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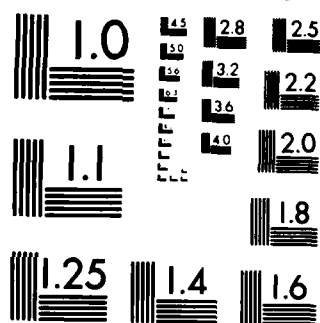
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ANALYSIS OF RADIATION EXPOSURE FOR NAVAL PERSONNEL AT OPERATION IVY

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

15 March 1983

Technical Report

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20. ABSTRACT (Continued)

Fallout from Shot KING was minimal. From the reconstructed operations and radiological environments, equivalent personnel film badge doses are calculated and compared with available dosimetry data for fourteen of the ships. Calculated doses for the majority of the ships are in good agreement with the film badge data; however, for three of the participating destroyers (DDEs), calculated doses are significantly lower than the dosimetry data indicates.

Calculated mean doses for typical shipboard personnel range from a high of 0.062 rem on the HORIZON to a low of 0.001 rem on the SPENCER F. BAIRD; for island-based personnel, calculated mean doses are less than 0.06 rem.

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Section 1

INTRODUCTION

Operation IVY was a nuclear test series conducted by the Atomic Energy Commission at the Pacific Proving Grounds (PPG) during the fall of 1952. With the Chief of Staff of the Army acting as executive agent for the Joint Chiefs of Staff, Joint Task Force 132 was formed from elements of the Army, Navy, Air Force, and civilian scientists to support the operation. While over 11,000 people were assigned to JTF 132, approximately 5,500 were attached to the Naval element--Task Group 132.3.

Generally, most of the TG 132.3 ships remained clear of radiological areas, which were well defined. However, radioactivity from secondary (late-time) fallout did result in widespread, low-level exposure. Therefore, it is necessary to reconstruct the radiation dose using radiological data, ship logs, and crew activity scenarios to verify the available dosimetry data. This report describes the operation, the radiological situation, and the *time-space relationships of each ship with respect to the nuclear environment*. The results are portrayed as film badge doses for the crews of each of the 18 vessels that supported the operation. Because some of the task group personnel were on the residence islands of Kwajalein, Bikini, and Enewetak Atolls* during the periods of fallout, the radiation environment on these islands has also been reconstructed.

1.1 BACKGROUND

Enewetak is one of the several atolls making up the Marshall Island group and, along with Bikini, had been the site of previous nuclear tests. Figure 1-1 shows the main features of Enewetak Atoll and the Operation IVY shot locations. The two detonations of the operation were Shots MIKE and KING. Pertinent details of each test are summarized in Table 1-1. MIKE was the first nuclear fusion device. Although

*A better understanding of the Marshall Islands language has permitted a more accurate transliteration of Marshall Islands names into English. The newer names/spellings are used in this report.

