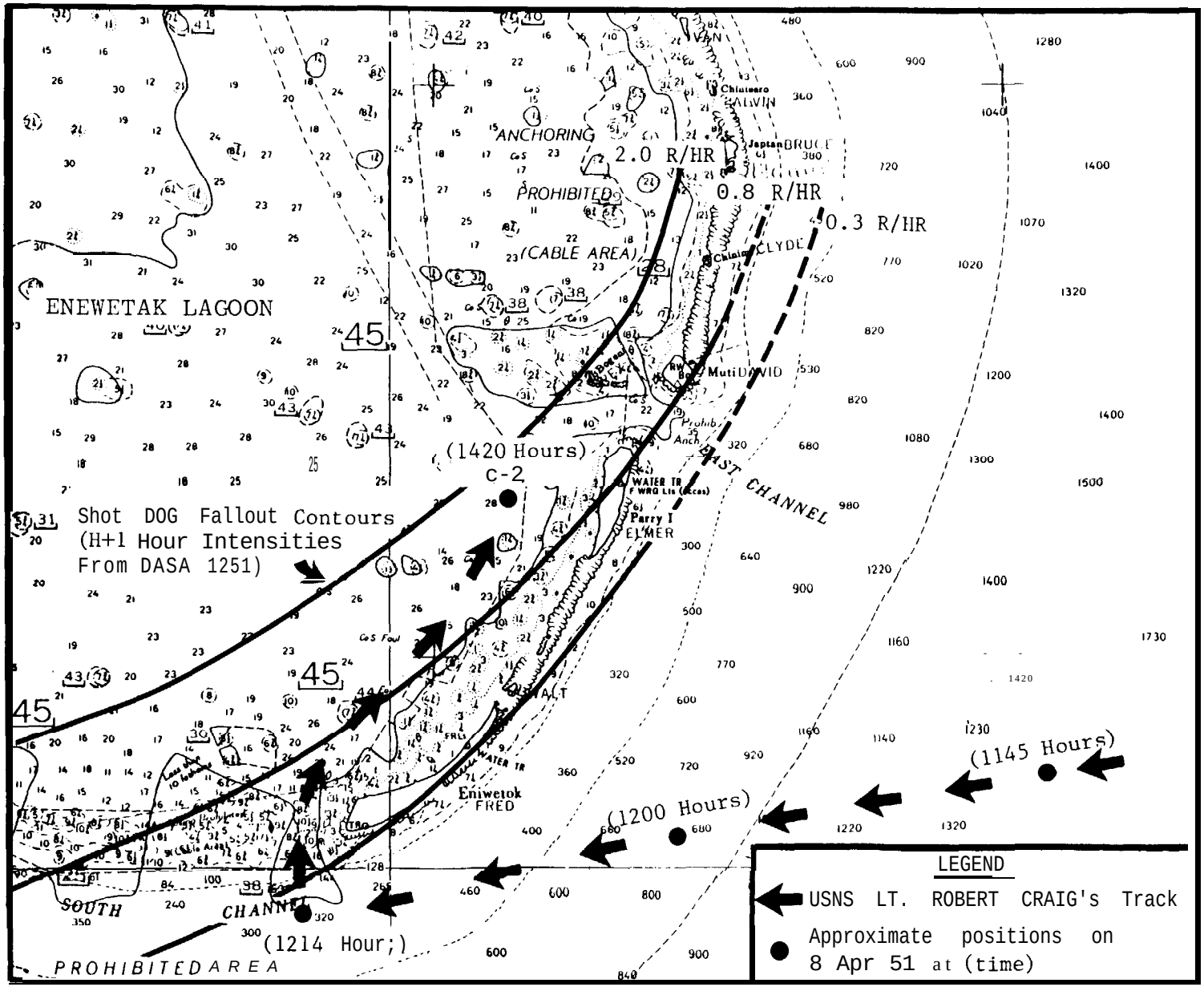


Figure 2-24. USNS LT. ROBERT CRAIG's Approach to Enewetak Lagoon - 8 April 1951

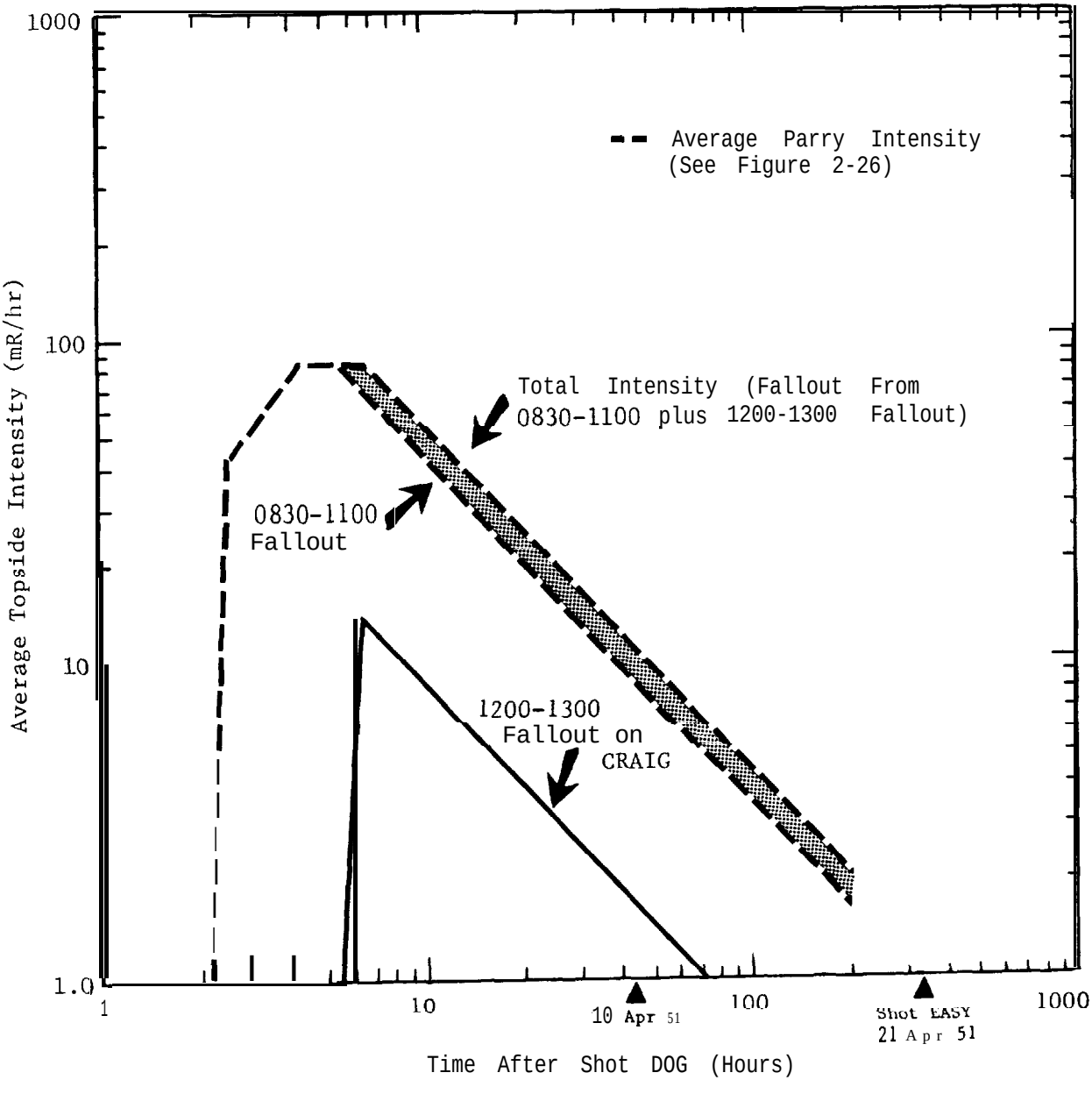


Figure 2-25. USNS LT. ROBERT CRAIG (TAK-252) Ship Intensity Following Shot DOG

Table 2-14. Daily Integrated Free-Field Intensity, USNS LT. ROBERT CRAIG

DATE	DOG	EASY*	GEORGE*	ITEM*
8 April 1951	98.4 mR			
9	67.6			
10	33.7			
11	22.3			
12	16.6			
13	13.1			
14	10.9			
15	9.3			
16	8.0			
17	7.1			
18	6.3			
19	5.7			
20	5.3			
21	4.9			
22	4.4			
23	4.1			
24	3.9			
25	3.6			
26	3.4			
27	3.1			
28	3.0			
29	2.9			
30	2.7			
1 May	2.6			
2	2.4			
3	2.4			
4	2.3			
5	2.1			
6	2.1			
7	2.0			
8	2.0			
9	1.9			
10	1.9			
11	1.7			
12	1.7			
13	1.7			
14	1.6			
15	1.6			
16	1.6			
17	1.4			
18	1.4			
19	1.4			
20	1.4			
21	1.3			
22	1.3			
23	1.3			
24	1.3			
25	1.1			
26	1.1			
27	1.1			
28	1.1			
29	1.1			
30	1.1			
31	1.0			

*CRAIG did not participate at the remaining GREENHOUSE shots.

The average topside intensity depicted in Figure 2-25 is integrated to determine the daily integrated free-field intensity onboard the CRAIG. Calculations are carried through 31 May and are presented in Table 2-14.

2.8 RESIDENCE ISLANDS OF ENEWETAK ATOLL

As previously noted, fallout was experienced on all the residence islands of Enewetak Atoll following Shots DOG, EASY, and ITEM. These islands, Enewetak, Parry, and Japtan, received essentially the same fallout as the ships in the southern anchorage area (Figure 1-l). Free-field intensities on the islands, however, were higher than the shipboard intensities because the ships were equipped with effective washdown systems.

Following Shot DOG, the first survey of the residence islands (at 1500 hours, 8 April) indicated intensities of 25, 60, and 70 mR/hr on Enewetak, Parry, and Japtan, respectively. This south-to-north gradient of increased fallout intensity is consistent with the shipboard data, which showed less fallout occurring on the CABILDO (anchored off Enewetak) than on the CURTISS (anchored off Parry). Subsequent surveys on 9, I 1, 12, and 13 April revealed that Parry and Japtan Islands had received essentially the same fallout, while intensities on Enewetak were approximately one-half to one-third those on the other two islands. Table 2-15 is a summary of the island survey data obtained during the five days following Shot DOG.

Table 2-15. Residence Island Survey Data - Shot DOG

	Average Intensity (mR/hr)				
	1500 8 April	9 April	11 April	12 April	13 April
Enewetak	25	7	2	2	I
Parry	60	15	6	5	3
Japtan	70	12	6	5	3

The Parry and Japtan intensity data are plotted in Figure 2-26 while the Enewetak intensity data are plotted in Figure 2-27. These two figures depict the average free-field intensity on the three residence islands resulting from Shot DOG

