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Analysis of Radiation Exposure for Additional Naval Personnel at Operation CASTLE—Supplemental Report

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13. ABSTRACT *(Maximum 200 words)*

This report supplements DNA-TR-84-6 by analyzing the radiation exposure for typical crewmembers of eight additional ships at Operation CASTLE in 1954: RECLAIMER, SHEA, COCOPA, MENDER, MOLALA, TAWAKONI, PC-1546, and LST-1146. Utilizing the reconstructed radiation environments from deck contamination, water shine, proximate ship shine, and contaminated hulls and piping, equivalent film badge doses are calculated and compared with analyzed film badge dosimetry. Comparisons are hampered by a shortage of badge readings and by cohort badging that may have emphasized non-representative crew activities. Considering this, agreement is good (within a few hundred millirem) when doses were high but less when doses were low. In all cases, overall totals appear to be in excellent agreement.

Compared to DNA-TR-84-6, this report utilizes additional data on lagoon and ship contamination and analyzes extensive microfilmed dosimetry records, as well as

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additional sources of exposure, such as from proximity to fallout-contaminated vessels.

Calculated mean doses range from a low of 0.30 rem for the crew of USS RECLAIMER to a high of 2.2 rem for the crew of USS COCOPA. The calculated doses should be used when badged members of cohorts, due to duties, ratings, and locations, do not appear to be representative of the cohort as a whole.

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Conversion factors for U.S. Customary to metric (SI) units of measurement

MULTIPLY → / TO GET ←	BY → / BY ←	TO GET / DIVIDE
curie (Ci)	3.700 x E 10	becquerel (Bq)
foot (ft)	3.048 x E -1	meter (m)
kiloton (kt)	4.183 x E 12	joule (J)
liter (l)	1.000 x E -3	$meter^3$ (m^3)
megaton (Mt)	4.183 x E 15	joule (J)
micron (μm)	1.000 x E -6	meter (m)
nautical mile (nm)	1.852	kilometer (km)
rem	1.000 x E -2	sievert (Sv)
roentgen (R)	2.580 x E -4	coulomb/kilogram (C/kg)

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SECTION 1

INTRODUCTION

Operation CASTLE was a series of atmospheric nuclear tests conducted by the Atomic Energy Commission (AEC) at the Pacific Proving Grounds (PPG) during the Spring of 1954. Radiological safety procedures generally included the issuance of film badges to about 10 percent of the personnel throughout the operation and to individuals during periods of potentially significant radiation exposure. Cohort badging, defined as group dose determination from one badge wearer, was the primary means of determining individual exposures. Recorded dosimetry is available for most personnel assigned to the ships. However, it is noted that available dosimetry forms are incomplete as to dates and times of recorded exposures. Moreover, recorded dosimetry from cohort badging has been shown to be not always representative of the entire cohort due to dissimilar activities within the group. Hence, reconstructed doses, including uncertainty analyses, are necessary for well-defined assessments of the doses received by these personnel. Reference 1 reports the results of dose reconstructions for personnel on sixteen of the ships participating at Operation CASTLE, as well as for island-based personnel on Enewetak and Kwajalein Atolls; this companion report documents the analysis for eight additional ships of interest. The methodology of Reference 1 is employed herein. Appropriate material from the reference is repeated for reader convenience. For brevity, detailed derivations, discussions, and listings are cited but not repeated.

As in the case of the sixteen ships evaluated in Reference 1, this report describes the operations, the radiological situation, and the time-space relationships of each of the eight ships with respect to the radiological environment. The results are portrayed as equivalent film badge doses for the crews of each of the ships.

1.1 BACKGROUND.

There were six shots in the Operation CASTLE test series: BRAVO, ROMEO, KOON, UNION, YANKEE, and NECTAR. The first five were detonated on Bikini Atoll; Shot NECTAR was detonated on Enewetak. Figure 1 depicts the locations of Bikini and Enewetak with respect to the other atolls comprising the northern Marshall Islands. Figures 2 and 3 show the main features of Bikini and Enewetak, respectively, and the locations of the CASTLE detonations; the pertinent details of each test are summarized in table 1 (Reference 2).

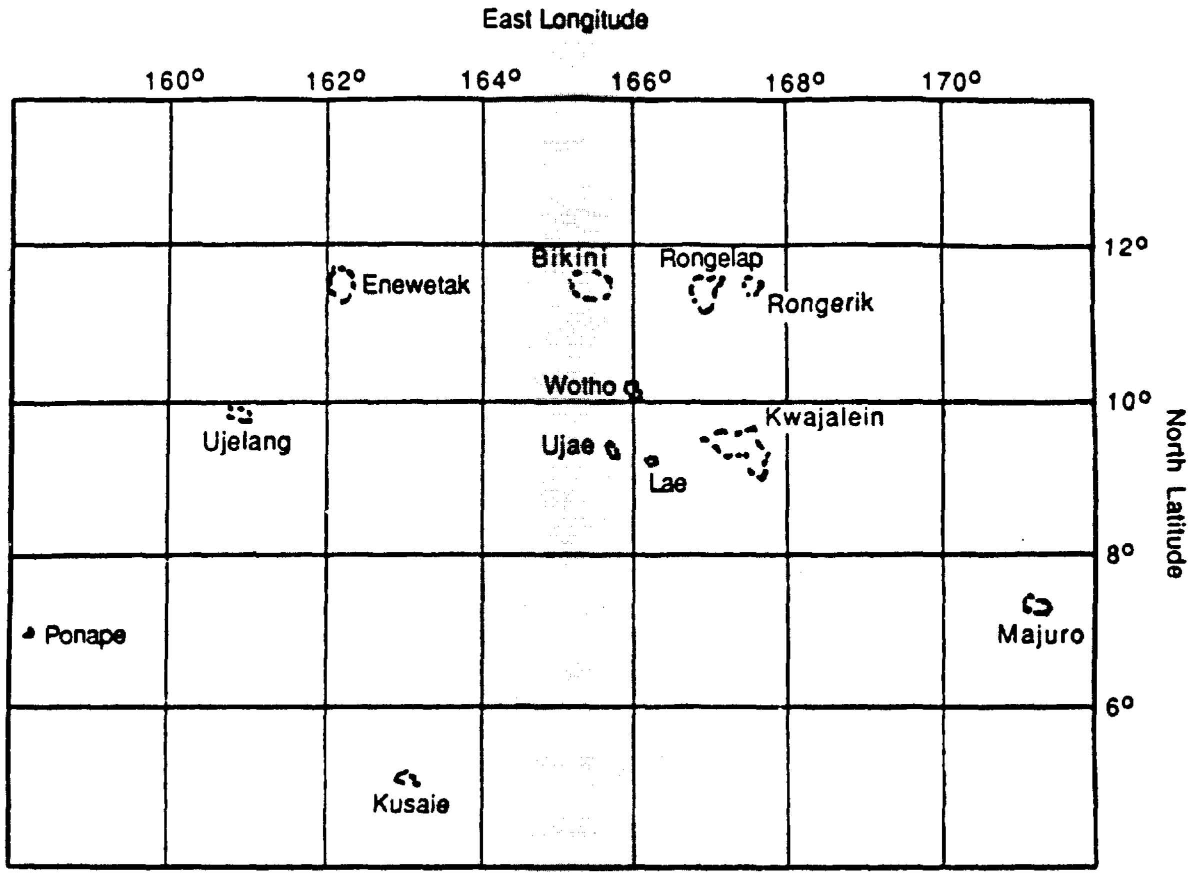


Figure 1. Northern Marshall Islands.

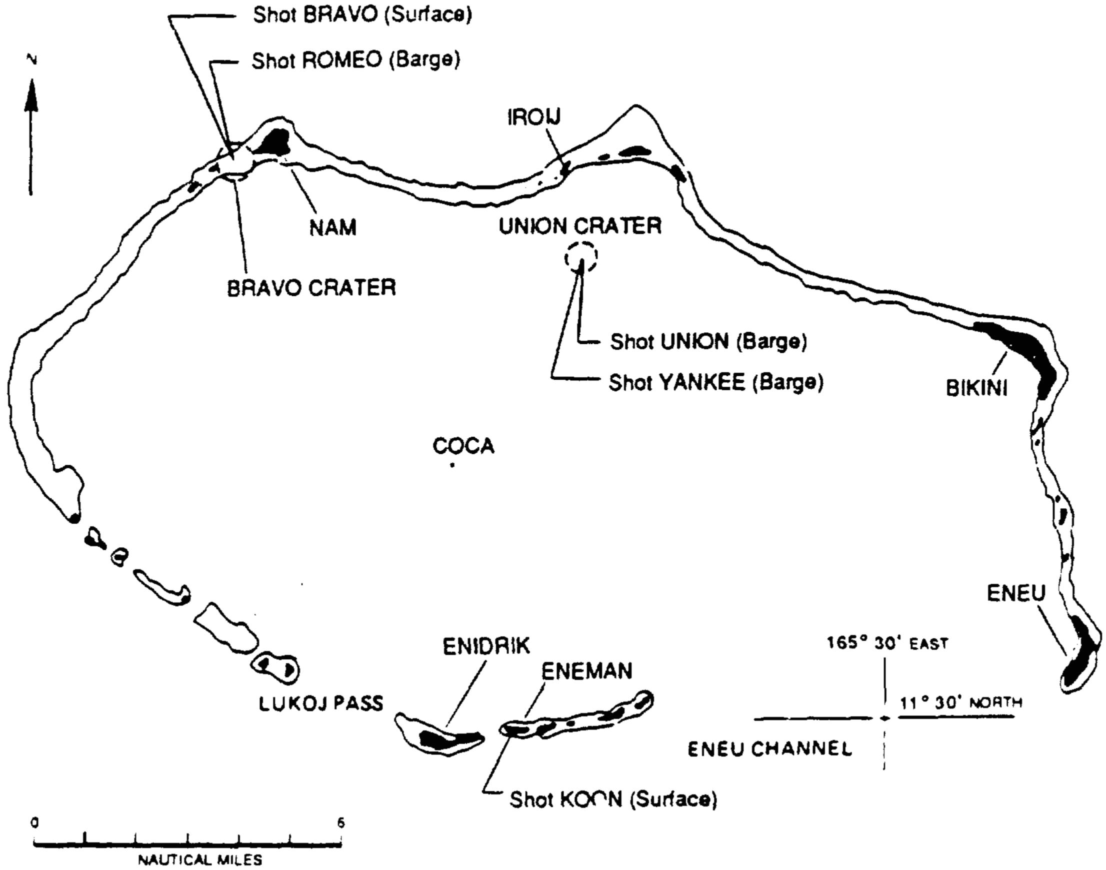


Figure 2. Bikini Atoll, Operation CASTLE shot locations.

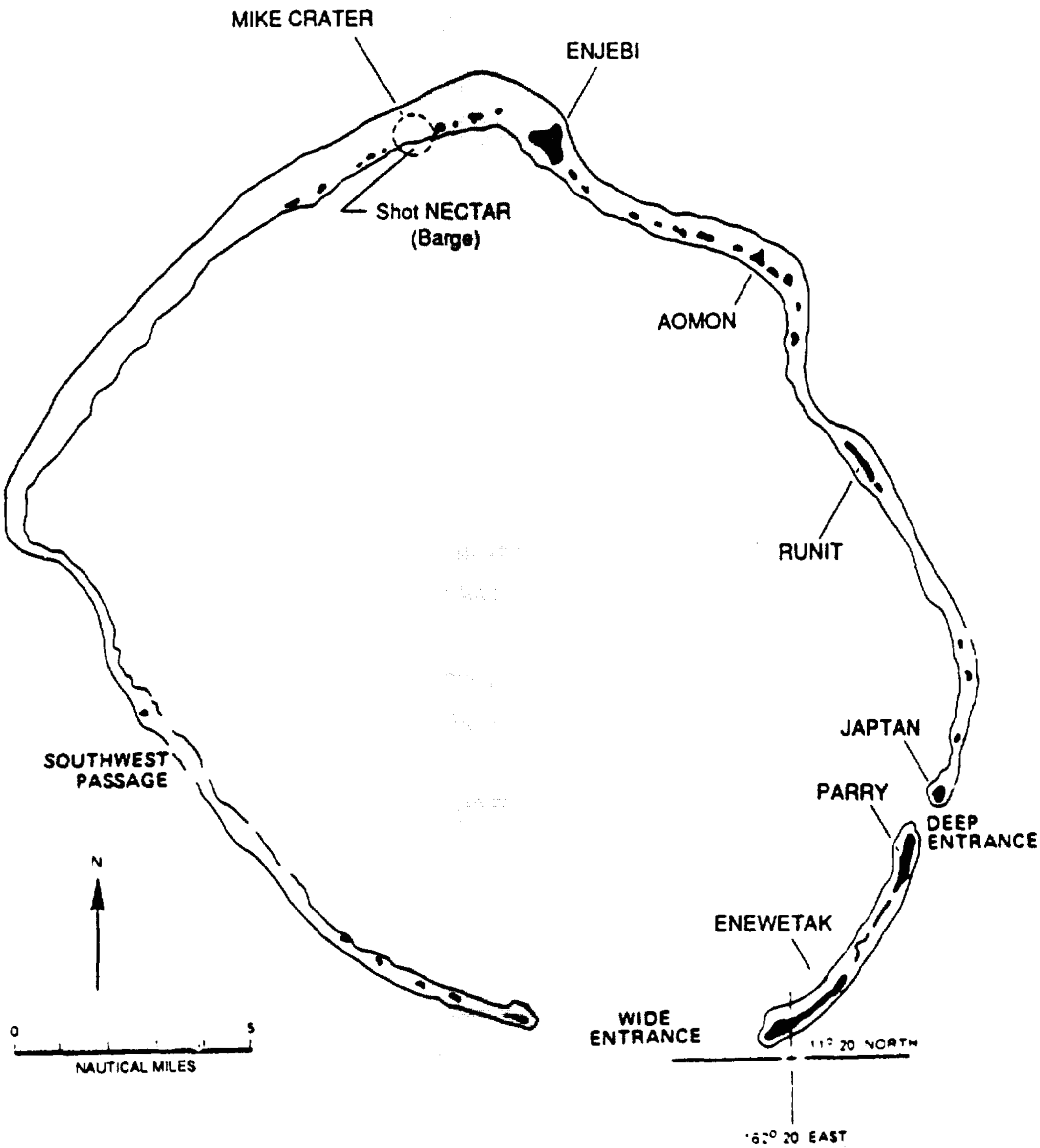


Figure 3. Enewetak Atoll, Operation CASTLE shot location.

Table 1. Operation CASTLE shot data.

Shot Name	Local Date (time)		Yield	Location
BRAVO	1 Mar 54	(0645)	15 Mt	Bikini (Sand pit off Nam Island)
ROMEO	27 Mar 54	(0630)	11 Mt	Bikini (Barge, BRAVO crater)
KOON	7 Apr 54	(0620)	110 Kt	Bikini (Eneman Island)
UNION	26 Apr 54	(0605)	6.9 Mt	Bikini (Barge off Iroij Island)
YANKEE	5 May 54	(0610)	13.5 Mt	Bikini (Barge, UNION crater)
NECTAR	14 May 54	(0620)	1.69 Mt	Enewetak (Barge, MIKE crater).

1.2 NAVAL PARTICIPATION.

The nuclear tests were conducted by a joint military organization designated as Joint Task Force Seven (JTF-7). Although military in form, it was comprised of military, civil service, and contractor personnel. JTF-7 was organized into five main task groups, with Task Group 7.3 being the naval contingent. Most of the approximately 6,000 personnel assigned to TG 7.3 were aboard the various task group ships; however, approximately 650 were stationed on Enewetak and Kwajalein Atolls. Table 2 lists the TG 7.3 ships and the task units to which they were assigned, for which dose reconstructions are specifically addressed in this report. Also tabulated are the approximate number of personnel assigned to each ship.

1.3 METHODOLOGY.

In Reference 1, procedures developed in previous dose reconstruction efforts were adapted to the shipboard radiological environments of Operation CASTLE. The basic procedures used in Reference 1 have been utilized in this companion report. Each step is pursued to a level of detail governed by the availability of data. Sufficient data were recorded at the time and enough have survived to understand the ship and land operations and to characterize the radiation environment. Individual ship deck logs (Reference 3) serve as an authoritative source of ship position and activity.

Radiation intensity data and crew activity scenarios are applied to reconstruct the time-dependent radiation environment for a typical crewman on each of the eight ships of interest.

Table 2. Operation CASTLE ships addressed in this report.

Ship	Personnel Assigned
Task Unit 7.3.1 Surface Security Unit	
USS PC-1546	62
Task Unit 7.3.5 Utility Unit	
USS COCOPA (ATF-101)	82
USS MENDER (ARSD-2)	72
USS MOLALA (ATF-106)	88
USS TAWAKONI (ATF-114)	80
Task Element 7.3.7.2 Mine Project Element	
USS SHEA (DM-30)	279
USS RECLAIMER (ARS-42)	94
Task Unit 7.3.9 Transport Unit	
USS LST-1146	95

Characterization of the radiation environment starts with the determination of on-deck (topside) and surrounding water 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 radiological intensity as a function of time. At times following the last reported shipboard survey, a power law function determined from Bikini Atoll radiological data is utilized. Despite differences in decay rate between ship and shore because of prompt washdown, decontamination, and weathering, late-time decay, mostly from insoluble particles adhering to shipdeck or soil, is taken › be the same. As ships operated in the contaminated waters of Bikini Lagoon, their hulls and .ltwater piping systems accumulated radioactive materials, thus increasing the radiation exposure to crew members while below-deck. The radiation environment due to ship contamination is derived from a previously-developed ship contamination model (Refer=nce 4). When ships were in contaminated waters, the "shine" of radiation therefrom exposed topside personnel. Likewise, shine from contaminated vessels that were approached led to increased topside radiation levels. Both of these types of transient exposure are quantified to augment the mean topside intensities. Specific data and detailed methodology for the development of the time-dependent radiation environments are presented in section 2 of this report. Section 3 defines the radiation environments, as dependent on the movements and operations of each ship, and determines the daily exposure potential.

Shipboard radiation surveys indicated a considerable variation in topside intensities because of ship geometry, redistribution of fallout during washdown and decontamination, and non-uniform adherence of fallout particles to ship materials. If only an average survey reading was reported, this value is used. In those cases where readings were taken at many predetermined positions on the ship's exposed surfaces, they represent the topside radiation field. The ship's crew is presumed to have been located at random positions when on deck; thus, mean survey readings, appropriately decayed, are used to determine the mean intensities encountered by the crew when topside. Average topside intensities are also used where water shine or ship shine is involved. The limited data from Operation CASTLE that relate shine levels to radiation source strength are supplemented by radiation transport calculations that accommodate specific ship geometries.

The analysis of radiation exposure to the crew also requires estimation of radiation intensities below deck and the apportionment in time of crew activities below and topside. In addition to ship contamination, the fallout on deck has been noted as a contributor to below-deck intensities. A ship-shielding factor is defined as the ratio of the intensity below to the mean intensity topside from fallout. This factor, previously determined for each type of ship of interest in Reference 1, is roughly 0.1 and is nearly constant over the usual crew locations within a ship. Thus, the time spent topside usually dominates the fallout dose. In some cases, 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. Otherwise, the fraction of time spent topside is assumed to be 0.4. This follows from reasonable topside intervals such as 0800-1200, 1330-1700, and 1800-2000 hours.

The calculated dose to the crew is obtained from time integration of intensity for all intervals below and on deck; a conversion factor is used to account for body shielding by the badge wearer (Reference 5). Day-by-day and cumulative film badge doses to the average crewman of each ship are calculated and presented in section 4. Calculations are continued to the end of the operation and into the post-operational period until the dose accrual falls below 1 mrem per day. An uncertainty analysis of the dose calculations is provided in section 5. In section 6, the available dosimetry records are analyzed and compared with the calculated doses. Conclusions and a total dose summary are presented in section 7.

SECTION 2

RADIATION ENVIRONMENTS

Since an understanding of the radiation environments encountered by the ships participating at Operation CASTLE is essential for the dose reconstructions that are presented in section 4, the discussion thereof in Reference 1 is repeated and augmented. With the exception of the operational activities of PC-1546, LST-1146, and MOLALA, activities conducted in conjunction with project support requirements by the remainder of the ships discussed herein, occurred primarily within the confines of Bikini Lagoon. Figure 4 depicts the areas within the lagoon where the ships were required to spend most of their time during the operation. Areas Nan (off Eneu Island) and Tare (north of Eneman Island) were the primary anchorages for all of the task force ships throughout the operation. Areas Charlie, Dog, Fox, George, and How in the northern lagoon, were visited during technical project support activities.

2.1 RADIOACTIVE FALLOUT.

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

Extensive radiation intensity readings obtained on Bikini Island (Bikini Atoll) following Shot BRAVO indicated decay rates that varied considerably from the traditional $t^{-1.2}$ rule (Reference 6). Average values for the decay exponent, obtained from several gamma ionization time-intensity meter measurements on Bikini, are as follows:

$3 < t \leq 10$ hours;	$k = -1.19$
$10 < t \leq 48$ hours;	$k = -0.82$
$48 < t \leq 480$ hours;	$k = -1.50$
$t > 480$ hours;	$k = -1.20$

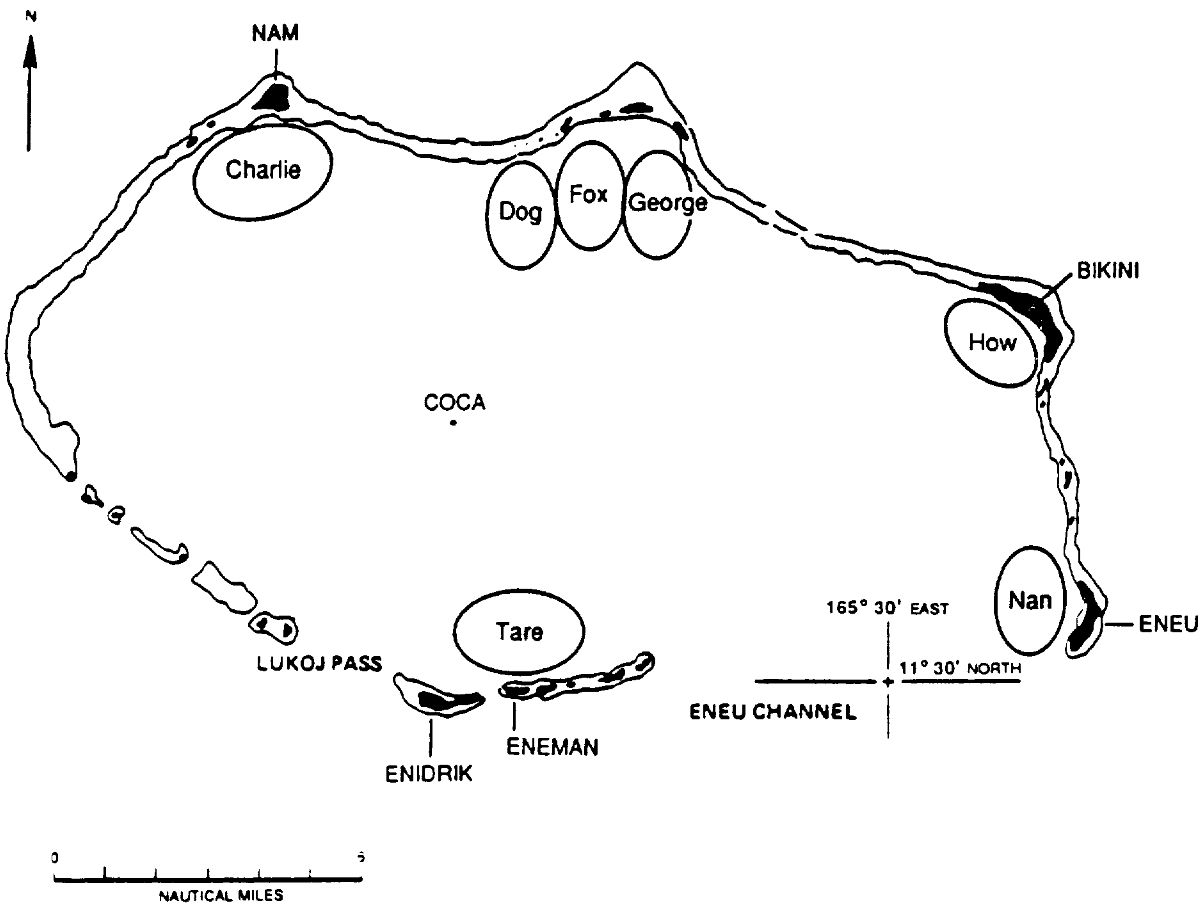


Figure 4. Major anchorages and operating areas within Bikini Lagoon.

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

The topside radiation environment was perturbed when a ship encountered contamination in addition to the fallout on its deck. Some of the ships considered in this report serviced vessels that had remained in heavy primary fallout. Mere proximity to such "hot" vessels raised the topside intensities and thus contributed to the dose of typical crewmembers. Determinations of intensity of the shine from proximate ships are based on the geometries of both vessels and radiation transport calculations that are further discussed in the Appendix. Similar techniques are used to adapt island intensity curves for shipboard use, as required.

2.2 SHIP CONTAMINATION MODEL.

The water in Bikini Lagoon became contaminated following the five detonations conducted there. As ships steamed or anchored in the contaminated water, radioactive materials began to accumulate on the hulls below the water line and in the saltwater piping systems within the ships. As a result, radiation intensities below deck began to increase, adding to the crew's exposure. However, when compared to the topside radiation environments resulting from Shots BRAVO and ROMEO fallout, this radiation was "considered more of an operational nuisance than a hazard" (Reference 7).

The same phenomenon was observed on the ships at Operation CROSSROADS conducted at Bikini Atoll in 1946. A model was developed in Reference 4 to determine personnel exposure aboard the ships at CROSSROADS due to ship contamination. Although only limited lagoon water contamination data have been found for Operation CASTLE, water intensities are derivable from nearby land measurements; thus, this model is applied to all of the ships participating at this operation.

Two basic assumptions are made in developing the ship contamination model. The first is that the mixture of fission products present in the accumulated radioactive material on the hull and in the piping of a ship decayed radiologically as $t^{-1.3}$. This decay rate was verified experimentally for fission products deposited in seawater and on the decks of target ships at CROSSROADS. The use of $t^{-1.3}$ decay for CASTLE ship contamination calculations is a better approximation than the land data suggest. The gamma emissions of the actinide radionuclides contributing to the variable decay exponent on land are less energetic than the average. Thus, they are selectively attenuated in water and through ship hulls, leaving the fission products to dominate the intensities pertinent to ship contamination calculations.

The second assumption involves the rate of contamination buildup on the hull and interior piping. The radioactive buildup on a previously uncontaminated ship is assumed to be initially proportional to the radiation intensity of the water surrounding the ship, but, as buildup progresses, a limiting or saturation value of contamination is approached asymptotically. The occurrence of such a saturation effect is indicated by hull intensity readings taken on various ships after their departure from the lagoon following CROSSROADS operations. Based on these assumptions, the exterior gamma intensity of the hull $I_h(t)$ of a contaminated ship at time t is given by:

$$I_h(t) = St^{-1.3}\left[1-\exp\left\{-CS^{-1}D_w(t)\right\}\right] \quad \text{(mR/day)},$$

where C and S are constants, and $D_w(t)$, is a parameter proportional to exposure from contamination-bearing material,

$$D_w(t) = \int_0^t t^{1.3}\, I_w(t)\, dt \quad (\text{mR-day}^{1.3}).$$

Here, $I_w(t)$ is the intensity of the water in which the ship is operating at time t. It is evident that, as a ship spends sufficient time in contaminated water, D_w becomes large and the hull intensity approaches a saturation value:

$$I_h(t) \rightarrow St^{-1.3} \quad \text{(mR/day)}.$$

The constants S and C were evaluated from CROSSROADS support ship intensity data, as discussed in Reference 4; derived values of S are 1800 mR-day$^{0.3}$ for destroyers, 2240 mR-day$^{0.3}$

for PGMs (patrol craft), and 1570 mR-day$^{0.3}$ for all other ships; C has a value of 11.0 day^{-1} for all ships.

The exterior hull gamma intensity (I_h) is then used to determine the average interior ship intensity. This analysis, as described in detail in Reference 4, results in an apportionment factor F_a, which relates average interior intensities (I_i) to exterior hull gamma intensities (I_h) by the relation:

$$I_i = F_a I_h \ .$$

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

$$I_i(t) = F_a S t^{-1.3} \ [\ 1 - \exp\{-CS^{-1} D_w(t)\}\ ] \ .$$

The saturation levels and apportionment factors (from Reference 4) are given below for the pertinent CASTLE ship types.

Ship Type	S (mR-day$^{0.3}$)	F_a
ATF, ARS, ARSD	1570	0.39
DM	1800	0.39
LST	1570	0.33
Patrol Craft	2240	0.67

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

Some elaboration of the steaming factor concept is required for application to CASTLE, where multiple lagoon departures and shots were involved. The first 50 percent achieved of saturation is regarded as permanent, whereas subsequent resaturations are regarded as fully removable by steaming thereafter. Thus, once saturation is achieved, levels between 50 and 100 percent of saturation are maintained thereafter. As steaming removes material that contains contaminants rather than selectively removing contaminant activity, the intensity is not constrained to remain at least 50 percent of the maximum. This occurs when more intense, fresh contaminants overlie those from an earlier shot, because the former are regarded as fully removable.

2.3 WATER INTENSITY MODEL.

The fundamental data needed to apply the CROSSROADS ship contamination model to CASTLE are water intensities, I_W, from each shot. Although values of I_W were infrequently reported, they may be approximated from the intensities on islands adjacent to the anchorages and operating areas (from Reference 2), coupled with a measured correlation between land and water readings. Data of 6 May 1954 indicated that, if local fallout from Shot YANKEE dominated the Nan anchorage water intensity and the Eneu Island intensity, a water intensity of 7 mR/hr at H+24 hours corresponded to a 100 R/hr land intensity at H+1 (Reference 8). The contribution of previous-shot fallout to the land and water readings was negligible. Neither the similar fallout deposition from Shot BRAVO on the area, decayed over two months, nor the lesser Shot UNION deposition, from ten days previous, would have exceeded the order of 1 percent of these intensities on land or in the water. Therefore, the land/water intensity correlation is taken from these readings without modification.

Reference 8 corroborates the derived levels of Bikini Lagoon contamination and indicates their persistence. The data, expressed as water activity concentrations, may be interpreted as water intensities through the conversion from Reference 4 of 1 mR/hr per 1μCi/l. The maximum stated water activities in the Nan anchorage convert to 8.4 mR/hr. In order not to conflict with YANKEE shot-day water intensities reported in the same reference, this value is taken to apply only after general ship reentry into the lagoon. It likely refers to the YANKEE water intensity on D+1 (when ships reanchored), stated above as 7 mR/hr, or to the slightly higher value of 10.5 mR/hr derived for the Nan anchorage following Shot BRAVO (see section 2.4).

The YANKEE shot-day water intensity data reflect the rapid vertical mixing of contaminants that led to the low ratio of water-to-land intensity that prevailed at the later times of ships' crew exposures. The decrease from 500 mR/hr at H+4.6 to 22 mR/hr at H+10.8 in the Nan anchorage was almost tenfold greater than that from decay alone, but decay accounts for the subsequent decrease to 7 mR/hr at D+1. Similar results were obtained by Project 2.7 (Reference 9) in the open ocean. Rapid shot-day mixing progressed in two days down to the thermocline, where the stable stratification minimized further vertical diffusion during CASTLE.

In the lagoon, contamination at the surface was observed to drift slowly westward under the action of the tradewinds. The radioactivity either adhered to the western reef, flowed over it into the open ocean, or recirculated at depth in the lagoon. There is no clear indication that the latter phenomenon led to a meaningful reappearance of contamination in the Nan area. After Shot ROMEO, which among CASTLE shots was uniquely lacking in widespread fallout in Bikini Lagoon, no reports of fresh contamination in the anchorages have been found in CASTLE documents; after other shots, reported intensity buildups are explicable by local fallout in the water that led to progressive ship contamination.

The one circumstance that could have replenished the westward-drifting surface contamination was an influx from the ocean. The east-west radiation isopleths for Shots UNION and YANKEE (Reference 2) suggest this possibility; however, it would have been most pronounced for BRAVO, where intensities increased eastward of Nan for some 100 miles. The available lagoon data that likely reflect this process are the 0.1 to 0.3 mR/hr water intensities that were typically present at the Nan anchorage during CASTLE (Reference 8). Without replenishment, lagoon drift would have led to lower levels within the eights weeks between Shots BRAVO and UNION. In the mean, the reported levels are roughly consistent with decreased intensity from decay alone.

2.4 BIKINI LAGOON WATER INTENSITIES.

The foregoing phenomenology and the paucity of radiological data suggest that the best available model for time dependence of water intensities is to assume no net transport of contaminants and to diminish the intensities by decay alone. This approach is most applicable for the anchorage areas and after Shot BRAVO; it likely high-sides the intensities after other shots. For the northern operating areas near surface zeros, where drift is of clearer significance in the long term, most exposures were soon enough after the shots so that little drift had occurred.