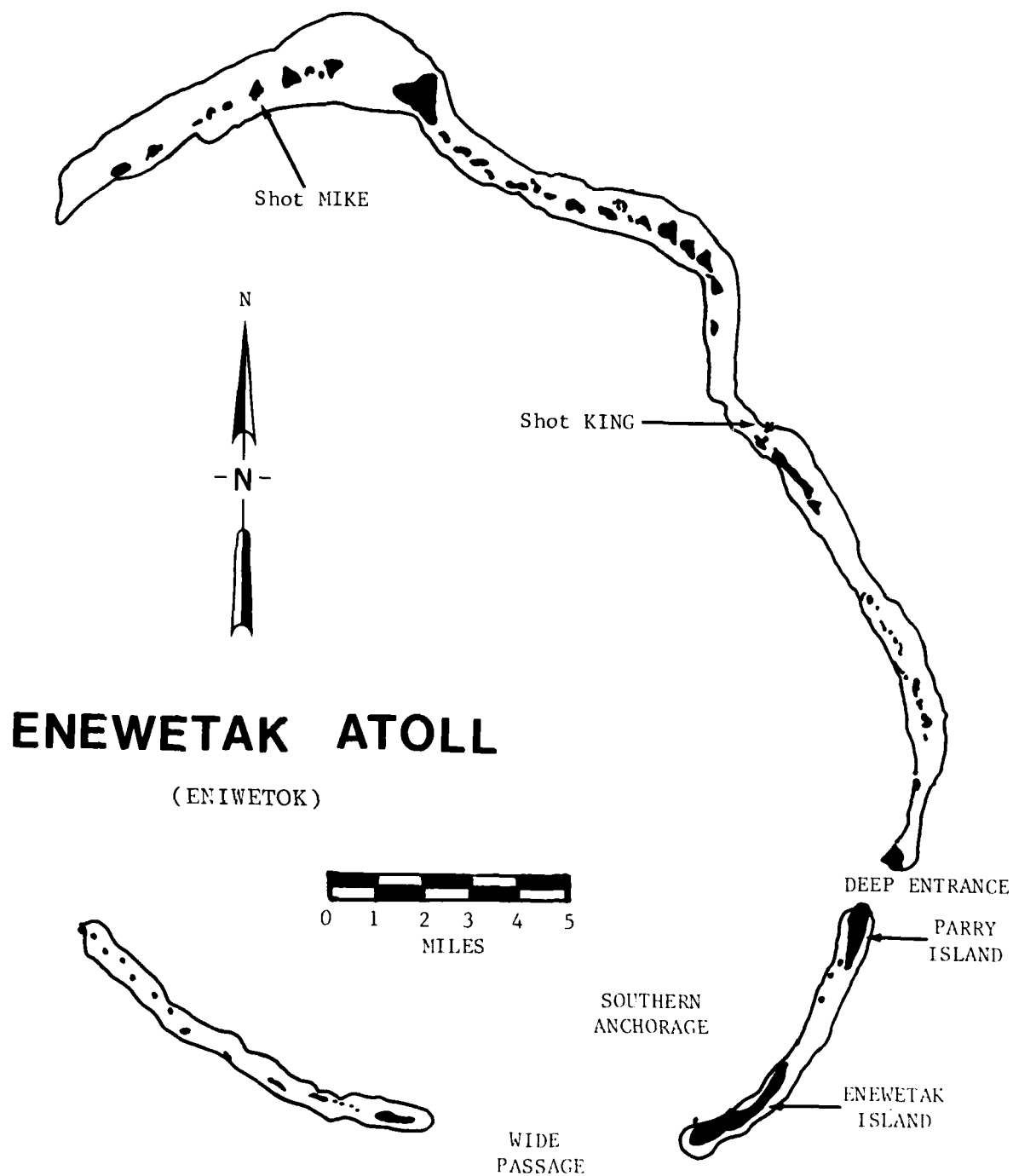


Figure 1-1. Operation IVY Shot Locations

the complexity of the experiment made yield prediction difficult, designers expected a yield of at least 4 MT and perhaps as much as 10 MT. Even at the lower yield, Shot MIKE would have been the most powerful nuclear device ever detonated. The yield for Shot KING was predicted to be about 500 KT, making it the most powerful fission device ever detonated. Consequently, planning for both shots was dominated by the concern for safety of task force personnel and the camps on Enewetak and Parry islands from the blast, thermal, and radiation effects, as well as from the resulting fallout. For Shot MIKE, only evacuation of the entire atoll offered an adequate margin of safety.

Table 1-1.
Operation IVY Shot Data

Shot Name	MIKE	KING
Date	1 Nov 1952	16 Nov 1952
Time (Local)**	0715	1130
Site (Island)	Flora (Elugelab Is.)	Yvonne (Runit Is.)
Height of Burst	Surface	1,480 ft
Yield	10.4 MT	500 KT

Source: Reference 1.

1.2 NAVAL OPERATIONS

The Naval support units were organized as Task Group 132.3 and provided the main transportation and logistical support to the task forces at Enewetak.

The Naval Task group had the following missions:

**Local Time was 12 hours ahead of GMT.

1. Provide for the security of the Enewetak danger area by detecting, warning, and escorting unauthorized vessels and aircraft out of the danger area.
2. Meet the requirements of the scientific task group for suitable water transportation and shipboard assembly facilities for the MIKE device.
3. Provide shipboard command facilities for the task force commander as well as for the commanders of the subordinate task groups.
4. Provide ship-to-shore and intra-atoll surface and helicopter transportation, including that for damage survey and recovery of scientific samples and film.
5. Provide shipboard facilities to house the entire joint task force while afloat.

A summary of naval ships/units and personnel is contained in Table 1-2. Task Group 132.3 was organized into seven major components as shown in Figure 1-2. With the exception of the members of the Patrol Plane Unit, which was based on Kwajalein, most task group personnel apparently were billeted aboard the task group ships.