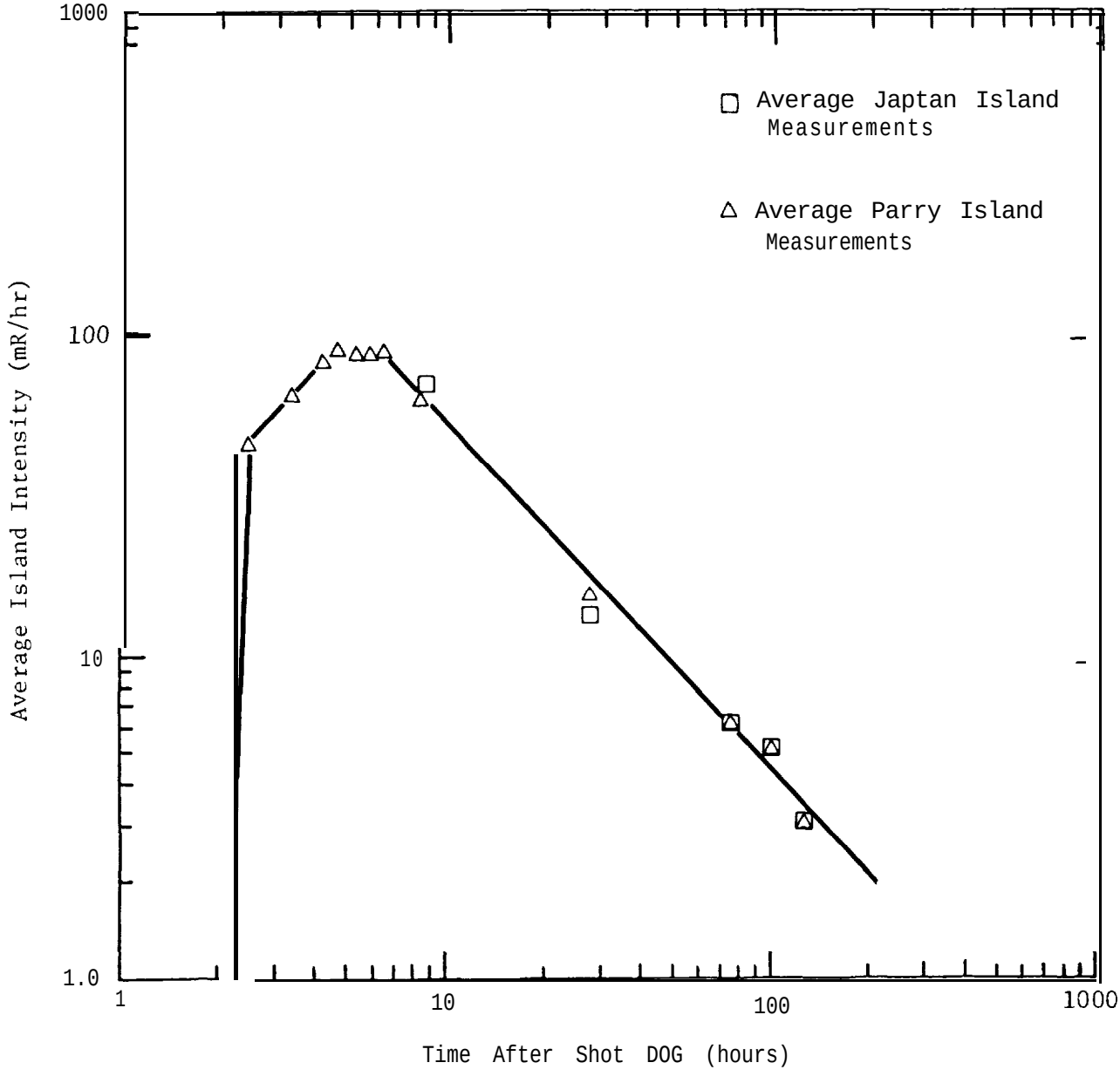


Figure 2-26. Parry and Japtan Island Intensity Following Shot DOG

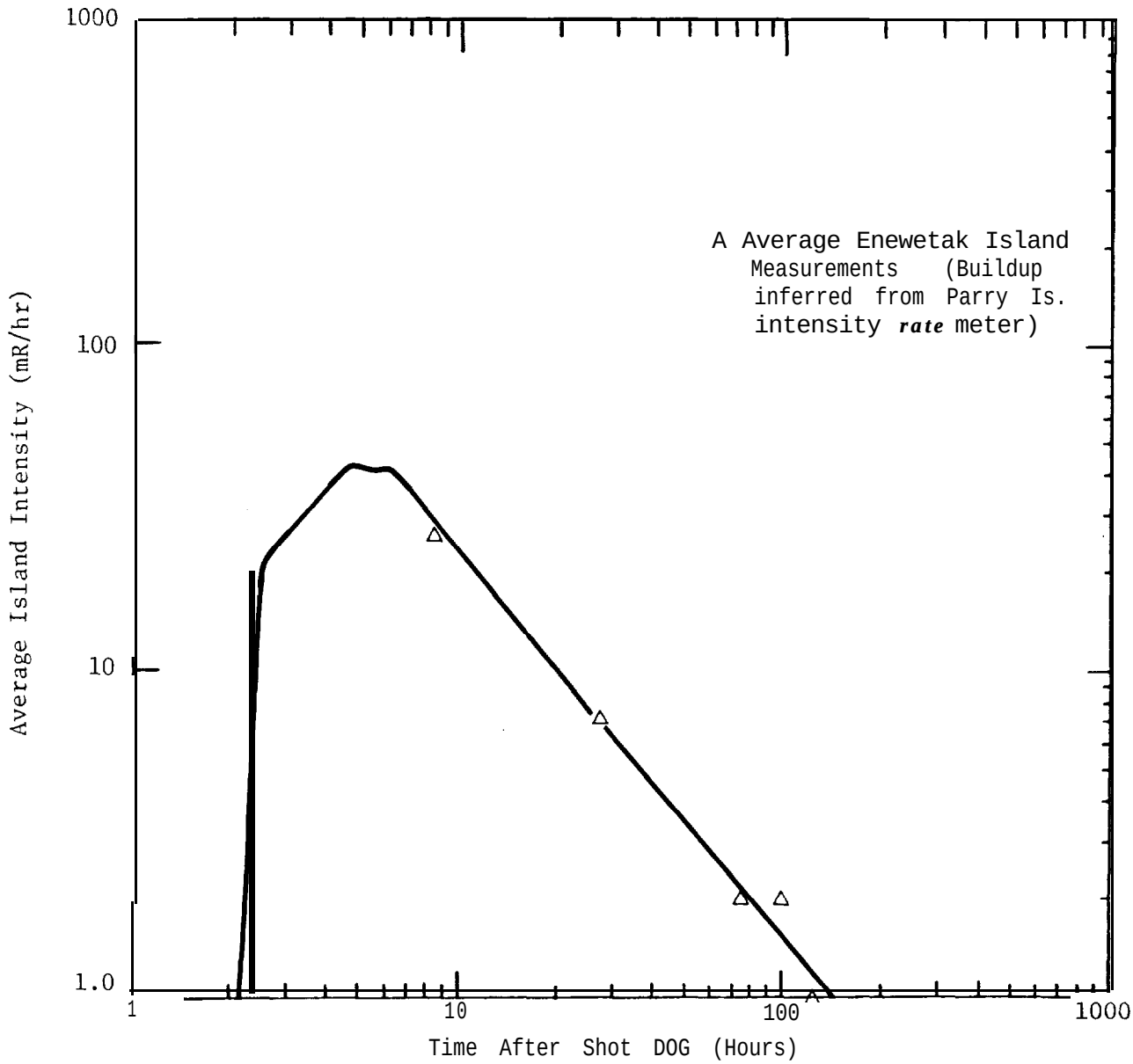


Figure 2-27. Enewetak Island Intensity Following Shot DOG

fallout. The buildup and decay of the fallout between 0850 hours, 8 April, and the first survey at 1500 hours (H+8.4) is inferred from a recording on a gamma intensity rate meter outside the radiological safety building on Parry Island (Reference 6).

Very light fallout occurred on the residence islands following Shot EASY on 21 April. It began late in the evening and ended during the early morning of 22 April. The maximum intensity of this fallout on Parry was reported as two to three times the residual radiation from Shot DOG, which had recently been measured to be 0.5 mR/hr. It is assumed that fallout from Shot EASY began at 2230 hours (H+16) and that the peak intensity occurred at about 0630 hours, 22 April (H+24). Table 2-16 is a summary of the Parry Island survey data following Shot EASY. Post-shot surveys were not obtained on Enewetak or Japtan but it is assumed they received the same fallout.

Table 2-16. Parry Island Survey Data - Shot EASY

	Average Intensity (mR/hr)			
0730 21 April	22 April	23 April	24 April	25 April
0.5	--	0.8	0.6	0.6

These data are plotted in Figure 2-28 to depict the average free-field intensity on Parry and Japtan Islands following Shot EASY. The Shot EASY contribution is obtained by subtracting the Shot DOG background from the survey data obtained on 23, 24, and 25 April; these data are also shown in Figure 2-28. A power law fit to these three data points, when extrapolated back in time to H+24 (the assumed time of occurrence of the peak intensity), yields a maximum contribution from Shot EASY of approximately 1.0 mR/hr. When added to the Shot DOG residual, the peak intensity on Parry following Shot EASY would be approximately 1.5 mR/hr, which is consistent with the statement in Reference 6 that the EASY fallout "was insignificant, amounting only to 2 or 3 times the background." In Figure 2-29, the Shot EASY contribution calculated on Parry is added to the Shot DOG residual on Enewetak Island to arrive at the total free-field intensity on that island. The differences between Figures 2-28 and 2-29 are slight, due only to small differences between the Shot DOG residual radiation on the three residence islands.

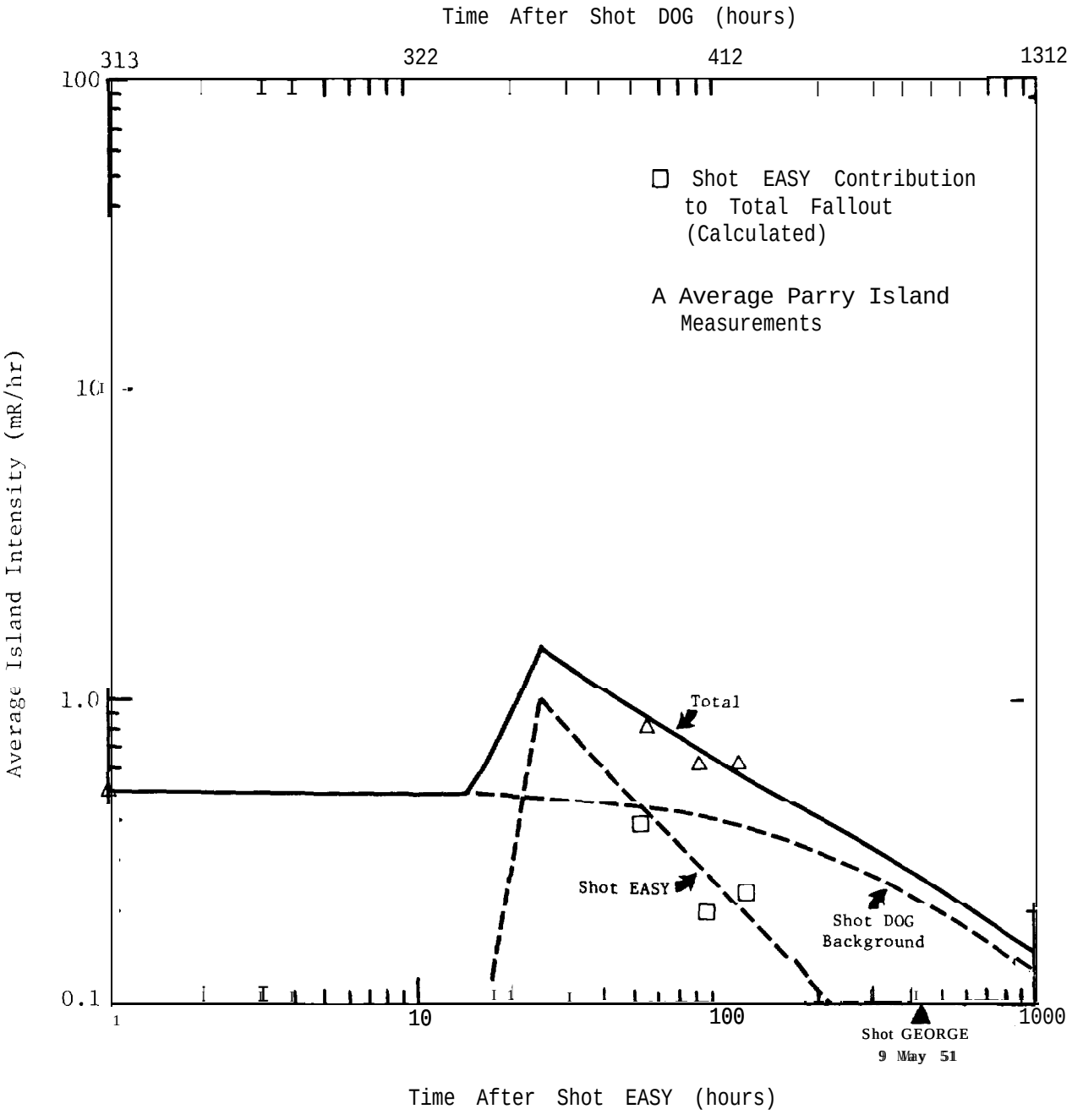


Figure 2-28. Parry and Japtan Island Intensity Following Shot EASY

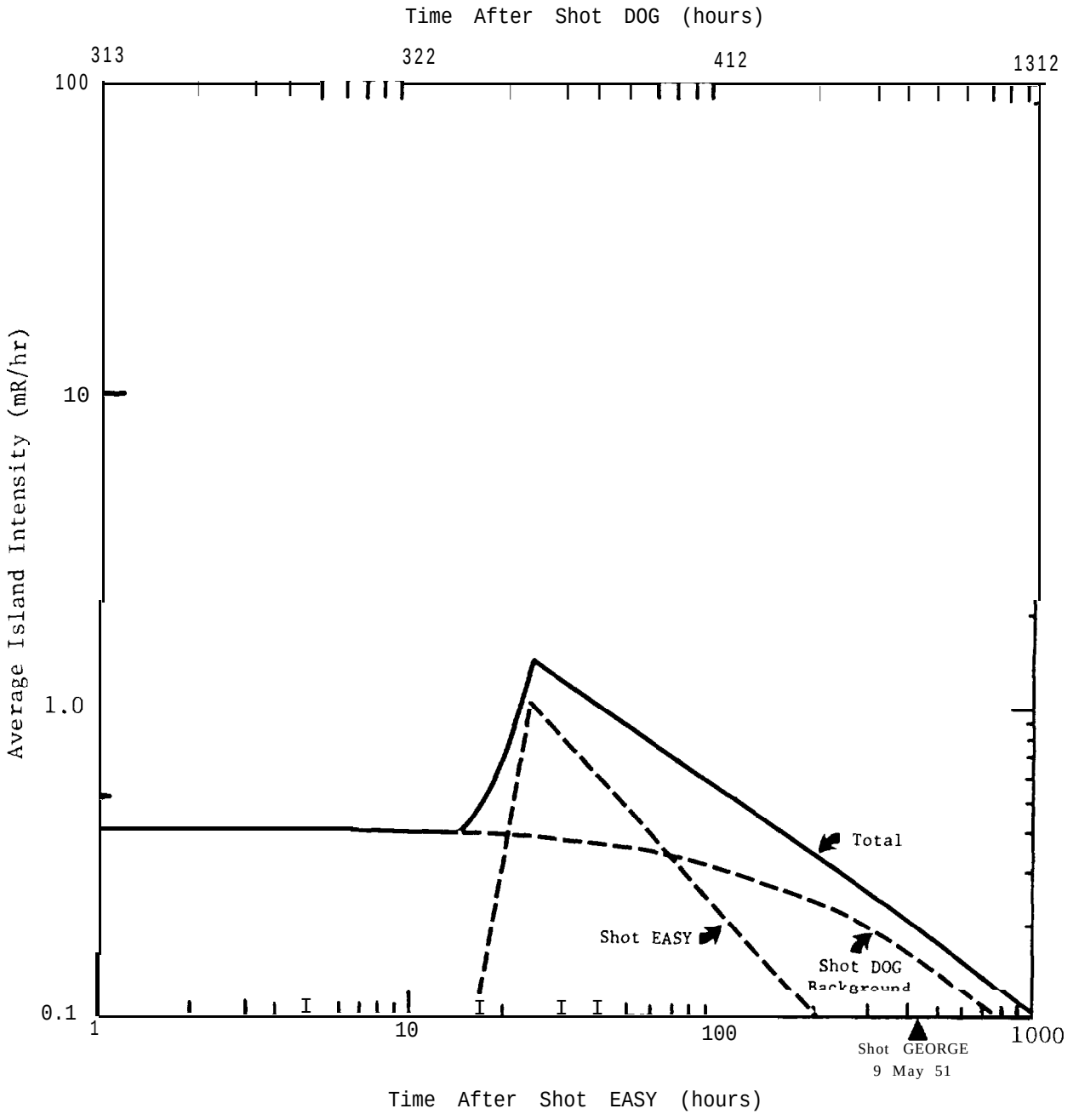


Figure 2-29. Enewetak Island Intensity Following Shot EASY

Considerable fallout occurred on the residence islands on 25 May following Shot ITEM. At approximately 0945 hours (H+3.3), a gamma intensity recorder at the radiological safety building on the southern end of Parry Island detected a steady rise in intensity due to fallout, which lasted approximately 1% hours. After decaying for approximately three hours, intensity readings began to rise when fallout started once more at approximately eight hours after the detonation; this second "wave" of fallout lasted for approximately six hours. The buildup and subsequent decay of the fallout on southern Parry Island, as recorded, is reproduced in Figure 2-30. At approximately the same time, "an incomplete but reasonably representative survey of Enewetak Island indicated that the fallout situation there was almost identical with that of Parry" (Reference 6). Intensity readings obtained on Enewetak on 25-28 May, also depicted in Figure 2-30, tend to substantiate this statement.

At approximately 1800 hours on 25 May, a survey conducted on the northern end of Parry Island "established the fact that the intensity there was less by about 50 percent than that on the southern end of the island and was approximately the same as the fallout on Japtan" (Reference 6). The results of the surveys on northern Parry during the period 25-28 May are depicted in Figure 2-31. Fallout buildup is inferred from the time-intensity recording data obtained at the rad-safe building on the southern end of the island. This is also the same fallout that was reported to have occurred on Japtan. Table 2-17 summarizes the intensity data obtained on Enewetak and Parry islands during the period 25-28 May. Radiation intensities on Japtan are assumed to be the same as those on Northern Parry.