Owing to the complexity of the model equations, the determination of radiation intensities from ship contamination and water shine is accomplished by numerical techniques. All logged ship movements and reported or derived water intensities are tracked throughout the operation. The time-dependent below-deck intensity is so obtained for each ship. Numerical integration with a time step of 0.01 day generates the personnel exposures. This time step offers a precision compatible with that of the position-time data for the ships.

The Bikini Lagoon contamination after each shot is discussed below.

Shot BRAVO

Although significantly contaminating the lagoon, BRAVO more immediately impacted ships and islands through heavy fallout; hence, the reported radiological-safety data emphasize the latter. The applicable land-based intensities (H+1) are 150 R/hr for the Nan anchorage, 50 R/hr for Tare, 500 R/hr for How, and 1,000 R/hr for each of the northern operating areas. Corresponding water intensities (D+1) are 10.5, 3.5, 35 and 70 mR/hr, respectively.

Shot ROMEO

Lagoon contamination from ROMEO was significant only in the vicinity of surface zero. This affected the Charlie area to roughly the level of 1,000 R/hr (H+1 land value). A D+1 water intensity of 70 mR/hr is implied.

Shot KOON

The Tare anchorage was principally affected, yielding land values (Eneman Island) of 500 R/hr at H+1, H+1 land values of 7, 50, 100, 120, and 25 R/hr pertain to the Charlie, Dog, Fox, George and How areas, respectively. Corresponding water intensities are 35, 0.5, 3.5, 7, 8.4 and 1.75 mR/hr (D+1). The Nan anchorage was unaffected.

Shot UNION

Because of low water intensities (0.5 mR/hr, D+1, derived from 7 R/hr, H+1 on land), ship contamination at the Nan anchorage was appreciable only after five days post-shot (Reference 7). Project activities in the northern lagoon involved much greater intensities. In Areas Fox and George, water intensities were at least 14 mR/hr on D+1 (200+ R/hr land intensity at H+1). In Area How, a land intensity of [illegible]0 R/hr (H+1) corresponds to a water intensity of 10.5 mR/hr (D+1). COCOPA, operating in the vicinity of the most intense surface zero contamination, recorded a 500 mR/hr water intensity on 27 April in Area Dog. South of Dog, ship operations were conducted in water intensities of about 7 mR/hr, D+1 (100 R/hr land value, H+1).

Shot YANKEE

Aside from the Nan anchorage, only Area Fox was visited by any of these ships. The COCOPA likely encountered water intensities of roughly 100 mR/hr during its D+1 activity in the area (1400 R/hr land value at H+1).

Shot NECTAR, at Enewetak, did not result in significant lagoon contamination; fallout was primarily to the north of the anchorage areas (Reference 2).

The above intensity data suggest that meaningful direct exposures also occurred when ships were present in significantly contaminated water. Indeed, measurements obtained onboard USS SIOUX (AFT-75) as that ship steamed through contaminated water following Shot YANKEE, indicated that deck level (topside) intensities due to shine from the contaminated water were approximately 40 percent of the measured water intensities (Reference 9).

SECTION 3

SHIP OPERATIONS

This section describes the assignments, activities, and movements of the eight TG 7.3 ships of interest at the Pacific Proving Grounds during Operation CASTLE, and correlates these movements with the radiation environment following the six detonations in the test series. Ship movements are reconstructed primarily from data contained in the deck logs (Reference 3).

3.1 PROJECT SUPPORT.

As indicated in the following chronologies, task unit assignments do not fully describe the activities of the various ships. In several cases, ships were called upon to provide assistance and services to projects conducted at several of the events. To the extent that these assignments involved radiation exposures, they are documented and included in the dose calculations for the personnel. However, such activities that involved boarding of other vessels by limited parties are not included in the determination of dose to typical crewmembers.

A brief discussion of the projects and activities conducted by the various ships supporting the projects follows.

3.1.1 Project 3.4 - Sea Minefield Neutralization by Means of a Surface Detonated Nuclear Explosion (Reference 10).

RECLAIMER, SHEA, and LST-1157 participated in this project, conducted by the U.S. Navy Bureau of Ordnance. The project involved emplacement of a field of 121 naval mines in a set of "strings" at various distances from surface zero prior to Shot UNION. NOTE: Dose calculations for USS LST-1157 have been provided previously--Reference 11.)

Prior to the . ctual mine laying operations, RECLAIMER, assisted by LST-1157, laid marker buoys for the minefield in Areas Dog and Fox (figure 4). The mines, which were inert, had been assembled in strings aboard LST-1157 and were then transferred to RECLAIMER. RECLAIMER planted the first set of 96 mines during the period 10-13 April in anticipation of the originally-scheduled date for Shot UNION (16 April). The remaining 25 mines were originally planned for emplacement at Shot YANKEE. Several weather delays reduced the time window available between Shot UNION (ultimately rescheduled for 26 April) and Shot YANKEE (5 May), which resulted in a decision to plant all of the mines for Shot UNION; the remaining mines were therefore planted by RECLAIMER and LST-1157 on 25 April.

Recovery of the mines by RECLAIMER was accomplished over a period of several days, commencing on 28 April. The recovered mines were washed down to reduce the levels of radioactivity as they were brought aboard. Personnel handling the mines and recovery gear used special clothing, gloves and equipment. While on RECLAIMER and later after transfer to LST-1157, the mines were kept topside and were constantly checked for radioactivity; those mines with higher levels of radioactivity were washed or scrubbed down.

The mines and the mine project personnel were transferred from LST-1157 to SHEA on 3 May; SHEA transported the mines to Pearl Harbor for final analysis.

3.1.2 Project 1.4 - Underwater Pressure Measurements (Reference 12).

This project involved placement, servicing and recovery of several large instrument buoys (cans) and was conducted at Shots BRAVO and ROMEO (Area Charlie), Shot UNION (Area Dog), and Shot YANKEE (Area Fox), in Bikini Lagoon (see figure 4). COCOPA, MENDER and TAWAKONI, along with support barges and several small boats, were involved in the various project activities. The project was also conducted at Shot NECTAR at Enewetak by contractor personnel from Holmes and Narver (H&N).

After the initial laying of the buoys for Shot BRAVO, all of the laying, servicing, and recovery operations were conducted in radiation-contaminated waters; the buoys themselves were also contaminated.

COCOPA was the principal participant in buoy servicing and recovery operations through the first three shots. Primarily as a result of recovery operations in Area Dog following Shot UNION (see figure 4), the ambient radioactivity levels aboard COCOPA became higher than the permissible limit and the mission was transferred to TAWAKONI for the remainder of the project participation at Bikini. The project report states that protective clothing was worn while handling the contaminated buoys; the same report indicates that swimmers from the support ships were also utilized in the recovery operations.

3.1.3 Project 6.4 - Proof Testing of Atomic Weapons Ship Countermeasures (Reference 13).

This project evaluated the effectiveness of washdown systems in reducing the effects of fallout on ships. Two converted liberty ships, YAG-39 and YAG-40, were instrumented for radiation measurements and equipped with remote controls. A washdown system was installed on YAG-39 only. At Shots BRAVO, ROMEO, UNION and YANKEE, the two ships were sailed into areas of anticipated heavy fallout. During Shots BRAVO and ROMEO, both ships were unmanned and remotely controlled from a P2V-5 aircraft, with a secondary control party aboard USS BAIROKO (CVE-115). Experience from these tests indicated that manning YAG-39 was both desirable and feasible. YAG-39 was manned for Shots UNION and YANKEE by a shielded skeleton crew that received instructions as to the course from the secondary control party on BAIROKO. The ships were boarded after each test and radiation records were retrieved; comparisons of radiation levels onboard each ship indicated the effectiveness of the washdown system on YAG-39.

Two fleet tugs, MOLALA and TAWAKONI, participated in this project by escorting the YAGs and debarking their crews before the shots and retrieving and towing the YAGs to Enewetak after the shots. At Shot BRAVO, both YAGs were retrieved by the tugs and towed unmanned from Bikini to Enewetak. At Shots ROMEO, UNION, and YANKEE, YAG-39 was manned (remanned after Shot ROMEO) and brought to Enewetak under her own power, while YAG-40 was towed back by MOLALA. MOLALA was also utilized at Enewetak to aid in the decontamination of the YAGs, if necessary, after each test. MOLALA was involved in these activities for all of the Bikini tests except Shot KOON. TAWAKONI was involved in supporting Project 6.4 for only the first two shots (BRAVO and ROMEO).

3.1.4 Miscellaneous Support Activities.

As listed in table 2, PC-1546 was a unit of the Surface Security Unit (TU 7.3.1). This involved pre- and post-shot security patrols outside the lagoon (primarily ASW patrols) as well as screening and escort assignments with major units when they sortied for each shot. PC-1546 was also assigned special tasks that involved sorties to other nearby atolls (Enewetak, Rongerik, Ailinginae) during the operation.

USS LST-1146 was assigned to the Transport Unit (TU 7.3.9) for only a brief period during March and April 1954. Its primary duties were to transport passengers and freight between Bikini and Enewetak Atolls.

The following sub-sections detail the activities of each of the eight ships of interest. The activities are superimposed on the radiological environments due to both radioactive fallout and contaminated lagoon water. Integrated intensities topside (from fallout and from contaminated water and contaminated ships/boats) and below (from ship contamination) are calculated on a daily basis for each ship through 31 May 1954.

3.2 USS RECLAIMER (ARS-42).

RECLAIMER was at Pearl Harbor during the first two CASTLE tests and was just arriving at Kwajalein Atoll (see figure 1) when Shot KOON was detonated at 0620 hours, 7 April. RECLAIMER departed Kwajalein at approximately noon the same day and arrived at Bikini at 0832 hours on 8 April (Reference 3).

Shortly after RECLAIMER arrived at Bikini, it began mine laying operations in Area Fox (figure 4) to support Project 3.4. During the period 8-12 April, RECLAIMER and LST-1157 laid approximately 96 mines in preparation for Shot UNION, which was initially scheduled for 16 April (Reference 10). With mine laying operations completed, divers from RECLAIMER assisted in recovering submerged instrumentation in Area Charlie (see figure 4) on 13 April (Reference 3). At noon on 15 April, RECLAIMER departed Bikini Lagoon enroute to its assigned operating area for Shot UNION, approximately 25 nmi southeast of the atoll. When Shot UNION was postponed due to weather, RECLAIMER reentered the lagoon at approximately 1900 hours, 16 April.

During the period 17-24 April, RECLAIMER remained in the lagoon performing diving and salvage operations as directed, while unfavorable weather resulted in repeated delays for Shot UNION. Project 3.4 personnel became concerned that there would not be enough time between Shots UNION (now scheduled for 26 April) and YANKEE (5 May) to allow recovery of the first mine field and the placement of the second, planned for Shot YANKEE (Reference 10). It was therefore decided to use all 121 mines at Shot UNION and, on 25 April, RECLAIMER and LST-1157 planted the last 25 mines in Area Fox. At 1639 hours, 25 April, RECLAIMER got underway for its assigned operating area approximately 50 nmi southeast of the Shot UNION surface zero.

Shot UNION was detonated at 0605 hours, 26 April. Approximately 12 hours later RECLAIMER reentered the lagoon and anchored in the Nan anchorage. During the night of 26-27

April, some of the other ships anchored off Eneu Island reported small amounts of light, secondary fallout as follows (Reference 7):

Ship	Date/Time	Avg. (mR/hr)	Max. (mR/hr)
COCOPA	26/2200	2	4
MENDER	26/2100	2	4
LST-1157	26/1930	2	3
SHEA	27/0730	3	5

Considering the location of RECLAIMER relative to the ships reporting fallout, it is assumed RECLAIMER was exposed to similar fallout. The topside radiation environment on RECLAIMER due to Shot UNION fallout is depicted in figure 5 and is obtained by averaging the environments reported on the other ships anchored in the Nan anchorage.

Being a surface (barge) detonation, Shot UNION significantly contaminated the lagoon water in the vicinity of surface zero (Reference 8). Most of the surface contamination spread to the west and southwest; however, by 1 May, even the water in the Nan anchorage off Eneu Island showed increased radiation levels (Reference 7). Because of the contamination in the northern lagoon, Project 3.4 mine recovery operations did not begin until the afternoon of 28 April when RECLAIMER began hoisting the mines from their underwater moorings. Mines that displayed sufficient damage to conclude that they were neutralized were cut loose and allowed to fall back into the lagoon. Those mines visually undamaged were hosed down to reduce radioactivity prior to being brought aboard RECLAIMER. Special clothing, gloves, and equipment were used by personnel who handled the mines (Reference 10). By 1 May, the majority of the mines had been recovered and those mines to be shipped back to Pearl Harbor for further analysis were transferred from RECLAIMER to LST-1157. RECLAIMER continued searching for "lost" mines on 2 and 3 May; however, there is no indication that more mines were recovered and transferred to LST-1157 after 1 May (Reference 3). At 1445 hours, 4 May, RECLAIMER, having completed mine recovery operations, departed Bikini Atoll enroute to Guam.

Daily contributions to the integrated free-field radiation environment on USS RECLAIMER (ARS-42) resulting from Shot UNION fallout, shine from contaminated lagoon water, and from ship contamination during the period 8 April to 31 May 1954 are summarized in table 3.

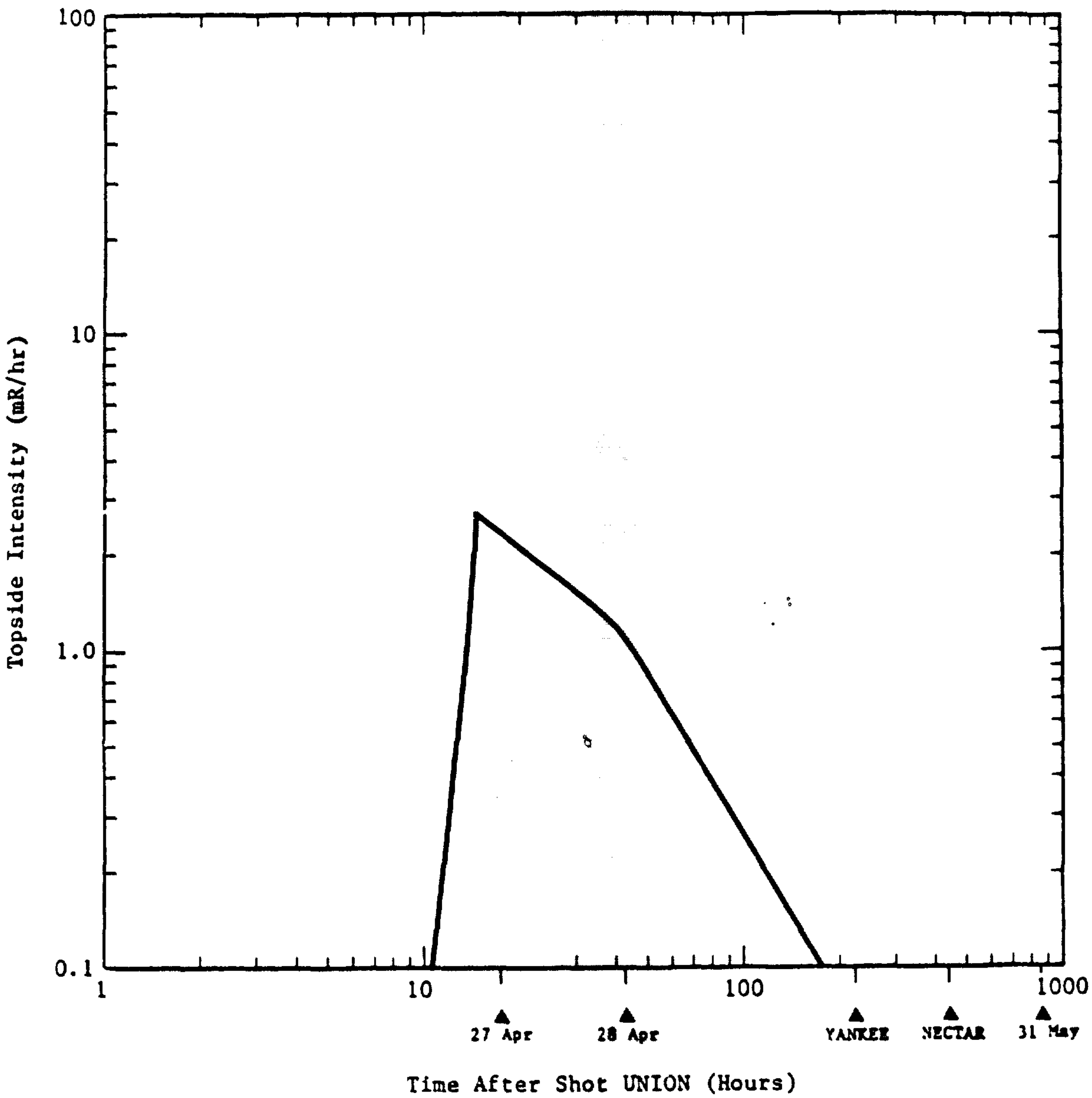


Figure 5. Estimated topside intensity on USS RECLAIMER (ARS-42) following Shot UNION.

Table 3. Daily integrated intensity, USS RECLAIMER (ARS-42).

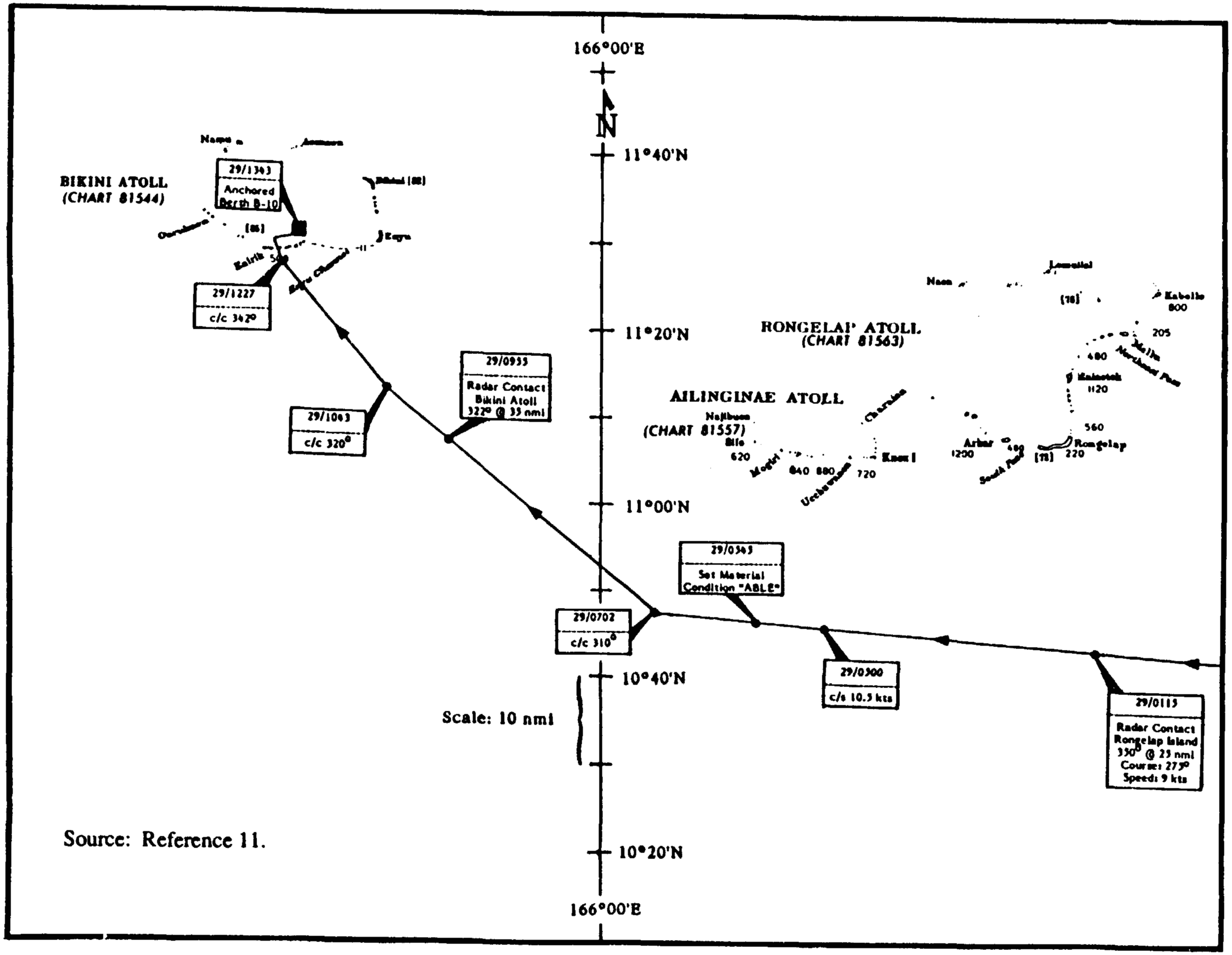
March	Integrated Intensity (mR) Topside Fallout	Topside Shine	Below Contam	April	Integrated Intensity (mR) Topside Fallout	Topside Shine	Below Contam	May	Integrated Intensity (mR) Topside Fallout	Topside Shine	Below Contam
1 (BRAVO)				1				1	4.2	15.7	37.1
2				2				2	3.1	9.9	29.5
3				3				3	2.4	6.3	24.5
4				4				4	2.0	4.2	13.6
5				5				5 (YANKEE)	1.6	0	1.3
6				6				6	1.4	0	1.3
7				7 (KOON)				7	1.2	0	1.3
8				8	0	11.7	10.1	8	1.0	0	1.3
9				9	0	16.3	29.9	9	0.9	0	1.2
10				10	0	14.8	39.9	10	0.8	0	1.2
11				11	0	10.4	43.2	11	0.7	0	1.2
12				12	0	7.9	36.6	12	0.6	0	1.2
13				13	0	3.6	30.1	13	0.6	0	1.1
14				14	0	0.6	12.7	14 (NECTAR)	0.5	0	1.1
15				15	0	0.4	3.0	15	0.5	0	1.1
16				16	0	0.1	2.1	16	0.4	0	1.1
17				17	0	1.0	2.9	17	0.4	0	1.1
18				18	0	0.7	3.5	18	0.4	0	1.1
19				19	0	0.6	3.8	19	0.4	0	1.0
20				20	0	0.6	3.8	20	0.4	0	1.0
21				21	0	0.6	3.1	21	0.3	0	1.0
22				22	0	1.2	3.3	22	0.3	0	1.0
23				23	0	0.6	3.0	23	0.3	0	1.0
24				24	0	0.6	3.3	24	0.3	0	1.0
25				25	0	0.8	2.7	25	0.3	0	0.9
26				26 (UNION)	12.5	2.2	2.9	26	0.3	0	0.9
27 (ROMEO)				27	37.5	3.2	10.6	27	0.3	0	0.9
28				28	18.4	18.9	19.0	28	0.3	0	0.9
29				29	9.7	29.5	59.2	29	0.2	0	0.9
30				30	6.1	20.7	47.9	30	0.2	0	0.9
31								31	0.2	0	0.9

3.3 USS SHEA (DM-30).

On 1 March 1954, when Shot BRAVO was detonated, SHEA was moored at Long Beach, California. On 13 March, SHEA departed Long Beach enroute to Pearl Harbor, where it arrived on 19 March. SHEA departed Pearl Harbor on 22 March and crossed the International Date Line enroute to Bikini Atoll when Shot ROMEO was detonated on 27 March. On 29 March, SHEA was following the same route to Bikini as that of LST-1157 (see figure 6), but was approximately 35 nmi behind; SHEA anchored in Berth B-9 (Tare anchorage), next to LST-1157, at 1407 hours that day. Shot ROMEO fallout at Bikini had ceased at approximately 0800 hours, 29 March. Apparently, the cloud drifted off to the west of Bikini, as Enewetak Atoll received essentially the same fallout (adjusted for radiological decay) approximately one day later. It is unlikely that SHEA received any of this secondary fallout from Shot ROMEO as it approached Bikini Atoll from the southeast.

On 30 March SHEA departed Bikini enroute to Enewetak where it arrived during the morning of 31 March. At 1824 hours on 4 April, SHEA, in company with LST-1157, departed Enewetak enroute to their assigned operating area for Shot KOON, scheduled for 7 April. When Shot KOON was detonated at 0620 hours on 7 April, SHEA, LST-1157, and MENDER were in their assigned operating area approximately 35-40 nmi southeast of the KOON ground zero on Eneman Island, Bikini Atoll (figure 2). At approximately noon the same day, SHEA entered Bikini Lagoon and anchored in the Nan anchorage off Eneu Island.

During the period 8-12 April, SHEA spent most of the time in the northern lagoon with RECLAIMER and LST-1157, probably assisting with Project 3.4 mine laying operations. With a scheduled date of 16 April for Shot UNION, SHEA departed Bikini at 1300 hours on 15 April for its assigned operating area approximately 40 nmi southeast of the UNION surface zero. As previously mentioned, Shot UNION was delayed due to unfavorable weather until 26 April. SHEA returned to the lagoon during the evening of 16 April and, with the exception of brief (1-2 day) patrol assignments outside Bikini Lagoon on 19 and 20 April, the ship remained in the Nan anchorage area until 23 April. During the morning of 23 April, SHEA got underway for a patrol assignment in an area north of Bikini Atoll. The ship returned to Bikini and anchored in Area Fox with RECLAIMER and LST-1157 during the morning of 25 April. After a brief sortie out of the lagoon during the afternoon of 25 April, SHEA returned to Bikini and anchored in the Nan anchorage. At 1715 hours on 25 April, SHEA got underway for its assigned operating area for the UNION test.



Source: Reference 11.

Figure 6. Path of USS LST-1157, 29 March 1954.

Shot UNION was detonated at 0605 hours, 26 April; SHEA reentered the lagoon and anchored in the Nan anchorage at 1726 hours the same day. At 0730 hours on 27 April, SHEA reported a small amount of light, secondary fallout with an average intensity of 3 mR/hr and a maximum of 5 mR/hr. Other ships in the anchorage reported average intensities of 2 mR/hr and maximums of 4 mR/hr at about 1900-2200 on 26 April (see section 3.2). The topside radiation environment on SHEA due to Shot UNION fallout is depicted in figure 7.

During the period 28 April to 2 May, SHEA assisted RECLAIMER and LST-1157 in the Project 3.4 mine recovery operations in Area Fox. On 3 May, the ship moored alongside LST-1157 in Area How (see figure 4) from 1400-1647 hours to take on those mines that were to be returned to Pearl Harbor for further analysis. The mines had been kept topside on the LST and were repeatedly checked for radiation. Those indicating "abnormal" radioactivity had been washed and scrubbed down prior to being transferred to SHEA (Reference 10). Nine personnel from EODU#1 and thirty-two personnel from Mine Project Six also transferred to SHEA on 3 May for further transportation to Pearl Harbor, their duties aboard LST-1157 being complete (Reference 11).

During the afternoon of 4 May, SHEA got underway for Pearl Harbor via Kwajalein Atoll. After a brief stop at Kwajalein, SHEA proceeded to Pearl Harbor, arriving there on 12 May. The mines were off-loaded and given a final check for operability on 13, 14 and 15 May (Reference 10).

Table 4 details the contributions to the free-field integrated intensity on USS SHEA (DM-30) from Shot UNION fallout, shine from contaminated lagoon water, and ship contamination during the period 29 March to 31 May 1954.

3.4 USS COCOPA (ATF-101).

When Shot BRAVO was detonated at 0645 hours on 1 March 1954, COCOPA was in its operating area approximately 50 nmi southeast of Bikini with two Project 1.4 barges (YCV-9 and YFN-934) in tow. It remained in this general area until approximately 0800 hours when, due to fallout on several of the task force ships (BAIROKO, ESTES, and PHILIP), all ships were ordered to proceed on a southerly course that would take them out of the fallout area (Reference 7). COCOPA steamed south until approximately 1100 hours, when it was directed to proceed on a north-northwesterly course toward Bikini. The ship began receiving fallout at approximately 1300 hours when it was 40 nmi south-southeast of the atoll. Fallout continued for

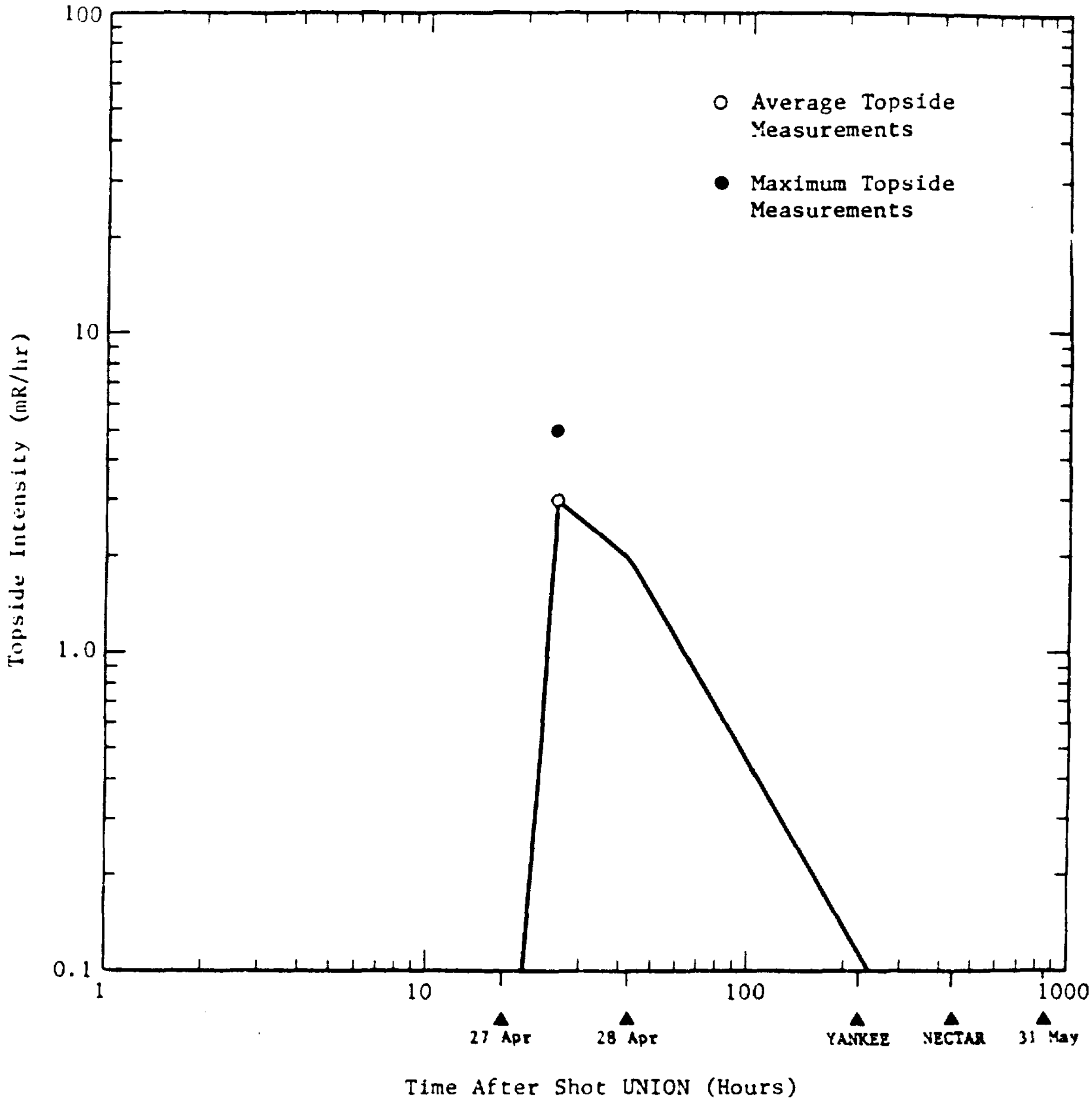


Figure 7. Topside intensity on USS SHEA (DM-30) following Shot UNION.

Table 4. Daily integrated intensity, USS SHEA (DM-30).

March	Integrated Intensity (mR) Topside Fallout	Topside Shine	Below Contam
1 (BRAVO)			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
16			
17			
18			
19			
20			
21			
22			
23			
24			
25			
26			
27 (ROMEO)			
28			
29	0	0.2	0.4
30	0	0.3	3.1
31	0	0	3.7

April	Integrated Intensity (mR) Topside Fallout	Topside Shine	Below Contam
1	0	0	3.6
2	0	0	3.4
3	0	0	3.3
4	0	0	3.2
5	0	0	3.0
6	0	0	2.9
7 (KOON)	0	0.4	3.3
8	0	8.2	8.5
9	0	24.3	62.5
10	0	14.8	65.7
11	0	10.4	53.3
12	0	7.9	42.7
13	0	1.9	11.5
14	0	0.7	4.3
15	0	0.4	3.7
16	0	0.1	2.4
17	0	0.7	3.7
18	0	0.7	4.4
19	0	0.2	2.9
20	0	0	2.2
21	0	0.3	2.3
22	0	0.6	3.6
23	0	0.2	2.5
24	0	0	2.0
25	0	0.2	1.9
26 (UNION)	0	2.6	3.5
27	44.8	4.0	15.7
28	32.6	23.5	35.3
29	17.1	29.5	68.5
30	10.8	15.5	54.1

May	Integrated Intensity (mR) Topside Fallout	Topside Shine	Below Contam
1	7.5	15.7	42.4
2	5.6	9.0	33.8
3	4.3	3.9	28.1
4	3.5	4.8	16.7
5 (YANKEE)	2.9	0	1.5
6	2.4	0	1.5
7	2.0	0	1.5
8	1.8	0	1.4
9	1.6	0	1.4
10	1.4	0	1.4
11	1.2	0	1.4
12	1.1	0	1.3
13	1.0	0	1.3
14 (NECTAR)	0.9	0	1.3
15	0.8	0	1.3
16	0.8	0	1.2
17	0.7	0	1.2
18	0.7	0	1.2
19	0.7	0	1.2
20	0.6	0	1.2
21	0.6	0	1.1
22	0.6	0	1.1
23	0.5	0	1.1
24	0.5	0	1.1
25	0.5	0	1.1
26	0.5	0	1.1
27	0.5	0	1.0
28	0.4	0	1.0
29	0.4	0	1.0
30	0.4	0	1.0
31	0.4	0	1.0

the remainder of the afternoon and early evening and, by 2000 hours, 1 March, when fallout ceased, average topside intensities on COCOPA were 110 mR/hr. Figure 8 depicts the topside radiation environment on COCOPA resulting from Shot BRAVO fallout. There is no mention in the ship's log of the washdown system being utilized during fallout; however, the rapid decrease in topside intensities between 2000 and 2400 hours, 1 March (H+13.25 to H+17.25), and again from 0400 to 1200 hours, 2 March (H+21.25 to H+29.25), indicates that some shipboard decontamination was likely accomplished prior to COCOPA returning to the Nan anchorage at approximately 1530 hours, 2 March. Reference 8 states that all major ships exposed to BRAVO fallout at Bikini required decontamination.