While the task force was afloat for the MIKE detonation, each ship's radiation safety element was responsible for personnel radiological safety, subject to control by the CJTF 132, through the CTG 132.3. During the rest of the operational period, prime responsibility for radiological safety rested with TU 132.1.7, a unit of the scientific group, using its own resources and with assistance, as required, from the rad-safe elements of the other three task groups.

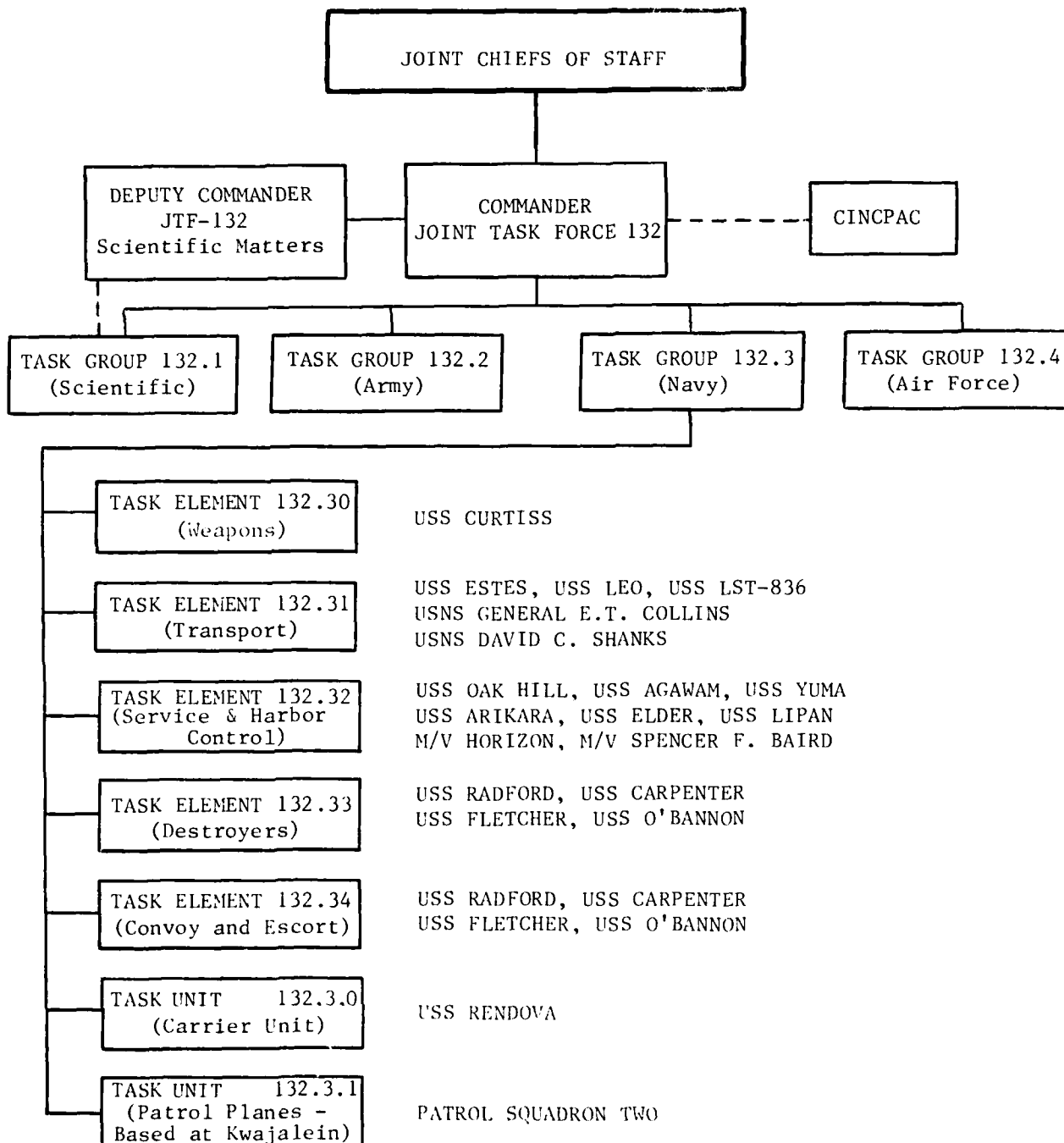
Operation IVY posed some unique problems because of the predicted large yield of the detonations. The MIKE shot was expected to produce a yield far surpassing that of any earlier test. There was concern that a device detonated in the atmosphere might significantly contaminate the lagoon and restrict its use. Radiological safety of