Table Z-17. Enewetak and Parry Island Survey Data - Shot ITEM

	Average Intensity (mR/hr)			
	1030 25 May	26 May	May	May
Enewetak and Southern Parry	45	40	28	30
Northern Parry and Japtan	6	30	18	10

The island intensity curves in Figures 2-26 through 2-31 are time-integrated, by day, from 8 April through 31 May 1951, to obtain the daily integrated free-field intensities on each of the residence islands resulting from fallout from Shots DOG,

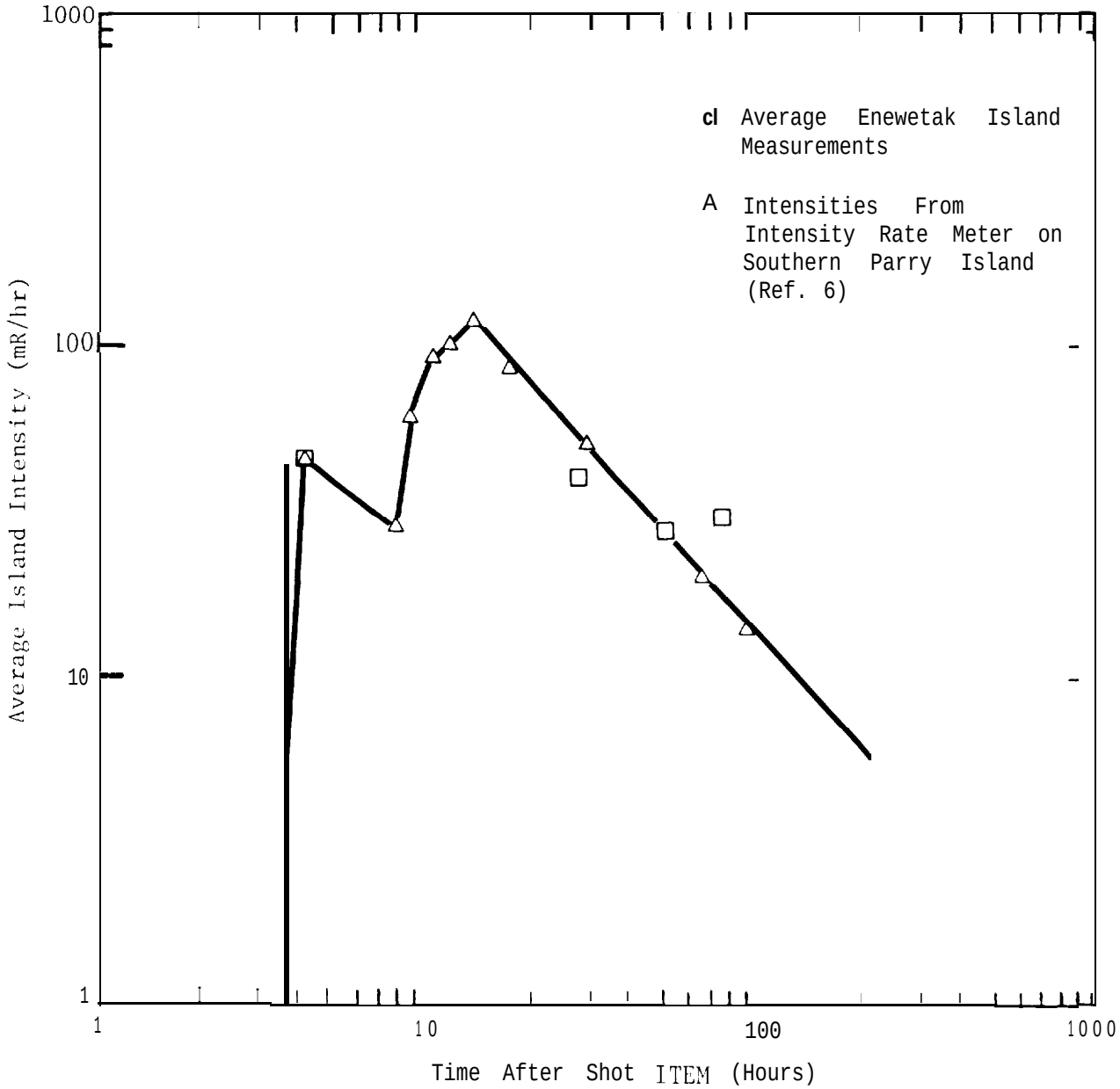


Figure 2-30. Enewetak and Southern Parry Island Intensity Following Shot ITEM

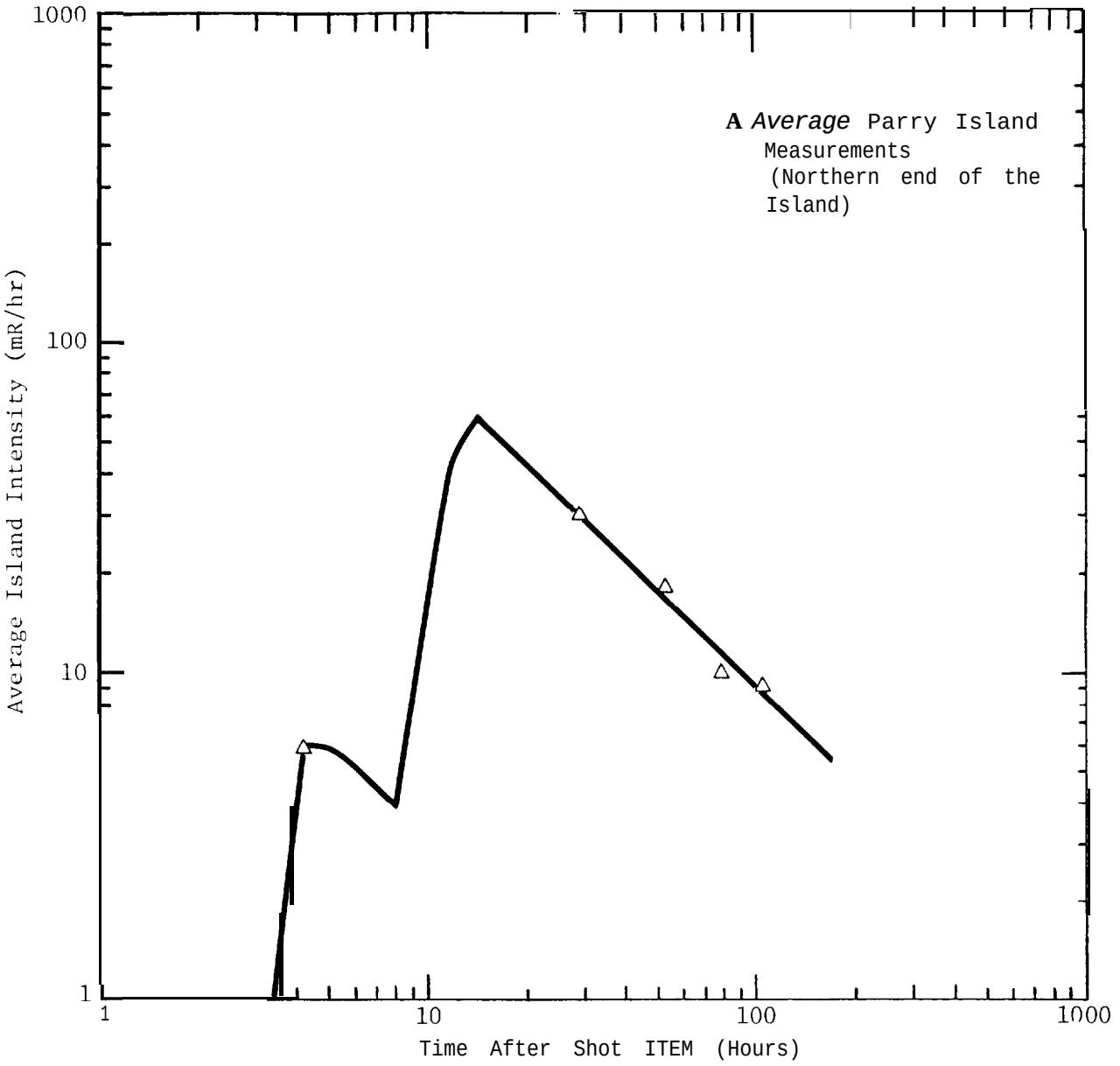


Figure -31. Japtan and Northern Parry Island Intensity Following Shot ITEM

EASY, and ITEM. The results are presented in Tables Z-18, 2-19, and 2-20 for Enewetak, Parry, and Japtan Islands, respectively. The integrated free-field intensities on Parry following Shot ITEM are obtained by averaging the integrated intensity on the southern portion of Parry (or Enewetak) with that on the northern part of Parry (or Japtan). This is done under the assumption that anyone assigned to Parry would spend equal amounts of time on each half of the island.

2.9 SHIP SHIELDING

Dose estimates for crewmembers require consideration of the shielding provided by the ship structure for radioactive fallout deposited on the weather surfaces of the ships. A ship shielding factor, defined as the ratio of radiation intensity at an interior location to an intensity topside, depends on several variables: time after detonation, distribution of fallout on the weather surface, amount of intervening material (decking, bulkheads, piping, etc.) from weather surface to point of interest, and distance from weather surface. Consequently, while ship shielding effects have been experimentally and theoretically studied by the Navy since Operation CROSSROADS (1946), values of shielding factors remain uncertain. Readings taken on target ships during Operation CROSSROADS, and on two test ships (YAG-39 and YAG-40) during Operations CASTLE (1954) and REDWING (1956) gave preliminary estimates of shielding factors (References 8, 9, 10). However, a significant fraction of the radiation penetrating to the interior of these ships, especially at the lower depths, apparently came from radioactive materials in the water and on the hulls of the ships. Thus, these shielding factors are not directly applicable to the present problem.

Experimental results reported by W.F. Waldorf (Reference 11) on radiation from Cobalt-60 and Cesium-137 sources on the flight deck penetrating the interior of a light aircraft carrier (USS COWPENS) indicated that an average shielding factor could be correlated with the thickness of deck plating directly above the point of interest in the ship. He further showed that the effects of bulkheads, piping, and other miscellaneous intervening material could be approximated (somewhat high-sided) by doubling the deck plating thickness in shielding calculations. Results from British experiments on a carrier, destroyer, and light cruiser, referenced by Waldorf, verified these conclusions and indicated that this factor of two may apply to most ship types. C.F. Ksanda

Table 2-18. Daily Integrated Free-Field Intensity, Enewetak Island

DATE	DOG	EASY	GEORGE	ITEM
8 April 51	363.7 mR			
9	159.2			
10	76.3			
II	49.4			
12	36.1			
13	28.2			
14	23.1			
15	19.5			
16	16.8			
17	14.7			
18	13.1			
19	11.7			
20	10.6			
21	9.7	0.2 mR		
22	9.0	15.4		
23	8.3	9.8		
24	7.7	6.5		
25	7.2	4.8		
26	6.7	3.8		
27	6.3	3.1		
28	6.0	2.6		
29	5.7	2.3		
30	5.4	2.0		
1 May	5.1	1.8		
2	4.9	1.6		
3	4.6	1.5		
4	4.4	1.4		
5	4.3	1.3		
6	4.1	1.2		
7	3.9	1.1		
8	3.8	1.0		
9	3.6	1.0	0	
10	3.5	0.9	0	
II	3.4	0.9	0	
12	3.3	0.8	0	
13	3.2	0.8	0	
14	3.1	0.7	0	
15	3.0	0.7	0	
16	2.9	0.7	0	
17	2.8	0.6	0	
18	2.7	0.6	0	
19	2.6	0.6	0	
20	2.6	0.6	0	
21	2.5	0.5	0	
22	2.4	0.5	0	
23	2.4	0.5	0	
24	2.3	0.5	0	
25	2.3	0.5	0	1043.0 mR
26	2.2	0.5	0	1293.9
27	2.2	0.4	0	642.7
28	2.1	0.4	0	423.6
29	2.1	0.4	0	313.8
30	2.0	0.4	0	248.1
31	2.0	0.4	0	204.5

Table 2-19. Daily Integrated Free-Field intensity, Parry Island

DATE	DOG	EASY	GEORGE	ITEM
8 April 51	363.7 mR			
9	159.2			
10	76.3			
II	49.4			
12	36.1			
13	28.2			
14	23.1			
15	19.5			
16	16.8			
17	14.7			
18	13.1			
19	11.7			
20	10.6			
21	9.7	0.2 mR		
22	9.0	15.4		
23	8.3	9.8		
24	7.7	6.5		
25	7.2	4.8		
26	6.7	3.8		
27	6.3	3.1		
28	6.0	2.6		
29	5.7	2.3		
30	5.4	2.0		
1 May	5.1	1.8		
2	4.9	1.6		
3	4.6	1.5		
4	4.4	I.4		
5	4.3	1.3		
6	4.1	1.2		
7	3.9	1.1		
8	3.8	1.0		
9	3.6	1.0	0	
10	3.5	0.9	0	
11	3.4	0.9		
12	3.3	0.8		
13	3.2	0.8	0	
14	3.1	0.7	0	
15	3.0	0.7	0	
16	2.9	0.7	0	
17	2.8	0.6	0	
18	2.7	0.6	0	
19	2.6	0.6	0	
20	2.6	0.6	0	
21	2.5	0.5	0	
22	2.4	0.5	0	
23	2.4	0.5	0	
24	2.3	0.5	0	
25	2.3	0.5	0	723.5 mR
26	2.2	0.5	0	1007.5
27	2.2	0.4	0	514.4
28	2.1	0.4	0	344.8
29	2.1	0.4	0	258.5
30	2.0	0.4	0	206.4
31	2.0	0.4	0	171.5

Table 2-20. Daily Integrated Free-Field Intensity, Japtan Island

DATE	DOG	EASY	GEORGE	ITEM
8 April 51	791.2mR			
9	407.3			
10	203.3			
11	134.6			
12	100.1			
13	79.4			
14	65.6			
15	55.8			
16	48.5			
17	42.8			
18	38.3			
19	34.6			
20	12.9			
21	11.8	0.2mR		
22	10.9	15.4		
23	10.1	9.8		
24	9.5	6.5		
25	8.9	4.8		
26	8.3	3.8		
27	7.9	3.1		
28	7.5	2.6		
29	7.1	2.3		
30	6.7	2.0		
1 May	6.4	1.8		
2	6.1	1.6		
3	5.9	1.5		
4	5.6	1.4		
5	5.4	1.3		
6	5.2	I.2		
7	5.0	1.1		
8	4.8	1.0		
9	4.7	1.0	0	
10	4.5	0.9	0	
11	4.4	0.9	0	
12	4.2	0.8	0	
13	4.1	0.8	0	
14	4.0	0.7	0	
15	3.9	0.7	0	
16	3.7	0.7	0	
17	3.6	0.6	0	
18	3.5	0.6	0	
19	3.4	0.6	0	
20	3.4	0.6	0	
21	3.3	0.5	0	
22	3.2	0.5	0	
23	3.1	0.5	0	
24	3.0	0.5	0	
25	3.0	0.5	0	403.9mR
26	2.9	0.5	0	721.1
27	2.8	0.4	0	386.1
28	2.8	0.4	0	265.9
29	2.7	0.4	0	203.2
30	2.7	0.4	0	164.6
31	2.6	0.4	0	138.5

(References 8, 13) performed detailed calculations on an aircraft carrier (USS RANGER), presenting the shielding factors graphically as functions of deck plating thickness for various times after detonation. Following Waldorf, he accounted for miscellaneous shielding materials by doubling the deck plating thickness when performing the calculations. The results of the Waldorf experiment and the geometric means of Ksanda's upper and lower limit shielding factors for unfractionated U-235 fission products at one day after detonation are displayed in Figure 2-32. Due to geometric attenuation, these curves approach values less than one as deck plating thickness becomes small. Comparison indicates that Ksanda's mean values represent a somewhat high-sided estimate of the shielding factor, since the average gamma energy for the times of interest (several hours to days after detonation) is similar to the 0.66 MeV from the cesium source. Because of the detailed nature of Ksanda's effort, and the general agreement with experiment, the Ksanda mean value for shielding factor versus deck plating thickness is used in the present calculations.

In applying Ksanda's results to the present analysis, it is assumed that, when topside, personnel experienced the average external topside intensity, and any shielding provided by the superstructure is neglected. Large variations in personnel activities and shielding factors preclude a more accurate assessment of this factor, It is further assumed that, when below decks, personnel were located on the second deck, with only the thickness of the main deck to provide radiation shielding. Personnel below the second deck, and in those portions of the second deck under the superstructure, were afforded additional radiation shielding not included in these calculations. The main deck thicknesses and the shielding factors used for the seven ships are given in Table 2-21.