During the period 3-4 March, COCOPA spent most of the time in the Nan anchorage performing duties to support Project 1.4. These duties included aiding in the decontamination of YC-1081, a Project 1.4 barge that had been left in the lagoon for Shot BRAVO. During the afternoon of 5 March, COCOPA steamed to Area Charlie (see figure 4) to lay the moor for Project 1.4 instrument cans being set up for Shot ROMEO. The following day, the ship departed Bikini enroute to Enewetak Atoll, returning to Bikini at approximately 0830 hours, 9 March.

On 10 and 11 March, COCOPA completed laying Project 1.4 buoys and instrument cans in Area Charlie and, on 12 March, the ship got underway with the two Project 1.4 barges (YCV-9 and YFN-934) in tow for its assigned operating area for Shot ROMEO, scheduled for the following day. Shot ROMEO was postponed due to unfavorable weather and COCOPA returned to Bikini and anchored in the Nan anchorage at 1043 hours, 13 March. Continued unfavorable weather delayed Shot ROMEO for two more weeks. During the interim period, COCOPA remained in the lagoon performing various duties as directed, primarily in support of Project 1.4. Because of the long weather delay, batteries and time clocks in the instrument cans had run down and it was necessary to recover the instrument cans for maintenance (Reference 12). At 2012 hours on 26 March, COCOPA proceeded to its assigned operating area for Shot ROMEO with only one project barge (YFN-934) in tow (the decision had been made to leave YCV-9 in the Nan anchorage for Shot ROMEO).

When Shot ROMEO was detonated at 0630 hours, 27 March, COCOPA was approximately 40 nmi southeast of surface zero. At approximately 1400 hours, the ship returned to Bikini and anchored in the Nan anchorage off Eneu Island. The ship shifted berths to the Tare anchorage just north of Eneman Island (see figure 4) during the morning of 28 March and, during the late afternoon, the ship began receiving secondary fallout from the Shot ROMEO cloud. Topside intensities peaked at midnight on 28 March when a radiological survey indicated average

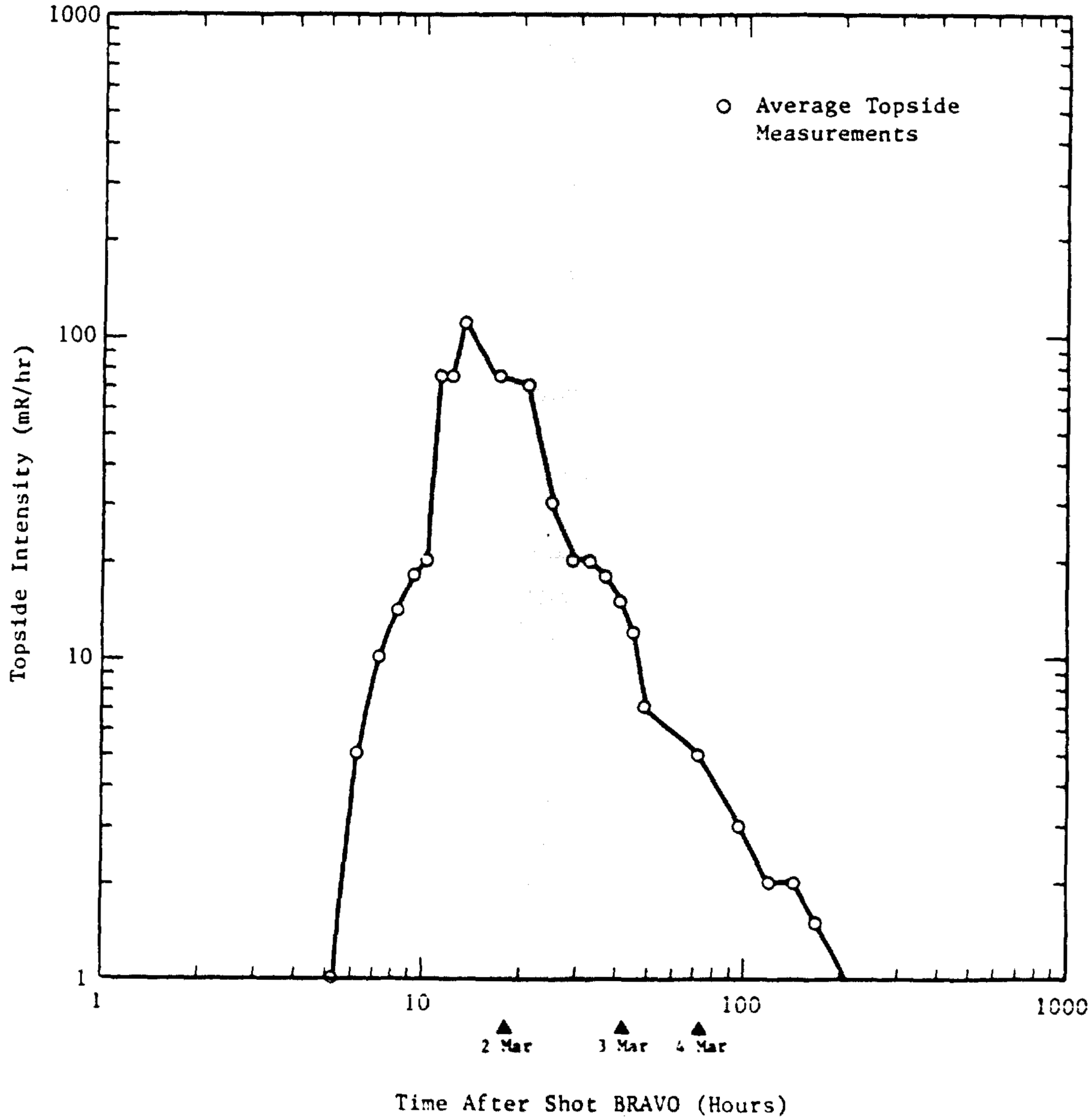


Figure 8. Topside intensity on USS COCOPA (ATF-101) following Shot BRAVO.

topside intensities of 25 mR/hr. Figure 9 depicts the topside radiation environment on COCOPA resulting from Shot ROMEO fallout. On 30 and 31 March, COCOPA recovered Project 1.4 instrument cans in Area Charlie, returning to the Tare anchorage each afternoon. During the early afternoon of 1 April, COCOPA got underway for Enewetak Atoll where it arrived at 0700 hours, 2 April.

When Shot KOON was detonated at Bikini on 7 April, COCOPA was still at anchor in Enewetak Lagoon. It got underway for Bikini at 1737 hours on 7 April, arriving there and mooring alongside YC-1081 in the Nan anchorage at 0925 hours, 8 April. Entries in the ship's log indicate activities associated with Project 1.4 instrument recovery in Area Charlie on 9 April, and instrument placement for Shot UNION in Area Dog (see figure 4) from 10 to 15 April. At 1230 hours, 15 April, COCOPA got underway for its assigned operating area for Shot UNION which was scheduled for the following day. As previously mentioned (section 3.2), Shot UNION was delayed due to unfavorable weather and COCOPA returned to the Nan anchorage at approximately 2000 hours, 16 April. During the period 17-25 April, COCOPA made almost daily trips to Area Dog to maintain the Project 1.4 instrument cans in place for Shot UNION, which, due to continued unfavorable weather, was rescheduled for 26 April. At approximately 1730 hours, 25 April, COCOPA got underway for its assigned operating area for Shot UNION with YFN-934 in tow.

Shot UNION was detonated at 0605 hours, 26 April, and COCOPA returned to Bikini and anchored in the Nan anchorage at 1843 hours the same day. At approximately 2100 hours, COCOPA experienced the same light fallout that several other ships in the Nan anchorage reported (see section 3.2). Average topside intensities on COCOPA leveled off at 2 mR/hr with a maximum intensity of 4 mR/hr being recorded at 2200 hours; the shipboard radiation environment resulting from Shot UNION fallout is depicted in figure 10.

During the morning of 27 April, COCOPA was involved in decontaminating YCV-9 and YC-1081, the two Project 1.4 barges that were left in the lagoon for Shot UNION. At 1345 hours, COCOPA got underway for Area Dog to recover one of the Project 1.4 instrument cans that was moored approximately 1.3 nmi southwest of surface zero (Reference 12). Being a barge shot over relatively deep water, Shot UNION significantly contaminated the lagoon water in the vicinity of surface zero. The general drift of the surface water in the contaminated pool around surface zero was to the west and southwest, toward Area Dog (Reference 8). At 1538 hours the ship approached the instrument can and, by 1640 hours, the instrument can was hoisted aboard the ship which then departed Area Dog enroute to Nan. It is assumed that the instrument can itself was

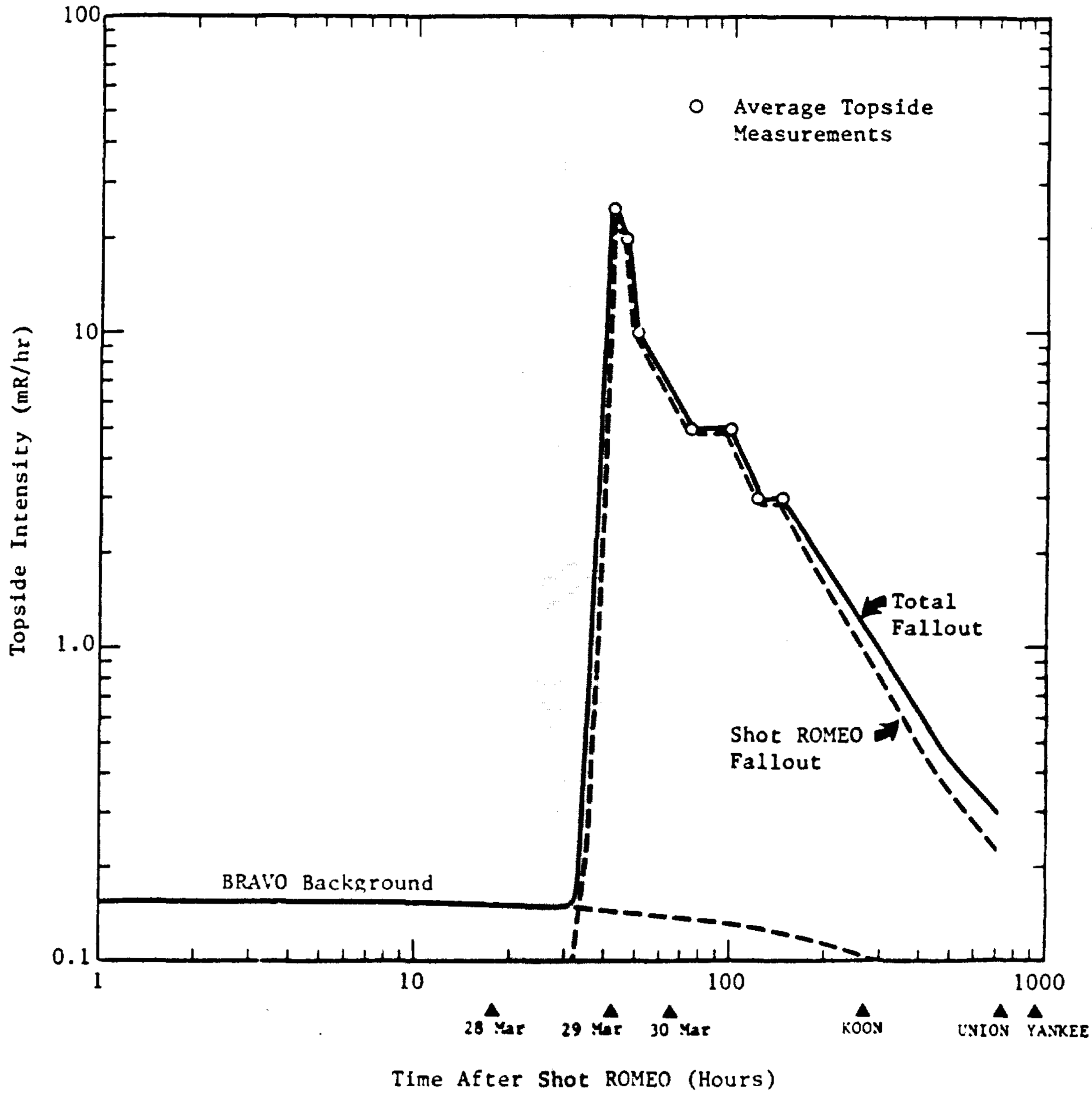


Figure 9. Topside intensity on USS COCOPA (ATF-101) following Shot ROMEO.

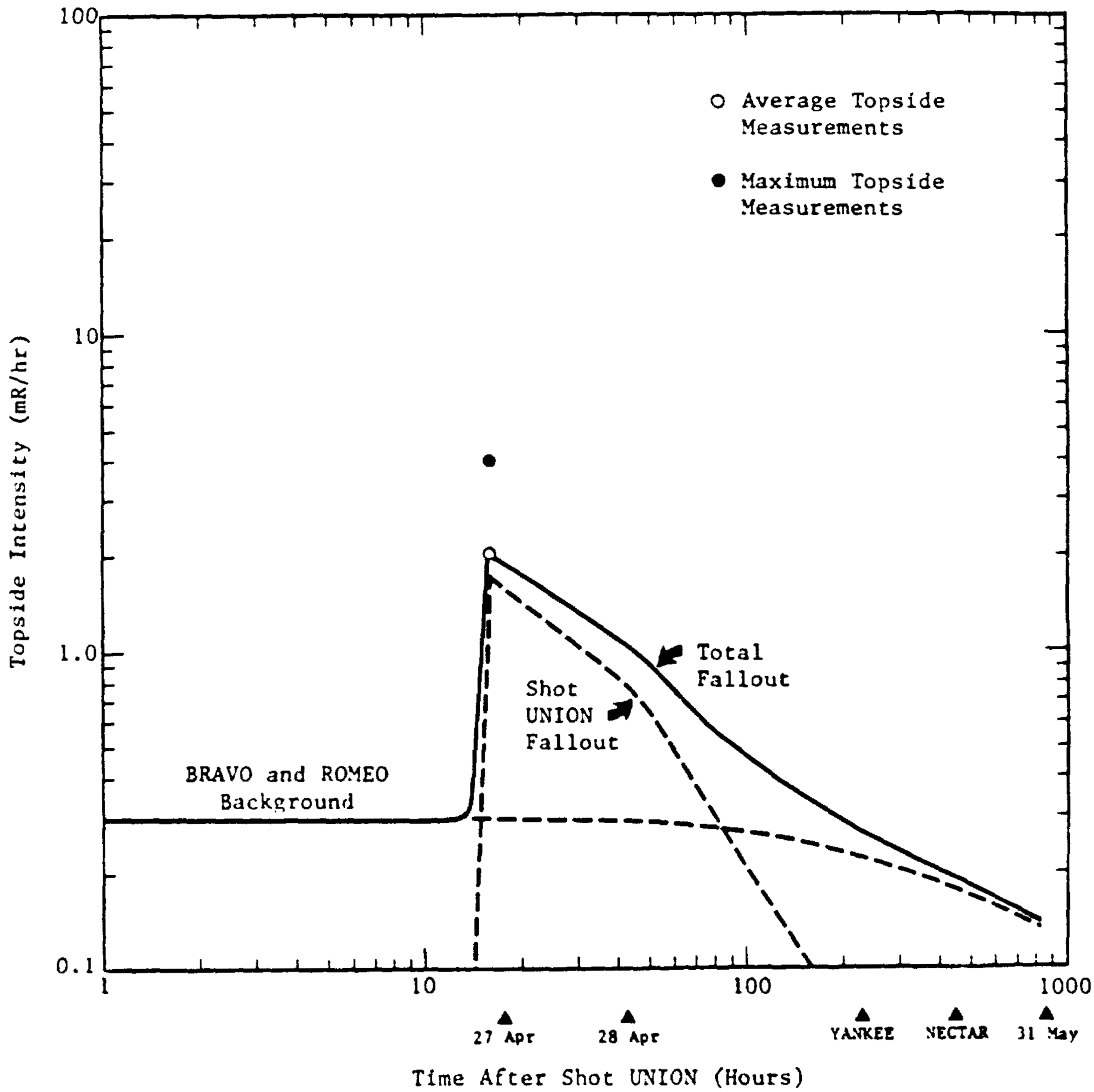


Figure 10. Topside intensity on USS COCOPA (ATF-101) following Shot UNION.

brought aboard ship, as opposed to any instruments housed within the can. The intensity of the lagoon water in the recovery area was 500 mR/hr and that of the instrument can itself, 1200 mR/hr (Reference 12). This was the only attempt to recover any instrumentation in Area Dog on 27 April. The contaminated can was transferred to YC-1081 in the Nan anchorage at approximately 1820 hours, 27 April. It is estimated the crew was exposed to "shine" from the contaminated lagoon water for approximately 1.2 hours while in Area Dog. Assuming a topside intensity 40 percent of the water intensity, crewmen topside on COCOPA during Project 1.4 recovery operations on 27 April received an integrated exposure of approximately 240 mR due to shine from contaminated water.

COCOPA continued assisting in Project 1.4 recovery operations in Area Dog on 29 and 30 April, and again on 1 May. Although lagoon water intensities in the recovery area had significantly decreased due to radioactive decay and diffusion, continued operations in the contaminated water had led to a buildup of significant radioactive contamination on COCOPA's exterior hull below the water line and in the saltwater piping (Reference 12). In order to reduce the ship contamination problem, COCOPA departed Bikini Lagoon for sea at approximately 1800 hours, 1 May, where it steamed in "clean" water until 0630 hours the following day. This method of decontaminating the ship's exterior hull and internal saltwater systems was employed by many of the support ships at Operation CROSSROAD in 1946 when it was found that steaming in clean water outside of the lagoon reduced the accumulated contamination by about half during the first day after leaving the lagoon, but that subsequent steaming had a much smaller effect (Reference 4).

After returning to the lagoon on 2 May and anchoring near TAWAKONI, the captain departed the ship for approximately 1 1/2 hours; it is assumed he made arrangements for transfer of Project 1.4 support to TAWAKONI at this time (reported in Reference 12 as being necessary due to accumulated contamination of COCOPA).

On 3 and 4 May, COCOPA visited Area Fox in the northern lagoon (see figure 4), where it likely assisted TAWAKONI in final preparations for Project 1.4 participation at Shot YANKEE, scheduled for 5 May. At approximately 1600 hours, 4 May, COCOPA departed Bikini enroute to its assigned operating area for the YANKEE detonation.

Shot YANKEE was detonated at 0610 hours, 5 May. Fallout and contaminated lagoon water resulting from Shot YANKEE significantly increased radiation levels in the vicinity of the Nan anchorage area off Eneu Island. Consequently, COCOPA did not return to the lagoon until approximately 0800 hours on 6 May. By this time, intensity levels of the water in the anchorage area had decreased to 7 mR/hr (Reference 8). Between 1037 and 1137 hours, COCOPA was moored alongside YCV-9 and was probably involved with the decontamination of this barge. During the afternoon of 6 May, the ship visited Area Fox for 2 1/2 hours to recover some of the Project 1.4 instrumentation, returning to the Nan anchorage at 1832 hours. Between 1850 and 1930 hours, COCOPA moored alongside LCU-637 where it was likely involved in the decontamination of that boat; TAWAKONI was involved in the decontamination of LCU-638 at approximately the same time. Note: All LCUs and barges left in the Nan anchorage for Shot YANKEE became contaminated as a result of fallout from that test (Reference 7).

COCOPA remained in the Nan anchorage until 1735 hours on 8 May, when it got underway for Enewetak with YC-737 in tow. After dropping YC-737 off at Enewetak on 9 May, it returned to Bikini to pick up YC-1081 and an Army barge. The ship departed Bikini with these two barges in tow at approximately 2030 hours, 10 May, enroute to Enewetak where it arrived on 11 May.

COCOPA departed Enewetak during the evening of 11 May on a rehearsal for Shot NECTAR which was scheduled to be detonated at Enewetak on 14 May; the ship returned to the lagoon during the morning of 12 May. At 1630 hours, COCOPA took YC-1081 in tow and departed Enewetak for Bikini Atoll, arriving Bikini at approximately 1800 hours, 13 May. The ship remained at anchor in the Nan anchorage for Shot NECTAR on 14 May, and did not depart Bikini until 1400 hours, 17 May, when it got underway for Enewetak. COCOPA arrived at Enewetak at approximately 0700 hours, 18 May, and got underway that afternoon for Guam; COCOPA did not return to the PPG during the remainder of the operation.

The daily contributions to the integrated free-field intensity on USS COCOPA resulting from Shots BRAVO, ROMEO, and UNION fallout, shine from contaminated lagoon water, and from ship contamination during the period 1 March to 31 May 1954, are given in table 5. Those days when COCOPA was moored alongside contaminated LCUs and barges are annotated (*), and the resulting contribution to topside exposure on COCOPA (from the Appendix) is included in the shine column.

3.5 USS MENDER (ARSD-2).

When Shot BRAVO was detonated on 1 March, MENDER was at anchor in the harbor at Sasebo, Japan (Reference 3). The same day, the ship departed Japan enroute to Guam where it arrived on 8 March. MENDER remained anchored at Guam until 17 March when, after taking on

Table 5. Daily integrated intensity, USS COCOPA (ATF-101).

March	Integrated Intensity (mR) Topside Fallout	Topside Shine	Below Contam	April	Integrated Intensity (mR) Topside Fallout	Topside Shine	Below Contam	May	Integrated Intensity (mR) Topside Fallout	Topside Shine	Below Contam
1 (BRAVO)	628	0	0	1	75.3	0.2	4.4	1	9.3	144	29.0
2	796	20.4	29.9	2	68.1	0	3.4	2	8.2	2.9*	2.0
3	189	189*	160	3	54.3	0	3.2	3	7.5	1.4	5.0
4	107	123*	128	4	44.0	0	3.1	4	7.0	2.2	7.1
5	65.7	18.1*	93.3	5	36.6	0	3.0	5 (YANKEE)	6.6	0	1.3
6	48.4	11.9*	67.9	6	31.1	0	2.9	6	6.2	234*	64.0
7	44.6	0	28.5	7 (KOON)	26.8	0	2.8	7	6.0	24.0	103
8	34.5	0	23.5	8	23.4	0.5	3.3	8	5.7	14.0*	51.5
9	27.3	3.6*	23.9	9	20.7	0.9	3.9	9	5.5	0	1.2
10	22.0	19.0	29.4	10	18.5	2.0	4.1	10	5.3	9.8*	5.4
11	18.1	18.0	29.6	11	16.7	1.3	3.5	11	5.1	0	1.2
12	15.2	1.5	22.3	12	15.1	1.2	3.5	12	5.0	1.1*	1.2
13	12.9	2.1	14.0	13	13.8	1.1	3.4	13	4.8	1.0	1.8
14	11.1	6.5*	19.2	14	12.7	1.8	4.8	14 (NECTAR)	4.7	3.7	10.5
15	9.7	7.2	18.9	15	11.7	0.9	4.8	15	4.5	3.2	13.8
16	8.5	20.7*	17.8	16	11.0	0.1	2.1	16	4.4	2.9	13.6
17	7.6	18.0	16.4	17	10.4	0.8	2.8	17	4.3	1.5	8.0
18	6.8	16.6	15.2	18	9.9	0.7	3.5	18	4.2	0	1.1
19	6.1	6.7	12.0	19	9.5	1.0	3.7	19	4.1	0	1.0
20	5.5	6.3	10.6	20	9.0	1.1	5.5	20	4.0	0	1.0
21	5.1	6.5*	10.4	21	8.6	0.9	3.1	21	3.9	0	1.0
22	4.8	7.3	9.9	22	8.3	0.9	4.6	22	3.8	0	1.0
23	4.5	11.9	10.9	23	8.0	0.7	2.4	23	3.8	0	1.0
24	4.3	6.3	10.2	24	7.6	0.6	2.9	24	3.7	0	1.0
25	4.1	1.6	9.7	25	7.4	0.4	2.6	25	3.6	0	0.9
26	3.9	2.7	8.4	26 (UNION)	10.8	2.0	2.7	26	3.5	0	0.9
27 (ROMEO)	3.7	0.6	4.9	27	32.9	271*	67.8	27	3.5	0	0.9
28	16.8	0.8	7.2	28	20.5	1.7	111	28	3.4	0	0.9
29	272	0.4	7.5	29	13.8	187*	67.9	29	3.3	0	0.9
30	125	2.0	5.7	30	10.9	415	48.1	30	3.3	0	0.9
31	109	10.1	6.2					31	3.2	0	0.9

* Includes contribution while alongside contaminated LCUs and barges.

fresh provisions and fuel, it got underway for Bikini via Enewetak. After a short stop at Enewetak on 23 March, MENDER arrived at Bikini Atoll during the late afternoon of 24 March and moored alongside USS GYPSY (ARSD-1).

GYPSY, along with COCOPA, had been involved in laying moors and instrument cans and in instrument can recovery operations for Project 1.4 during the period 1-24 March. With GYPSY scheduled to depart the PPG on 26 March, MENDER had arrived at Bikini to relieve GYPSY of its support functions for Project 1.4. Project equipment was transferred from GYPSY to MENDER on 24-25 March, and, during the afternoon of 25 March, GYPSY accompanied MENDER on a familiarization trip to Area Charlie (see figure 4) where Project 1.4 instruments were already in place for Shot ROMEO, now scheduled for 27 March.

During the late afternoon of 26 March, MENDER got underway for its assigned operating area for Shot ROMEO, approximately 80 nmi east-southeast of surface zero. Shot ROMEO was detonated at 0630 hours on 27 March, and MENDER returned to the Nan anchorage area at approximately 1400 hours the same day. The ship shifted berths to the Tare anchorage area just north of Eneman Island (see figure 4) on 28 March. During the late afternoon of 28 March, MENDER began receiving secondary fallout from the Shot ROMEO cloud. Topside intensities increased during the evening and, by the time fallout ceased at midnight, average intensities of 27 mR/hr were measured on MENDER's weather decks. The radiation environment on the ship resulting from Shot ROMEO fallout is depicted in figure 11.

Between 29 March and 5 April, MENDER made several trips between the Tare and Nan anchorages and, at approximately noon on 5 April, MENDER got underway for its assigned operating area for Shot KOON, 35 nmi southeast of the KOON ground zero.

Shot KOON was detonated at 0620 hours on 7 April, and MENDER returned to the lagoon and anchored in the Nan anchorage at noon. On 8 April, the ship steamed to Area Dog in the northern lagoon (see figure 4) and began laying buoys for Project 1.4 instrument cans for participation at Shot UNION, scheduled for 16 April. Between 9 and 14 April, MENDER made amost daily trips to Areas Dog and George where it conducted various salvage operations and assisted COCOPA with mooring Project 1.4 instrument cans. At approximately 1130 hours on 15 April, MENDER departed the lagoon for its assigned operating area for Shot UNION. Due to unfavorable weather, Shot UNION was postponed and MENDER returned to Bikini during the evening of 16 April.

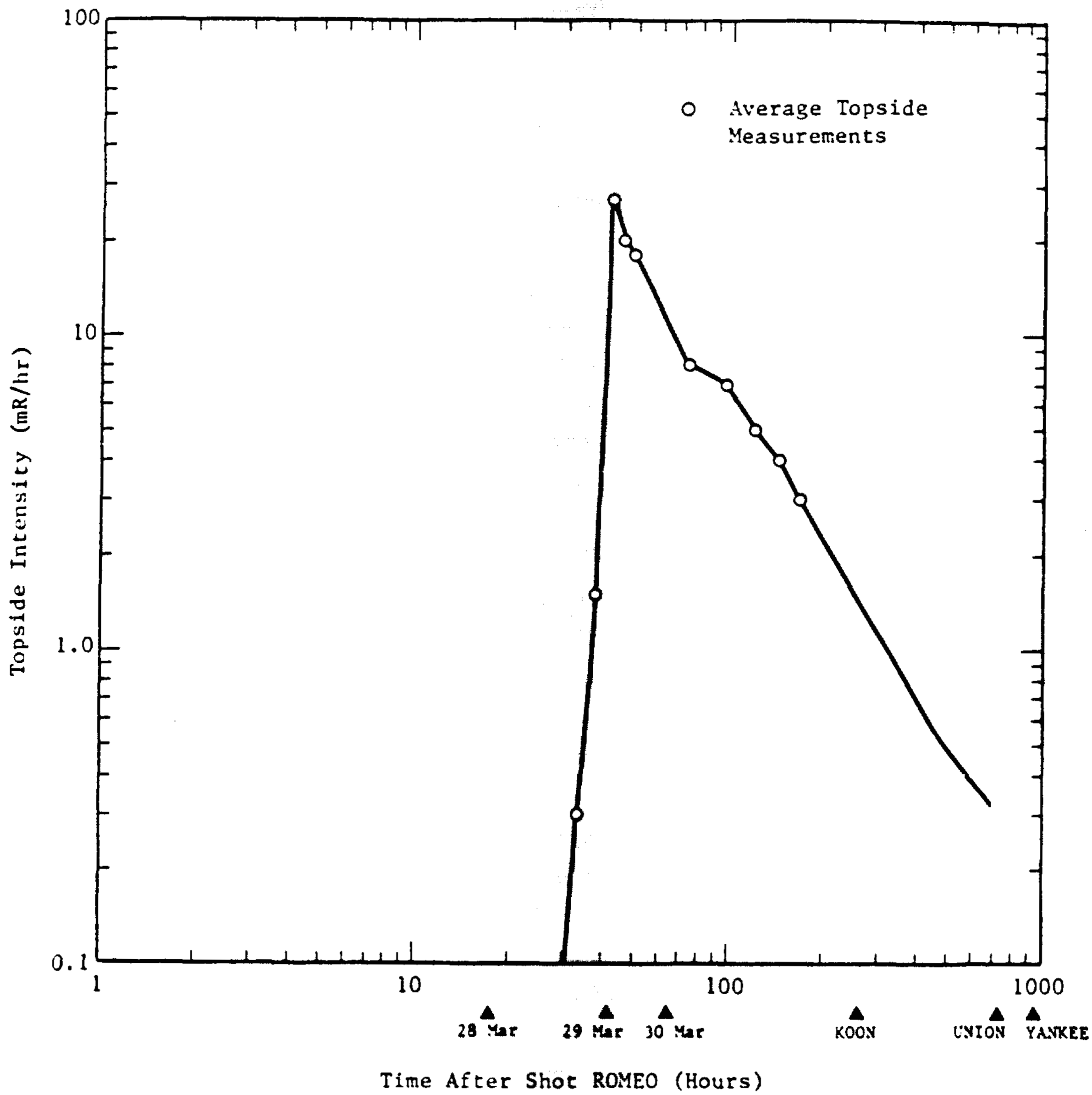


Figure 11. Topside intensity on USS MENDER (ARSD-2) following Shot ROMEO.

Continued bad weather resulted in delaying Shot UNION until 26 April. MENDER remained in the Nan anchorage on 17 and 18 April, conducted salvage operations in Area George on 19 and 20 April, and on 21 April, departed Bikini enroute to Enewetak. The ship returned to Bikini for approximately one hour on 25 April, prior to getting underway for its assigned operating area for Shot UNION.

When Shot UNION was detonated at 0605 hours, 26 April, MENDER was steaming in an area approximately 35 nmi southeast of Bikini; the ship returned to the lagoon at 1847 hours and moored alongside LCU-1224 in the Nan anchorage until 2006 hours (although not stated in the ship's deck log, it is likely MENDER was involved in decontaminating this boat). At approximately 2100 hours, MENDER experienced the same light fallout from the Shot UNION cloud that was reported on several other ships anchored nearby. Average topside intensities on MENDER were 2 mR/hr at 2100 hours with maximum intensities of 4 mR/hr being reported. Shown in figure 12 is the topside radiation environment on MENDER resulting from Shot UNION fallout.