Table 2-2 1. Ship Shielding Factors

Ship	Main Deck Thickness (inches)	Shielding Factor
CABILDO (LSD-16)	.6	.08
CURTISS (AV-4)	.6	.08
LST-859	.3	.15
MOWER (TAP-186)	.5	.10
SPROSTON (DDE-5 17)	.35	.14
WALKER (DDE-577)	.35	.14
CRAIG (YAK-2521	.5	.10

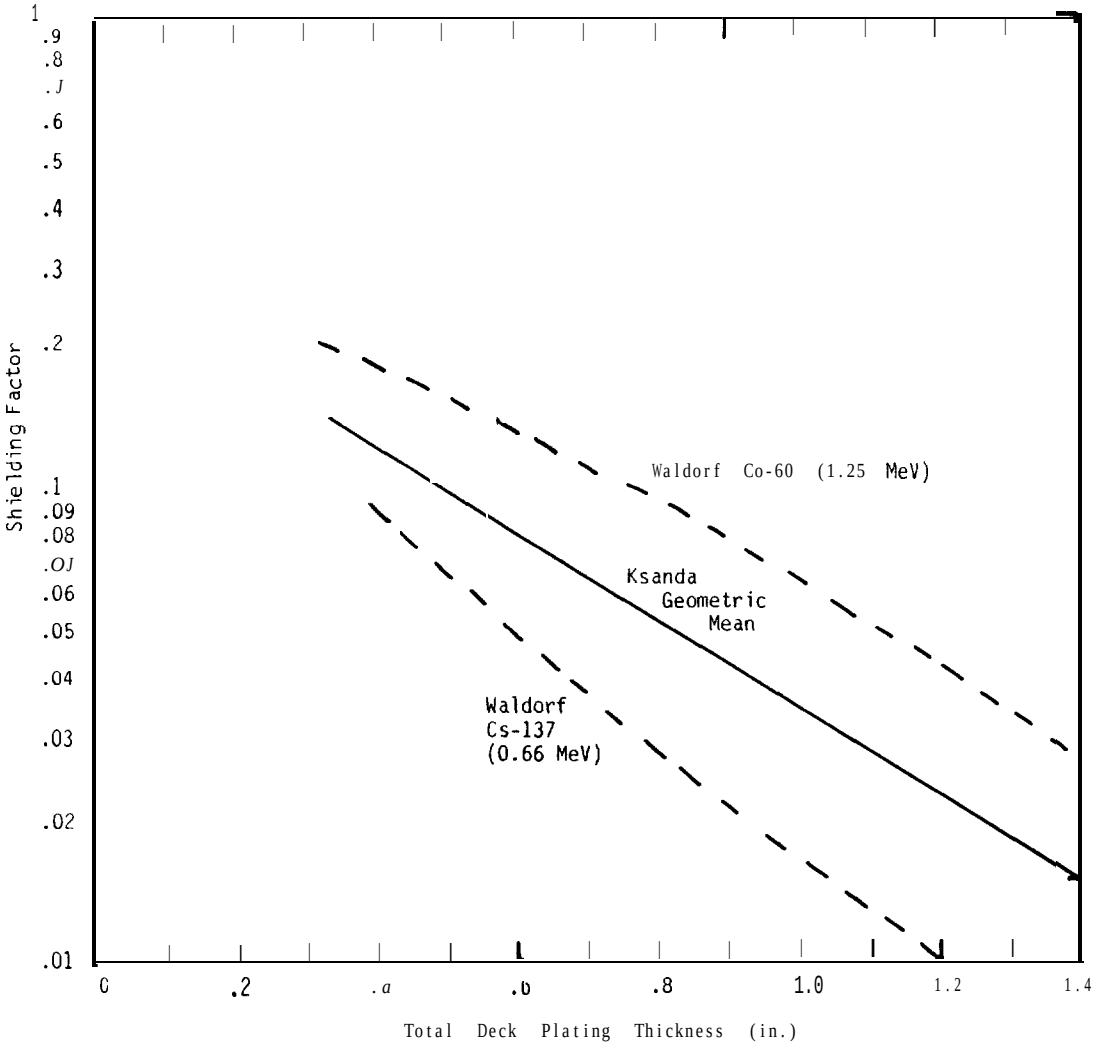


Figure 2-32. Ship Shielding Factor vs. Deck Plating Thickness

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 from Section 2 are adjusted to account for personnel activities, either documented or assumed. The adjusted exposures (mR) are then multipled by a film badge conversion factor to determine a daily film badge dose (mrem) as described in Reference 12. Results are presented as a daily cumulative dose to personnel through 31 May 1951, when the GREENHOUSE roll-up phase was nearly complete. For shipboard personnel, dose calculations are continued on a monthly basis until the dose is 30 mrem per month or less, i.e., less than 1 mrem per day. At the end of May, heavy rains set in and apparently washed away most of the radioactive material from the inhabited islands (Reference 6). This statement is supported by the observation of a former member of the rad-safe unit at GREENHOUSE who states that "on June 1 (1951), heavy rains again occurred reducing the fallout dose rate from ITEM shot to background values" (Reference 14). Based on these statements, dose calculations for the island-based personnel are terminated on 32 May.

3.1 PERSONNEL ACTIVITIES

An estimate of personnel movements is critical in determining the film badge dose, especially during fallout deposition and at early times when intensities are relatively high and intensity levels are changing through decay and decontamination. As inferred from deck logs, normal crew activities were somewhat altered during the day that fallout occurred and during the following day when decontamination was underway. On the morning of the second day after fallout, normal crew duties were generally resumed.

With the exception of 8-V April (Shot DOG fallout), 21-22 April (Shot EASY fallout), and 25-26 May (Shot ITEM fallout), when actual times topside and below are used, the free-field integrated intensities 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 typical 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 Section 2.9, it is estimated that ship-shielding factors vary from approximately 0.08 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 0.45 to 0.49. 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.

3.2 CALCULATED PERSONNEL FILM BADGE DOSES

Dose calculations for shipboard personnel are complicated by the fact that on D-Day and D+1, the magnitude of the fallout required normal crew routines to be altered. On D+1, even though normal crew routines were generally adhered to, intensity levels were still such that specific periods above and below deck must be determined. For all other days, the ship-specific, time-averaged shielding factor is applied to the daily free-field intensities to account for ship shielding. These adjusted exposures are then converted to an equivalent film badge dose using a conversion factor of 0.7 mrem/mR.

In order to demonstrate the effect of crew activities on the calculated personnel film badge dose, an example of the calculations is shown below. The Shot DOG fallout on the USS CURTISS is selected as typical. First, a crew activity time-line is inferred from the CURTISS deck log for the 8th, 9th and 10th of April (See Figure A-2, Appendix A). This figure indicates the times during these three days that an average crewmember would have been above and below deck. For those periods when the crew would have been topside, the integrated free-field intensity (from Section 2) is used. For those time periods spent below, the integrated intensity is adjusted to account for

the shielding provided by the ship's **structure** (see Section 2.9). The contributions from each period are added to determine an adjusted exposure for the average crewmember. These adjusted exposures are then converted to a film badge dose. For personnel aboard the CURTISS after Shot DOG, the film badge dose on 8 and 9 April is calculated as follows:

USS CURTISS - Shot DOG (0634 hours, 8 April)

April	I(t) DOG	Integrated Intensity (mR)	x	Ship-Shielding Factor	=	Adjusted Exposure (mR)
0825-0900	$.238\ t^{4.0}$	2.9		1.0		2.9
0900-1010"	$.238\ t^{4.0}$	25.0		.08		2.0
1010-1300"	$307.6\ t^{-1.59}$	70.4		.08		5.6
1300-1330*	$44.2\ t^{-.547}$	7.9		.08		0.6
1330-1700	$44.2\ t^{-.547}$	47.8		1.0		47.8
1700-1800"	$44.2\ t^{-.547}$	12.0		.08		1.0
1800-2000	$44.2\ t^{-.547}$	22.2		1.0		22.2
2000-2400"	$44.2\ t^{-.547}$	39.7		.08		3.2
		227.9 (Table 2-4)				85.3

8 April film badge dose = (85.3 mR)(0.7 mrem/mR) = 59.7 mrem (Table 3-2)

9 April

0000-0800"	$44.2\ t^{-.547}$	66.7		.08		5.3
0800-L 130	$44.2\ t^{-.547}$	25.4		1.0		25.4
1130-1200	$268.5\ t^{-1.083}$	3.4		1.0		3.4
1200-1330"	268.5 t -1.083	10.0		.08		0.8
1330-1700	268.5 t -1.083	21.6		1.0		21.6
1700-1800"	$268.5\ t^{-1.083}$	5.7		.08		0.5
1800-2000	$268.5\ t^{-1.083}$	11.0		1.0		11.0
2000-2400"	268.5 t -1.083	20.1		.08		1.6
		163.9 (Table 2-4)				69.6

9 April film badge dose = (69.6 mR)(0.7 mrem/mR) = 48.7 mrem (Table 3-2)

"Denotes time periods below deck (from Figure A-2)

Starting on D+2, the crews on all ships are estimated to have spent approximately 40 percent of the day above deck and 60 percent below; therefore on D+2 and subsequent days, a time-averaged shielding factor is used to calculate the adjusted exposure. On 10 April and the following days, the time-averaged shielding factor for the CURTISS is 0.4 + (0.6)(.08) = 0.45, as described in Section 3.1, where .08 is the ship-shielding factor for the CURTISS. Similar calculations are made for the crews of the other six ships for each of the detonations where fallout occurred on the ships. The results of these calculations are given in Tables 3-1 through 3-7. The calculations are continued until the total monthly accumulated dose to the crew is less than 30 mrem.

When Shot DOG fallout began on the residence islands, rad-safe personnel at Parry evaluated the situation and concluded that personnel activities could continue as usual; there would be no disruption of the routine (Reference 14). Thus, for the island-based personnel, normal routines were not altered by the occurrence of fallout. Personnel film badge doses are calculated by multiplying the free-field integrated intensities by the appropriate time-averaged shielding factor and by the film badge conversion factor. Results of these calculations are given in Tables 3-8, 3-9, and 3-10 for Enewetak, Parry, and Japtan Islands, respectively.

Table 3-1. Calculated Personnel Film Badge Dose, USS CABILDO

DATE	DOG	EASY	GEORGE	ITEM	CUMULATIVE
8 April 1951	10.1 mrem				10
9	19.0				29
10	12.4				42
II	8.2				50
12	5.6				55
13	4.4				60
14	3.5				63
15	3.0				66
16	2.5				69
17	2.2				71
18	1.9				73
19	1.7				75
20	1.6				76
21	I.4	0.0 mrem			78
22	1.3	5.4			84
23	I.2	3.1			89
24	1.1	2.0			92
25	1.0	1.5			94
26	1.0	1.2			96
27	0.9	1.0			98
28	0.9	0.9			100
29	0.8	0.7			102
30	0.8	0.6			103
I May 1951	0.7	0.6			104
2	0.7	0.5			106
3	0.7	0.5			107
4	0.6	0.5			108
5	0.6	0.4			109
6	0.6	0.4			110
7	0.5	0.4			111
8	0.5	0.3			112
9	0.5	0.3	0		112
10	0.5	0.3	0		113
II	0.5	0.3	0		114
12	0.5	0.3	0		115
13	0.4	0.2	0		115
14	0.4	0.2	0		116
15	0.4	0.2	0		117
16	0.4	0.2	0		117
17	0.4	0.2	0		118
18	0.4	0.2	0		118
19	0.4	0.2	0		118
20	0.4	0.2	0		119
21	0.3	0.2	0		I 20
22	0.3	0.2	0		121
23	0.3	0.2	0		121
24	0.3	0.1	0		121
25	0.3	0.1	0	32.3 mrem	154
26	0.3	0.1	0	60.5	215
27	0.3	0.1	0	34.0	249
28	0.3	0.1	0	22.4	272
29	0.3	0.1	0	16.6	289
30	0.3	0.1	0	13.1	303
31	0.3	0.1	0	10.8	314
June 51	6	3	0	104.0	427
July 51	4	2	0	33.0	466
August 51	3	1	0	19.0	489
TOTAL	112.9	30.3	0	345.7	489 mrem

Table 3-2. Calculated Personnel Film Badge Dose, USS CURTISS

DATE	DOG	EASY	GEORGE	ITEM	CUMULATIVE
8 April 1951	59.7 mrem				60
9	48.7				108
10	27.9				136
11	18.5				15.5
12	13.7				169
13	10.9				179
14	9.0				188
15	7.7				196
16	6.7				203
17	5.9				209
18	5.3				214
19	4.3				219
20	4.3				223
21	4.0	0 mrem			227
22	3.6	5.4			236
23	3.4	3.1			243
24	3.2	2.0			248
25	3.0	1.5			252
26	2.8	I.2			256
27	2.7	1.0			260
28	2.5	0.9			263
29	2.4	0.7			266
30	2.3	0.6			269
1 May	2.2	0.6			272
2	2.1	0.5			275
3	2.0	0.5			277
4	1.9	0.5			280
5	1.8	0.4			282
6	1.8	0.4			284
7	1.7	0.4			286
8	1.6	0.3			288
9	1.6	0.3	0		290
10	1.5	0.3	0		292
11	I.4	0.3	0		293
12	I.4	0.3	0		295
13	1.4	0.2	0		297
14	1.4	0.2	0		298
15	1.3	0.2	0		300
16	1.3	0.2	0		301
17	1.2	0.2	0		303
18	1.2	0.2	0		304
19	1.2	0.2	0		306
20	1.1	0.2	0		307
21	1.1	0.2	0		308
22	1.1	0.2	0		309
23	1.0	0.2	0		311
24	1.0	0.1	0		312
25	1.0	0.1	0	73.5 mrem	386
26	1.0	0.1	0	51.9	439
27	0.9	0.1	0	29.3	470
28	0.9	0.1	0	20.2	491
29	0.9	0.1	0	15.4	507
30	0.9	0.1	0	12.5	521
31	0.9	0.1	0	10.5	532
June	20	3	0	113	668
July	14	2	0	41	725
August	10	1	0	26	762
September	8	1	0	18	789
TOTAL	346.2	31.3	0	411.4	789 mrem

Table 3-3. Calculated Personnel Film Badge Dose, USS LST-859

DATE	DOG	EASY	GEORGE	ITEM*	CUMULATIVE
8 April 1951	147.8 mrem				148
9	23.4				171
10	14.8				186
II	9.8				196
12	7.3				203
13	5.8				209
14	4.8				214
15	4.1				218
16	3.5				221
17	3.1				224
18	2.8				227
19	2.5				230
20	2.3				232
21	2.1	0 mrem			234
22	2.0	5.8			242
23	1.8	3.4			247
24	1.7	2.2			251
25	1.6	1.7			254
26	1.5	1.3			257
27	1.4	1.1			260
28	1.3	0.9			262
29	1.3	0.8			264
30	1.2	0.7			266
I May	1.1	0.6			268
2	1.1	0.5			269
3	1.0	0.5			271
4	1.0	0.5			272
5	1.0	0.4			274
6	0.9	0.4			275
7	0.9	0.4			276
8	0.9	0.3			277
9	0.8	0.3	0		278
10	0.8	0.3	0		280
11	0.8	0.3	0		281
12	0.7	0.3	0		282
13	0.7	0.2	0		283
14	0.7	0.2	0		283
15	0.7	0.2	0		284
16	0.7	0.2	0		285
17	0.6	0.2	0		286
18	0.6	0.2	0		287
19	0.6	0.2	0		288
20	0.6	0.2	0		288
21	0.6	0.2	0		289
22	0.6	0.2	0		290
23	0.5	0.2	0		291
24	0.5	0.1	0		291
25	0.5	0.1	0		292
26	0.5	0.1	0		293
27	0.5	0.1	0		293
28	0.5	0.1	0		294
29	0.5	0.1	0		294
30	0.5	0.1	0		295
31	0.5	0.1	0		296
TOTAL	269.8	26.3	0		296 mrem

● LST-859 was enroute to Bikini at the time of Shot ITEM.

Table 3-4. Calculated Personnel Film Badge Dose, USNS SGT. CHARLES E. MOWER

DATE	DOG	EASY	GEORGE ITEM		CUMULATIVE
8 April 1951	96.9 mrem				97
9 .	14.3				111
10	7.7				119
11	5.1				124
12	3.8				128
13	3.0				131
14	2.5				133
15	2.1				135
16	1.8				137
17	1.6				139
18	1.5				140
19	1.3				142
20	1.2				143
21	1.1	0 mrem			144
22	1.0	5.5			150
23	0.9	3.2			155
24	0.9	2.1			158
25	0.8	1.6			160
26	0.8	1.2			162
27	0.7	1.0			164
28	0.7	0.9			165
29	0.6	0.7			167
30	0.6	0.6			168
1 May	0.6	0.6			169
2	0.6	0.5			170
3	0.6	0.5			171
4	0.5	0.5			172
5	0.5	0.4			173
6	0.5	0.4			174
7	0.5	0.4			175
8	0.5	0.3			176
9	0.4	0.3	0		176
10	0.4	0.3	0		177
11	0.4	0.3	0		178
12	0.4	0.3	0		178
13	0.4	0.2	0		179
14	0.4	0.2	0		179
15	0.4	0.2	0		180
16	0.4	0.2	0		181
17	0.3	0.2	0		181
18	0.3	0.2	0		182
19	0.3	0.2	0		182
20	0.3	0.2	0		183
21	0.3	0.2	0		183
22	0.3	0.2	0		184
23	0.3	0.2	0		184
24	0.3	0.1	0		185
25	0.3	0.1	0	116.2 mrem	302
26	0.3	0.1	0	148.2	450
27	0.3	0.1	0	81.1	532
28	0.3	0.1	0	53.3	585
29	0.3	0.1	0	39.5	625
30	0.2	0.1	0	31.2	657
31	0.2	0.1	0	25.7	683
June	6	3	0	246	938
July	4	2	0	79	1023
August	3	2	0	46	1074
September	3		0	31	1109
October	2	1	0	25	1137
TOTAL	180.6	33.8	0	922.2	1137 mrem

Table 3-5. Calculated Personnel Film Badge Dose, USS SPROSTON

DATE	DOG	EASY	GEORGE	ITEM	CUMULATIVE
8 April 51	38.9 mrem				39
9	12.3				51
10	6.7				58
11	4.4				62
12	3.3				66
13	2.6				68
14	2.2				70
15	1.9				72
16	1.6				74
17	1.4				75
18	1.3				77
19	1.1				78
20	1.1				79
21	1.0	2.9 mrem			83
22	0.9	82.2			166
23	0.8	0			167
24	0.8	0			167
25	0.7	0			168
26	0.7	0			169
27	0.6	0			169
28	0.6	0			170
29	0.6	0			171
30	0.5	0			171
1 May	0.5	0			172
2	0.5	0			172
3	0.5	0			173
4	0.5	0			173
5	0.4	0			174
6	0.4	0			174
7	0.4	0			174
8	0.4	0			175
9	0.4	0	0		175
10	0.4	0	0		176
11	0.3	0	0		176
12	0.3	0	0		176
13	0.3	0	0		176
14	0.3	0	0		177
15	0.3	0	0		177
16	0.3	0	0		177
17	0.3	0	0		178
18	0.3	0	0		178
19	0.3	0	0		178
20	0.3	0	0		179
21	0.3	0	0		179
22	0.3	0	0		179
23	0.3	0	0		179
24	0.3	0	0		180
25	0.2	0	0	0.6 mrem	181
26	0.2	0	0	0.8	182
27	0.2	0	0	0.7	182
28	0.2	0	0	0.4	183
29	0.2	0	0	0.3	184
30	0.2	0	0	0.2	184
31	0.2	0	0	0.2	184
TOTAL	96.0	85.1	0	3.2	184 mrem

Table 3-6. Calculated Personnel Film Badge Dose, USS WALKER

DATE	DOG	EASY	GEORGE	ITEM	CUMULATIVE
8 April1951	35.9 mrem				36
9	7.9				44
10	4.2				48
11	2.8				51
12	2.1				53
13	1.6				55
14	1.3				56
15	1.2				57
16	1.0				58
17	0.9				59
18	0.8				60
19	0.7				60
20	0.6				61
21	0.6	13.9 mrem			76
22	0.5	7.6			84
23	0.5	4.0			88
24	0.5	2.7			91
25	0.4	2.0			94
26	0.4	1.5			96
27	0.4	1.3			97
28	0.4	1.1			99
29	0.3	1.0			100
30	0.3	0.8			101
I May	0.3	0.7			102
2	0.3	0.7			103
3	0.3	0.6			104
4	0.3	0.6			105
5	0.3	0.5			106
6	0.2	0.5			107
7	0.2	0.4			107
8	0.2	0.4			108
9	0.2	0.4	0		108
10	0.2	0.4	0		109
II	0.2	0.3	0		109
12	0.2	0.3	0		110
13	0.2	0.3	0		110
14	0.2	0.3	0		111
15	0.2	0.3	0		111
16	0.2	0.3	0		112
17	0.2	0.2	0		112
18	0.2	0.2	0		113
19	0.1	0.2	0		113
20	0.1	0.2	0		113
21	0.1	0.2	0		114
22	0.1	0.2	0		114
23	0.1	0.2	0		114
24	0.1	0.2	0		115
25	0.1	0.2	0	51.7 mrem	167
26	0.1	0.2	0	18.6	185
27	0.1	0.2	0	4.0	190
28	0.1	0.2	0	2.7	193
29	0.1	0.2	0	2.1	195
30	0.1	0.2	0	1.7	197
31	0.1	0.1	0	I.4	199
June	3	3	0	15	220
TOTAL	74.4	49.1	0	97.2	220 mrem

Table 3-7. Calculated Personnel Film Badge Dose, USNS LT. ROBERT CRAIG

DATE	DOG	EASY*	GEORGE*	ITEM*	CUMULATIVE
8 April 1951	37.5 mrem				38
9	19.7				57
10	10.9				68
11	7.2				75
12	5.3				81
13	4.2				85
14	3.5				88
15	3.0				91
16	2.6				94
17	2.3				96
18	2.0				98
19	1.8				100
20	1.7				102
21	1.5				103
22	1.4				105
23	1.3				106
24	1.2				107
25	1.2				108
26	1.1				109
27	1.0				110
28	1.0				111
29	0.9				112
30	0.9				113
1 May	0.8				114
2	0.8				115
3	0.8				116
4	0.7				116
5	0.7				117
6	0.7				118
7	0.7				118
8	0.6				119
9	0.6				120
10	0.6				120
11	0.6				121
12	0.6				121
13	0.5				122
14	0.5				122
15	0.5				123
16	0.5				123
17	0.5				124
18	0.5				124
19	0.5				125
20	0.4				125
21	0.4				126
22	0.4				126
23	0.4				127
24	0.4				127
25	0.4				127
26	0.4				128
27	0.4				128
28	0.4				129
29	0.4				129
30	0.3				129
31	0.3				130
TOTAL	129.5				130 mrem

* CRAIG did not participate at the remaining GREENHOUSE shots.

Table 3-8. Calculated Personnel Film Badge Dose, Enewetak Island

DATE	DOG	EASY	GEORGE	ITEM	CUMULATIVE
8 April 51	203.7 mrem				204
9	89.2				293
10	42.7				336
11	27.7				363
12	20.2				383
13	15.8				399
14	12.9				412
15	10.9				423
16	9.4				433
17	8.2				441
18	7.3				448
19	6.6				455
20	5.9				461
21	5.4	0.1 mrem			466
22	5.0	8.6			480
23	4.6	5.5			490
24	4.3	3.6			498
25	4.0	2.7			504
26	3.8	2.1			510
27	3.5	1.7			515
28	3.4	1.5			520
29	3.2	1.3			525
30	3.0	1.1			529
I May	2.9	1.0			533
2	2.7	0.9			536
3	2.6	0.8			540
4	2.5	0.8			543
5	2.4	0.7			546
6	2.3	0.7			549
7	2.2	0.6			552
8	2.1	0.6			555
9	2.0	0.6			557
10	2.0	0.5	0		560
11	1.9	0.5	0		562
12	1.8	0.4	0		564
13	1.8	0.4	0		567
14	1.7	0.4	0		569
15	1.7	0.4	0		571
16	1.6	0.4	0		573
17	1.6	0.3	0		575
18	1.5	0.3	0		577
19	1.5	0.3	0		578
20	1.5	0.3	0		580
21	1.4	0.3	0		582
22	1.3	0.3	0		583
23	1.3	0.3	0		585
24	1.3	0.3	0		587
25	1.3	0.3		584.1 mrem	1172
26	1.2	0.3	8	724.6	1898
27	1.2	0.2		359.9	2260
28	1.2	0.2	8	237.2	2498
29	1.2	0.2	0	175.7	2675
30	1.1	0.2	0	138.9	2816
31	1.1	0.2	0	114.5	2932
TOTAL	554.8	42.2	0	2334.9	2932

Table 3-9. Calculated Personnel Film Badge Dose, Parry Island

DATE	DOG	EASY	GEORGE	ITEM	CUMULATIVE
8 April 51	443.1 mrem				443
9	228.1				671
10	113.8				785
II	75.4				860
12	56.1				916
13	44.5				961
14	36.7				998
15	31.2				1029
16	27.2				1056
17	24.0				1080
18	21.4				1101
19	19.4				1121
20	7.2				1128
21	6.6	0.1 mrem			1135
22	6.1	8.6			1150
23	5.7	5.5			1161
24	5.3	3.6			1170
25	5.0	2.7			1177
26	4.6	2.1			1184
27	4.4	1.7			1190
28	4.2	1.5			1196
29	4.0	1.3			1201
30	3.8	1.1			1206
1 May	3.6	1.0			1211
2	3.4	0.9			1215
3	3.3	0.8			1219
4	3.1	0.8			1223
5	3.0	0.7			1227
6	2.9	0.7			1230
7	2.8	0.6			1234
8	2.7	0.6			1237
9	2.6	0.6	0		1240
10	2.5	0.5	0		1243
II	2.5	0.5	0		1246
12	2.4	0.4	0		1249
13	2.3	0.4	0		1252
14	2.2	0.4	0		1254
15	2.2	0.4	0		1257
16	2.1	0.4	0		1259
17	2.0	0.3	0		1262
18	2.0	0.3	0		1264
19	1.9	0.3	0		1266
20	1.9	0.3	0		1268
21	1.8	0.3	0		1270
22	1.8	0.3	0		1273
23	1.7	0.3	0		1275
24	1.7	0.3	0		1277
25	1.7	0.3	0	405.2 mrem	1684
26	1.6	0.3	0	564.2	2250
27	1.6	0.2	0	288.1	2540
28	1.6	0.2	0	193.1	2735
29	1.5	0.2	0	144.8	2882
30	1.5	0.2	0	115.6	2999
31	1.5	0.2	0	96.0	3096
TOTAL	1247.2	42.2	0	1807.0	3096 mrem

Table 3-10. Calculated Personnel Film Badge Dose, Japtan Island

DATE	DOG	EASY	GEORGE	ITEM	CUMULATIVE
8 April 51	443.1 mrem				443
9	228.1				671
10	113.8				785
II	75.4				860
12	56.1				916
13	44.5				961
14	36.7				998
15	31.2				1029
16	27.2				1056
17	24.0				1080
18	21.4				1101
19	19.4				1121
20	7.2				1128
21	6.6	0.1 mrem			1135
22	6.1	8.6			1150
23	5.7	5.5			1161
24	5.3	3.6			1170
25	5.0	2.7			1177
26	4.6	2.1			1184
27	4.4	1.7			1190
28	4.2	1.5			1196
29	4.0	1.3			1201
30	3.8	1.1			1206
1 May	3.6	1.0			1211
2	3.4	0.9			1215
3	3.3	0.8			1219
4	3.1	0.8			1223
5	3.0	0.7			1227
6	2.9	0.7			1230
7	2.8	0.6			1234
8	2.7	0.6			1237
9	2.6	0.6	0		1240
10	2.5	0.5	0		1243
11	2.5	0.5	0		1246
12	2.4	0.4	0		1249
13	2.3	0.4	0		1252
14	2.2	0.4	0		1254
15	2.2	0.4	0		1257
16	2.1	0.4	0		1259
17	2.0	0.3	0		1262
18	2.0	0.3	0		1264
19	1.9	0.3	0		1266
20	1.9	0.3	0		1268
21	1.8	0.3	0		1270
22	1.8	0.3	0		1273
23	1.7	0.3	0		1275
24	1.7	0.3	0		1277
25	1.7	0.3	0	226.2 mrem	1505
26	1.6	0.3	0	403.8	1910
27	1.6	0.2	0	216.2	2128
28	1.6	0.2	0	148.9	2279
29	1.5	0.2	0	113.8	2395
30	1.5	0.2	0	92.2	2489
31	1.5	0.2	0	77.6	2568
TOTAL	1247.2	42.2	0	1278.7	2568 mrem

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 include radiation intensities on deck, the positions of personnel (hence their exposure) on deck, the time spent on deck, and the shielding afforded to those below.

Intensity levels on deck are determined from shipboard radiological survey data, supplemented at late times by decay rates measured on nearby islands. 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 crewmember 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 for each survey focuses attention on the positioning of the crew relative to those intensities. The specific locations of each survey reading are reported in some instances; from these it is judged that the readings adequately define the topside radiation environment. 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 of the magnitude is obtained by assuming 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. It should be noted that, for personnel moving continuously about the deck, their dose approaches the calculated mean.

In order to arrive at dose distributions, the intensity readings of each radiation survey are taken to represent a normal distribution, characterized by the mean (μ) and standard deviation (σ). Where more than one set of survey data is available for a given shot and ship, the average fractional (of mean) standard deviation is used, for simplicity, at all times on deck. The fractional standard deviations (σ/μ) obtained, or inferred, from the ship survey data and used in the uncertainty analysis are given in Table 4-1.

Table 4-1. Fractional Standard Deviation (σ/μ) for Shipboard Radiation Survey Data

	DOG	EASY	ITEM
CABILDO	0.821	1.277	0.543
CURTISS	0.625	1.277""	0.585
LST-859	0.858	1.277**	n/a
MOWER	0.555	1.277**	0.531"""
SPROSTON	0.547	0.547"	0.547"
WALKER	0.547"	0.547"	0.547"
CRAIG	0.547"	n/a	n/a

* No Survey Data - inferred from SPROSTON, Shot DOG
** No Survey Data - inferred from CABILDO, Shot EASY
*** No Survey Data - inferred from CABILDO, Shot ITEM (before decontamination)

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 reality approaches a limit with time, a finite distribution remains around the mean total dose. Distributions for each ship and each shot (where survey data are available) are reported at the 90-percent level, i.e., $+1.65\sigma$ (5th to 95th percentile). Although exposure below deck makes some contribution to the mean total dose, it is not used in generating a 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. For the island survey data, only average intensities are reported. Since the ships were anchored in close proximity to the islands when fallout was experienced, it is reasonable to assume the distribution of island intensities can be approximated utilizing the shipboard data. The distribution of island intensities around the reported mean is inferred by averaging the fractional standard deviation of the shot-specific, shipboard survey data.