Between 0800 and 1140 hours the following day (27 April), MENDER was involved with decontaminating "various LCUs" that remained in the lagoon for the test and thus received primary (early-time) fallout from Shot UNION. At 1445 hours, MENDER was directed to proceed to Area George to conduct salvage operations, arriving and anchoring there at 1555 hours. The log is not specific as to which project was supported by this action, but Project 1.4 did have two instrument cans moored in the George area. MENDER's anchorage was approximately 1.6 nmi east-southeast of the UNION surface zero, which was fortunate, since the general drift of surface water in the contaminated pool was to the west and southwest. At about the same time, COCOPA was recovering a Project 1.4 instrument can that was moored in Area Dog, approximately 1.3 nmi southwest of surface zero, and that ship encountered sea water intensities of 500 mR/hr--section 3.4. Apparently, lagoon water intensities in Area George never approached the levels they were in Area Dog since MENDER remained anchored in this area until the morning of 29 April. Divers aboard MENDER did conduct diving operations during much of the day on 28 April, and could have been exposed to relatively high levels of radiation found in the sub-surface lagoon water around surface zero.

MENDER returned to the Nan anchorage briefly on 29 April, but at 1320 hours the ship returned to the northern anchorage to continue its Project 1.4 support. The deck log states that at 1510 hours, MENDER was "Anchored in area George, Bikini Lagoon," but the anchor bearings noted in the log indicate the ship was in Area Dog ("Concrete House on Dog, 063.5°T" implies a

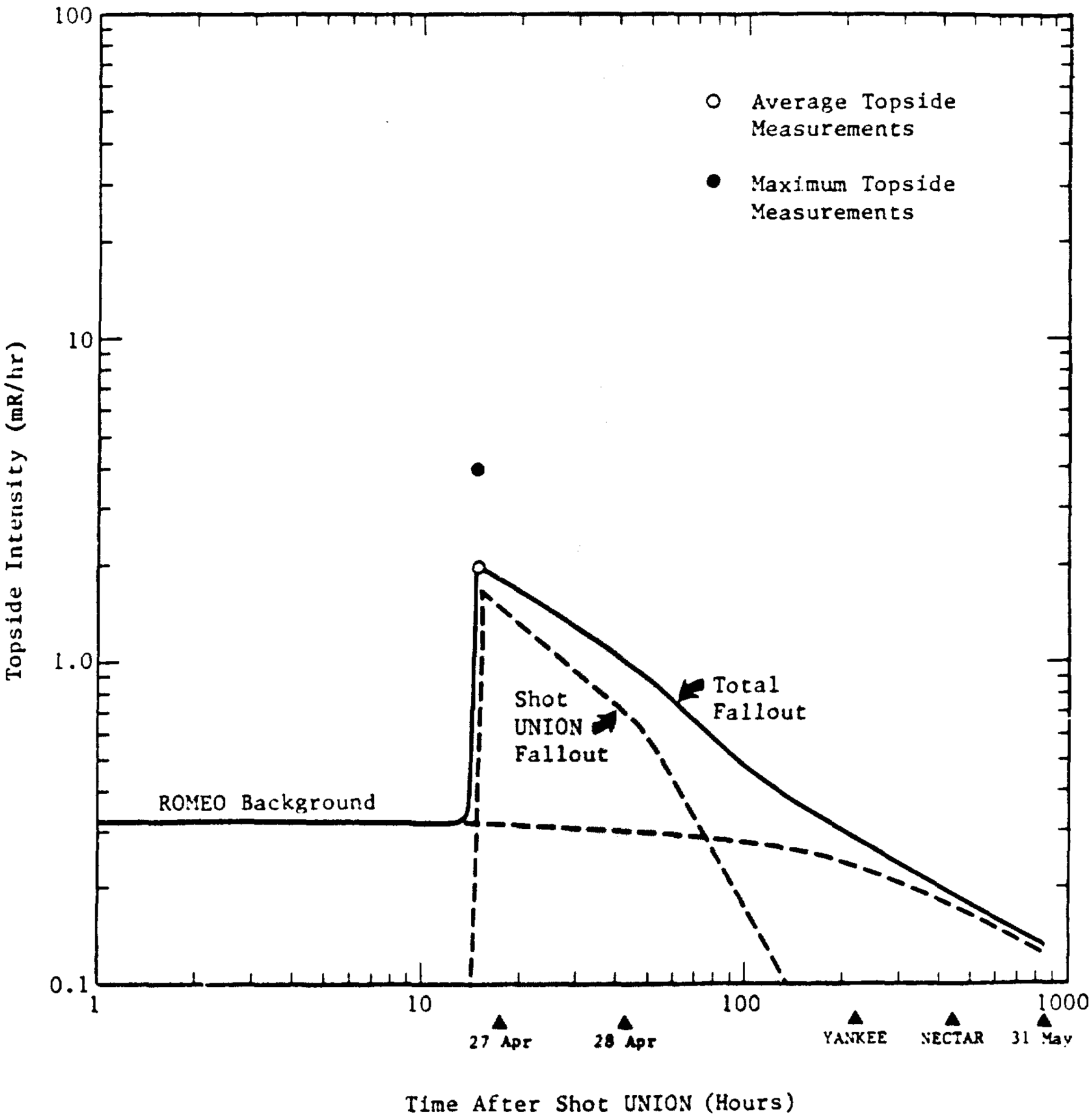


Figure 12. Topside intensity on USS MENDER (ARSD-2) following Shot UNION.

position southwest of that island, whereas Area George is to the southeast--figure 4). MENDER remained in this area assisting COCOPA in salvage operations (Project 1.4 instrument can recovery) until approximately 1530 hours, 30 April, when it returned to the Nan anchorage. MENDER resumed operations in the northern lagoon between 1800 hours, 1 May, and approximately 1600 hours, 2 May, when it returned to the Nan anchorage. On 4 May, the ship departed Bikini for its assigned operating area for Shot YANKEE, scheduled for 5 May.

When Shot YANKEE was detonated at 0610 hours, 5 May, MENDER was steaming in an area 30-35 nmi southeast of the YANKEE surface zero. Fallout and contaminated lagoon water resulting from Shot YANKEE significantly increased radiation levels in the Nan anchorage. Consequently, MENDER did not return to the lagoon until approximately 0800 hours on 6 May. By this time intensity levels of the water in the anchorage area had decreased to 7 mR/hr (Reference 8). Between 1022 and 1847 hours, 6 May, MENDER was utilized to washdown "various LCUs" that had remained in the lagoon during the test and had received primary fallout from Shot YANKEE (Reference 3). MENDER continued washing down the LCUs on 7 May between 0755 and 1102 hours, and again between 1302 and 1610 hours. Intensities onboard the LCUs on 7 May are reported as ranging from 275 mR/hr (6 LCUs) to 500 mR/hr (3 LCUs) and are in good agreement with the derived values of 475 and 410 mR/hr used in the ship shine calculations (Appendix).

On 8 May, MENDER got underway for Enewetak Atoll where it arrived at approximately 0600 hours the following morning. The ship remained at Enewetak until the evening of 11 May, when it departed the atoll on a rehearsal for Shot NECTAR, scheduled for 14 May. MENDER returned to Enewetak on the morning of 12 May and, after taking on provisions, fresh water, and fuel, departed Enewetak at 1755 hours, enroute to Pearl Harbor via Johnston Island. The ship arrived at Pearl Harbor on 23 May and did not return to the PPG for Operation CASTLE.

The daily contributions to the integrated free-field intensity on USS MENDER resulting from Shots ROMEO and UNION fallout, shine from the contaminated lagoon water, and that due to ship contamination are detailed in table 6 for the period 24 March to 31 May 1954. Those days when MENDER was moored alongside contaminated LCUs and barges are annotated (*), and the contribution to topside exposure on MENDER (from the Appendix) is included in the shine column.

Table 6. Daily integrated intensity, USS MENDER (ARSD-2).

March	Integrated Intensity (mR) Topside Fallout	Topside Shine	Below Contam	April	Integrated Intensity (mR) Topside Fallout	Topside Shine	Below Contam	May	Integrated Intensity (mR) Topside Fallout	Topside Shine	Below Contam
1 (BRAVO)				1	116	0.9	6.8	1	9.4	12.0*	36.8
2				2	90.1	1.1	6.7	2	8.4	5.4	29.5
3				3	69.2	1.1	6.4	3	7.7	0.4	24.8
4				4	55.7	1.0	6.2	4	7.1	0.2	14.5
5				5	45.9	0.5	4.4	5 (YANKEE)	6.7	0	1.3
6				6	38.5	0	2.9	6	6.4	507*	39.2
7				7 (KOON)	32.9	0.4	3.2	7	6.1	245*	79.4
8				8	28.4	3.0	4.6	8	5.8	5.9	24.8
9				9	24.9	0.9	4.4	9	5.6	0	1.2
10				10	22.0	0.8	4.9	10	5.4	0	1.2
11				11	19.6	1.2	4.3	11	5.2	0	1.2
12				12	17.6	2.5	4.7	12	5.0	0	1.2
13				13	15.9	3.1	7.0	13	4.8	0	1.1
14				14	14.4	0.7	4.1	14 (NECTAR)	4.7	0	1.1
15				15	13.2	0.3	3.1	15	4.6	0	1.1
16				16	12.3	0.1	2.1	16	4.4	0	1.1
17				17	11.6	0.7	3.4	17	4.3	0	1.1
18				18	10.9	0.7	3.9	18	4.2	0	1.1
19				19	10.4	1.2	3.2	19	4.1	0	1.0
20				20	9.9	1.3	3.1	20	4.0	0	1.0
21				21	9.4	0.3	2.3	21	3.9	0	1.0
22				22	9.0	0	1.8	22	3.8	0	1.0
23				23	8.6	0	1.8	23	3.7	0	1.0
24		0.5	0.7	24	8.2	0	1.7	24	3.7	0	1.0
25		5.4	7.4	25	7.9	0	1.6	25	3.6	0	0.9
26		4.5	7.8	26 (UNION)	12.7	23.9*	2.6	26	3.5	0	0.9
27 (ROMEO)		0.6	4.9	27	31.2	61.2*	28.7	27	3.4	0	0.9
28	39.8	0.8	7.2	28	20.1	48.3	91.2	28	3.4	0	0.9
29	384	0.4	7.5	29	13.7	537	66.2	29	3.3	0	0.9
30	193	0.6	7.3	30	10.9	794*	48.1	30	3.2	0	0.9
31	157	0.9	7.1					31	3.2		0.9

* Includes contribution while alongside contaminated LCUs and barges.

3.6 USS MOLALA (ATF-106).

Between 0414 and 0442 hours on 1 March, MOLALA embarked the skeleton crews of YAG-39 and YAG-40, the two remote-controlled ships supporting Project 6.4 (section 3.1), in an area approximately 45 nmi southwest of the Shot BRAVO ground zero. The ship then proceeded on a southeasterly course and, at 0645 hours when Shot BRAVO was detonated, MOLALA was approximately 45 nmi south-southwest of the detonation. Following the test, MOLALA steamed on an easterly course for approximately one hour and then southeasterly until it rendezvoused with TAWAKONI in an area approximately 45 nmi south-southeast of Bikini Atoll at 1045 hours. These two ships then steamed on a westerly course to intercept the two YAGs. At approximately noon, the skeleton crew of YAG-39, which had remained on MOLALA for the test, was transferred to TAWAKONI; the two ships then headed generally west-northwest in the anticipated direction of the YAGs, which, by now, were dead in the water.

At 1400 hours, while in an area 30-35 nmi southwest of Bikini, MOLALA sighted YAG-40 at a range of 13 nmi. At 1445 hours, MOLALA began its approach to YAG-40, but prior to going alongside to hook up the tow wire, it approached cautiously in order to determine any radiological hazards associated with towing this vessel. Because of a change in wind direction prior to the detonation, the YAGs were not in an area of anticipated heavy fallout and topside intensities on YAG-40 were only 30-40 mR/hr (Reference 13). At 1600 hours, 1 March, MOLALA took YAG-40 in tow with 1,550 feet of main tow wire, enroute to Enewetak Atoll (Reference 3).

By steaming in a westerly direction following their rendezvous at 1045 hours, both MOLALA and TAWAKONI avoided the significant BRAVO fallout experienced by many of the task force ships (e.g., COCOPA and PC-1546) when those ships were directed to proceed north-northwest toward Bikini at 1100 hours. Air sampling data obtained onboard MOLALA (and TAWAKONI) does indicate, however, that these two ships received some fallout (although insignificant compared to the other ships) commencing at approximately 1600 hours, 1 March (Reference 13). Unfortunately, the air sampling was terminated at approximately 2000 hours on both ships and the time of cessation can only be estimated. On YAG-40, which was being towed by MOLALA during the period of interest, the air sampling equipment remained in operation until 2300 hours and, at that time, airborne contamination levels were falling off rapidly; therefore, it is estimated that fallout on the two manned ships also ended at this time.

The available radiological data for MOLALA and nearby ships on 1 March are air sample activities rather than topside intensities. As only partial measurement of the airborne concentrations of radioactive fallout are available during fallout deposition on MOLALA, the more complete measurements obtained onboard YAG-40 (1,550 feet behind) are used to estimate the environment on MOLALA. Shot BRAVO wind data obtained at H-hour and H+6 hours reveal very little change in wind direction and speed in the layer from the surface to 6.1 km, i.e., easterly trade winds of 10 to 15 knots below 2.1 km and west-northwesterly winds of 10 to 15 knots between 2.1 and 6.1 km (Reference 2). Based on these winds, fallout originating from the BRAVO cloud stem in the upper portion of that layer, at about a 5 km height, would have been deposited in a wide area extending tens-of-miles southwest of ground zero. The mid-time of fallout deposition on YAG-40 was H+12.5 hours, implying an average particle fall speed of approximately 400 m/hr. Air samples on YAG-40 measured about 0.5 $\mu Ci/m^3$ of activity throughout a 7-hour period of fallout deposition, and imply a buildup rate of approximately 200 $\mu Ci/m^2/hr$. With decay accounted for, some 1.2 $\mu Ci/m^2$ had deposited on the weather decks by the time fallout ceased at H+16 hours. This corresponds to a peak intensity of approximately 6 mR/hr at the conclusion of fallout deposition (Reference 14). Figure 13 depicts the estimated topside radiation environment of MOLALA based on the YAG-40 air sampling data. Radiological decay after 2300 hours, 1 March (H+16), is based on measured decay rates on other ships receiving Shot BRAVO fallout.

At 1317 hours, 2 March, MOLALA shortened the tow wire to YAG-40 as it prepared to enter Enewetak Lagoon (Reference 3). At 1708 hours, YAG-40 was cast off in berth G-7, approximately 2 nmi west of Parry Island (see figure 3); MOLALA anchored approximately 500 yards north in berth F-7. MOLALA remained at anchor in Enewetak Lagoon until 11 March, when, after embarking several Project 6.4 personnel, it got underway for Bikini Atoll in company with YAG-39 and YAG-40. These three ships arrived at Bikini at 0830 hours on 12 March and, at 1630 hours, they got underway for their assigned operating area for Shot ROMEO, scheduled for 13 March. Shot ROMEO was postponed and all three ships reentered Bikini Lagoon during the morning of 13 March and anchored in the Nan anchorage area (figure 4).

On 14 March, MOLALA moored alongside YAG-40 to refuel from 1625 to 1747 hours. Topside intensities on YAG-40 had decayed to less than 0.5 mR/hr by this time (Reference 13); hence, exposure to MOLALA's crew while alongside YAG-40 is insignificant (see Appendix).

Shot ROMEO was delayed until 27 March, and during the interim period 15-25 March, except for a brief 4-hour sortie out of the lagoon on 21 March, MOLALA remained in the southern

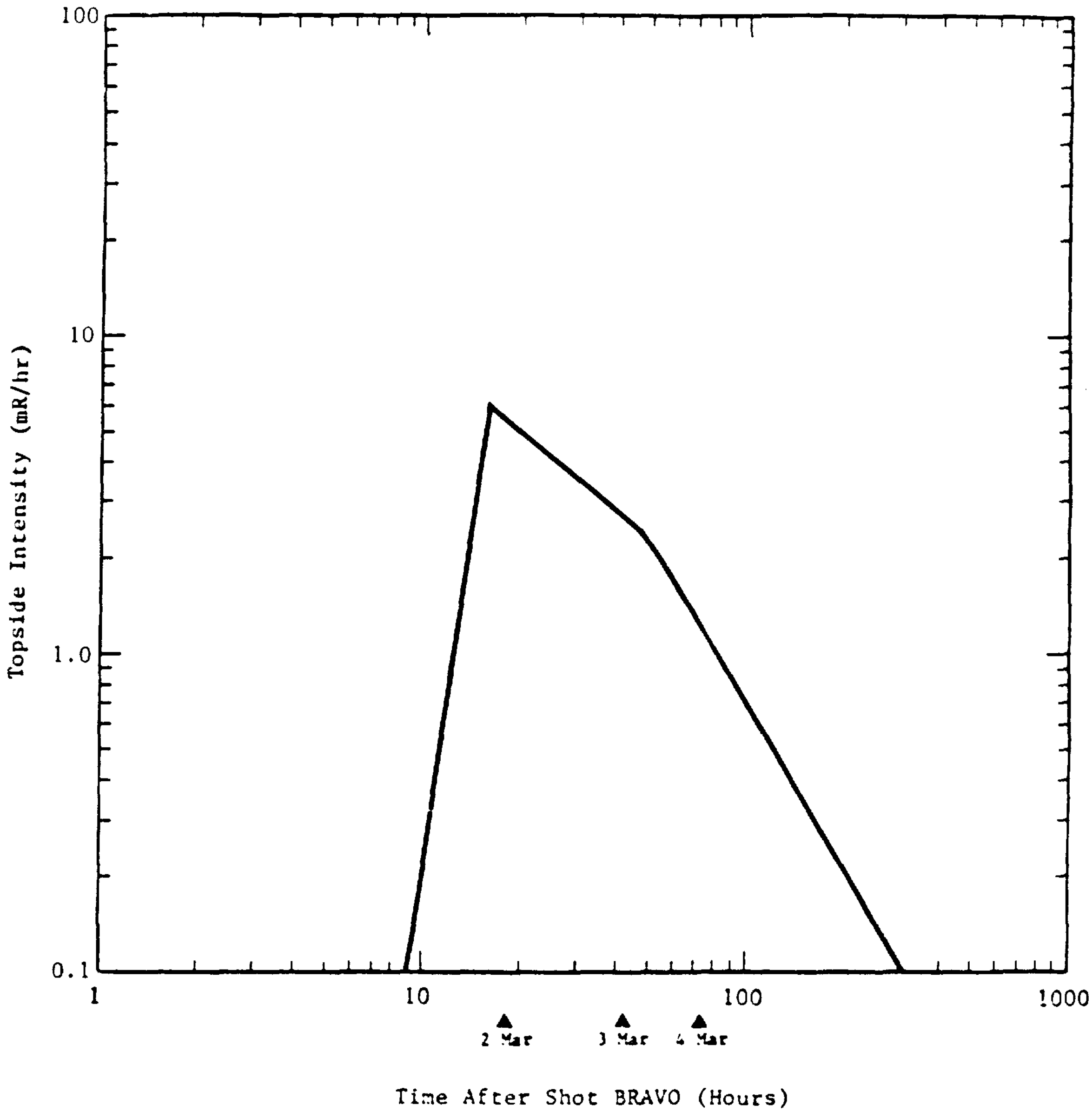


Figure 13. Estimated topside intensity on USS MOLALA (ATF-106) following Shot BRAVO.

anchorage areas of Nan and Tare (figure 4) until 26 March. At 1850 hours, 26 March, MOLALA departed Bikini in company with YAG-39 and YAG-40 enroute to their assigned operating area for Shot ROMEO.

Between 0300 and 0400 hours, 27 March, while in an area approximately 25 nmi west of Enewetak Atoll, the skeleton crews from YAG-39 and YAG-40 transferred to MOLALA. When Shot ROMEO was detonated at 0630 hours, MOLALA was operating in an area approximately 40 nmi southwest of the ROMEO surface zero. After the test, MOLALA steamed generally to the south and by 0835 hours, when MOLALA first sighted TAWAKONI, both ships were in an area approximately 25 nmi south of Bikini. MOLALA rendezvoused with TAWAKONI at approximately 0900 hours and the crew of YAG-39 was transferred from MOLALA to TAWAKONI at 1006 hours. The two ships remained in an area generally to the south of Bikini steaming on an east-west racetrack until approximately 1800 hours, when they steamed in a northwesterly direction to intercept the YAGs.

MOLALA continued on a northwesterly course until approximately midnight, 27 March. At this time the ship was approximately 50 nmi northwest of Bikini and it began receiving relatively light fallout from the Shot ROMEO cloud. Topside intensities on the ship increased throughout the morning of 28 March and, by 0800 hours, when fallout ceased, average topside intensities of 13 mR/hr were reported. Meanwhile, TAWAKONI had intercepted YAG-39 in an area due west of Bikini at 2200 hours, 27 March, at which time it apparently returned to Bikini; by doing so, it avoided the fallout encountered by MOLALA northwest of the atoll--see section 3.7. Figure 14 depicts the average topside radiation environment on MOLALA resulting from Shot ROMEO fallout (Reference 7).

According to MOLALA's log, the ship remained in an area northwest of Bikini during the remainder of the morning of 28 March while conducting a search for YAG-40. YAG-40 was first sighted by the crew at 1033 hours and, between 1120 and 1242 hours, 28 March, MOLALA maneuvered in the vicinity to determine the radiological hazards associated with towing this vessel to Enewetak; topside intensities on YAG-40 were approximately 6.5 R/hr at this time (Reference 13). At 1252 hours, MOLALA had YAG-40 in tow with 1,500 feet of main tow wire and set a course to Enewetak Atoll.

MOLALA entered Enewetak Lagoon at approximately 1030 hours, 29 March, and by 1330 hours, the ship moored in berth B-3, about 1 nmi west of Parry Island; YAG-40 was then moored in the same berth. At 1554 hours, MOLALA got underway for berth C-1, approximately

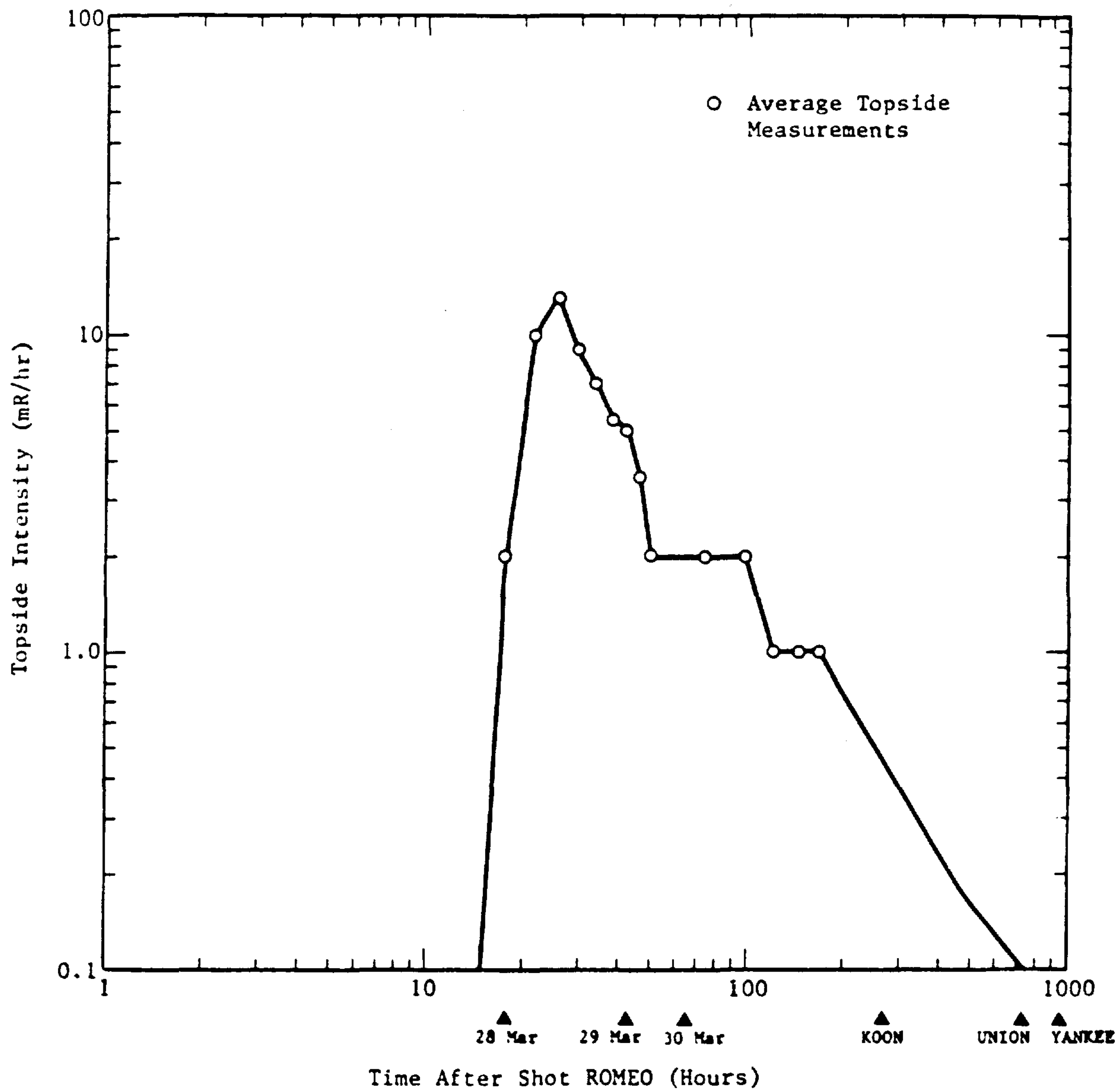


Figure 14. Topside intensity on USS MOLALA (ATF-106) following Shot ROMEO.

1,000 yards from YAG-40. During the afternoon of 29 March and continuing until approximately noon on 30 March, Parry Island received relatively light fallout from the Shot ROMEO cloud. Topside intensities on MOLALA were measured only one time throughout this period (H+58 to H+78) and no decrease (or increase) in intensity was noted (see figure 14); it is possible that the light fallout was not detected on MOLALA and radioactive decay was being offset by the occurrence of this secondary fallout.

MOLALA remained at anchor in berth C-1 on 30 March but, on 31 March, it moored alongside YAG-40 from 0838 to 1502 hours in berth B-3, returning to berth C-1 at 1508 hours. The purpose of this "visit" is not specified in the ship's log, but it is likely that efforts to decontaminate YAG-40 were undertaken at this time; topside intensities on YAG-40 were 1560 mR/hr on 31 March (Reference 13). On 1 April, MOLALA towed YAG-40 to a new mooring in berth D-1 between 0958 and 1055 hours.

MOLALA remained anchored at Enewetak for Shot KOON on 7 April and, on 9 April, it moored alongside YAG-40 between 0850 and 1102 hours, and again from 1115 to 1530 hours, returning to berth C-1 at 1539 hours. By this time, topside intensities on YAG-40 had been reduced to 106 mR/hr through decontamination. According to Reference 13, 9 April was the last day before Shot UNION that decontamination was carried out on YAG-40.

On 14 April, after embarking Project 6.4 personnel at 0945 hours, MOLALA got underway for Bikini in company with YAG-39 and YAG-40. The three ships arrived at Bikini at approximately 0800 hours on 15 March, and, at 1230 hours, MOLALA got underway for its assigned operating area for Shot UNION, scheduled for the following day. Shot UNION was postponed due to unfavorable weather and MOLALA, along with YAG-39 and YAG-40, returned to Bikini at approximately 2130 hours on 16 A ~l, anchoring in the Nan anchorage area.

Shot UNION was ultimately rescheduled for 26 April. During the period 17 to 24 April, MOLALA remained at anchor in the Nan anchorage. On 25 April, after a brief sortie to Area Dog (see figure 4) to tow a Project 1.4 barge back to the Nan anchorage, MOLALA, in company with YAG-39 and YAG-40, got underway for their assigned operating areas for Shot UNION.

Between 0300 and 0347 hours, MOLALA embarked personnel from YAG-39 and YAG-40 while in an area approximately 25 nmi east of Bikini. A skeleton crew remained onboard YAG-39 for Shots UNION and YANKEE in order to provide more direct control of the course of this ship and that of YAG-40, which was still unmanned and maneuvered by remote control from

YAG-39. When Shot UNION was detonated at 0605 hours on 26 April, MOLALA was approximately 35 nmi southeast of the UNION surface zero. MOLALA remained southeast of the atoll until approximately 1400 hours when it steamed on a north-northeasterly course to intercept YAG-39 and YAG-40. At 1725 hours, MOLALA approached YAG-39 in an area approximately 40 nmi northeast of Bikini to transfer personnel to that ship; the transfer was completed at 1812 hours. Topside intensities on YAG-39 were approximately 160 mR/hr at this time, but the ship was equipped with a shielded control room where all personnel remained while the ship returned to Enewetak Atoll under its own power.

At 1911 hours, MOLALA began approaching YAG-40 to ascertain radiological conditions on that ship prior to hooking up the main tow wire. Topside intensities on YAG-40 were approximately 1 R/hr and no one boarded (Reference 13). At 2015 hours, MOLALA was enroute to Enewetak with YAG-40 in tow with 1,500 feet of main tow line.

While recovering the YAGs between 1700 and 2200 hours, MOLALA was steaming in water recently contaminated by Shot UNION fallout. Background levels onboard MOLALA due to shine from the water were 30 mR/hr when measured by Project 6.4 personnel (Reference 13). Crewmen remaining topside on MOLALA during recovery operations on 26 April received an integrated exposure of approximately 150 mR due to shine from the contaminated water.

MOLALA arrived back at Enewetak at approximately noon on 28 April. For reasons not indicated in the ship's log, it was in the process of entering the lagoon when it returned to sea with YAG-40 still in tow. The ship steamed in open water in the vicinity of Enewetak Atoll and did not reenter the lagoon until approximately 1000 hours, 29 April. After disconnecting the tow at 1130 hours, MOLALA proceeded to berth B-1 where it anchored at noon.

On 1 May, MOLALA moored alongside YAG-40 from 0947 to 1203 hours; topside intensities on the YAG were 138 mR/hr at this time. Reference 13 indicates that significant efforts to decontaminate YAG-40 were not undertaken following the UNION test.

During the afternoon of 3 May, MOLALA got underway for Bikini Atoll. Apparently, YAG-39 and YAG-40 had departed earlier in the day and MOLALA did not overtake them until approximately 2000 hours, 3 May (Reference 3). At 1045 hours on 4 May, the three ships entered Bikini Lagoon and anchored in the Nan anchorage area. At approximately 1400 hours, all three ships got underway for their assigned operating area for Shot YANKEE, scheduled for the following day.

Between 0200 and 0330 hours, 5 May. MOLALA embarked personnel from YAG-39 and YAG-40 in an area 20 nmi east-northeast of Bikini Atoll; by the time shot YANKEE was detonated at 0610 hours, MOLALA had steamed to a position approximately 50 nmi southeast of surface zero. The ship remained in this general area until approximately 1100 hours when it steamed northward to intercept the YAGs. At 1433 hours, the crew sighted YAG-39 approximately 40 nmi east of the atoll; YAG-39 personnel were transferred to that ship from MOLALA between 1530 and 1630 hours. YAG-40 was very close by and, at 1700 hours, MOLALA was enroute to Enewetak Atoll with YAG-40 in tow on 1,600 feet of main tow line.

Both of the YAGs experienced heavy fallout from the Shot YANKEE cloud. During the recovery operations, topside intensities on YAG-39 were approximately 1.3 R/hr, while those on YAG-40 were 16 R/hr (Reference 13). Between approximately 1440 and 1910 hours, MOLALA was steaming in water contaminated by the YANKEE fallout. Background levels onboard MOLALA due to shine from the water were 6 mR/hr throughout this period (Reference 13); therefore, crewmen remaining topside during the recovery operations on 5 May received an integrated exposure of 27 mR due to shine from the contaminated water.

MOLALA, with YAG-40 still in tow, arrived back at Enewetak Atoll during the morning of 7 May; at 1135 hours, YAG-40 was moored just south of berth C-1 and, at 1214 hours, MOLALA anchored 600 yards south of berth D-4, approximately 1.5 nmi west of Parry Island (figure 3).

The following day, MOLALA moored alongside YAG-40 from 1011 to 1140 hours. At this time. topside intensities on YAG-40 averaged 3.7 R/hr (Reference 13). The ship's log gives no indication of why the ship went alongside the YAG on this date, because apparently it had been decided to let YAG-40 cool-off before putting decontamination teams aboard.

On 9, 10, and 11 May, MOLALA spent a good deal of time moored alongside YAG-39 while decontamination of that ship was in progress. All decontamination operations conducted aboard YAG-39 were controlled from MOLALA during this period. A contamination control zone was roped off on MOLALA and a contamination check station was set up at the boundary of the zone; all movement of personnel and equipment from YAG-39 was through the control zone on MOLALA (Reference 13).

During the afternoon of 11 May, MOLALA took YAG-40 in tow and departed the lagoon for a rehearsal of Shot NECTAR, scheduled to be detonated on a barge over the IVY-

MIKE crater on 14 May (see figure 3). MOLALA and YAG-40 returned to the lagoon during the afternoon of 12 May, and both ships moored in berth C-3 (YAG-40 was still connected to MOLALA with 700 feet of tow line). On 13 May, MOLALA cast off the tow line from YAG-40 and, between 1039 and 1055 hours, the ship washed down YAG-40's weather decks with high pressure hoses (Reference 3). At 1642 hours, 13 May. MOLALA, with YAG-40 in tow, departed Enewetak Lagoon for their assigned operating area for Shot NECTAR.