Because the distribution of survey readings typically shows deviations from normality (either with ostensible outliers or a lognormal appearance), a combined distribution is generated numerically to gauge the applicability of normal analysis. One of the most significantly skewed distributions is a set of 30 survey readings from the LST-859, with a maximum of five times the mean and a fractional standard deviation of about unity. These readings are taken to apply to a hypothetical exposure in six intervals of uniform duration and no radiological decay. Such a construct of two-day exposure simulates a longer exposure of ever-decreasing intensity. As all readings are weighted equally, each possible sum of readings over the six intervals makes an equal contribution to the total dose distribution. The complete, computer-generated distribution, although markedly skewed, is essentially continuous and can be described in terms of percentiles of the maximum possible value. Figure 4-l depicts this distribution and compares it with that obtained through normal analysis. At the level of one standard deviation are the 12th and 27th percentiles; at the 90-percent level are the 10th and 33rd percentiles. These compare favorably with those obtained from the assumption of normality in the survey readings, which are the 12th and 28th, and

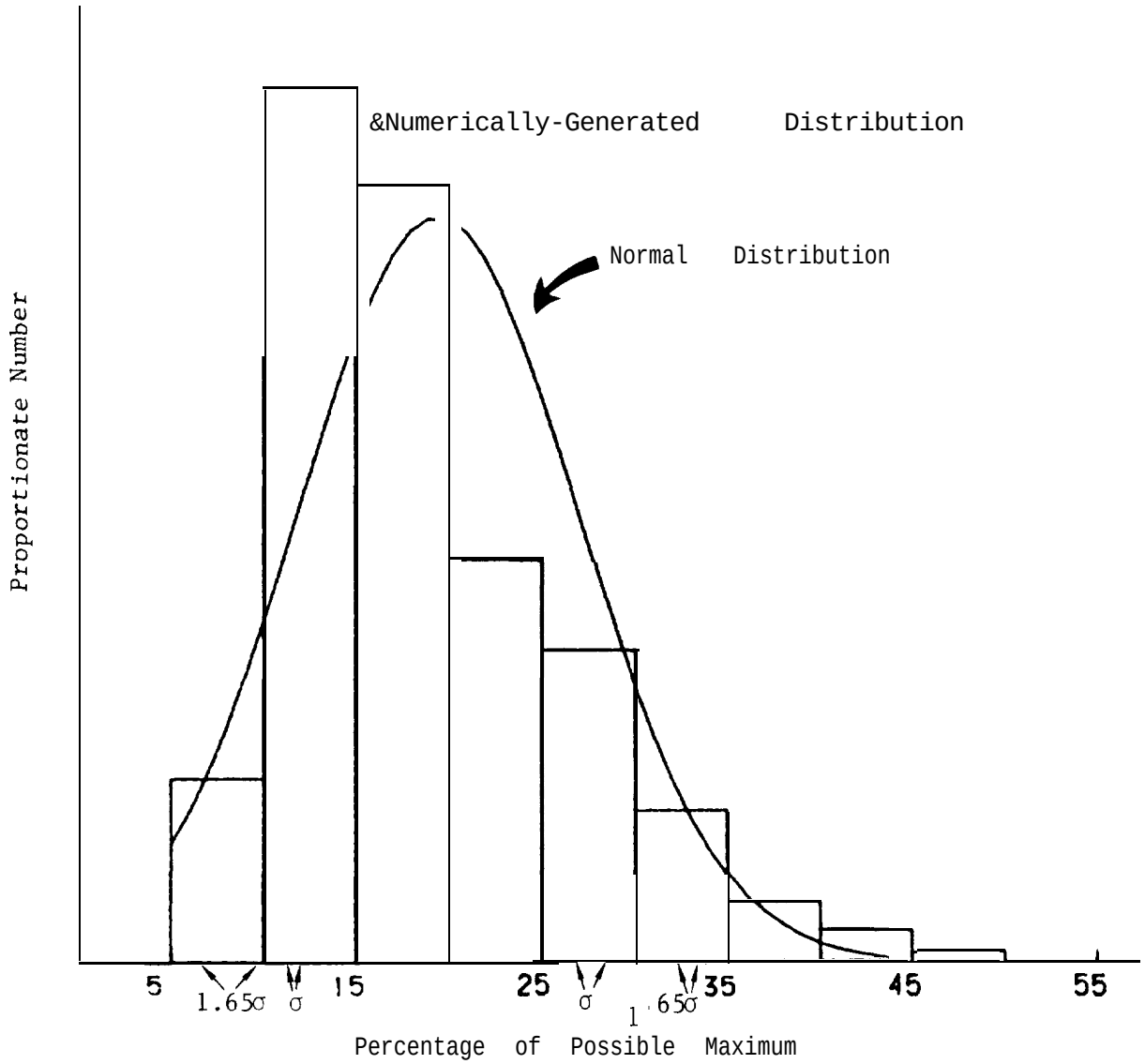


Figure 4-l. Hypothetical Dose Distributions

7th and 34th percentiles, respectively. On this basis, the assumption of normality of the survey distributions is considered to be generally satisfactory as utilized.

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 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 50.05, 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.

Section 5

FILM BADGE DOSIMETRY

Calculated personnel film badge doses are compared with the available dosimetry data. Film badges were issued to selected personnel aboard the ships "in order to obtain a record of exposure to radiation in various parts of the ship at the time of, and subsequent to, the detonation" (Reference 15). Film badge readings are available for 231 personnel exposures (Reference 16) aboard six of the ships for which dose calculations were made. This data is summarized by ship and shot-related time period in Figures 5-l through 5-4. The circles in the figures represent the actual film badge data while the triangles depict the calculated average film badge dose (from Section 3).

With the exception of the badged periods for Shot GEORGE (Figure 5-3), where agreement between calculated doses and dosimetry data from all ships is very good, the calculated average dose generally underestimates the exposures indicated by the dosimetry data. In spite of this, there appears to be a very good correlation between the calculated doses and dosimetry data on a ship-to-ship basis, i.e., if the dosimetry data suggests Ship A received more fallout than Ship B, calculated doses for both ships support this observation. This correlation suggests that the difference between the calculated average dose and average of the dosimetry data on each ship is a systematic underestimation (i.e., the calculated doses are all low by "x" percent).

A closer look at the personnel who were badged for each shot explains, for the most part, why the calculated average doses are lower than the dosimetry data. Virtually all of the film badges were worn by personnel whose duties required them to be on deck a greater percentage of the day than assumed for the average crew-member. These include personnel assigned to the signal bridge, coxswains and boatswain's mates assigned to the weather decks, members of damage control and repair parties, and rad-safe monitors. This observation alone could account for a 20 percent increase in the calculated dose (see Section 4). Further, most of the badged

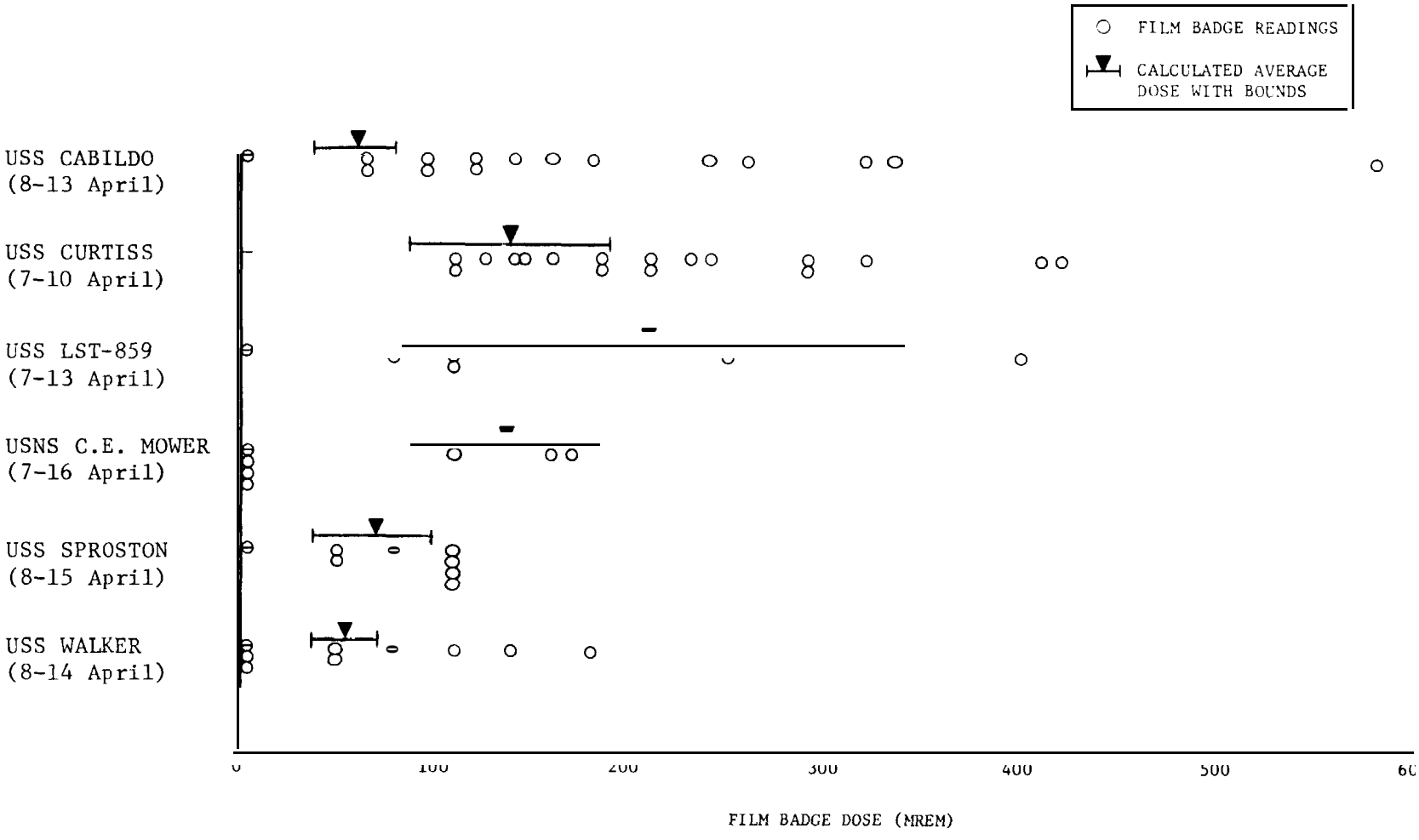


Figure 5-1. Shot DOG Dosimetry Data

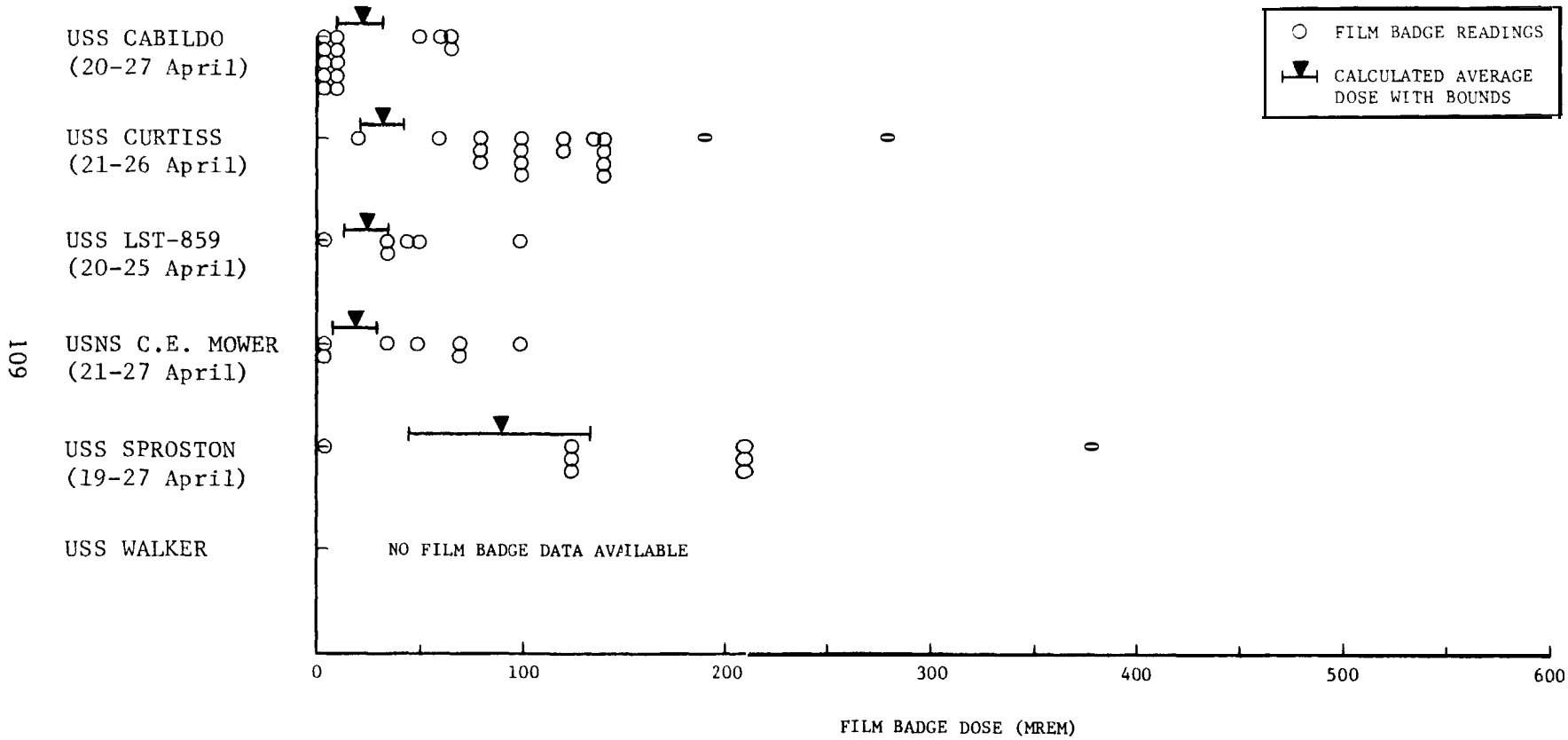


Figure 5-2. Shot EASY Dosimetry Data

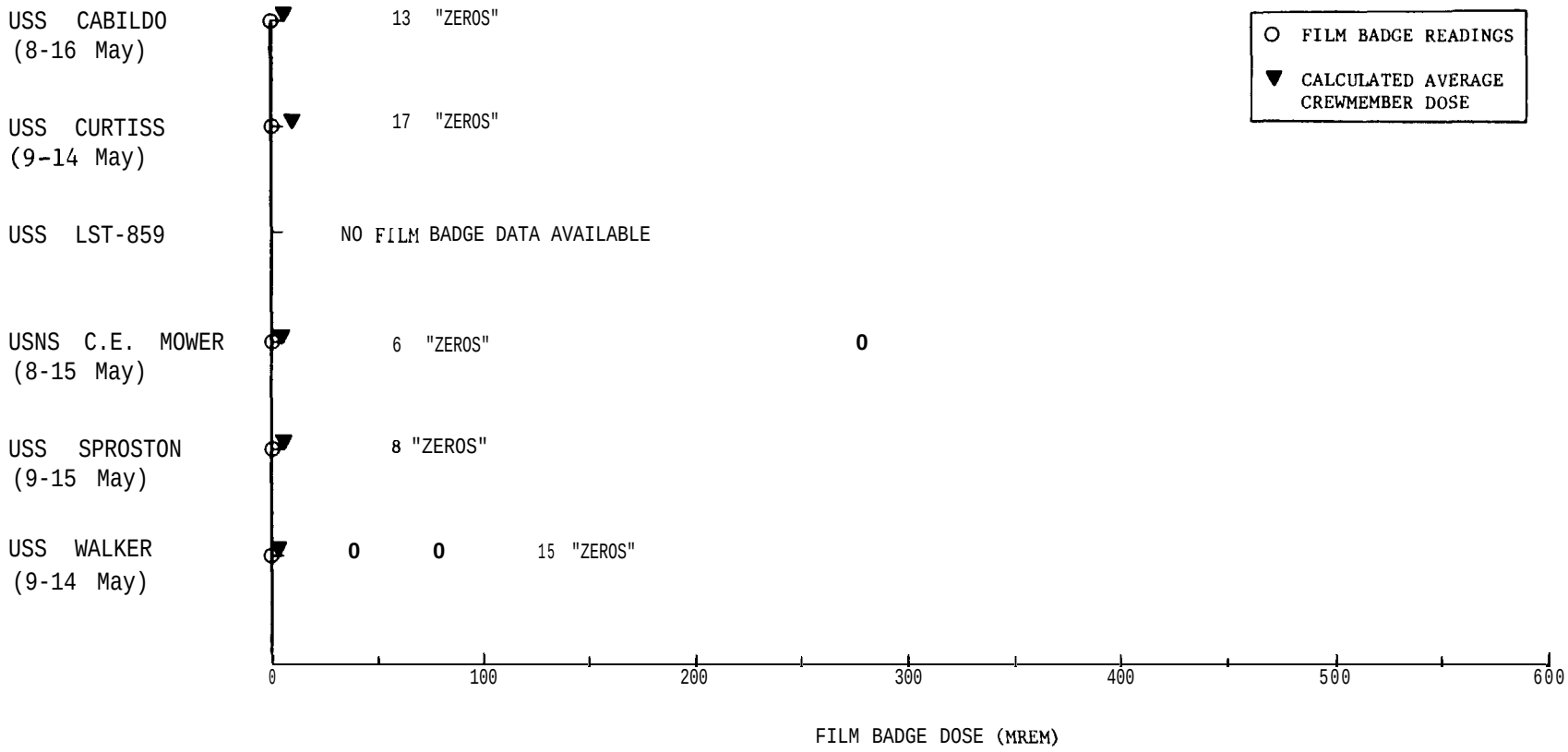


Figure 5-3. Shot GEORGE Dosimetry Data

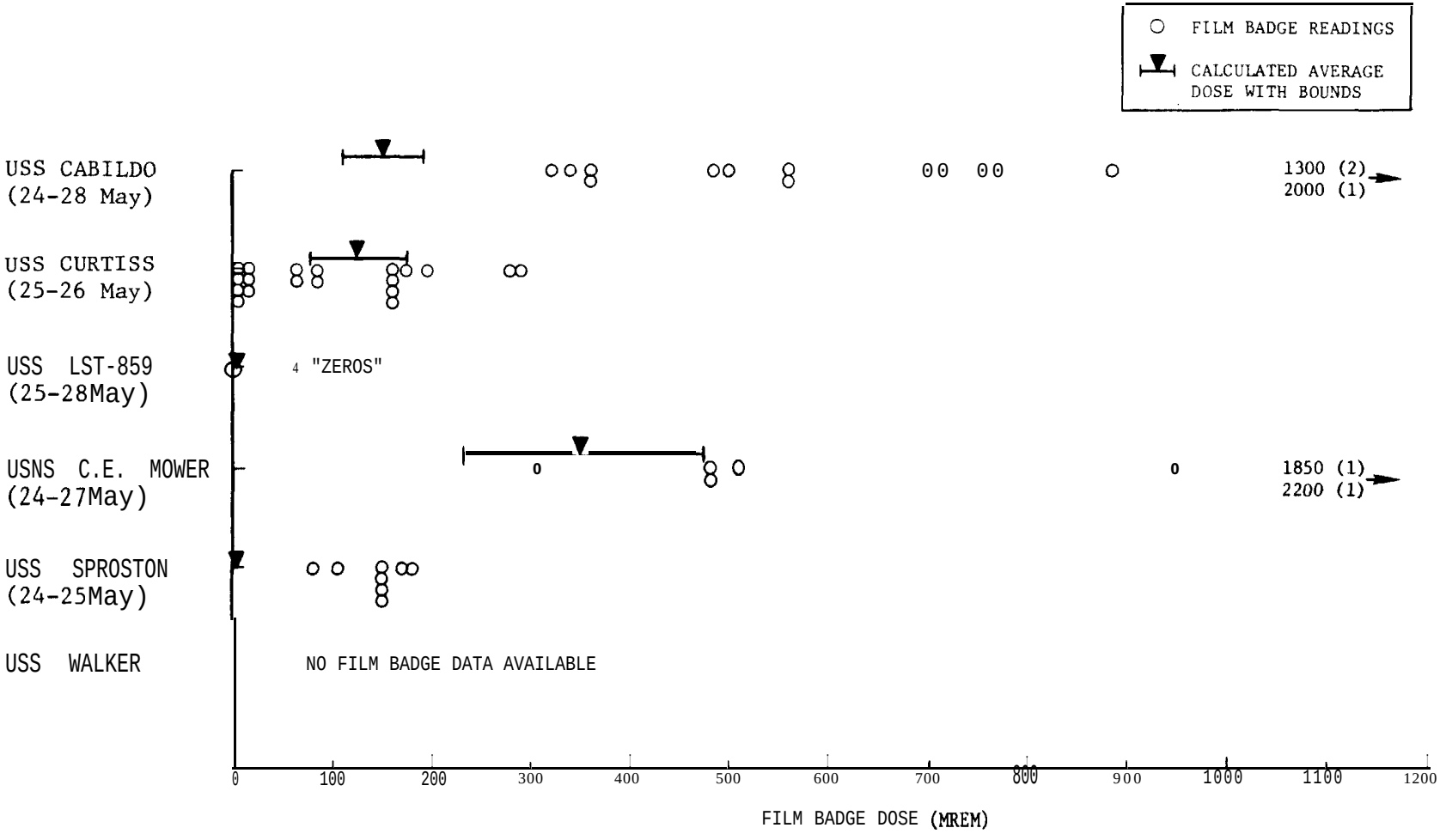


Figure 5-4. Shot ITEM Dosimetry Data

personnel, especially the rad-safe monitors and the damage control and repair parties, would have been required to be topside in spite of or even because of fallout deposition. These personnel were exposed during periods of early fallout deposition when the dose calculations assume the average crewmember was below deck. It has been noted in previous dose reconstructions for shipboard personnel (Reference 17) that, on the day fallout occurs, personnel involved with monitoring and decontamination can easily receive 50-60 percent of the daily (24-hour) topside dose. As an example, the average integrated free-field intensity on the CURTISS on 8 April was 228 mR (Table 2-4). Sixty percent of this would be 137 mR and, when converted to an equivalent film badge dose, would result in a calculated film badge dose of 96 mrem. On 9 and 10 April, an additional 77 mrem was accrued by the average crew; assuming a 20 percent increase due to time spent topside, the high exposure personnel would have received 92 mrem. The total dose received by these personnel during the 7-10 April badged period would be 188 mrem, compared to 136 mrem calculated for the average crew (Table 3-2). This compares quite favorably with a dose of 220 mrem obtained by averaging the actual film badge readings. Similar calculations can be made for the other ships and shots with generally good agreement between the dosimetry data and the calculated film badge doses for these high exposure personnel.

Section 6

CONCLUSIONS AND TOTAL DOSE SUMMARY

In Section 5, a comparison between calculated doses and dosimetry data for the crews of six ships indicated a systematic underestimation by the calculated doses in portraying the actual doses received by the badge wearers during most badged periods. When the shipboard duties of the badged personnel are accounted for in the dose calculations (by considering extended periods of time topside), agreement between the calculated doses and the dosimetry data is significantly improved.

Table 6-l summarizes, by shot, the calculated dose due to fallout for the seven ships considered in this report and for the residence islands of Enewetak Atoll. The total dose (with bounds) is tabulated and, in the absence of dosimetry data, should be used for dose determination. The uncertainity in dose due to assumed time topside is not reflected in the mean or bounds (see Section 4); the inclusion of this uncertainity will increase (or decrease) the mean and bounds by 20 percent depending on the assumed or documented personnel activity scenario.

Table 6-1. Summary of Calculated Doses

Shipboard Personnel	Dose (mrem) Contribution From Shot DOG	EASY	GEORGE	ITEM	Total Dose (rem)*
USS CABILDO	115±20	30±10	0	345±40	0.49±.05
USS CURTISS	345±55	30±10	0	410±50	0.79±.08
USS LST-859	270±130	25±10	0		0.30±.13
USNS SGT. C.E. MOWER	180±50	35±10	0	920±110	1.14±.12
USS SPROSTON	95±30	85±45	0	5	0.19±.05
USS WALKER	75±15	50±10	0	95±40	0.22 ±.04
USNS LT. ROBERT CRAIG	130±30				0.13 ±.03
Island-Based Personnel					
Enewetak	555±160	40±15	0	2335±565	2.93±.59
Parry	1245±370	40±15	0	181 0±430	3.10±.57
Japtan	1245±370	40±15	0	1280±300	2.57±.48

*Values are rounded to the nearest 0.01 rem.

Section 7
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13. Supplemental material supplied by C.F. Ksanda to Reference 8, September 1960.

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15. “Film Badges, Procurement, Distribution, and Processing: Information Concerning,” letter from CTG 3.3 to TG 3.3, 22 March 1951.

16. “Film Badge Summaries for Six GREENHOUSE Ships,” enclosure (2) to letter from Navy NTPR to DNA, 14 June 1983.

17. “Estimate of Radiation Dose to Shipboard Personnel, Shot BRAVO, Operation CASTLE,” memorandum from Science Applications, Inc. to NNTPR, 28 June 1982.

Appendix

SHIPBOARD CREW ACTIVITIES

In order to transform the average topside dose into a more meaningful crewmember dose, as is shown in Section 3 of this report, it is necessary to determine the amount of time spent on and below deck by an average crewmember. For whatever day fallout occurred onboard a ship and on the following day, when radiation intensities were still relatively high, not only the total time on deck, but also the actual time of day spent on deck, becomes significant. The reason is that a crewmember on deck has virtually no protection, while a crewmember below deck is afforded varying degrees of shielding depending on the material between him and the source of the gamma rays--usually the weather deck surfaces (see Section 2.9).

For the seven ships participating in Operation GREENHOUSE, crew activity time lines are derived or inferred from each deck log. These time lines depict when normal crew activities occurred topside and when these were suspended due to fallout deposition on the ships and during subsequent attempts at decontamination. Generally, on the second day after fallout, normal crew activities were resumed. With the knowledge of when and for how long a crewmember was topside or below deck, the appropriate shielding factor is applied to the average free-field integrated intensity for that same period (corrected for film badge equivalence) to arrive at the calculated film badge dose to crew personnel.

The crew activity time lines depicted in Figures A-l through A-5 are used in the dose calculations of Section 3. It is apparent from these figures that, when fallout was heavy, variations in the normal crew activities occurred during the first two days. After two days, all crews had returned to their normal work routine, spending approximately 9½ hours on deck each day. At these later times, when shipboard radiation intensities were significantly reduced, the time of day when a crewmember was on deck becomes relatively unimportant, and only the daily time topside is needed to estimate an average shielding factor. This is applied to the integrated intensities derived in Section 2 as described in Section 3.