When Shot NECTAR was detonated at 0620 hours, 14 May, MOLALA was approximately 40 nmi southeast of surface zero. The ship, still towing YAG-40, returned to Enewetak Lagoon during the early afternoon of shot-day. YAG-40 was moored alongside YAG-39 in berth C-3 at 1300 hours, and MOLALA anchored in berth C-4 fifteen minutes later. During the period 15-19 May, while decontamination experiments were being carried out aboard YAG-40, YAG-39 was moored alongside and served as the control station for movement of personnel and equipment from YAG-40. While anchored in berth C-4 it is assumed MOLALA received the same fallout that occurred on Parry Island between 1830 and 2100 hours, 14 May; Shot NECTAR intensities on Parry Island (Reference 1), as modified for MOLALA geometry (see Appendix), are depicted in figure 15. On 15 May, MOLALA and SIOUX were utilized to map out the fallout area north of Enewetak Atoll resulting from Shot NECTAR. This was accomplished in the same area where SIOUX and TAWAKONI had layed out buoys in support of the experiment in late April (see section 3.7).

MOLALA returned to Enewetak Lagoon on 16 May and anchored in berth B-1 at approximately 0700 hours. The ship remained in this anchorage until 25 May, when it got underway enroute to Pearl Harbor in company with YAG-39 and YAG-40. During the period 16-21 May, decontamination work on YAG-40 was performed on a daily basis by teams drawn from several ships that remained at Enewetak Atoll after Shot NECTAR; MOLALA provided 25 crewmen (named) for this task.

During the period 1 March to 13 May 1954, MOLALA was either alongside or in close proximity to the contaminated YAGs on 22 occasions. Shine from the contaminated ships increased the topside radiation levels on MOLALA and thus the typical crewman's dose on each occasion. The details of each exposure and calculations to assess their effect on crew dose are described in the Appendix. The daily contributions to the integrated intensity on USS MOLALA resulting from Shots BRAVO, ROMEO and NECTAR fallout, and from ship contamination, are detailed in table 7 for the period 1 March to 31 May 1954. The topside exposure includes shine

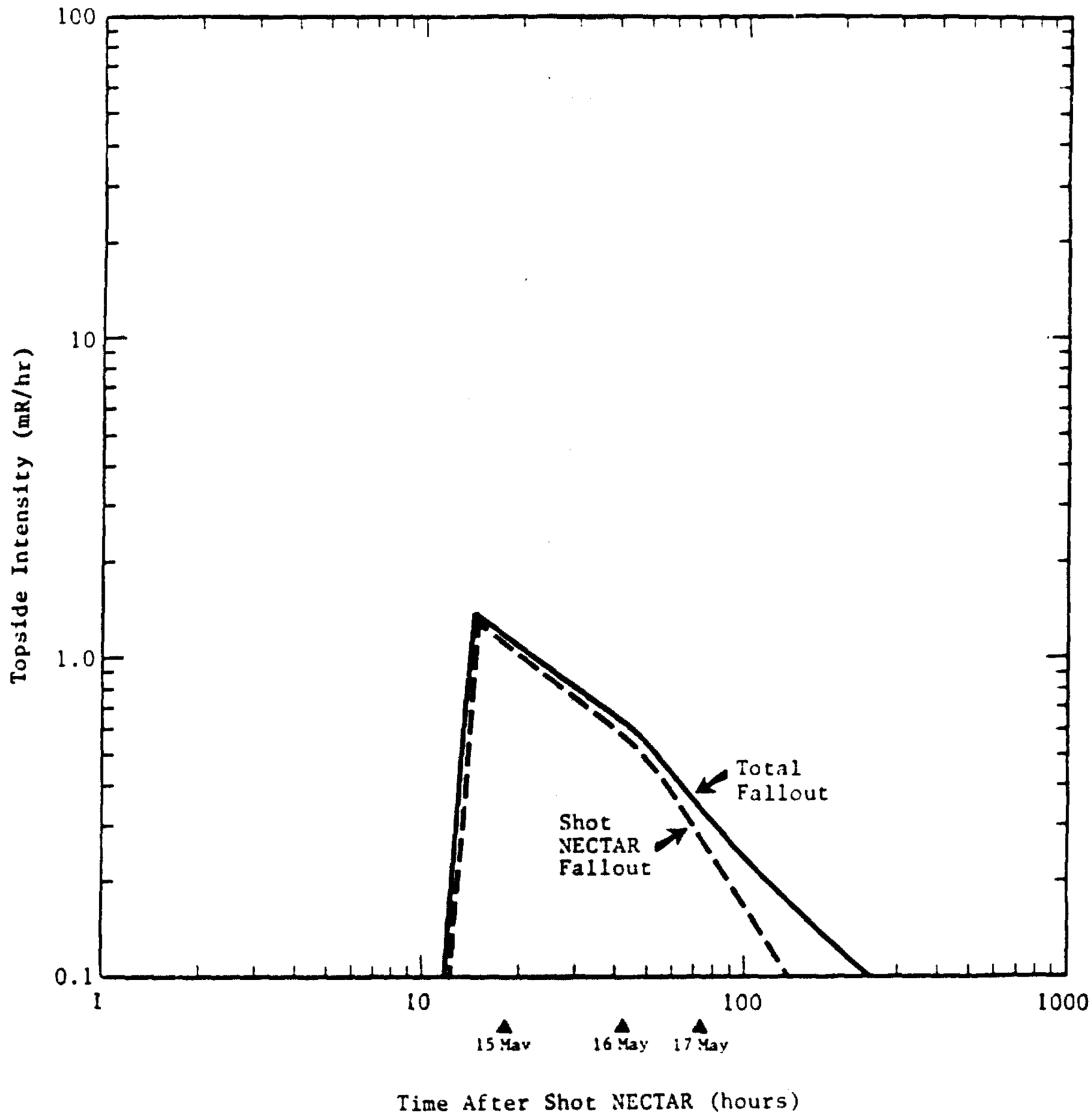


Figure 15. Estimated topside intensity on USS MOLALA (ATF-106) following Shot NECTAR.

Table 7. Daily integrated intensity, USS MOLALA (ATF-106).

	Integrated Intensity (mR)				Integrated Intensity (mR)				Integrated Intensity (mR)		
	Topside		Below		Topside		Below		Topside		Below
March	Fallout	Shine	Contam	April	Fallout	Shine	Contam	May	Fallout	Shine	Contam
1 (BRAVO)	28.4	1.5*	0	1	25.8	15.9*	3.5	1	2.4	55.2*	1.5
2	91.9	0	0	2	24.7	0	3.4	2	2.3	0	1.4
3	49.9	0	0	3	23.4	0	3.2	3	2.3	0	1.4
4	26.6	0	0	4	19.2	0	3.1	4	2.2	0	1.4
5	16.7	0	0	5	15.9	0	3.0	5 (YANKEE)	2.1	586*	12.5
6	11.6	0	0	6	13.4	0	2.9	6	2.1	0	1.3
7	8.6	0	0	7 (KOON)	11.5	0	2.8	7	2.0	0	1.3
8	6.7	0	0	8	10.0	0	2.7	8	2.0	886*	1.3
9	5.4	0	0	9	8.8	114*	2.6	9	1.9	205*	1.2
10	4.4	0	0	10	7.8	0	2.5	10	1.9	94*	1.2
11	3.7	0	0	11	7.0	0	2.4	11	1.8	80*	1.2
12	3.2	1.5	5.7	12	6.3	0	2.4	12	1.8	0	1.2
13	2.7	2.3	13.4	13	5.8	0	2.3	13	1.7	120*	1.1
14	2.4	3.6*	19.4	14	5.3	0	2.2	14 (NECTAR)	6.3	0	1.1
15	2.1	3.2	19.1	15	4.8	0.1	2.2	15	19.7	23.8	22.5
16	1.9	1.9	17.6	16	4.5	0.1	2.1	16	11.7	7.6	15.8
17	1.7	0.9	16.4	17	4.3	0.7	3.3	17	7.3	0	1.1
18	1.5	0.8	15.1	18	4.1	0.7	3.8	18	5.4	0	1.1
19	1.4	1.5	13.9	19	3.9	0.6	3.8	19	4.3	0	1.0
20	1.3	1.4	13.0	20	3.7	0.6	3.8	20	3.6	0	1.0
21	1.2	1.0	10.5	21	3.5	0.6	3.7	21	3.2	0	1.0
22	1.1	1.9	9.3	22	3.4	0.6	3.6	22	2.8	0	1.0
23	1.0	1.8	10.5	23	3.2	0.6	3.5	23	2.6	0	1.0
24	1.0	1.7	10.3	24	3.1	0.6	3.4	24	2.4	0	1.0
25	0.9	1.1	9.6	25	3.0	0.5	2.7	25	2.2	0	0.9
26	0.9	0.8	8.1	26 (UNION)	2.9	199*	53.2	26	2.1	0	0.9
27 (ROMEO)	2.5	0	4.4	27	2.8	0	1.6	27	2.0	0	0.9
28	188	276*	4.2	28	2.7	0	1.6	28	1.9	0	0.9
29	60.3	260*	4.0	29	2.6	0	1.5	29	1.8	0	0.9
30	48.8	0	3.8	30	2.5	0	1.5	30	1.7	0	0.9
31	42.6	1597*	3.6					31	1.7	0	0.9

* Includes contribution while alongside contaminated YAGs.

from the contaminated YAGs (from the Appendix) when MOLALA was near those ships on the days indicated, and shine from contaminated water.

3.7 USS TAWAKONI (ATF-114).

When Shot BRAVO was detonated at 0645 hours on 1 March, TAWAKONI was approximately 50 nmi east-southeast of ground zero. The ship remained in this general area until approximately 0800 hours, when, due to fallout on several of the task force ships at this time, all ships in the area were directed to proceed south in order to avoid the fallout area. TAWAKONI turned south and steamed until 1045 hours, when it rendezvoused with MOLALA in an area approximately 45 nmi south-southeast of Bikini. These two ships then steamed on a westerly course to intercept the two remotely-controlled YAGs that were supporting Project 6.4 (section 3.1). At approximately noon on 1 March, a YAG-39 skeleton crew was transferred to TAWAKONI from MOLALA; the two ships then headed generally west-northwest in the anticipated direction of the YAGS, which, by now, were dead in the water.

At approximately 1700 hours, TAWAKONI intercepted YAG-39 in an area approximately 50 nmi southwest of Bikini Atoll. Prior to going alongside to hook up the tow, TAWAKONI slowly approached from several directions to determine any radiological hazards associated with towing this vessel. Because of a change in wind direction prior to the detonation, the YAGs were not in the area of anticipated heavy fallout and topside intensities on YAG-39 were only 60-70 mR/hr (Reference 13). At 1845 hours, TAWAKONI was enroute to Enewetak with YAG-39 in tow with 1,600 feet of main tow line.

By steaming in a westerly direction following their rendezvous at 1045 hours, both TAWAKONI and MOLALA avoided the significant BRAVO fallout experienced by many of the task force ships (e.g., COCOPA and PC-1546) when those ships were directed to proceed north-northwest toward Bikini at 1100 hours. Air sampling data obtained onboard TAWAKONI (and MOLALA) does indicate, however, that these two ships received some fallout, although insignificant compared to the other ships, commencing at approximately 1600 hours, 1 March. Unfortunately, the air sampling was terminated at approximately 2000 hours on both ships and the time of cessation can only be estimated. On YAG-40, which was being towed by MOLALA, the air sampling equipment remained in operation until 2300 hours and, at that time, airborne contamination levels were falling off rapidly; therefore, it is estimated that fallout on the two manned ships also ended at this time. Since airborne activity concentrations measured on TAWAKONI between 1600 and 2000 hours are about the same as those measured on YAG-40 (approximately 0.5 $\mu Ci/m^3$), it is assumed that both ships received similar fallout. The estimated topside radiation environment on TAWAKONI is, therefore, the same as that depicted for MOLALA in figure 13 (refer to discussion in section 3.6).

At approximately 1300 hours, 2 March, as TAWAKONI was approaching Enewetak Atoll, the ship launched a motor whale boat for a crew to board YAG-39. The boarding party was likely the YAG-39 skeleton crew (eight personnel); however, individuals from TAWAKONI may have accompanied them. At 1900 hours, TAWAKONI was moored in the anchorage off Parry Island (figure 3); with the assistance of two M-boats and a tug, TAWAKONI completed mooring YAG-39 at 2205 hours, 2 March. Having completed its Project 6.4 support for Shot BRAVO, TAWAKONI got underway for Bikini Atoll at 2225 hours.

TAWAKONI arrived at Bikini at approximately 1400 hours on 3 March. On 4 and 5 March, the ship remained in the southern anchorage areas (Nan and Tare) performing duties in support of Project 1.4. Between 6 and 9 March, while COCOPA sortied to Enewetak Atoll, TAWAKONI spent most of each day in Area Charlie laying buoys and instrument cans in support of Project 1.4 for Shot ROMEO, scheduled for 13 March. On 12 March, TAWAKONI towed a Project 1.4 barge (YCV-9) from Area Charlie to the Nan anchorage and, at 1635 hours, the ship departed Bikini enroute to its assigned operating area for Shot ROMEO with the barge in tow. After departing the lagoon TAWAKONI transferred tow of the barge to COCOPA (see section 3.4). Shot ROMEO was postponed due to unfavorable weather and TAWAKONI returned to Bikini and anchored in the Nan anchorage at 0821 hours, 13 March. Continued unfavorable weather delayed Shot ROMEO until 27 March. In the interim, TAWAKONI remained in the lagoon performing various duties as directed, primarily in support of Project 1.4 in Area Charlie. One exception to this routine occurred on 16 March when the ship was involved with activities associated with Project 6.4. At 0851 hours, TAWAKONI moored alongside YAG-40 and took on fuel. At 1110 hours, the ship proceeded to YAG-39 (also anchored at Nan), and moored alongside YAG-39 from 1133-1325 hours and again from 1510 to 1532 hours, when it returned to pick up a working party. On 16 March, topside intensities on the YAGs were less than 1 mR/hr; hence, any exposure associated with work performed topside on YAG-39 is insignificant (Reference 13).

At 1820 hours, 26 March, TAWAKONI departed Bikini in company with COCOPA enroute to their assigned operating areas for Shot ROMEO. When Shot ROMEO was detonated the next morning, TAWAKONI was approximately 30 nmi southeast of the ROMEO surface zero. After the shot, TAWAKONI rendezvoused with MOLALA at approximately 0900 hours and, at

1006 hours, the skeleton crew of YAG-39 transferred to TAWAKONI from MOLALA. The two ships remained in an area generally to the south of Bikini steaming on an east-west racetrack until approximately 1800 hours, when they turned to the northwest to intercept the YAGs. From the ship's log, it appears that TAWAKONI intercepted YAG-39 at approximately 2200 hours, 27 March, and it is likely that the skeleton crew was transferred to YAG-39 at this time. Apparently it was decided that, if YAG-39 was not significantly contaminated, the skeleton crew would board the ship and YAG-39 would steam back to Enewetak under its own power, as opposed to being towed by TAWAKONI.

A brief entry in TAWAKONI's log at 0756 hours, 28 March, implies the ship was preparing to enter Bikini Atoll; however, for unknown reasons, TAWAKONI returned to sea to stand by YAG-39. This ship had gone dead in the water 4 1/2 hours after Shot ROMEO, and it is possible that the skeleton crew had encountered difficulties in reactivating the ship's propulsion or in controlling the ship from their remote position. At approximately 1500 hours, 28 March, TAWAKONI, in company with YAG-39, proceeded on a westerly course toward Enewetak, arriving there at approximately 0900 hours, 29 March.

TAWAKONI remained at Enewetak until 1841 hours on 30 March when it got underway for Bikini. It is assumed this ship received the second wave of ROMEO fallout that descended on Enewetak between the afternoon of 29 March and noon, 30 March. The topside intensity on TAWAKONI resulting from this fallout, as corrected in the Appendix for the ship, is depicted in figure 16.

TAWAKONI arrived at Enewetak at approximately 1500 hours on 31 March and anchored in the Tare anchorage. The ship remained in the southern anchorages until 3 April, when it departed for Enewetak Atoll. TAWAKONI remained at Enewetak until approximately 0630 hours on 6 April when it got underway for its assigned operating area for Shot KOON, approximately 30 nmi southeast of surface zero on Eneman Island, Bikini Atoll (figure 2).

After Shot KOON on 7 April, TAWAKONI returned to the lagoon that evening and anchored in the Nan anchorage off Eneu Island. With the exception of several short sorties to the northern anchorage areas on 10, 12, and 13 April, where it provided some support for Project 1.4, TAWAKONI remained in the southern anchorage off Eneu Island until the afternoon of 15 April, when it got underway for its assigned operating area for Shot UNION. Due to unfavorable weather, Shot UNION was postponed and TAWAKONI returned to the lagoon during the late afternoon of 16 April; the ship anchored in Area Dog at 1940 hours.

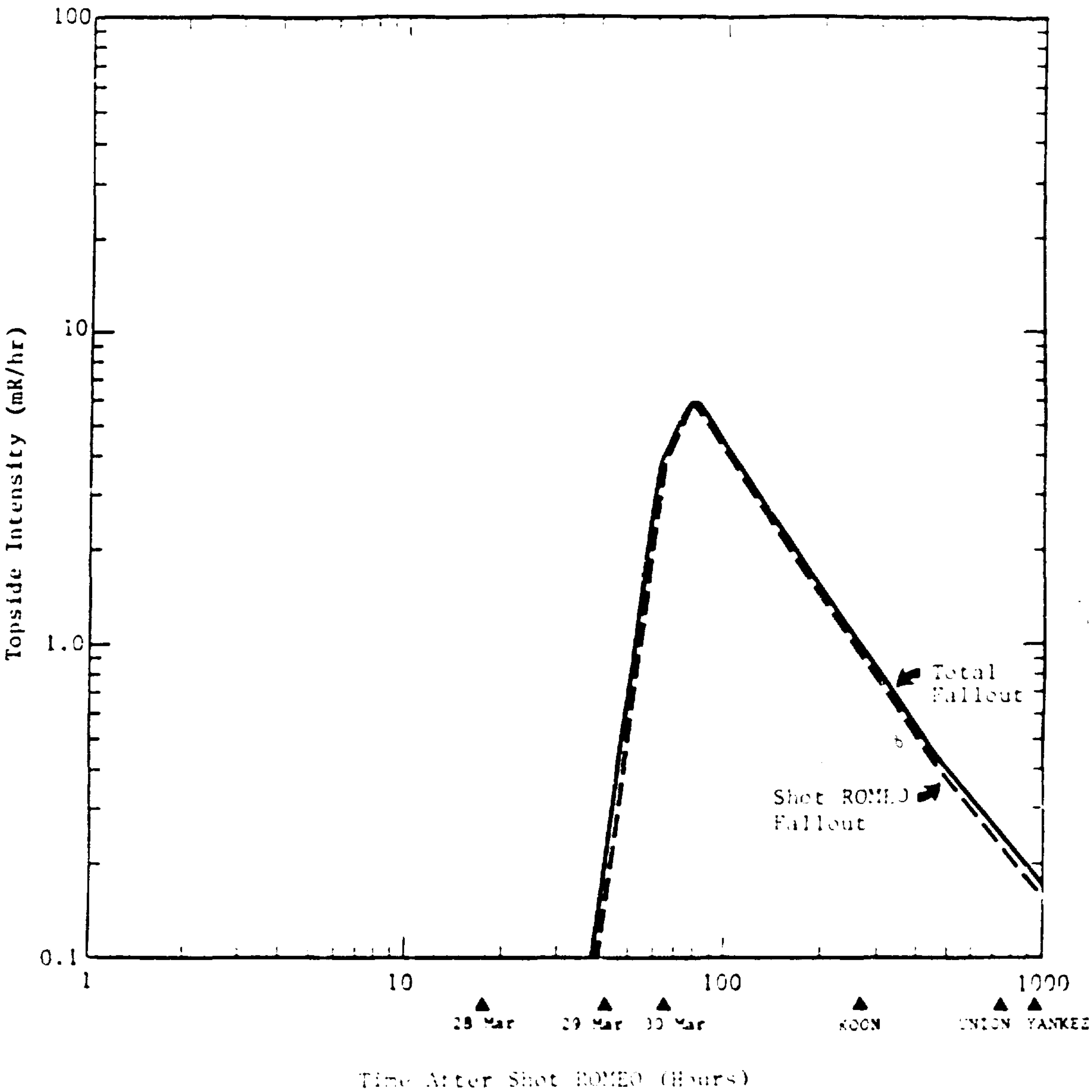


Figure 16. Estimated topside intensity on USS TAWAKONI (ATF-114) following Shot ROMEO.

Continued bad weather resulted in repeated postponements of the UNION test, ultimately rescheduled for 26 April. Between 17-23 April, TAWAKONI remained in an anchorage between Bikini and Eneu (see figure 4) until 24 April, when it got underway for Enewetak. The ship arrived at Enewetak on 25 April and remained anchored in the lagoon until Shot UNION was detonated at Bikini on 26 April. During the period 27-29 April, TAWAKONI assisted USS SIOUX (ATF-75) in laying out buoys in an area north of Enewetak Atoll in support of an over-water fallout collection experiment for Shot NECTAR. TAWAKONI got underway from Enewetak at approximately 1700 hours on 30 April, enroute to Bikini Atoll, arriving there during the morning of 1 May.

During the period 1-4 May, TAWAKONI provided direct support for Project 1.4 preparations for Shot YANKEE. Transfer of Project 1.4 support to TAWAKONI from COCOPA was necessitated by COCOPA becoming radiologically contaminated during Project 1.4 recovery operations following Shot UNION--see section 3.4. This included laying moors, buoys, and instrument cans in Areas Fox and Dog (see figure 4) prior to Shot YANKEE, scheduled for 5 May. At 1600 hours, 4 May, with Project 1.4 preparations for Shot YANKEE complete, TAWAKONI got underway for its assigned operating area approximately 60 nmi southeast of surface zero.

Shot YANKEE was detonated at 0610 hours, 5 May. Fallout and contaminated lagoon water resulting from Shot YANKEE significantly increased radiation levels in the Nan anchorage area (Reference 7). As a result, TAWAKONI did not return to Bikini until approximately 0800 hours, 6 May; by this time intensity levels in the Nan anchorage had decreased to 7 mR/hr (Reference 8). Between 1803 and 1926 hours, 6 May, and again between 1120 and 1746 hours on 7 May, TAWAKONI joined COCOPA (section 3.4) and MENDER (section 3.5) in washing down LCUs and barges that remained in the lagoon for the YANKEE detonation and had received primary fallout from the YANKEE cloud (Reference 3).

TAWAKONI remained in or near the Nan anchorage until 1608 hours, 8 May, when it got underway from Bikini enroute to Pearl Harbor with a Project 1.4 barge (YCV-9) in tow. The ship arrived at Pearl Harbor on 18 May and did not return to the PPG during Operation CASTLE.

The daily contributions to the integrated free-field intensity on USS TAWAKONI resulting from Shots BRAVO and ROMEO fallout, and from ship contamination, are detailed in table 8 for the period 1 March to 31 May 1954. The topside exposure includes shine from the

Table 8. Daily integrated intensity, USS TAWAKONI (ATF-114).

March	Integrated Intensity (mR) Topside Fallout	Integrated Intensity (mR) Topside Shine	Integrated Intensity (mR) Below Contam	April	Integrated Intensity (mR) Topside Fallout	Integrated Intensity (mR) Topside Shine	Integrated Intensity (mR) Below Contam	May	Integrated Intensity (mR) Topside Fallout	Integrated Intensity (mR) Topside Shine	Integrated Intensity (mR) Below Contam
1 (BRAVO)	28.4	3.9*	0	1	70.2	0.4	4.9	1	5.1	3.0	6.6
2	91.9	1.8*	0	2	54.0	0.7	5.6	2	4.9	2.6*	13.8
3	49.9	17.7*	21.2	3	43.3	0.5	5.2	3	4.7	2.5*	15.5
4	26.6	25.1*	101	4	37.5	0	3.1	4	4.6	0.8	10.9
5	16.7	15.7	90.2	5	30.1	0	3.0	5 (YANKEE)	4.5	0	1.3
6	11.6	14.2*	69.9	6	25.9	0	2.9	6	4.3	172*	36.9
7	8.6	14.7*	56.5	7 (KOON)	22.6	0.2	2.8	7	4.2	168*	78.7
8	6.7	11.1	46.1	8	19.9	0.9	4.5	8	4.1	22.3*	44.2
9	5.4	17.9	39.3	9	17.7	0.9	5.0	9	4.0	0	1.2
10	4.4	22.4	33.5	10	15.9	2.0	4.5	10	3.9	0	1.2
11	3.7	28.2*	29.6	11	14.4	0.8	4.1	11	3.8	0	1.2
12	3.2	14.7	22.1	12	13.1	1.4	4.0	12	3.7	0	1.2
13	2.7	2.5	14.8	13	12.0	0.9	3.2	13	3.6	0	1.1
14	2.4	14.0	19.9	14	11.1	0.7	3.9	14 (NECTAR)	3.5	0	1.1
15	2.1	21.3	19.4	15	10.3	0.9	3.1	15	3.4	0	1.1
16	1.9	11.3*	17.4	16	9.7	0.6	2.4	16	3.3	0	1.1
17	1.7	11.3	16.2	17	9.1	1.7	4.6	17	3.3	0	1.1
18	1.5	16.6	15.2	18	8.7	0.7	3.7	18	3.2	0	1.1
19	1.4	9.4*	13.9	19	8.2	0.6	3.8	19	3.1	0	1.0
20	1.3	2.6*	13.0	20	7.8	0.6	3.8	20	3.0	0	1.0
21	1.2	3.4	10.3	21	7.5	0.6	3.7	21	3.0	0	1.0
22	1.1	1.6	9.4	22	7.1	0.6	3.6	22	2.9	0	1.0
23	1.0	0.6	10.2	23	6.8	0.6	3.5	23	2.9	0	1.0
24	1.0	0.6	9.9	24	6.5	0.4	3.0	24	2.8	0	1.0
25	0.9	0.5	9.5	25	6.3	0	1.7	25	2.8	0	0.9
26	0.9	0.5	7.9	26 (UNION)	6.0	0	1.6	26	2.7	0	0.9
27 (ROMEO)	0.9	0	4.4	27	5.8	0	1.6	27	2.6	0	0.9
28	1.1	0	4.2	28	5.6	0	1.6	28	2.6	0	0.9
29	36.0	0	4.0	29	5.4	0	1.5	29	2.6	0	0.9
30	124	0	3.8	30	5.2	0	1.5	30	2.5	0	0.9
31	96.6	0.1	3.7					31	2.5	0	0.9

* Includes contribution while alongside contaminated YAGs, LCUs, and barges.

contaminated YAGs, LCUs, and barges when TAWAKONI was moored near those vessels on the days indicated, and shine from contaminated lagoon water.

3.8 USS PC-1546.

PC-1546 was approximately 30-35 nmi east-southeast of Bikini Atoll when Shot BRAVO was detonated at 0645 hours, 1 March 1954. The ship remained in this general area until approximately 0800 hours when, due to fallout on several of the task force ships (BAIROKO, ESTES, and PHILIP), all ships were ordered to proceed on a southerly course that would take them out of the fallout area (Reference 7). Thus, PC-1546 escaped the early BRAVO fallout; however, at approximately 1100 hours the ship was directed to proceed northwest toward Bikini (Reference 3) and about noon it began receiving significant fallout from the BRAVO cloud. Topside intensities increased rapidly and by the time fallout ceased at 1900 hours, the average topside intensity on PC-1546 was 90 mR/hr (Reference 7). When fallout started, the entire crew, with the exception of the CO who remained topside maneuvering the ship through rainshowers in an effort to wash down the weather decks, and members of the Damage Control team that came topside to perform hourly radiological surveys, were ordered below (Reference 15). It is assumed that, after 1900 hours, crew routines were reestablished since, at about this time, PC-1546 began providing screen for PHILIP, BELLE GROVE, GYPSY, and COCOPA (Reference 3). Figure 17 depicts the average topside intensity on PC-1546 from 1200 hours, 1 March (H+5.3), to 0800 hours, 8 March (H+169.3). There is no entry in the ship's deck log that the crew engaged in any decontamination efforts after 1 March; however, accelerated decay rates between H+25 and H+37, and again after H+49 (see figure 17), are indicative of efforts to decontaminate the ship on 2 and 3 March, either by hosing down the weather surfaces or by intentionally maneuvering the ship through rainshowers.

PC-1546 reentered Bikini Lagoon briefly to refuel on 2 March, before continuing its anti-submarine warfare (ASW) patrol south of the atoll. The ship was relieved of its patrol duties at approximately 1300 hours on 3 March, and anchored in the Nan anchorage area at 1450 hours. During the period 4-23 March, PC-1546 provided ASW patrols outside Bikini Lagoon on approximately 10 occasions, each lasting between 12 and 48 hours, anchoring or mooring in the lagoon between each patrol.

At 1830 hours on 23 March, the ship departed Bikini enroute to Enewetak Atoll, arriving Enewetak at 0846 hours on 24 March. It remained at anchor in the lagoon in an un-named berth north of Parry Island (see figure 3) from 24 to 31 March. It is assumed PC-1546 received

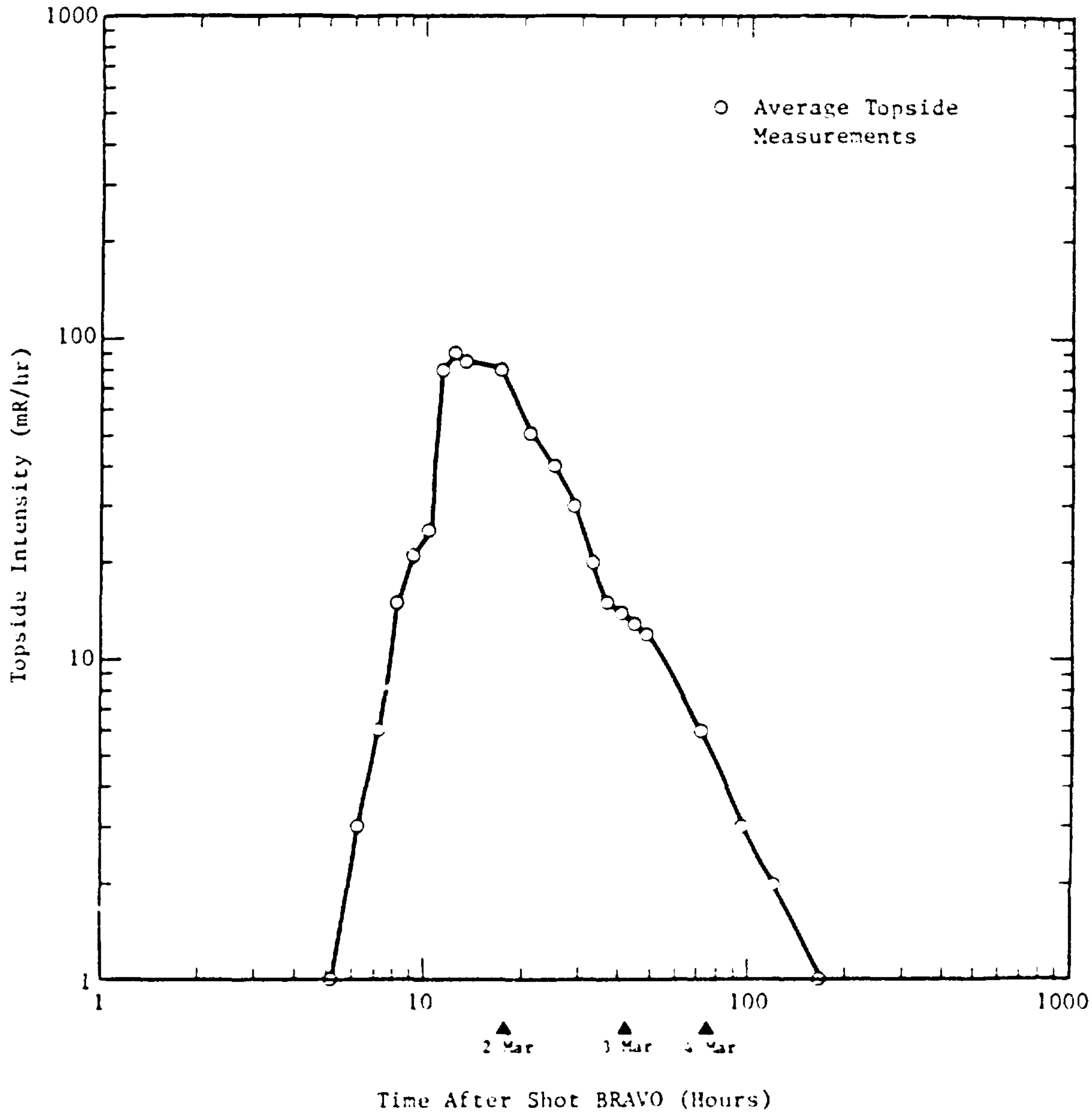


Figure 17. Topside intensity on USS PC-1546 following Shot BRAVO.

the same fallout as Parry Island between 1700 hours, 27 March and 1200 hours, 30 March; the radiation environment on Parry Island resulting from Shot ROMEO fallout, as corrected for shipboard use in the Appendix, is depicted in figure 18 (Reference 1).