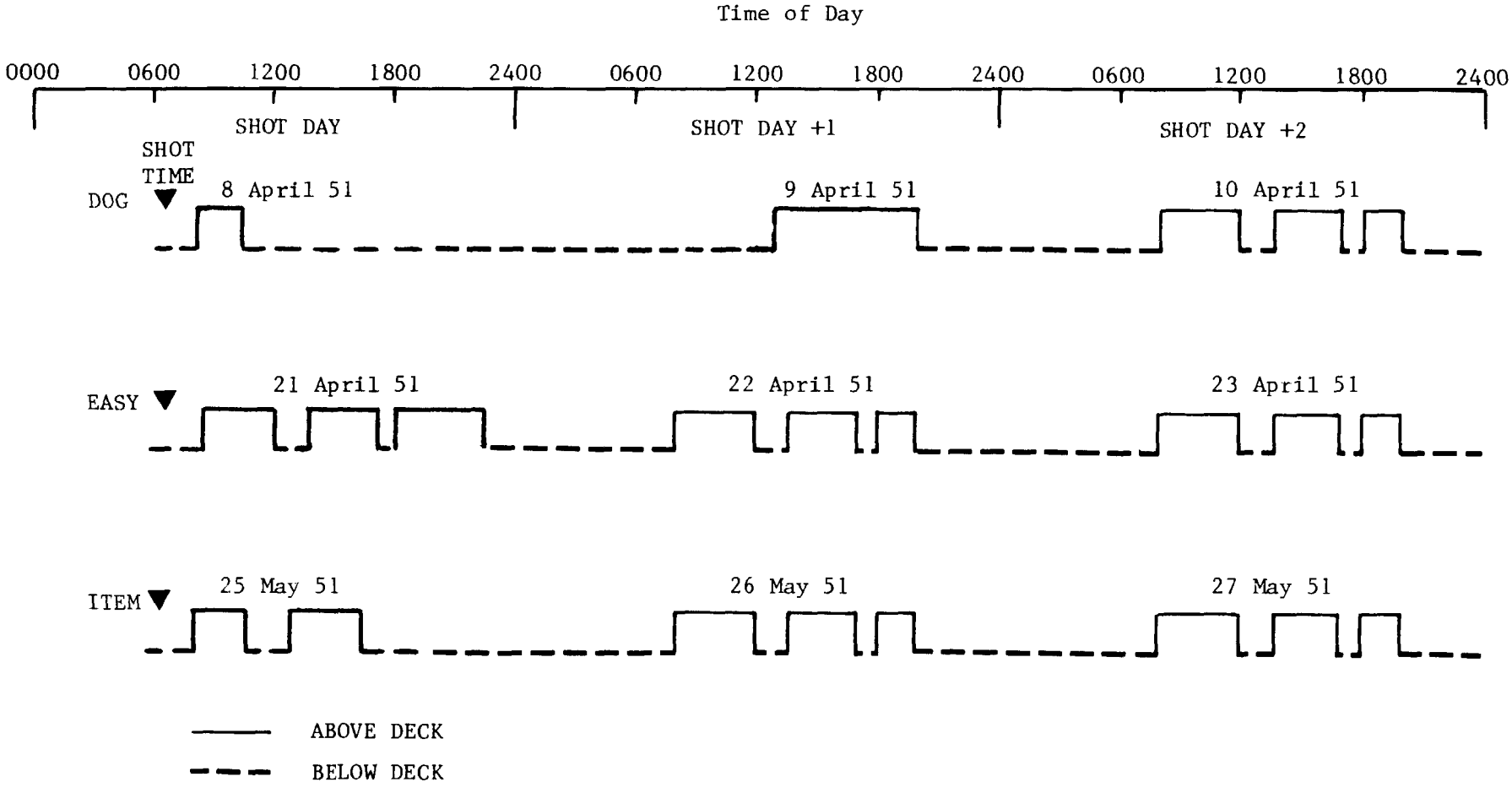

Figure A-1. USS CABILDO Crew Activity Time Lines—Operation GREENHOUSE

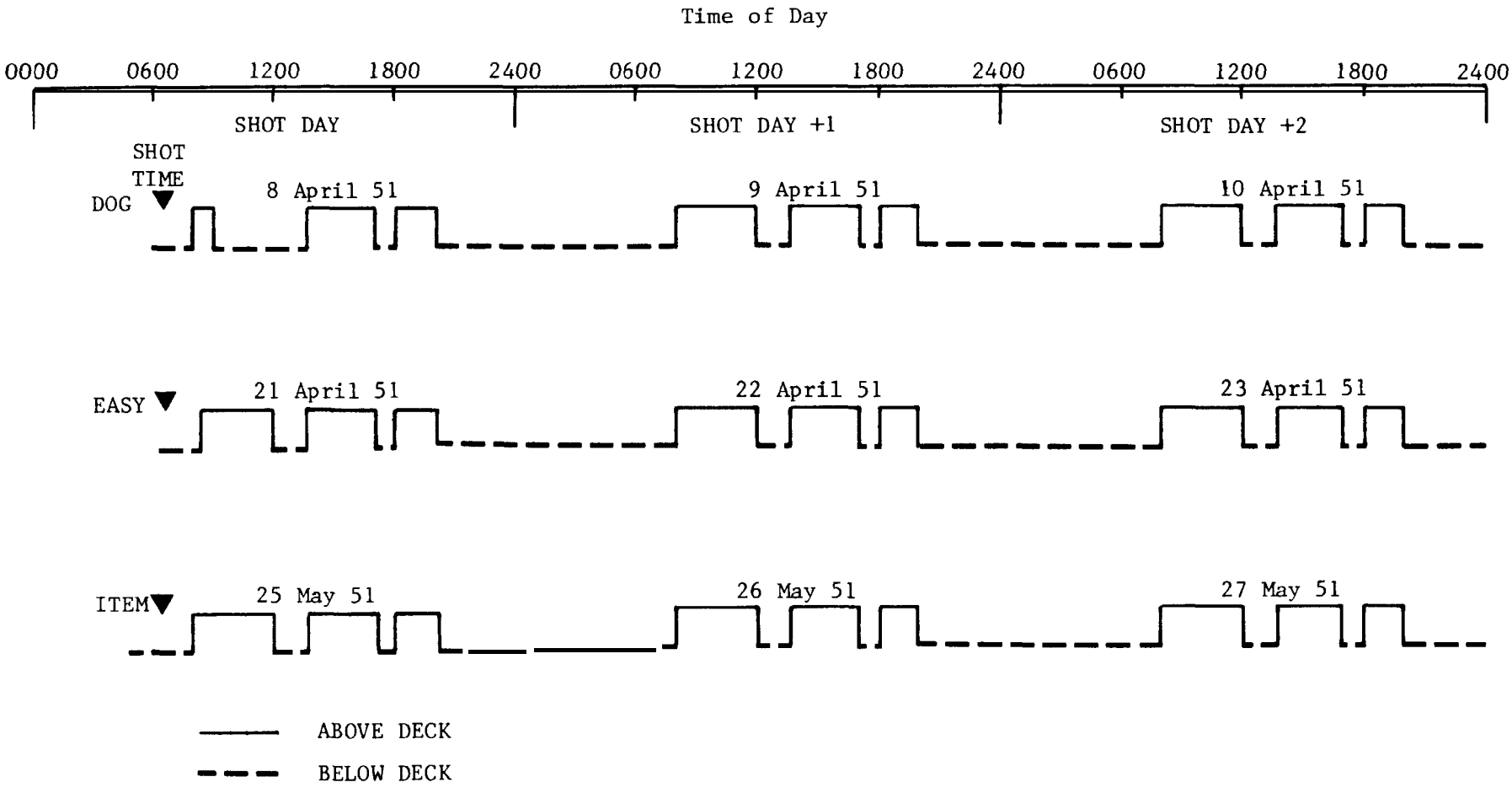

Figure A-2 USS CURTISS Crew Activity Time Lines—Operation GREENHOUSE

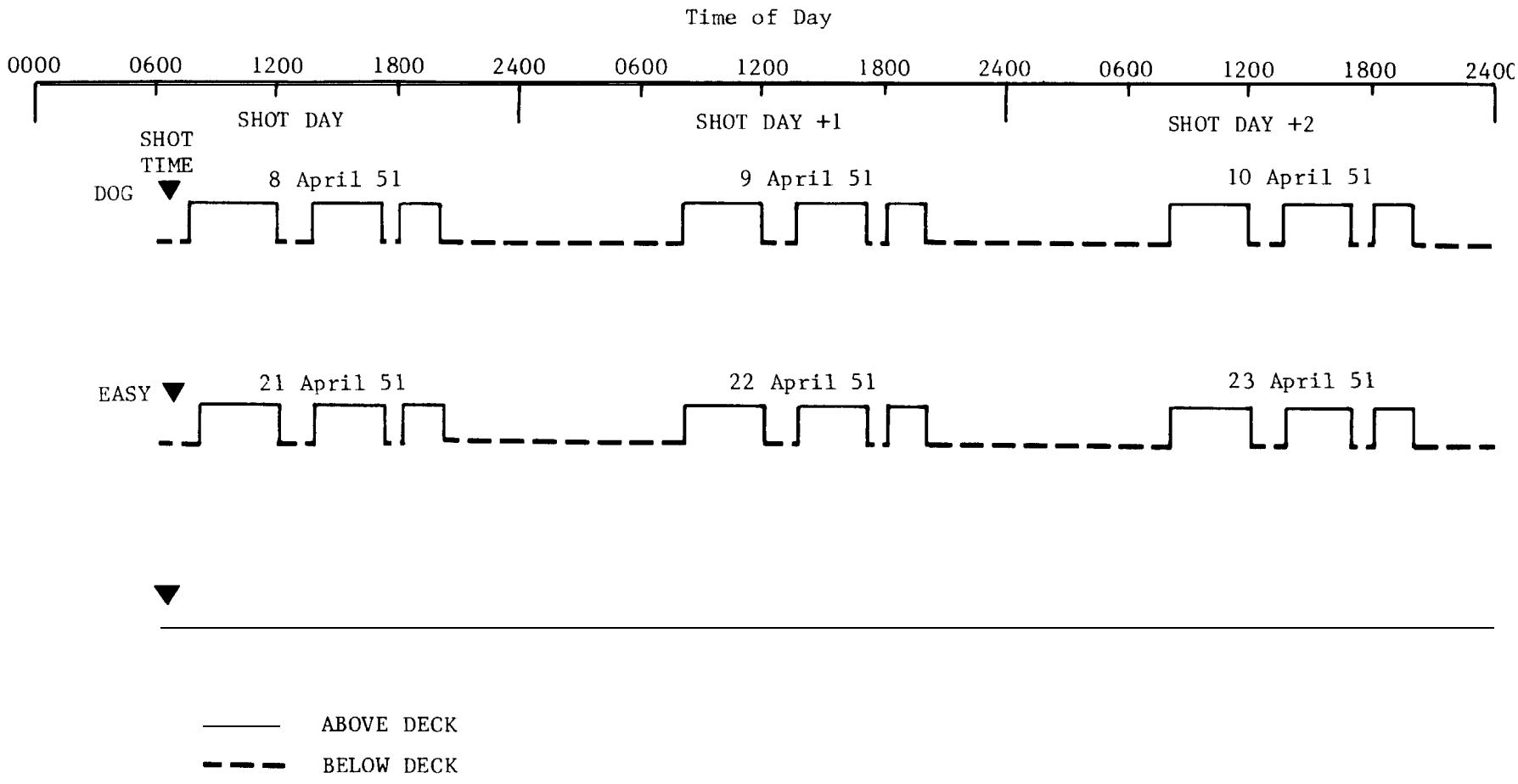

Figure A-3. USS LST-859 Crew Activity Time Lines—Operation GREENHOUSE

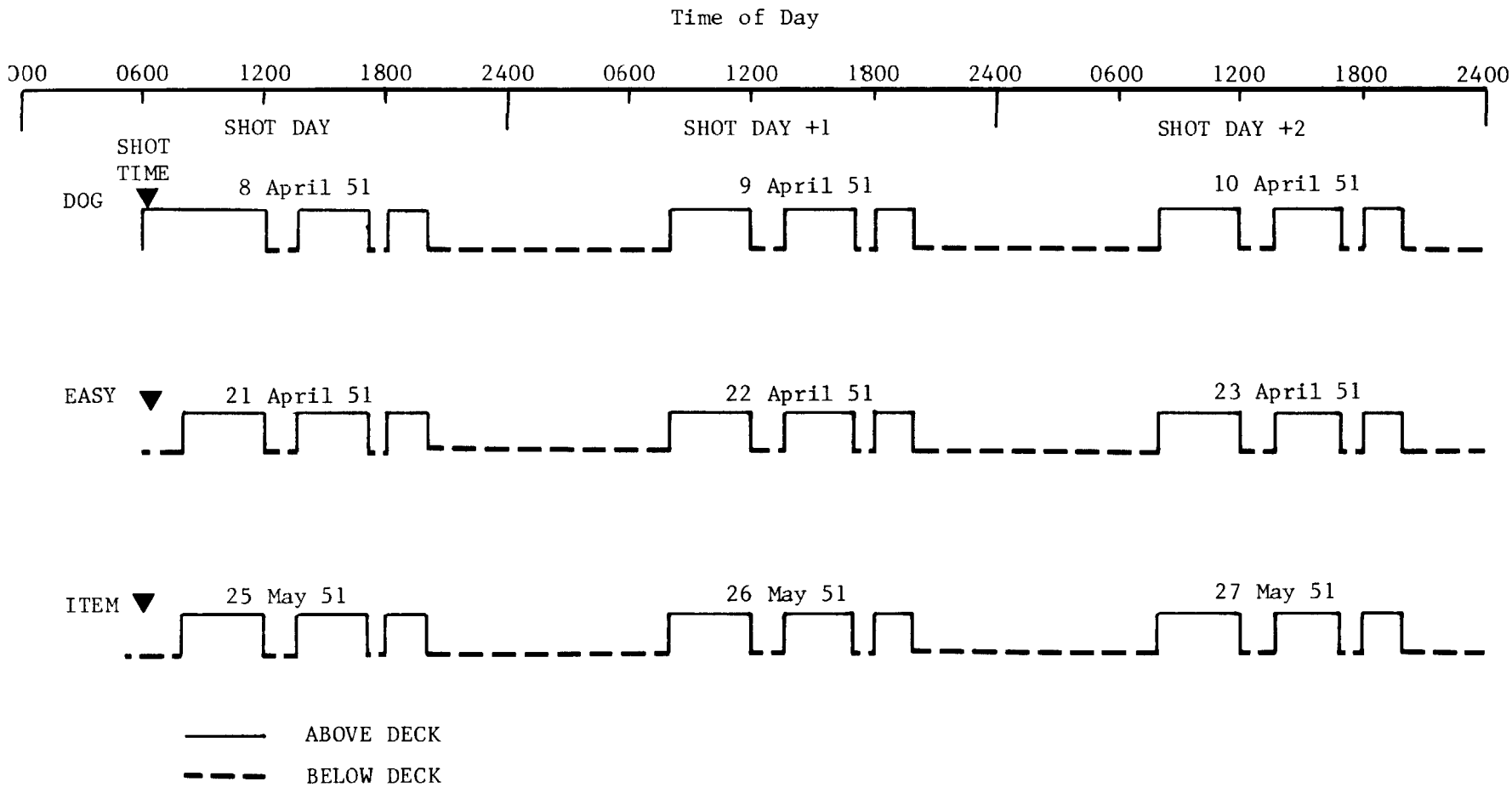

Figure A-4. USNS SGT. C. E. MOWER Crew Activity Time Lines—Operation GREENHOUSE

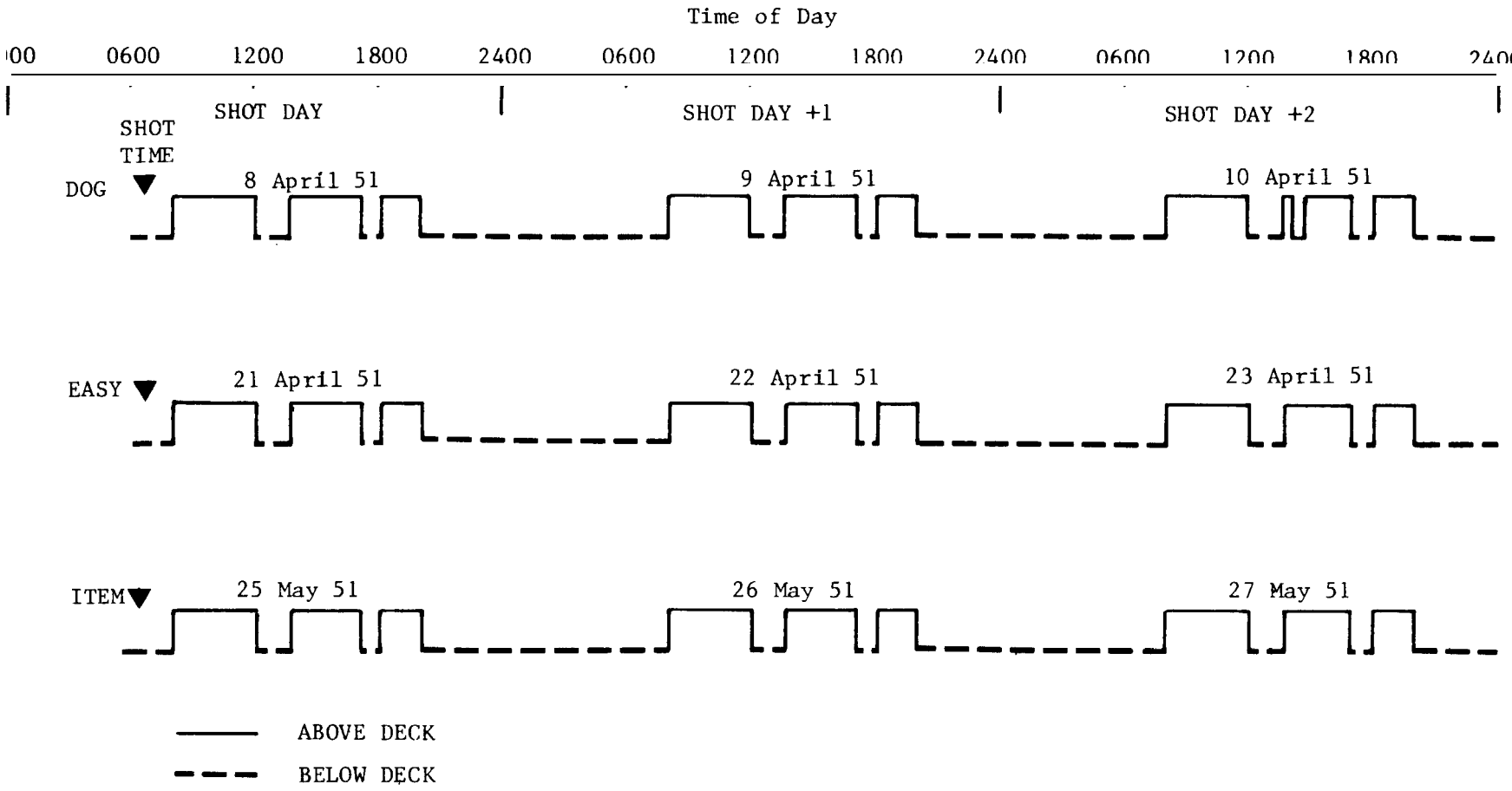

Figure A-5. USS SPROSTON, USS WALKER, and USNS CRAIG (Shot DOG only) Crew Activity Time Lines - Operation GREENHOUSE

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