At 1744 hours on 31 March, PC-1546 got underway for Bikini Atoll, where it made a brief stop between 0735 and 0833 hours on 1 April, prior to resuming its ASW patrols around that atoll. The ship conducted three such patrols on 1, 9, and 10 April, each lasting 1-2 days. On 5 April, PC-1546 departed Bikini enroute to its assigned operating area for Shot KOON in the vicinity of Ailinginae Atoll, approximately 50 nmi east-southeast of Bikini (see figure 6). Shot KOON was detonated on Eneman Island, Bikini Atoll, at 0620 hours, 7 April; PC-1546 departed Ailinginae Atoll at 0928 hours, 7 April, and arrived back at Bikini at 1928 hours the same day.

Late in the evening of 13 April, PC-1546 got underway from Bikini enroute to Rongerik Atoll, arriving Rongerik at 0918 hours on 14 April (see figure 1). The ship remained at Rongerik for Shot UNION on 26 April and did not return to Bikini until approximately 0700 hours, 27 April. The light fallout that was detected on several of the ships in the Nan anchorage during the evening of 26 April and early morning of 27 April is assumed to have not affected PC-1546.

Three more ASW patrols were conducted by PC-1546 in the vicinity of Bikini Atoll between 27 April and 2 May. At 1828 hours on 2 May, PC-1546 was again underway from Bikini for Rongerik Atoll. The ship remained at Rongerik for Shot YANKEE on 5 May, and on 6 May proceeded to Kwajalein Atoll, arriving there at 1649 hours. PC-1546 departed Kwajalein on 7 May en route to Pearl Harbor via Johnston Island, and did not return to Enewetak or Bikini during the remainder of Operation CASTLE.

The daily contributions to the integrated free-field radiation environment on USS PC-1546 resulting from Shots BRAVO and ROMEO fallout, shine from contaminated lagoon water, and from ship contamination are detailed in table 9 for the period 1 March-31 May 1954.

3.9 USS LST-1146.

When Shot BRAVO was detonated on 1 March, LST-1146 was enroute from Japan to Pearl Harbor. Late in the evening of 1 March, the ship was directed to Guam, where it arrived on 6 March. On 8 March, LST-1146 departed Guam enroute to Enewetak Atoll, arriving on 14 March. On 16 March, after taking on cargo destined for Bikini, LST-1146 departed for Bikini

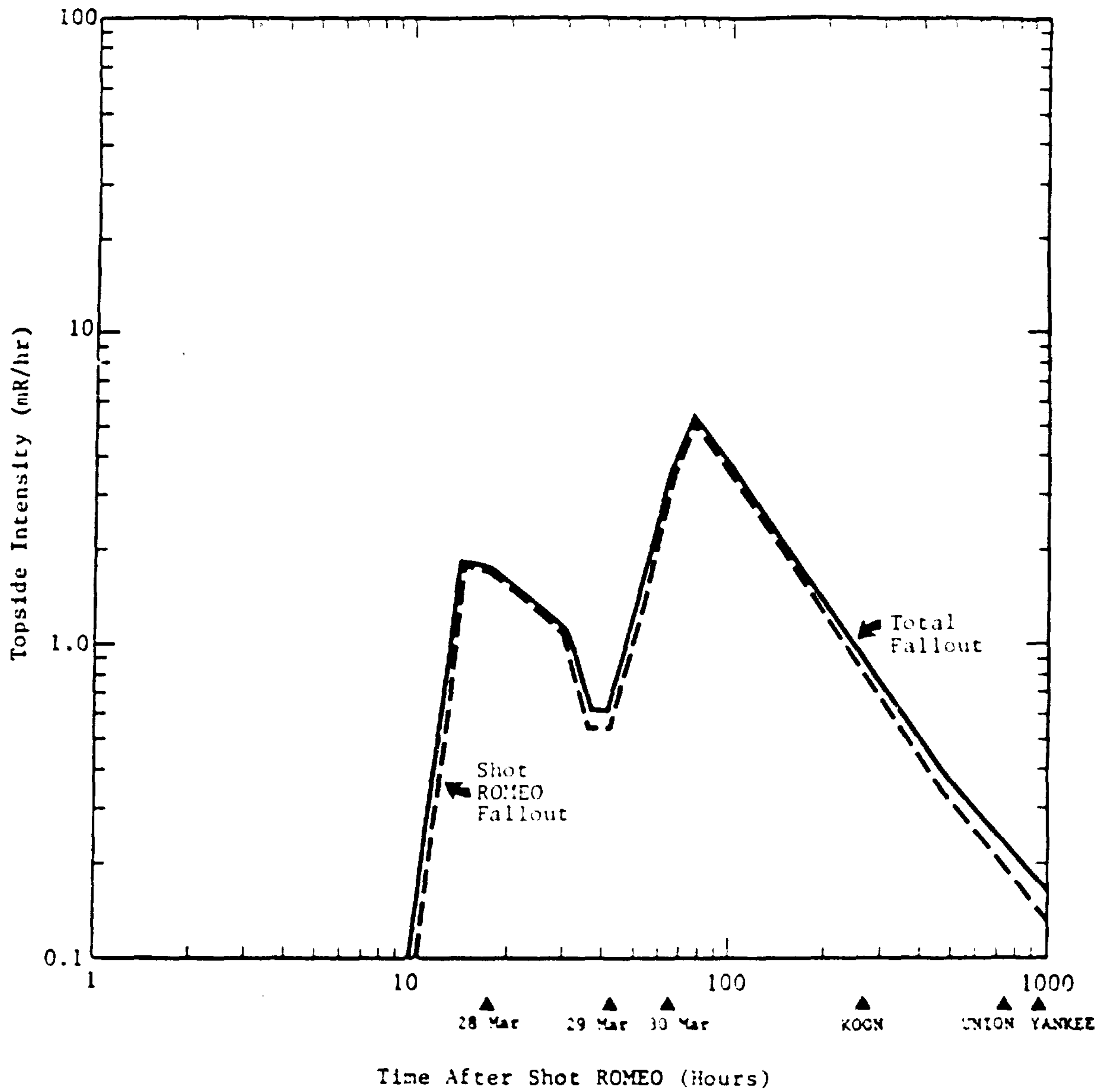


Figure 18. Estimated topside intensity on USS PC-1546 following Shot ROMEO.

Table 9. Daily integrated intensity, USS PC-1546.

March	Topside Fallout (mR)	Topside Shine (mR)	Below Contam (mR)
1 (BRAVO)	607	0	0
2	796	4.4	17.6
3	256	11.5	75.8
4	131	11.9	176
5	73.2	0	116
6	46.5	6.7	102
7	32.0	3.2	83.9
8	23.3	9.8	73.3
9	17.7	4.3	90.2
10	13.9	1.1	64.5
11	11.2	0	36.6
12	9.2	0.6	32.5
13	7.7	1.6	31.2
14	6.5	1.0	29.7
15	5.6	3.0	32.6
16	4.8	1.1	28.0
17	4.2	0.6	20.6
18	3.7	2.5	29.1
19	3.3	1.7	27.8
20	2.9	0.9	17.4
21	2.7	0.1	14.9
22	2.6	1.0	16.1
23	2.4	0.1	13.1
24	2.3	0	12.6
25	2.2	0	11.9
26	2.1	0	11.3
27 (ROMEO)	9.3	0	10.7
28	26.5	0	10.2
29	40.9	0	9.8
30	109	0	9.3
31	84.4	0	8.9

April	Topside Fallout (mR)	Topside Shine (mR)	Below Contam (mR)
1	61.6	0	8.5
2	47.6	0	8.2
3	38.3	0.2	8.2
4	31.7	0.3	10.1
5	26.9	0.1	8.8
6	23.2	0	7.1
7 (KOON)	20.3	0.2	6.9
8	18.0	0.9	10.1
9	16.1	0.4	8.9
10	14.5	0.4	6.3
11	13.2	0.4	6.6
12	12.0	0.8	9.8
13	11.1	0.3	7.2
14	10.2	0	5.5
15	9.5	0	5.3
16	8.9	0	5.1
17	8.4	0	5.0
18	8.0	0	4.9
19	7.6	0	4.7
20	7.3	0	4.6
21	7.0	0	4.5
22	6.7	0	4.4
23	6.4	0	4.3
24	6.1	0	4.2
25	5.9	0	4.1
26 (UNION)	5.7	0	4.0
27	5.5	2.1	9.3
28	5.3	0.9	6.1
29	5.1	0	3.7
30	4.9	0.3	4.2

May	Topside Fallout (mR)	Topside Shine (mR)	Below Contam (mR)
1	4.8	0.2	4.5
2	4.6	0.1	3.5
3	4.5	0	3.4
4	4.4	0	3.3
5 (YANKEE)	4.2	0	3.3
6	4.1	0	3.2
7	4.0	0	3.1
8	3.9	0	3.1
9	3.8	0	3.0
10	3.7	0	3.0
11	3.6	0	2.9
12	3.5	0	2.9
13	3.4	0	2.8
14 (NECTAR)	3.4	0	2.8
15	3.3	0	2.7
16	3.2	0	2.7
17	3.1	0	2.6
18	3.1	0	2.6
19	3.0	0	2.5
20	2.9	0	2.5
21	2.9	0	2.5
22	2.8	0	2.4
23	2.8	0	2.4
24	2.7	0	2.3
25	2.7	0	2.3
26	2.6	0	2.3
27	2.6	0	2.2
28	2.5	0	2.2
29	2.5	0	2.2
30	2.4	0	2.1
31	2.4	0	2.1

where, on 17 March, the ship beached on Eneman Island at 1753 hours. The cargo was off-loaded during the evening of 17 March and, on 18 March, cargo destined for Enewetak was onloaded. LST-1146 departed for Enwetak at 1632 hours on 18 March and arrived at approximately noon the following day. The ship remained at Enewetak until 22 March, when it made another round trip to Bikini, returning to Enewetak on 25 March.

When Shot ROMEO was detonated at Bikini Atoll on 27 March, LST-1146 remained anchored at Enewetak. During the early evening of 27 March, Enewetak Atoll received relatively minor fallout from the Shot ROMEO cloud. Fallout commenced at approximately 1700 hours and peaked at 2100 hours with average intensities of 3 mR/hr being reported on Parry Island; it is assumed LST-1146 received similar fallout during the evening of 27 March.

Another period of fallout occurred at Enewetak during the late evening of 28 March, but did not peak until approximately noon on 30 March (see figure 18). At 1248 hours, 29 March, while fallout was still occurring at Enewetak, LST-1146 departed for Bikini. Since the Shot ROMEO cloud was approaching Enewetak from the east, and LST-1146 was steaming on an easterly course, cessation of fallout on the ship occurred somewhat earlier than it did on Enewetak, where it peaked at noon on 30 March. Further, since the duration of fallout on the ship was less than on Enewetak, there is a corresponding decrease in peak shipboard intensities when compared to the 9 mR/hr peak on Enewetak. When the cloud's trajectory and the ship's course and speed are superimposed, fallout deposition on LST-1146 terminates at approximately 0200 hours on 30 March, with an estimated peak intensity of 7.5 mR/hr. An entry in the deck log of LST-1146 at 1802 hours, 29 March, which states "Secured number 1 fire and flushing pump and put number 2 on line.", indicates that the crew was aware of the fallout at this time and was conducting washdown. At 0200 hours, 30 March, LST-1146 passed LST-551 "abeam to port on reverse course, distance 3 1/2 miles." At this time radiation intensities onboard LST-551 were 12 mR/hr and decreasing (this ship had encountered fallout approximately 24 hours earlier while anchored at Bikini--Reference 1). The fact that intensities on LST-551 were decreasing as it passed LST-1146 indicates that neither ship was receiving fallout at this time; therefore, the estimated time of fallout cessation on LST-1146 (0200 hours, 30 March) may be high-sided. The topside radiation environment on LST-1146 resulting from ROMEO fallout is depicted in figure 19; no reduction in the topside intensity due to efforts to decontaminate the ship during fallout is assumed.

LST-1146 arrived at Bikini at approximately 1800 hours, 30 March. It remained at Bikini in the vicinity of Eneman Island (see figure 4) until 1849 hours, 1 April, when it got underway for Enewetak. LST-1146 remained at Enewetak until 4 April when, at 1147 hours, it

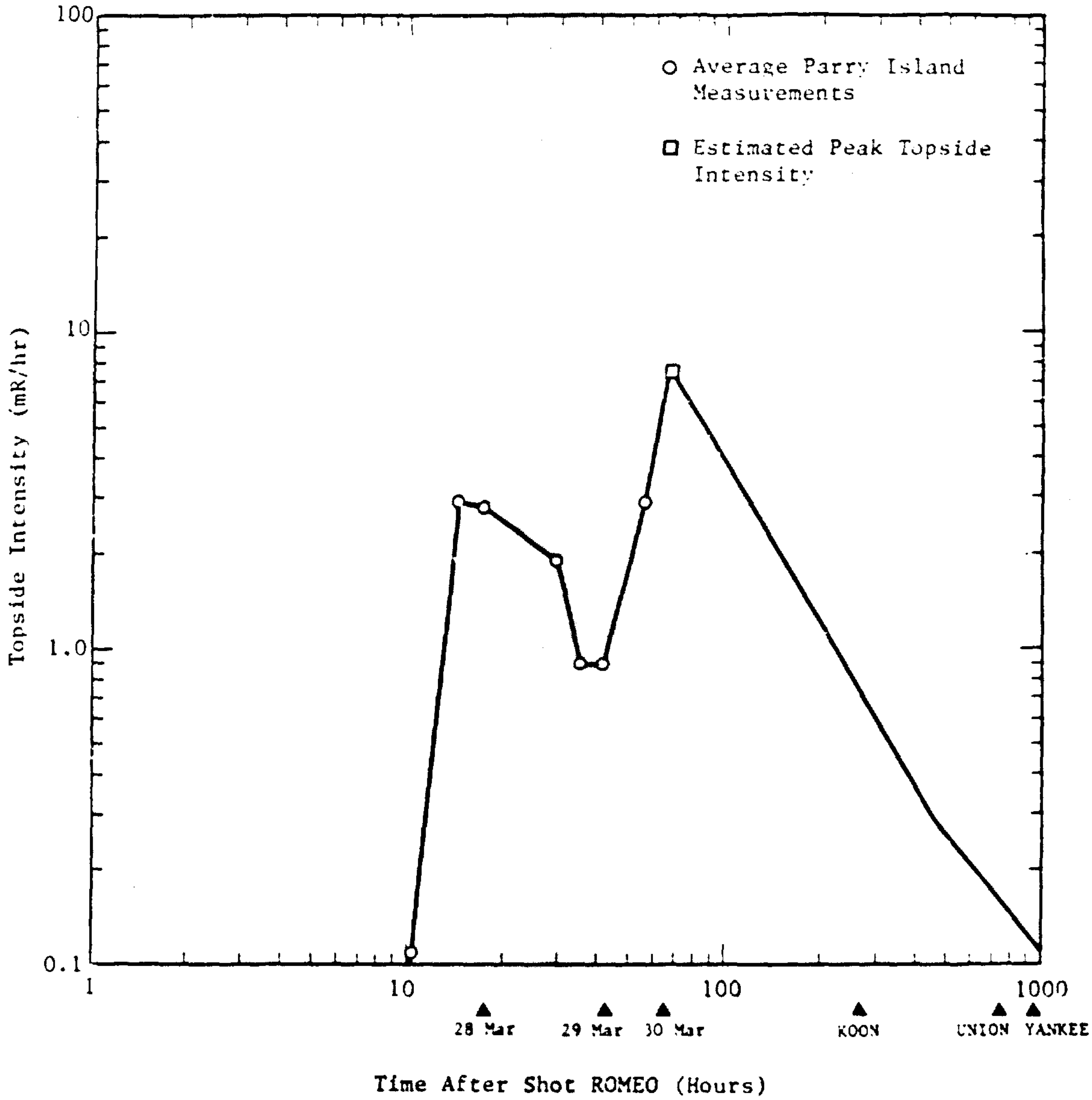


Figure 19. Estimated topside intensity on USS LST-1146 following Shot ROMEO.

got underway for Pearl Harbor. This ship did not return to Bikini or Enewetak during the remainder of Operation CASTLE.

Table 10 details the daily contributions to the integrated free-field radiation environment on USS LST-1146 resulting from Shot ROMEO fallout, shine from contaminated lagoon water, and from ship contamination while in Bikini Lagoon during the period 17 March to 31 May 1954.

Table 10. Daily integrated intensity, USS LST-1146.

March	Integrated Intensity (mR) Topside Fallout	Topside Shine	Below Contam	April	Integrated Intensity (mR) Topside Fallout	Topside Shine	Below Contam	May	Integrated Intensity (mR) Topside Fallout	Topside Shine	Below Contam
1 (BRAVO)				1	63.4	0.3	4.3	1	3.3	0	1.2
2				2	47.0	0	2.8	2	3.2	0	1.2
3				3	36.5	0	2.7	3	3.1	0	1.2
4				4	29.3	0	2.6	4	3.0	0	1.2
5				5	24.1	0	2.5	5 (YANKEE)	2.9	0	1.1
6				6	20.2	0	2.4	6	2.8	0	1.1
7				7 (KOON)	17.3	0	2.4	7	2.7	0	1.1
8				8	14.9	0	2.3	8	2.7	0	1.1
9				9	13.1	0	2.2	9	2.6	0	1.0
10				10	11.5	0	2.1	10	2.5	0	1.0
11				11	10.3	0	2.1	11	2.5	0	1.0
12				12	9.2	0	2.0	12	2.4	0	1.0
13				13	8.3	0	1.9	13	2.3	0	1.0
14				14	7.6	0	1.9	14 (NECTAR)	2.3	0	1.0
15				15	6.9	0	1.8	15	2.2	0	0.9
16				16	6.4	0	1.8	16	2.2	0	0.9
17	0	0.2	0.3	17	6.1	0	1.7	17	2.1	0	0.9
18	0	0.6	4.2	18	5.7	0	1.7	18	2.1	0	0.9
19	0	0	5.1	19	5.5	0	1.6	19	2.0	0	0.9
20	0	0	4.7	20	5.2	0	1.6	20	2.0	0	0.9
21	0	0	4.4	21	4.9	0	1.6	21	1.9	0	0.8
22	0	0	4.2	22	4.7	0	1.5	22	1.9	0	0.8
23	0	0.1	3.9	23	4.5	0	1.5	23	1.9	0	0.8
24	0	0.4	4.6	24	4.3	0	1.4	24	1.8	0	0.8
25	0	0	4.1	25	4.1	0	1.4	25	1.8	0	0.8
26	0	0	3.9	26 (UNION)	4.0	0	1.4	26	1.7	0	0.8
27 (ROMEO)	12.3	0	3.7	27	3.8	0	1.3	27	1.7	0	0.8
28	41.0	0	3.5	28	3.7	0	1.3	28	1.7	0	0.8
29	69.1	0	3.4	29	3.5	0	1.3	29	1.6	0	0.8
30	144	0.1	3.3	30	3.4	0	1.3	30	1.6	0	0.7
31	91.1	0.4	4.1					31	1.6	0	0.7

SECTION 4

DOSE CALCULATIONS

To determine the dose to personnel, consideration is given to the time spent topside and below decks and the radiation protection afforded by a ship. The daily, free-field integrated intensities (topside and below) from section 3 are adjusted to account for crew activities, either documented or assumed. The daily exposures (mR) are then converted to film badge equivalence (mrem). Results are presented as a daily cumulative dose to personnel through 31 May 1954, or into the post-operational period as necessary until shipboard dose accrual falls below 1 mrem per day.

An estimate of personnel movements is critical in determining a film badge dose, especially during fallout deposition and at early times when topside intensities are relatively high and intensity levels are changing through decontamination. Only two of the ships considered herein experienced significant fallout from Shot BRAVO--COCOPA and PC-1546. A review of the ship's logs gives no indication that normal crew duties were interrupted on 1 and 2 March due to the fallout; however, because intensity levels were still relatively high on these two ships, it is necessary to account for specific periods of time on deck in order to calculate personnel doses. Shot ROMEO fallout, on the other hand, peaked at approximately 0001-0400 hours, 29 March, on several of the ships while anchored in Bikini Lagoon. Rad-safe measures, such as turning on the ship's washdown system, were generally accomplished at a time when virtually all of the crew was already below deck. By the time crews were mustered at approximately 0800, shipboard intensity levels had been reduced to where normal crew duties could be resumed without restriction; hence, it is not necessary to detail personnel movements onboard the task group ships following Shot ROMEO to estimate their dose. Fallout from the remaining four shots in the CASTLE series did not seriously hamper normal crew activities on any of the ships considered herein; therefore, dose estimates for the crews of these ships are made without detailing personnel movements onboard ship during periods of fallout deposition.

With the exception of 1-2 March on COCOPA and PC-1546, when actual times topside and below are used, the integrated intensities topside due to fallout (from tables in section 3) are multiplied by a time-averaged shielding factor to account for the time spent topside and below during a typical work day. As discussed in section 1, the time spent below was 60 percent of the day (14 1/2 hours). While below, the crew was offered shielding provided by the ship's structure. In Reference 1, it was determined that ship-shielding factors vary from approximately 0.06 to

0.15, depending on the main deck thickness. A time-averaged shielding factor is computed as 0.4 + 0.6 x ship-shielding factor, where the 0.4 and 0.6 represent the fraction of the day spent topside and below, respectively. The time-averaged shielding factors vary from approximately 0.44 to 0.49. An average value of 0.46 (corresponding to a ship-shielding factor of 0.1) is used in this analysis.

The integrated intensities topside due to "shine" from contaminated water and/or ships (including LCUs and barges) is apportioned to account for time spent topside. No contribution to dose from shine is assumed for the time that the crew was below, as the radiation transport of the shine field to below is less effective than that of fallout on deck. Thus, the typical crew received 40 percent of the integrated intensity from shine.

In addition to being exposed to a fraction of the topside (fallout) radiation environment, crew members below were exposed to radiation from the ship's hull and saltwater systems that became contaminated while in the radioactive waters of Bikini Lagoon. Because the crew was below for an estimated 14 1/2 hours per day, they received 60 percent of the integrated intensity below due to ship contamination. No contribution to dose from ship contamination is assumed for the periods that crew were topside.

The appropriately adjusted contributions to exposure (R) from each "source," i.e., fallout, shine, and ship contamination, are summed and converted to an equivalent film badge dose (rem). The conversion factor has been determined to be 0.7 rem/R (Reference 5).

It is emphasized that the calculated dose is only applicable to a "typical" crewmember aboard each ship. Only those contributions to dose that impact the entire crew are used in the dose equation. For instance, increased topside exposure due to being moored alongside contaminated LCUs and barges affects the entire crew; hence, contributions from this source are considered. Individual exposures accrued while performing decontamination work onboard these craft are not considered, as they do not impact the dose for the entire crew. It is assumed that personnel who had a potential for exposure while performing "non-typical" crew duties were badged, and that dose is in addition to the calculated doses presented herein. The following sub-sections describe the dose calculations for shipboard personnel.

4.1 DOSE CALCULATIONS FOR USS RECLAIMER (ARS-42).

The assumed contamination on RECLAIMER resulting from Shot UNION fallout was minor and normal crew activities were not likely changed because of it. A daily dose is calculated by multiplying the integrated intensities topside from fallout and shine (from table 3) by 0.46 and 0.4, respectively; the integrated intensity below from ship contamination is multiplied by 0.6. Contributions from each source are summed and converted to a film badge dose. Table 11 details the cumulative film badge dose for the crew of RECLAIMER through 31 May 1954, by which time dose accrual falls below 1 mrem per day.

Table 11. Calculated film badge dose, USS RECLAIMER (ARS-42).

	Cumulative dose (mrem) through:		
Day	March	April	May
1			248
2			264
3			277
4			284
5			285
6			286
7			287
8		8	288
9		25	289
10		46	289
11		67	290
12		84	291
13		98	292
14		103	292
15		105	293
16		106	293
17		107	294
18		109	295
19		110	295
20		112	296
21		114	296
22		115	297
23		117	297
24		118	298
25		120	298
26		126	299
27		143	299
28		162	300
29		198	300
30		226	300
31			301

4.2 DOSE CALCULATIONS FOR USS SHEA (DM-30).

The only documented fallout on SHEA was minor contamination following Shot UNION. Normal crew activities onboard SHEA would not have been altered because of this fallout. A daily dose is calculated by multiplying the integrated intensities topside from fallout and shine (from table 4) by 0.46 and 0.4, respectively; the integrated intensity below from ship contamination is multiplied by 0.6. The cumulative film badge dose for the crew of SHEA through 31 May 1954, by which time dose accrual falls below 1 mrem per day, is detailed in table 12.

Table 12. Calculated film badge dose, USS SHEA (DM-30).

	Cumulative dose (mrem) through:		
Day	March	April	May
1		5	304
2		6	323
3		7	337
4		9	346
5		10	348
6		11	349
7		13	351
8		19	352
9		52	353
10		83	354
11		109	355
12		129	356
13		134	357
14		136	358
15		138	358
16		139	359
17		141	360
18		143	361
19		144	361
20		145	362
21		146	363
22		148	363
23		149	364
24		149	365
25		150	365
26		153	366
27		175	366
28		207	367
29	0	249	368
30	2	280	368
31	3		369

4.3 DOSE CALCULATIONS FOR USS COCOPA (ATF-101).

Dose calculations for COCOPA on 1-2 March 1954, when BRAVO fallout was encountered, are detailed in table 13. Time periods below deck are indicated by an asterisk (*). After 2 March, a daily dose is calculated by multiplying the integrated intensities topside from fallout and shine (from table 5) by 0.46 and 0.4, respectively; the integrated intensity below from ship contamination is multiplied by 0.6. Contributions from each source are summed and converted to a film badge dose. Cumulative film badge doses are given in table 14. Dose calculations are carried out through 22 June 1954, when dose accrual falls below 1 mrem per day.

Table 13. Dose calculations for USS COCOPA (ATF-101) on 1-2 March 1954.

Day	Time Period	Integrated Fallout Intensity (mR)	x	Ship Shielding Factor	=	Adjusted Exposure (mR)
1 March	0000-0600*	0				
	0600-1200	0				
	1200-1330*	5.0		0.1		0.5
	1330-1700	51.7		1.0		51.7
	1700-1800*	42.0		0.1		4.2
	1800-2000	166.6		1.0		166.6
	2000-2400*	362.5		0.1		36.3
		627.8 (table 5)				259.3

1 March fallout dose = (259.3 mR) (0.7 mrem/mR) = 181.5 mrem (table 14)

Day	Time Period	Integrated Fallout Intensity (mR)	x	Ship Shielding Factor	=	Adjusted Exposure (mR)
2 March	0000-0800*	476.1		0.1		47.6
	0800-1200	98.2		1.0		98.2
	1200-1330*	30.0		0.1		3.0
	1330-1700	70.0		1.0		70.0
	1700-1800*	19.0		0.1		1.9
	1800-2000	36.9		1.0		36.9
	2000-2400*	65.7		0.1		6.6
		795.9 (table 5)				264.2

2 March fallout dose = (264.2 mR) (0.7 mrem/mR) = 184.9 mrem.

Dose from shine and ship contamination = 18.3 mrem.

Cumulative film badge dose through 2 March = 385 mrem (table 14).

Table 14. Calculated film badge dose, USS COCOPA (ATF-101).

Day	Cumulative dose (mrem) through: March	April	May	June
1	182	1285	1935	2194
2	385	1309	1939	2195
3	566	1327	1944	2197
4	689	1343	1950	2198
5	754	1356	1953	2199
6	801	1367	2047	2201
7	828	1377	2099	2202
8	849	1386	2126	2203
9	869	1395	2128	2204
10	893	1403	2135	2205
11	917	1410	2137	2207
12	931	1417	2140	2208
13	942	1423	2142	2209
14	955	1429	2149	2210
15	968	1436	2157	2211
16	984	1440	2165	2212
17	999	1444	2170	2213
18	1012	1450	2172	2214
19	1021	1454	2174	2216
20	1029	1460	2176	2217
21	1037	1464	2177	2218
22	1044	1469	2179	2219
23	1054	1473	2181	2220
24	1061	1477	2182	2221
25	1067	1480	2184	
26	1073	1485	2185	
27	1076	1600	2187	
28	1085	1654	2188	
29	1175	1739	2190	
30	1218	1879	2191	
31	1259		2193	

4.4 DOSE CALCULATIONS FOR USS MENDER (ARSD-2).

Although MENDER received fallout following Shots ROMEO and UNION, it occurred either at such a time or at such low levels that routine crew duties were probably not interrupted by its presence. A daily dose is calculated by multiplying the integrated intensities topside from fallout and shine (from table 6) by 0.46 and 0.4, respectively; the integrated intensity below from ship contamination is multiplied by 0.6. Contributions from each source are summed and converted to a film badge dose. Cumulative film badge doses are given in table 15 for the period 24 March 1954 to 22 June 1954, when dose accural falls below 1 mrem per day.

Table 15. Calculated film badge dose, USS MENDER (ARSD-2).

	Cumulative dose (mrem) through:			
Day	March	April	May	June
1		314	1107	1468
2		346	1124	1469
3		372	1137	1471
4		392	1145	1472
5		409	1148	1473
6		423	1308	1474
7		435	1412	1476
8		447	1426	1477
9		457	1428	1478
10		466	1431	1479
11		475	1433	1480
12		483	1435	1482
13		492	1437	1483
14		498	1439	1484
15		504	1441	1485
16		509	1443	1486
17		514	1445	1487
18		520	1446	1488
19		525	1448	1489
20		529	1450	1490
21		534	1452	1491
22		537	1453	1492
23		541	1455	
24	0	544	1456	
25	5	547	1458	
26	10	559	1459	
27	12	598	1461	
28	28	657	1462	
29	155	839	1464	
30	220	1085	1467	
31	274		1467	

4.5 DOSE CALCULATIONS FOR USS MOLALA (ATF-106).

MOLALA experienced relatively light fallout following Shots BRAVO, ROMEO, and NECTAR, and routine crew duties were probably not altered by its occurrence. A daily dose is calculated by multiplying the integrated intensities topside from fallout and shine (from table 7) by 0.46 and 0.4, respectively; the integrated intensity below from ship contamination is multiplied by 0.6. Contributions from each source are summed and converted to a film badge dose. Cumulative film badge doses are given in table 16 and have been carried out through 31 May 1954, by which time dose accural falls below 1 mrem per day.

Table 16. Calculated film badge dose, USS MOLALA (ATF-106).

	Cumulative dose (mrem) through:		
Day	March	April	May
1	10	907	1137
2	39	917	1139
3	55	926	1140
4	64	933	1141
5	69	940	1311
6	73	945	1312
7	76	950	1314
8	78	955	1563
9	80	990	1621
10	81	994	1649
11	82	997	1672
12	86	1000	1673
13	93	1003	1708
14	103	1006	1710
15	113	1008	1733
16	121	1010	1745
17	129	1013	1748
18	136	1017	1750
19	143	1020	1752
20	149	1022	1754
21	154	1025	1755
22	159	1028	1756
23	164	1031	1758
24	169	1033	1759
25	174	1036	1760
26	178	1114	1761
27	180	1116	1762
28	320	1117	1763
29	414	1119	1764
30	431	1120	1765
31	893		1766

4.6 DOSE CALCULATIONS FOR USS TAWAKONI (ATF-114).

Only light fallout from Shots BRAVO and ROMEO occurred aboard TAWAKONI and normal crew duties were probably not altered by its presence. A daily dose is calculated by multiplying the integrated intensities topside from fallout and shine (from table 8) by 0.46 and 0.4, respectively; the integrated intensity below from ship contamination is multiplied by 0.6. Contributions from each source are summed and converted to a film badge dose. Cumulative film badge doses through 10 June 1954, when dose accrual falls below 1 mrem per day, are given in table 17.

Table 17. Calculated film badge dose, USS TAWAKONI (ATF-114).

	Cumulative dose (mrem) through:			
Day	March	April	May	June
1	10	578	767	999
2	40	599	775	1000
3	70	614	784	1001
4	128	627	790	1002
5	176	638	792	1003
6	213	647	857	1004
7	244	656	939	1005
8	268	664	965	1006
9	291	672	966	1007
10	313	680	968	1008
11	335	687	970	
12	349	693	972	
13	357	698	973	
14	370	704	975	
15	385	709	976	
16	396	713	978	
17	406	718	979	
18	418	723	981	
19	427	727	982	
20	433	731	984	
21	439	736	985	
22	444	740	986	
23	449	743	988	
24	453	747	989	
25	458	750	990	
26	461	752	992	
27	464	755	993	
28	466	757	994	
29	479	760	995	
30	520	762	996	
31	553		998	

4.7 DOSE CALCULATIONS FOR USS PC-1546.

Dose calculations for PC-1546 on 1-2 March 1954, when BRAVO fallout was encountered, are detailed in table 18. Time periods below deck are indicated by an asterisk (*). After 2 March, a daily dose is calculated by multiplying the integrated intensities topside from fallout and shine (from table 9) by 0.46 and 0.4, respectively; the integrated intensity below from ship contamination is multiplied by 0.6. Contributions from each source are summed and converted to a film badge dose. Cumulative film badge doses are given in table 19 and are carried out through 11 July 1954, when dose accrual falls below 1 mrem per day.

Table 18. Dose calculations for USS PC-1546 on 1-2 March 1954.

Day	Time Period	Integrated Fallout Intensity (mR)	x	Ship Shielding Factor	=	Adjusted Exposure (mR)
1 March	0000-0600*	0				
	0600-1200	0.4		1.0		0.4
	1200-1900*	189.7		0.1		19.0
	1900-2100	171.4		1.0		171.4
	2100-2400*	245.5		0.1		24.6
		607.0 (table 9)				215.4

1 March fallout dose = (215.4 mR) (0.7 mrem/mR) = 150.8 mrem (table 19)

Day	Time Period	Integrated Fallout Intensity (mR)	x	Ship Shielding Factor	=	Adjusted Exposure (mR)
2 March	0000-0800*	431.9		0.1		43.2
	0800-1200	138.6		1.0		138.6
	1200-1330*	42.2		0.1		4.2
	1330-1700	75.4		1.0		75.4
	1700-1800*	18.2		0.1		1.8
	1800-2000	31.8		1.0		31.8
	2000-2400*	57.9		0.1		5.8
		796.0 (table 9)				300.8

2 March fallout dose = (300.8 mR) (0.7 mrem/mR) = 210.6 mrem.

Dose from shine and ship contamination = 8.6 mrem.

Cumulative film badge dose through 2 March = 370 mrem (table 19).

Table 19. Calculated film badge dose, USS PC-1546.

Cumulative dose (mrem) through:

Day	March	April	May	June	July
1	151	1215	1423	1490	1530
2	370	1234	1426	1492	1531
3	488	1250	1429	1494	1532
4	607	1264	1432	1495	1533
5	679	1277	1434	1496	1534
6	739	1287	1437	1498	1535
7	786	1296	1440	1500	1536
8	827	1307	1442	1501	1537
9	871	1316	1445	1502	1538
10	903	1323	1447	1504	1539
11	922	1330	1449	1505	1540
12	939	1339	1452	1507	
13	955	1345	1454	1508	
14	970	1351	1456	1509	
15	986	1356	1459	1511	
16	1000	1361	1461	1512	
17	1010	1366	1463	1513	
18	1024	1371	1465	1515	
19	1037	1375	1467	1516	
20	1046	1379	1469	1517	
21	1053	1383	1471	1518	
22	1061	1387	1473	1520	
23	1067	1391	1475	1521	
24	1073	1395	1476	1522	
25	1079	1399	1478	1523	
26	1084	1402	1480	1524	
27	1092	1408	1482	1526	
28	1105	1413	1484	1527	
29	1122	1416	1485	1528	
30	1161	1419	1487	1529	
31	1192		1489		

4.8 DOSE CALCULATIONS FOR USS LST-1146.

Shot ROMEO was the only test that resulted in fallout on LST-1146. The fallout was relatively light and probably did not alter routine crew duties onboard the ship. A daily dose is calculated by multiplying the integrated intensities topside from fallout and shine (from table 10) by 0.46 and 0.4, respectively; the integrated intensity below from ship contamination is multiplied by 0.6. Contributions from each source are summed and converted to a film badge dose. Cumulative film badge doses through 31 May 1954, by which time dose accrual falls below 1 mrem per day, are given in table 20.

Table 20. Calculated film badge dose, USS LST-1146.

	Cumulative dose (mrem) through:		
Day	March	April	May
1		162	291
2		178	293
3		191	294
4		202	296
5		210	297
6		218	298
7		225	300
8		230	301
9		235	302
10		240	304
11		244	305
12		248	306
13		251	307
14		255	308
15		258	309
16		261	310
17	0	263	311
18	2	266	312
19	4	268	313
20	6	271	315
21	8	273	316
22	10	275	316
23	11	277	317
24	14	279	318
25	15	281	319
26	17	283	320
27	22	285	321
28	37	286	322
29	61	288	323
30	108	290	324
31	140		324

SECTION 5

UNCERTAINTY ANALYSIS

The uncertainty in calculated film badge doses for typical crewmembers is estimated from the underlying parameters. The basic uncertainties in the topside environment include radiation intensities from fallout deposited on deck, shine from contaminated lagoon water, and shine from contaminated ships alongside. Uncertainties in the conversion from topside environment to personnel dose include the time spent on deck, the positions of personnel (hence their exposure) on deck, and the shielding from fallout afforded to those below. Uncertainties in the radiation environment below due to ship contamination are dominated by the modeled buildup levels and rates of the radioactive material accumulated on the ship's hull and interior saltwater systems. The average intensities therefrom in representative crew spaces and the crew's time spent below are additional sources of uncertainty in personnel dose.

Intensity levels from fallout on deck are determined from shipboard radiological survey data, supplemented at late times by decay rates measured on Bikini Atoll. Individual meter readings on deck, where available, are taken as accurate, their inherent error having a negligible influence on the overall uncertainty in dose. Average on-deck intensity as a function of time is taken as accurate; the power law interpolation in time between surveys closely approximates fission product decay at the times after burst considered. Power law fitting is less accurate during fallout deposition and decontamination; however, the influence of this uncertainty is minimized because the typical crewmember was below during these intervals. Where shipboard data are unavailable, intensity data from neighboring islands are used with appropriate correction factors to minimize systematic error. Overall, error in on-deck intensity from fallout is usually small compared to other uncertainties. A possible uncertainty that is unquantifiable is whether decontamination took place subsequent to the latest shipboard intensity readings, if any. The ship logs did not always indicate decontamination activities; however, none are presumed without evidence.

For exposures involving shine from contaminated water, the dominant uncertainty is that in the water intensity. Both the estimation of land-equivalent radiation levels from nearby islands and their variation over the space of the operating areas contribute to water intensity uncertainty. The conversion factor from water to topside intensity is good to 10 percent based on the data of Reference 12. Where actual water intensities were reported, the shine therefrom is considered to be without error. Additional uncertainties in dose from those in decay and the land-water intensity correlation are secondary and are not quantified. Based on intensities depicted in Reference 2, the uncertainties in shine are estimated in table 21.

Table 21. Uncertainty in water intensity at operating sites.

Shot	Location	H+1 Land Intensity (R/hr)	D+1 Water Intensity (mR/hr)	Uncertainty
BRAVO	NAN	150	10.5	±50%
	TARE	50	3.5	±20%
	CHARLIE, DOG, FOX, GEORGE	1000	70	±50%
	HOW	500	35	±50%
ROMEO	CHARLIE	1000	70	±80%
KOON	TARE	500	35	±50%
	CHARLIE	7	0.5	±30%
	DOG	50	3.5	±50%
	FOX	100	7.0	±50%
	GEORGE	120	8.4	±20%
	HOW	25	1.75	±50%
UNION	NAN	7	0.5	±50%
	DOG, South of	100	7.0	±30%
	FOX, GEORGE	200	14	+100,-0%
	HOW	150	10.5	±50%
YANKEE	NAN	100	7.0	±50%
	FOX	1400	100	±80%

For the exposures of each crew, the water intensities are taken to have systematic errors by the stated amounts. Thus, the overall uncertainties in shine dose are calculated with all high-sided and all low-sided intensities used in series for the upper and lower limits, respectively, of the total shine dose.

The uncertainty in shine from proximity to contaminated ships is dominated by the uncertainty in intensity on those ships. Apart from YAG-39 and YAG-40, these vessels were usually encountered in the Nan anchorage, and thus have a 50-percent uncertainty in the fallout deposition thereon. With the ship geometries as obtained from Reference 17 and the radiation transport calculations as validated by the YAG-to-YAG shine data, the overall uncertainty in average topside intensity from ship shine is also about ±50 percent. As the YAG-39 to YAG-40 intensity ratio was consistent to within 25 percent of the mean on 12 of 14 comparisons made from Reference 13, and the computed ratio was within 20 percent of the observed mean, topside intensities based on YAG intensities are likely accurate to about ±20 percent.

The value for the fraction of time spent on deck is estimated to be accurate within ±20 percent for the average crewmember. For the typical day, this corresponds to about 8 to 11 1/2 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 total dose is reasonably high-sided by treating the uncertainty in time on deck as a systematic error; as such, the ±20 percent applies to all topside contributions to the total dose as well. Actually, only for the dose from fallout is the topside time fraction the leading quantified uncertainty. For shine, the typical 50 percent uncertainty in source intensity dominates. While the intensities on YAG-39 and YAG-40 were more accurately known, the brief exposures to them limit the applicability of long-term estimates of uncertainty in time spent topside. Thus, no such uncertainty is quantified for a typical MOLALA crewmember.

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

Reference 1 investigated the impact on the spatial variability of topside intensities on the distribution of crewmember doses. While data from YAG-30 and YAG-40 indicated considerable variation in readings across ship decks, the overall impact on personnel dose was small--about 10 to 20 percent for the ships analyzed in Reference 1. The distribution in personnel dose from this source for the ships of this report is likewise small. Wider distributions of personnel dose can be attributed to individual or rating-related variations in the time spent topside. An extreme example is the shine dose to MOLALA from the YAGs. Depending on their involvement with YAG-related activities, MOLALA crewmembers could have been entirely below to entirely topside during the YAG exposures. Thus, shine doses could range from nearly 0 to 2 1/2 times the calculated value.

The uncertainties in the parameters of the ship contamination model, as discussed in Reference 4, resulted in factor-of-three uncertainties in dose. However, a few data have emerged, such as on USS CURTISS as discussed in Reference 1, that suggest a much greater systematic accuracy than this for the model. Therefore, the present uncertainty analysis concentrates on the random variations of the parameters among ships. The largest such uncertainty is that in the saturation level of contaminants. The bounding S-values for each type of ship, as determined in Reference 4, are used. For destroyers, these are 1257 and 2683; for patrol craft, 1624 and 3092; and for all other ships, 1172 and 2820.

The degree to which the ship apportionment factor, F_a, may be unrepresentative of average crew positions below was estimated in Reference 4 as a factor of 1.5. This is used herein except for PC-1546, which has an apportionment factor of .67, vice the .39 or .33 of the other ship types in this report. Where little shielding is afforded by a ship, its fractional uncertainty tends to be less. Actually, fractional uncertainties are more constant for the quantity $1\text{-}F_a$. On this basis, a value of $.67 \pm .10$ is estimated for PC-1546.

The water intensities affect the time to saturation. However, except where ships moved frequently from one environment to another, the rate of buildup of contamination has only a modest effect on doses. Compared to the previous uncertainties, that in time spent below also has a minor impact on the dose from ship contamination.

Calculations are made involving coupled treatments of those components of dose based on water intensities. All attendant parameters are taken as systematically high-sided to determine an upper limit in dose (or low-sided for the lower limit). Thus, the highest water intensities, saturation levels, and apportionment factors are used throughout a crew's operational exposure to determine the combined upper-limit dose from ship contamination plus water shine. The uncertainties are taken to be systematic to obtain the greatest credible range of dose as well as to facilitate the partition of calculated doses into periods for comparison with film badge dosimetry (section 6).

These doses are combined with those from fallout and ship shine to determine the total dose. By class, the doses are independent, thus their attendant uncertainties are combined as the square root of the sum of squares. The upper and lower uncertainties are considered separately, reflecting the asymmetry in the ship contamination dose distribution. The results are presented in table 22. Because of the manner of estimation needed for some of the component uncertainties, no confidence level is ascribed to the total uncertainty range.

Table 22. Summary of uncertainties.

Crewmembers in:	Uncertainty in Dose from: Fallout	Ship Shine	Water Shine + Ship Contamination	Total Uncertainty
USS RECLAIMER	35±7	0	266^{+391}_{-124}	300^{+390}_{-120}
USS SHEA	49±10	0	320^{+397}_{-160}	370^{+400}_{-160}
USS COCOPA	1027±205	128±64	1066^{+1145}_{-430}	2200^{+1200}_{-500}
USS MENDER	571±114	215±108	706^{+503}_{-162}	1500^{+500}_{-200}
USS MOLALA	312±62	1208±242	246^{+262}_{-91}	1800±300
USS TAWAKONI	376±75	91±46	541^{+757}_{-286}	1000^{+800}_{-300}
USS PC-1546	865±173	0	675^{+406}_{-282}	1500^{+500}_{-300}
USS LST-1146	263±53	0	61^{+93}_{-30}	320^{+110}_{-60}

SECTION 6

FILM BADGE DOSIMETRY

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

In this section, available dosimetry data for each ship are analyzed for the purpose of comparison with the reconstructed doses for typical crew members. Cohort dosimetry is emphasized as most commonly reflecting typical activities. In analyzing cohort dosimetry, only those film badges whose recorded doses have been assigned to the cohort group are considered; lost or damaged badges (where the badge wearer has an assessed dose) are not included. Individual badges are considered during periods only when the entire crew was badged or when it is evident that only a portion of the crew was badged but the recorded doses were intended to be applicable to the unbadged portion of the crew (only dosimetry for RECLAIMER during the second badged period falls into this latter category of badging). The dosimetry data for each ship are depicted in this section by histograms, each representing a single badging period. Shown in each histogram are the number of film badges in each film badge dose "bin," e.g., 0-100 mrem, 100-200 mrem. Film badges recording a zero dose are accounted for in a separate dose bin. With each histogram is a summary of the corresponding dosimetry, including the dose dates for the badging period and the number of cohort film badges worn during that period. For comparison, the calculated film badge dose for the same period is also depicted. In many cases, badging periods are not well defined; detailed investigation was required to develop reasonable estimates of the actual periods represented by film badge records. Such estimated dates of film badge issue and turn-in are noted with each histogram.

Because of the above, coupled with the high percentage of cohort badging during Operation CASTLE, and because such badging was used to provide doses for unbadged personnel, it is necessary to evaluate the procedures employed for cohort badging, including an examination of the apparent irregularities. This evaluation is further prompted by a post-operation recommendation from the CO of USS CURTISS (AV-4) concerning badging procedures at Operation CASTLE, that every individual be issued a film badge; otherwise, because of the varying location of men at different times, there is no way possible of assigning an accurate dosage figure to men without badges (Reference 16). The purpose of this analysis is to evaluate the acceptability and validity for dose determination. It is necessary before utilizing the dosimetry data for comparisons with calculated doses. The analysis includes consideration of the following:

a) Percentage of the crew represented by valid cohort badges. For example, the 42 badges issued for a crew of 279 personnel in USS SHEA for the period 30 March-2 May reveals that 21 badges were listed as wet, missing, or lost. Personnel in these cohorts were apparently assigned doses of 200, 280, or 360 mrem.

b) Unique exposures of a cohort consisting of personnel whose enlisted ratings imply involvement in documented activities not typical of the average crew member. For example, for a one-day badging period (30 April) for USS COCOPA, there is a cohort of one Boatswain's Mate Chief (badged) and nine seamen; the reading is 785 mrem. There is an individual badge for the Chief Warrant Boatswain with a reading of 240 mrem. The remainder of valid cohort and individual badges for this ship for the same period are all less than or equal to 40 mrem. It is likely that the two individuals were directly involved in recovering instruments for Project 1.4. However, because of the difference between the two high readings, it is not clear that the 785 mrem reading is valid for all of the seamen in the cohort. Lacking further data, it is most prudent to assign the 785 mrem reading to these individuals but indicate that it is a high-sided assumption.

c) Readings of a small group of individual badges that are much higher than the remainder of the crew, when the entire crew was badged and where the enlisted ratings indicate that it is likely that these individuals were involved in activities that would have resulted in such exposures. For example, there are nine individual badges for the USS RECLAIMER over the period 28 April-3 May. These badges, with readings ranging from 760 to 2185 mrem, were assigned to several Boatswain's Mates, metalsmiths, a damage controlman and a seaman. This identifies them as the personnel directly involved in handling and/or securing contaminated mines and their doses are not compared to those calculated for the typical crew.

d) Cohort badges with readings that are markedly different from all other cohorts and whose badge wearer appears to be a poor exemplar for the cohort composition. For example, for the period 1 through 8 May on COCOPA, the badge wearer for a cohort of twelve enlisted men was a Hospital Corpsman First Class. He had a recorded reading of 3150 mrem. The cohort consisted of ships cooks, storekeepers, stewardsmen, and one seaman, most of whom were in the same cohort for three other badging periods, with readings of 190, 0, and 175 mrem (all below the overall averages for those periods). It is doubtful that a hospital corpsman could have received such a dose. Stipulating that he did, it is very unlikely that the other members of the cohort had similar exposures.

These and other similar examples, such as obvious alphabetical cohorts with disparate rating groups, generated a need to develop a set of rules for interpretation and evaluation of cohort badging data. The approach adopted is illustrated in tables 23 and 24. As indicated by the wording of the entries in the tables, the resultant two-step screening process is qualitative and requires experienced judgment in application. As applied in this evaluation, the process is a useful tool.

The first step, indicated in table 23, consists of a general evaluation of the apparent statistical validity of the results of cohort badging of a given unit for a given period. The results are then compared with the reconstructed dose for the period. If it is found that the average reading of the cohort badging for the period is significantly higher than the reconstructed dose, but the overall quality of the badging procedure is evaluated as low in all or nearly all of the criteria in the table, the reconstructed dose should be assigned. In all other cases, it may be advisable to assign the higher of the two values.

Table 24 summarizes the results of the cohort dosimetry analysis. In units with more than one cohort badging period, there are significant variations in the memberships of cohorts. Therefore, the table is applied to each badging period and in the context of the preceding evaluation in table 23. Where a cohort badge reading is significantly higher than the average of all the cohort badges for the period, but the validity of assignment of the indicated dose to an unbadged individual in the cohort is generally low, the calculated dose is more credible.

Figures 20 and 21 summarize the cohort dosimetry data available for RECLAIMER and SHEA, respectively. These two ships have similar exposure scenarios (both provided support for Project 3.4 during the same time-frame), and the radiation environments in which they operated

Table 23. Evaluation of cohort badging of a given unit for a given badging period.

CRITERIA	COHORT QUALITY High	Medium	Low
1. General composition of enlisted rating groups in each cohort	Implies high degree of commonality of duties, activities, location	Some members of cohort unlikely to have had commonality	No apparent effort toward commonality (e.g., alphabetical)
2. Variations of numbers in each cohort	Fairly uniform	Some variation	Very large (e.g., 8, 10, 10, 18, 31)
3. Percentage of crew represented by valid cohort badges	All or nearly all	1/2 to 2/3	Less than 1/2
4. Numbers of valid cohort badges (sample size)	Large	Modest	Very few
5. Distribution of valid cohort badge readings	Clustered (or bimodal) by likely activities, exposures	Moderate spread	Widely spread

Table 24. Applicability of a cohort badge reading to an individual in the cohort.

CRITERIA	APPLICABILITY		
	High	Medium	Low
1. Badge reading for the cohort vs. average of all cohorts and/or reconstructed dose	Close agreement	Within reasonable range	Obvious outlier
2. Likelihood that the badged member of the cohort received the indicated dose	Very likely	Reasonable	Unlikely
3. Cohort composition by rating group and implied commonality of duties, activities, location	Close commonality	Modest commonality	Little or no commonality
4. Implied duty commonality of individual under consideration and the badged member of cohort	Close commonality	Modest commonality	Little commonality

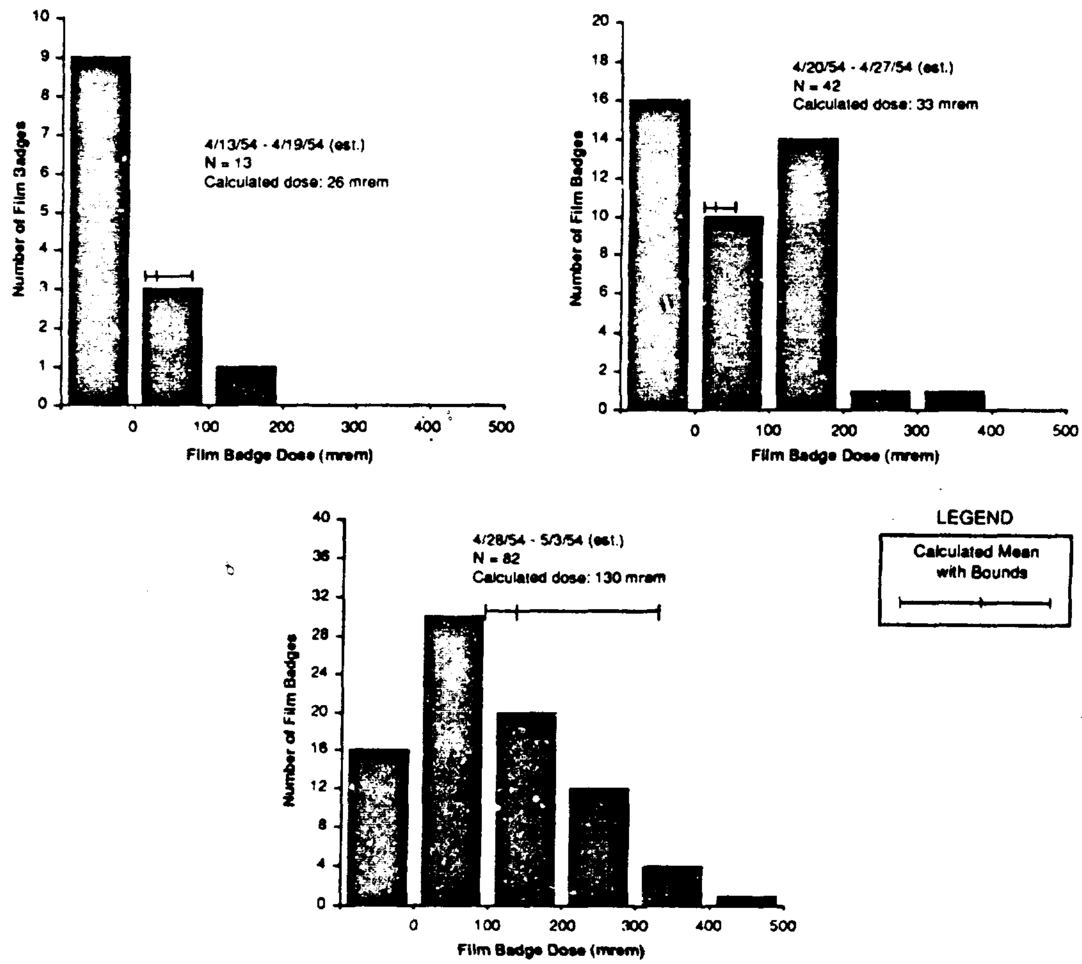


Figure 20. Film badge dosimetry for USS RECLAIMER (ARS-42).

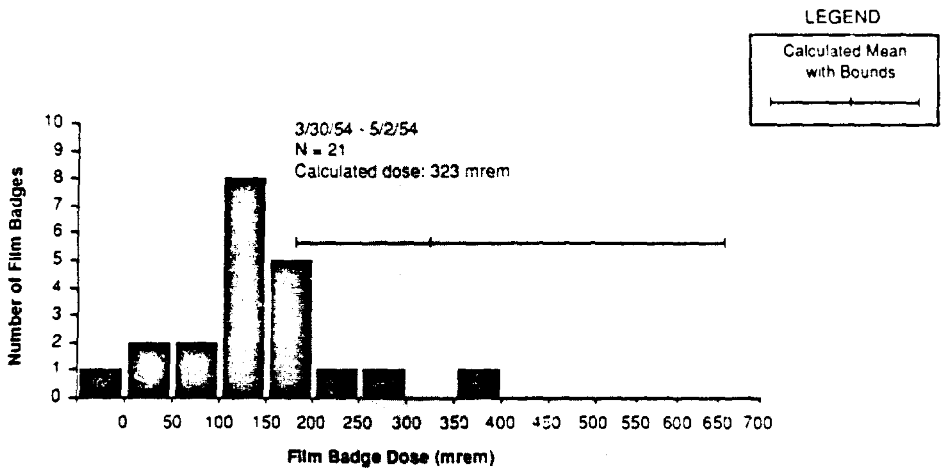


Figure 21. Film badge dosimetry for USS SHEA (DM-30).

are similar (light fallout following Shot UNION and working in the same contaminated waters of the lagoon); therefore, the dosimetry for these ships would be expected to reflect similar exposures to radiation during corresponding badging periods.

There are three badging periods on RECLAIMER, each being approximately one week long. During the first two periods (13-27 April), minimum exposure potential existed for the crew. Working in the northern lagoon, they were exposed only to very low levels of contaminated water. Although Shot UNION did result in some fallout on the ship during the evening of 26 April, crew exposure to this fallout is split about equally between the second and third badging periods--see table 3. The low potential for exposure is reflected in both the dosimetry data for RECLAIMER and calculated film badge doses for this ship during the period 13-27 April (figure 20). The last badging period for RECLAIMER starts the day the ship returned to the contaminated northern lagoon following Shot UNION to recover the Project 3.4 mines (28 April). Virtually the entire crew was badged during this period. A large majority of the film badges recorded doses of less than 500 mrem and are consistent with the calculated film badge dose for the typical crew of approximately 130 mrem (figure 20). The badges for nine individuals (identified previously) with doses greater than 700 mrem are not included in the figure. The significant difference in badge readings and the enlisted ratings of these personnel indicate that these men were likely directly involved in handling the contaminated mines as they were hoisted aboard the ship; thus, the doses they received are not typical.

Figure 21 shows the dose distribution of the cohort film badges on SHEA between 30 March and 2 May, the only badging period for this ship. The 21 wet, missing, or lost badges (reflecting assigned doses as previously discussed) are not included. The calculated film badge dose is higher than the average of the dosimetry data, which likely reflects that several of the cohorts with missing badges are composed of personnel whose rating groups would be expected to spend more than the average time topside. The loss of topside badges, which tend to show higher exposures, weights the average cohort dose toward the lower exposure value typical of badges used below-decks.

Figures 22 and 23 summarize the cohort dosimetry available for COCOPA and MENDER. These were the principal support ships for Project 1.4 (Underwater Pressure Measurements). However, as indicated in the figures, there are significant differences in the badging periods and the doses that represent differences in specific activities and exposures, as discussed in section 3.

Dosimetry for four badging periods for COCOPA is depicted in figure 22. Again, there are badges deleted as atypical that reflect unique activities of individuals or the cohorts represented. Two badges for the period 1-7 May with readings from 1300 to 1500 mrem for cohorts of 2 and 3 personnel are deleted as atypical. A third badge with an obviously anomalous reading of 3150 mrem is also deleted. This badge was worn by the ship's hospitalman and the cohort of 12 includes stewards, ship's cooks and storekeepers. While it is conceivable that the hospitalman may have uniquely experienced this high exposure, it is clearly not representative of the cohort or the crew.

A badge for a cohort of four with a reading of 1285 mrem is deleted from the final period for COCOPA (8-18 May). The rating of the badged individual, his badging history, and his other cohort assignments strongly indicate that he was one of the ship's divers and would therefore have been engaged in non-typical activities and exposures during this period.

As figure 22 shows, there is generally good agreement between the film badge dose and the calculated mean dose in three periods, subject to the observation that, in the second (10 March-29 April) and third (1-7 May) badge periods, the badge readings are unusally widely distributed, thereby suggesting the lack of a typical activity. The dosimetry in the last period apparently reflects some undocumented exposure(s).

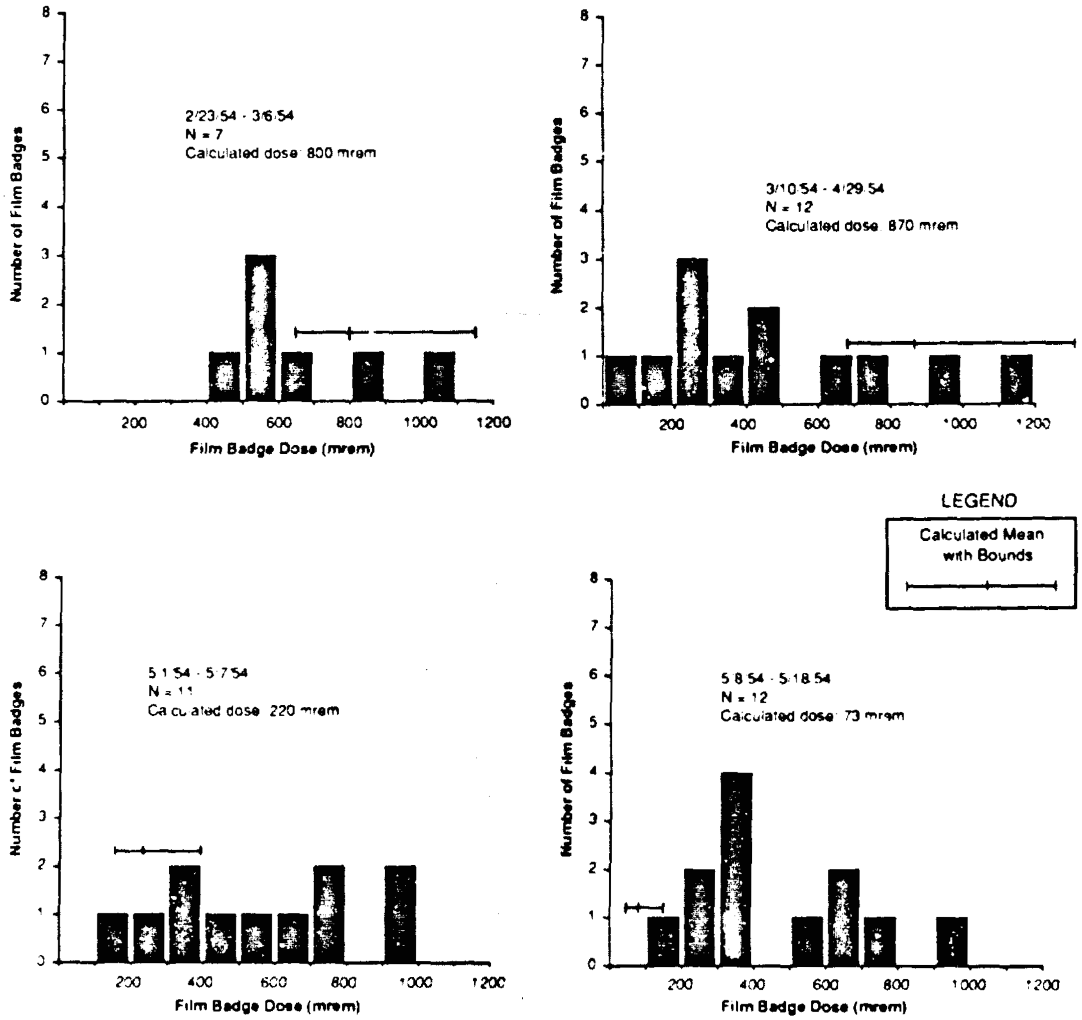


Figure 22. Film badge dosimetry for USS COCOPA (ATF-101).

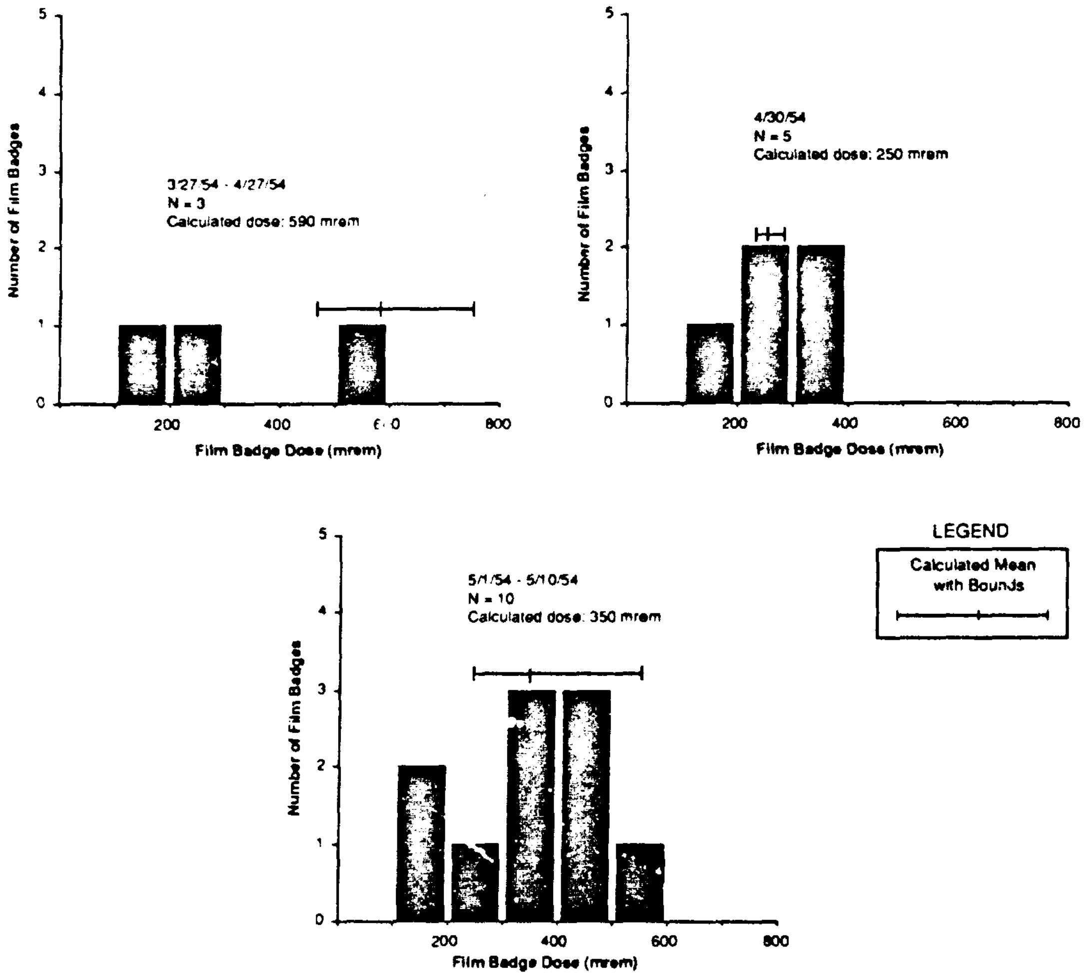


Figure 23. Film badge dosimetry for USS MENDER (ARS-2).

The MENDER dosimetry for three badging periods is shown in figure 23. The first period (27 March-27 April) includes an outlier at 1150 mrem for a cohort whose rating implies potential unique exposures from mine handling activities. Four higher cohort badges are not shown in the plot for the final badging period for MENDER (1-10 May). One badge, for a cohort of five seamen, is recorded at 5250 mrem; another, for a cohort of 4 enginemen, 3500 mrem. Two badges at 1000 and 1560 mrem, worn by a Boatswain's Mate and a Metalsmith, are also deleted as atypical.

The dosimetry data for MOLALA for six badging periods is shown in figure 24. All but the period 13-30 March show widespread badging of essentially the entire crew. Most of the badges lack issue or collection dates, but these are inferred from film number issue sequences and processing dates. Collection likely occurred one day before processing. The 13-30 March period consisted of 14 cohorts; one is listed as lost and another as wet. The distribution of the remaining 12 is shown in the plot. The date gap from 6 to 12 March is of no consequence as the ship's activities for this period result in a reconstructed dose of only 17 mrem.

Of greatest uncertainty is the 31 March-11 April badge period. However, as the dominant exposure within this period is shine from YAG-40 on 31 March, the precise closing date is not critical. This exposure suggests why many film badge readings are much below the calculated value; those personnel who remained below had little exposure potential.

The badging period of 12 April-2 May included three outliers with readings of 1580, 1620, and 3540 mrem. These were worn by a seaman, a Quartermaster, and a Boatswain's Mate and are deleted as atypical. Similarly, for the period 4-7 May, two badges with readings of 1200 and 1235 mrem worn by a Boatswain's Mate and a seaman are not plotted. For 8-16 May, Boatswain's Mates' readings of 1610 and 1740 mrem are excluded After deletion of high-reading outliers as representing unique exposure activities, the mean of film badge doses for the entire period of MOLALA's participation is quite close to the total reconstructed dose.

Figure 25 shows the available dosimetry data for TAWAKONI. All three of the periods (28 February-7 March, 12 March-3,4 May, and 3,4-8 May) utilized cohort badging. The reconstructed dose for the gap from 8 to 11 March is 91 mrem. An individual badge worn by a Metalsmith with a reading of 1100 mrem is deleted from the period 28 February-7 March. A cohort badge worn by the Warrant Machinist with a reading of 1065 mrem is deleted from the 3,4-8 May period.

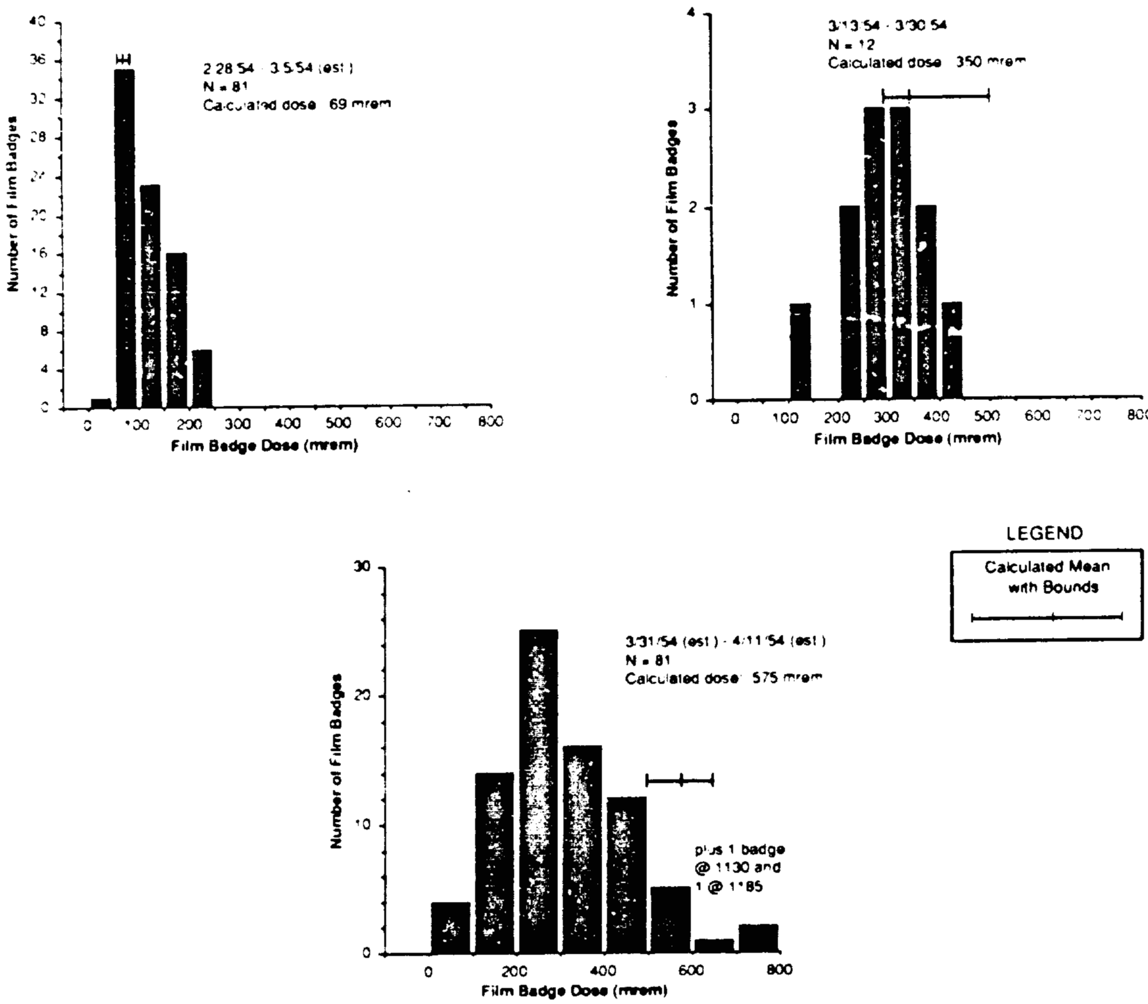


Figure 24. Film badge dosimetry for USS MOLALA (ATF-106).

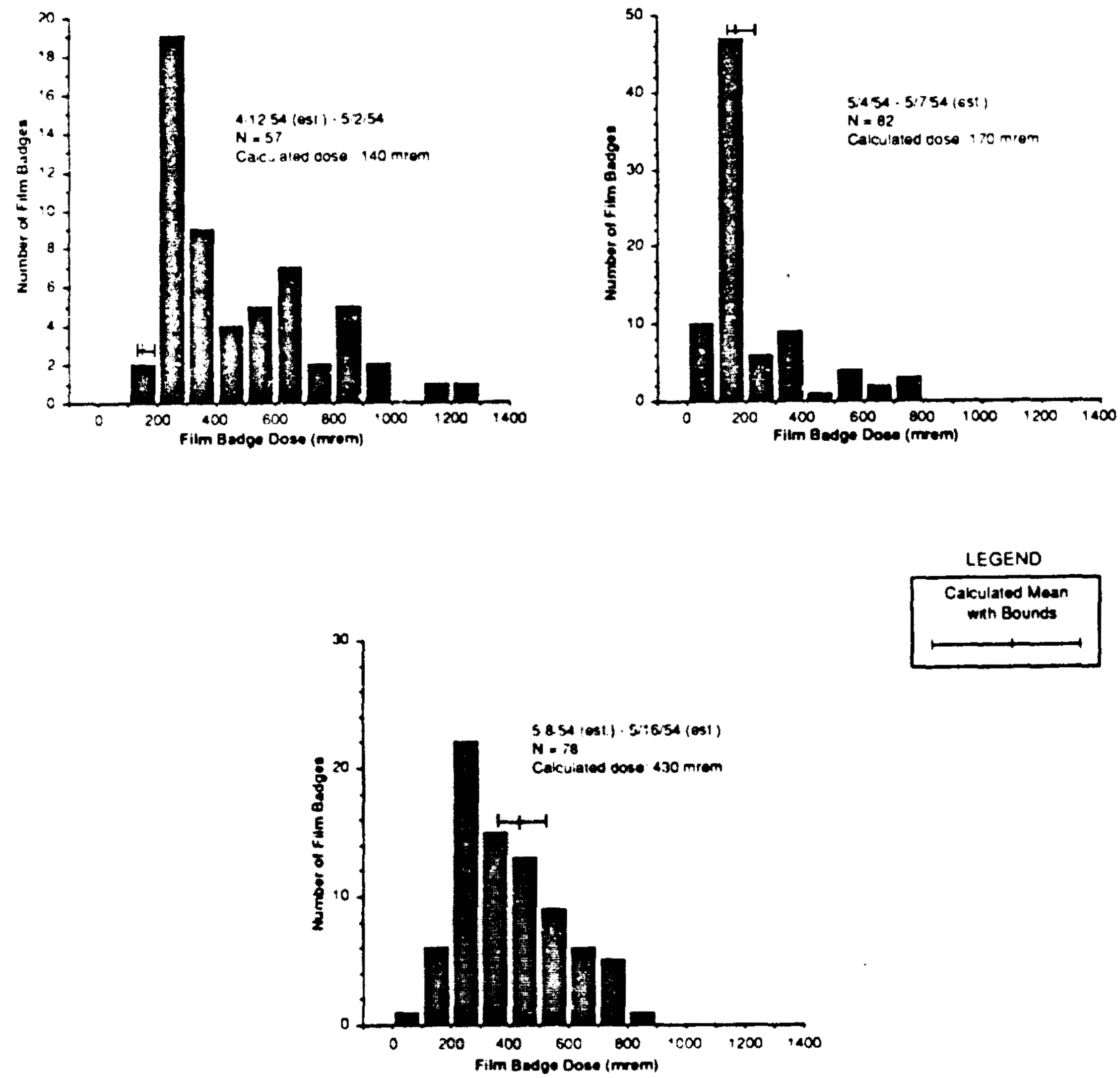


Figure 24. Film badge dosimetry for USS MOLALA (ATF-106) (Continued).

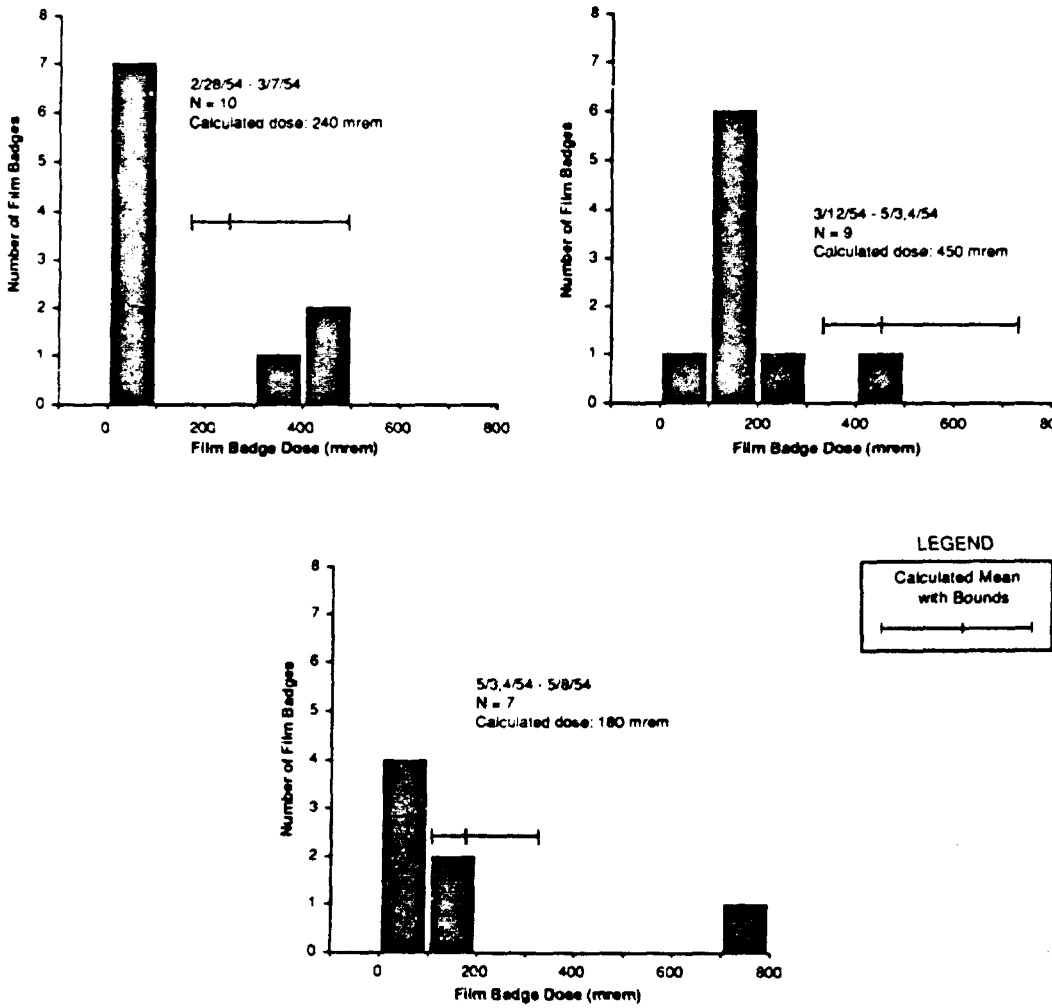


Figure 25. Film badge dosimetry for USS TAWAKONI (ATF-114).

As with MOLALA, after deletion of outliers, the mean of the film badge doses is reasonably close to the total reconstructed dose.

The dosimetry data for PC-1546 for two badging periods (24 February-6 March and 7 March-30 April) is plotted in figure 26. The numbers of valid cohort badges (N=4) for each period for the 62 personnel in this small ship weakens any inference that might be drawn from comparisons with the calculated dose for a typical crew member. Nonetheless, it is noteworthy that, within the available physical limits of a small PC, large differences in doses strongly imply unique activities. This was found to be the case in the first badging period for the cohort consisting of the Captain and Executive Officer. The Captain's badge, with a reading of 1600 mrem, was deleted as a result of recent telephone conversations with him, in which he stated that:

> *On the afternoon and early evening of Shot BRAVO day, after turning northward to return to Bikini, PC-1546 was alerted by other ships in the vicinity to fallout over their intended route. Lacking a washdown system and the pumping capacity for effective use of hoses to wash down the superstructure, I directed the entire crew to go below decks while I conned the ship alone from the flying bridge. I wore rain gear and, where possible, maneuvered the ship under rain clouds to achieve some degree of washdown.*

The Captain further indicated that a group of four individually badged personnel with badge readings of 720 to 1175 mrem were his radsafe monitors who conducted topside surveys for him during this period. These are also excluded from the plot. For the remaining badges, there is good correlation with the calculated dose for the first badging period. The correlation for the second period is not good, but neither period provides sufficient numbers for valid statistical inference.

The film badge dosimetry for LST-1146 for the period 19 March-3 April is shown in figure 27. There were fourteen cohorts. Two of the badges were indicated as wet and are not included; the apparent assignment of a dose of 80 mrem to these cohorts is also not included.

As shown, the calculated dose of 190 mrem for the typical crew member of LST-1146 is somewhat on the high side of the twelve cohort badges. The dominant component of the calculated dose for LST-1146 personnel is from fallout experienced on 29 March while transiting from Enewetak to Bikini. As previously detailed in section 3.9, the time of fallout cessation was

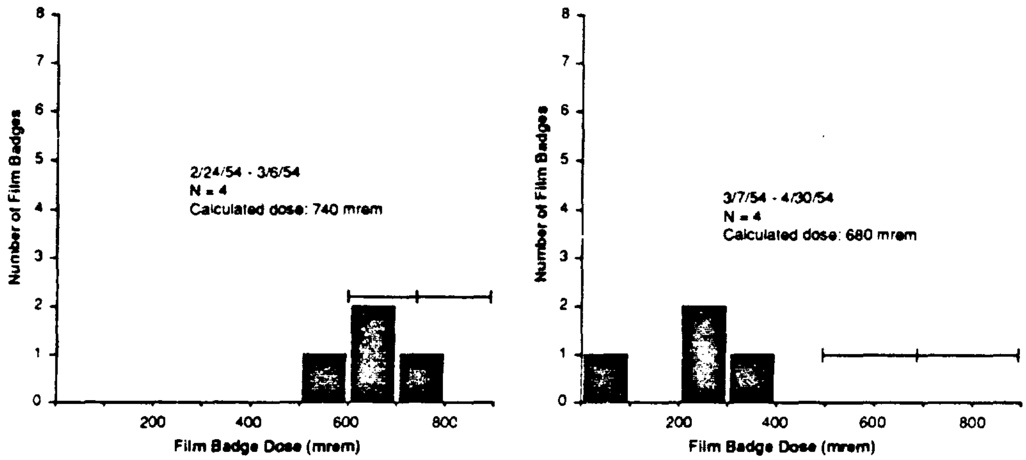


Figure 26. Film badge dosimetry for USS PC-1546.

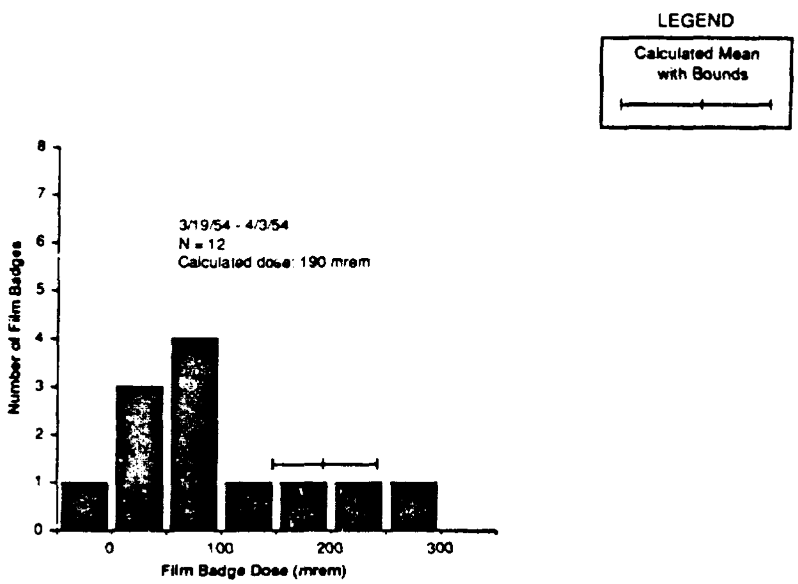


Figure 27. Film badge dosimetry for USS LST-1146.

likely somewhat earlier than that assumed in the dose reconstruction, thus the calculated dose is likely high-sided. The log of LST-1146 also indicates setting Condition Baker and operating the fire and flushing pumps over some unspecified period of time. This implies that the ship probably operated the washdown system, but the dose reconstruction assumes no reduction in topside intensity due to washdown. It is noteworthy that, of the twelve valid cohort badges, two of the three badges indicated in figure 27 with levels at or above the calculated dose (230, 290) were assigned to cohorts of deck and gunnery personnel, and personnel normally standing bridge watches underway. This may imply exposure of the badge wearers of these cohorts during the period of fallout, while the washdown reduced the subsequent integrated intensities below those used in the dose calculations. In this event, the calculated dose is further high-sided.

In summary, the film badge dosimetry records for the eight ships discussed herein are often incomplete and potentially misleading. As discussed, careful analysis and evaluation of these records is required. Notable problems include questionable validity of cohort composition, lack of recorded issue and turn-in data, and several cited cases of clearly unique but undocumented exposure activities by various individuals. Also, the tendency of badges covering Shot ROMEO exposure to read less than the reconstructed doses may reflect some undocumented exposure of the control badges, which is suggested by the unusually great optical densities (about 0.4) from base fog during this period.

It is noteworthy that, with careful application of the methods and logical inferences noted in the discussions and plotted results for each of the ships, the overall film badge doses for each ship show reasonable correlation with the reconstructed doses for the entire periods of participation. This is true even in the few cases where there is poor correlation for some of the discrete badging periods.

SECTION 7

CONCLUSIONS AND TOTAL DOSE SUMMARY

Radiation doses are determined in this report for the crews of eight of the ships that participated in Operation CASTLE in 1954. Contributions to dose include fallout deposited on weather decks, shine while in proximity of contaminated vessels and from contaminated water, and accumulated radioactivity on hulls and in saltwater systems. Doses with uncertainties are calculated for the typical crewman through 31 May 1954 and thereafter if the daily increment exceeds 1 mrem.

Film badge dosimetry is analyzed to establish its coverage of crew exposures and to compare with calculated doses. Cohort badging is assessed to determine its applicability to the crewmen involved, special exposures are identified, and periods of badge issue are estimated where inadequately documented. Suitable dosimetry is thus extracted for comparison with calculations over discrete periods. For most badge periods, the calculated dose lies within the distribution of typical crew doses, thereby affording confidence that all crew-wide exposures are adequately incorporated. Where there is a wide distribution of badge readings, it reflects the diverse activities of crewmen. Where dosimetry is complete, the total calculated doses are generally in good agreement with film badge totals for average crewmembers. Calculations lead to larger doses where gaps in dosimetry existed, reflecting unbadged radiation risk activities.

It is concluded that the reconstructed doses well serve to complete the exposure records for crewmen whose 1954-totalled doses do not fully or accurately reflect their individual exposures. While readings for the film badge wearers are credible, 1954-assigned doses on the basis of cohorts or in lieu of missing readings should be considered for replacement by reconstructed values.

The total calculated dose for each ship is presented in table 25.

Table 25. Summary of calculated total doses.

Ship	Total Dose (rem)
USS RECLAIMER (ARS-42)	$0.30^{+0.39}_{-0.12}$
USS SHEA (DM-30)	$0.37^{+0.40}_{-0.16}$
USS COCOPA (ATF-101)	$2.2^{+1.2}_{-0.5}$
USS MENDER (ARSD-2)	$1.5^{+0.5}_{-0.2}$
USS MOLALA (ATF-106)	1.8 ± 0.3
USS TAWAKONI (ATF-114)	$1.0^{+0.8}_{-0.3}$
USS PC-1546	$1.5^{+0.5}_{-0.3}$
USS LST-1146	$0.32^{+0.11}_{-0.06}$

SECTION 8

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APPENDIX

AUGMENTATION OF SHIPBOARD RADIATION ENVIRONMENTS

Ideally, an abundance of shipboard radiation measurements is available to define the topside environment. Where such data are lacking, auxiliary information is used, through appropriate conversions, to quantify topside intensities. The radioactive decay function described in section 2 is an example. For those ships totally lacking intensity readings, the land-equivalent radiation fields depicted in Reference 2 for fallout deposited on Bikini Lagoon provide readily convertible substitutes. The intensity curves depicted for all ships in section 3 do not include the transient contributions from shine. Aside from water shine, which is addressed in section 2, exposures occurred from proximity to contaminated vessels. As these vessels were often of unreported intensities, the foregoing approach is used for them as well.

Intensities on contaminated ships differ from land-equivalent intensities because of the limited extent, flatness, and nonporosity of ship decks. Conversion from land to ship levels is facilitated by a radiological quantity that is invariant to these differences, the surface activity per unit area. That quantity has been related to land intensity in Reference 18, and is related herein to all required ship intensities, through numerical methods of radiation transport. These calculations convert surface activity to intensity (peak or average) on a ship of specified dimensions, and to the associated shine on a proximate ship of specified dimensions and separation. The calculated ratio of shine to source vessel intensity, or shine factor, is confirmed for one ship configuration by the available data.

The radiation transport calculations assume ideally flat, rectangular deck surfaces with a uniform distribution of surface activity. Gamma intensity is calculated at points 3 feet above the deck through a spatial discretization of the radiation source. While the peak intensity is found through the summation of all contributions to the center point, the average intensity involves a double summation. This amount of computation is facilitated by applying radiation transport at a level commensurate with the accuracy of the underlying parameters. The unscattered photon flux, with a 1/e attenuation length of 300 feet in air, is computed to a satisfactory resolution for the geometry involved. This provides time- and cost-effective solutions that are reasonable for line-of-sight exposures for variously positioned ships.

Ship dimensions are based on information in Reference 17, which applies to the specific ships in this report or to vessels related by type and class; however, estimates are required for the barges. The approximated dimensions used in the calculations are: COCOPA, MOLALA, TAWAKONI, 205 x 39 ft.; MENDER, 210 x 45 ft.; PC-1546, 200 x 23 ft.; YAGs, 450 x 70 ft.; LCUs, 120 x 35 ft.; and barges, 70 x 35 ft.

Most large ships are calculated to have a topside intensity similar to the land-equivalent value. This occurs to the extent that the radiation lost because of a deck-limited fallout field is offset by losses on land to ground roughness. Intensity readings on land have an associated ground roughness factor, 0.7 traditionally and as in Reference 18, relative to those on an ideal infinite flat plane. Narrow and small vessels have intensities considerably less than the land-equivalent value. For the ATFs, the correction factor relative to land is 0.72, and for PC-1546, 0.60. These factors are applied in the average topside intensity curves of section 3 where shipboard measurements are unavailable. For peak intensities only on LCUs and barges, factors of 0.7-0.8 apply.

For a ship alongside a contaminated vessel, the following assumptions are made: a 5-foot separation of ships that are alongside amidships, thus maximizing the average shine; and equal deck heights, in accord with the computational scheme as well as maximizing shine. The topside-averaged shine factor for each ship alongside YAG-39 or YAG-40 is calculated to be within 20 percent of the factor derived from intensity readings on the YAGs. After Shots ROMEO and YANKEE, the YAGs were alongside each other on fourteen identified dates. YAG-40 had been heavily contaminated, YAG-39 not. The ratio of average intensities on each date (from Reference 13 data, with the minor contribution from fallout on YAG-39 eliminated) defines a shine factor. The average value of 0.16 (standard deviation of 0.04) is applied as the shine factor to those ships alongside YAG-39 or YAG-40.

With the YAG data providing confidence that the approximations underlying the numerical methods are satisfactory, shine factors for other ship interactions are used directly as computed. The values are considerably less where long ships were alongside short vessels. In these cases, the proximity of the bow and stern to the radiation source is perforce limited, and the average shine is reduced thereby. Thus, for an ATF alongside a barge, the shine factor is only 1/3 as much as for a YAG radiation source; for MENDER alongside an LCU, it is half as much.

Additional data from Reference 13 are used to estimate shine factors during recovery and towing operations. The attendant intensities on MOLALA from shine were measured after Shots ROMEO, UNION, and YANKEE, as a function of distance from YAG-40; the clearest data are minute-by-minute range findings. These are used to compute time-averaged shine factors for proximate vessels with like activities. Shine factors of 0.031, 0.038, and 0.046 are determined for the three shots, respectively; their average is used otherwise.

The calculated shine exposure for COCOPA, MENDER, MOLALA, and TAWAKONI for each contact with a contaminated vessel is shown in Table 26.

Table 26. **Additional topside exposure on support ships resulting from decontamination activities and special project participation.**

Date (1954)		Activity	Duration (hrs)	Source Vessel Intensity (mR/hr)	Shine Factor	Exposure to Ship Shine (mR)
		COCOPA				
Shot BRAVO						
March	3	Alongside YC-1081	4.62	622	0.053	152
	4	Alongside YC-1081	9.82	194	0.053	101
	5	Alongside YC-1081	0.40	83.0	0.053	1.8
	6	Alongside YC-1081	0.38	59.1	0.053	1.2
	9	Alongside YC-1081	0.63	30.5	0.053	1.0
	14	Alongside YC-1081	3.90	15.3	0.053	3.2
	16	Alongside LCU-638	0.60	23.6	0.08	1.1
	21	Alongside YFN-934	0.54	1.0	0.053	0.03
Shot UNION						
April	27	Alongside YC-1081/YCV-9	3.41	116	0.053	20.9
	27	Alongside YC-1081	1.33	60.2	0.053	4.2
	29	Alongside YC-1081	0.90	25.2	0.053	1.2
	29	Alongside YC-1081	1.70	22.0	0.053	2.0
May	2	Alongside YC-1081	0.61	9.3	0.053	0.3
	2	Alongside YC-1081	5.02	8.6	0.053	2.3
Shot YANKEE						
May	6	Alongside YCV-9	1.0	1580	0.053	83.7
	6	Alongside LCU-637	0.67	1280	0.08	68.6
	8	Alongside YC-737	0.33	152	0.053	2.7
	10	Alongside YC-1081	1.52	74.4	0.053	6.0
	12	Alongside YC-1081	0.43	47.8	0.053	1.1
		MENDER				
Shot UNION						
April	26	Alongside LCU-1224	1.32	209	0.08	22.1
	27	Alongside various LCUs	3.62	115	0.08	33.3
	30	Alongside LCU-1224	0.77	14.2	0.08	0.9
	30	Alongside LCU-1224	4.81	13.6	0.08	5.2
May	1	Alongside LCU-1224	7.59	12.5	0.08	7.6
	1	Alongside YC-1081	2.60	11.0	0.053	1.5
Shot YANKEE						
May	6	Vicinity of various LCUs and barges	8.42	1492	0.038	477
	7	Alongside various LCUs	3.12	475	0.08	119
	7	Alongside LCU-278	3.13	410	0.08	103

Table 26. Additional topside exposure on support ships resulting from decontamination activities and special project participation (Continued).

Date (1954)	Activity	Duration (hrs)	Source Vessel Intensity (mR/hr)	Shine Factor	Exposure to Ship Shine (mR)
		MOLALA			
Shot BRAVO					
March 1	Vicinity of YAG-40	1.1	36	0.038	1.5
14	Alongside YAG-40	1.3	0.3	0.16	0.06
Shot ROMEO					
March 28	Vicinity of YAG-40	1.37	6500	0.031	276
29	Vicinity of YAG-40	2.4	3500	0.031	260
31	Alongside YAG-40	6.4	1560	0.16	1597
April 1	Vicinity of YAG-40	0.9	570	0.031	15.9
9	Alongside YAG-40	6.7	106	0.16	114
26	Vicinity of YAG-40	1.0	25	0.031	0.8
Shot UNION					
April 26	Alongside YAG-39	0.7	160	0.16	17.9
26	Vicinity of YAG-40	0.8	1000	0.038	30.4
May 1	Alongside YAG-40	2.5	138	0.16	55.2
5	Vicinity of YAG-40	1.3	75	0.038	3.7
Shot YANKEE					
May 5	Alongside YAG-39	0.9	1300	0.16	187
5	Vicinity of YAG-40	0.5	16000	0.046	368
8	Alongside YAG-40	1.5	3690	0.16	886
9	Alongside YAG-39	7.6	169	0.16	206
10	Alongside YAG-39	7.5	78	0.16	93.6
11	Alongside YAG-39	2.9	60	0.16	27.8
11	Alongside YAG-40	0.25	1300	0.16	52.0
13	Vicinity of YAG-40	0.4	724	0.046	13.3
13	Alongside YAG-40	0.3	700	0.16	33.6
13	Alongside YAG-40	0.7	650	0.16	72.8

Table 26. Additional topside exposure on support ships resulting from decontamination activities and special project participation (Continued).

Date (1954)		Activity	Duration (hrs)	Source Vessel Intensity (mR/hr)	Shine Factor	Exposure to Ship Shine(mR)
		TAWAKONI				
Shot BRAVO						
March	1	Vicinity of YAG-39	1.58	65	0.038	3.9
	2	Vicinity of YAG-39	2.00	24	0.038	1.8
	3	Alongside YCV-9	3.43	28.1	0.053	5.1
	4	Alongside YCV-9	4.87	19.3	0.053	5.0
	6	Alongside YCV-9	2.65	9.2	0.053	1.3
	7	Alongside YCV-9	1.67	7.2	0.053	0.6
	11	Alongside YCV-9	6.12	3.2	0.053	1.0
	16	Alongside YAG-40	2.32	0.25	0.16	0.09
	16	Alongside YAG-39	1.87	0.9	0.16	0.3
	16	Alongside YAG-39	0.36	0.9	0.16	0.05
	19	Alongside YCV-9	2.02	1.4	0.053	0.2
	20	Alongside YCV-9	10.3	1.3	0.053	0.7
Shot UNION						
May	2	Alongside YC-1081	1.60	9.0	0.053	0.8
	3	Alongside YC-1081	2.53	7.2	0.053	1.0
Shot YANKEE						
May	6	Alongside LCU-636	1.38	1300	0.08	143
	7	Alongside YCV-9	6.43	423	0.053	144
	8	Alongside YC-1081	1.22	182	0.053	11.8

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