Table 1-2. Operation IVY Naval Personnel Summary (22 October 1952)

<u>Ship/Unit</u>	<u>Officers</u>	<u>Civilian</u>	<u>Enlisted</u>	<u>Total Personnel</u>
USS CURTISS (AV-4)	42	--	687	729
USS ESTES (AGC-12)	48	--	518	566
USS LST-836 (at Bikini)*	6	--	123	129
USNS DAVID C. SHANKS (TAP-180)	5	169	17	191
USNS GEN E.T. COLLINS (TAP-147)	5	171	16	192
USS LEO (AKA-60)	12	--	216	228
USS OAK HILL (LSD-7)	19	--	311	330
TG 132.3 BOAT POOL*	4	--	198	202
TG 132.3 UDU (at Enewetak)*	1	--	20	21
TG 132.3 SHORE DET (at Enewetak)*	--	--	--	18
USS AGAWAM (AOG-6)	8	--	114	122
YOG-69 (at Kwajalein)*	--	--	14	14
YON-146 (at Kwajalein)*	--	--	--	0
USS LIPAN (ATF-85)	5	--	74	79
USS YUMA (ATF-94)	5	--	71	76
USS ARIKARA (ATF-98)	5	--	75	80
USS ELDER (AN-20)	4	--	45	49
M/V HORIZON (ex-ATA)	--	35	1	36
M/V SPENCER F. BAIRD (ex-ATA)	Unk	Unk	Unk	70
USS CARPENTER (DDE-825)	15	--	261	276
USS FLETCHER (DDE-445)	17	--	241	258
USS RADFORD (DDE-446)	18	--	238	256
USS O'BANNON (DDE-450)	17	--	234	251
USS RENDOVA (CVE-114) (Includes Air Units)*	107	--	865	972
PATRON TWO (at Kwajalein)*	47	--	298	345
COMCORTDES DIV 11 (on CARPENTER)	5	--	5	10
COMTASKGROUP 132.3 (on RENDOVA)	17	1	44	62
TOTALS	412	376	4686	5562

Source: Reference 3

*The movements of these smaller units could not be followed in sufficient detail to be able to reconstruct their film badge doses.



Source: Reference 3.

Figure 1-2. Organization of Joint Task Force 132

all military and civilian personnel was specified as a command responsibility. Specific rad-safe responsibilities for TG 132.3 included the following (Reference 4):

1. Ensure that appropriate radiac equipment and qualified personnel are aboard each task group unit, and that each unit is prepared to carry out the rad-safe mission of the task group.
2. Provide and train rad-safe monitors, including one airborne monitor for each multiengine aircraft crew.
3. Provide monitors and decontamination crews aboard each ship.
4. Provide radiac equipment and protective clothing.
5. Provide repair, spare parts, and calibration facilities.
6. Provide a *limited laboratory facility for radiochemistry techniques, fallout studies, and film badge processing* for use by TG 132.1 rad-safe operations while the task force is embarked.
7. Provide decontamination facilities for task group aircraft not based on Kwajalein.
8. Provide necessary helicopter air service for postshot surveys before task force reentry (monitors furnished by TG 132.1).
9. Provide amphibious aircraft for monitoring fallout and for collecting water samples from adjacent inhabited islands and atolls.

Radiological safety was expressly designated as a command responsibility for each ship. The rad-safe function was designated to the shipboard damage control parties. Normal ship staffing for radiological warfare was considered adequate for rad-safe purposes. Prior to obtaining a final radiological clearance and being released

from the operational control of TG 132.3, the rad-safe team aboard each ship surveyed the entire vessel to insure that no areas of radioactive contamination exceeded 15 mR/day (0.6 mR/hr). If such intensities were found to exist, decontamination was undertaken until criteria were met.

1.3 METHODOLOGY

The procedures developed in previous dose reconstruction efforts (References 5 and 6) have been adapted to the shipboard and island radiological environments at Operation IVY. Figure 1-3 depicts the steps taken in calculating personnel doses. These steps are pursued to a level of detail governed by the availability of data. On many of the ships and atolls, sufficient data were recorded at the time and enough have survived to understand the Naval operations and to characterize the radiation environment. For some other ships, however, virtually no radiological data exist; their environments are estimated based on their position, i.e., proximity to other ships/atolls with known environments, and activity when fallout was encountered. Individual ship deck logs (Reference 7) serve as an authoritative source of ship position and activity. It is assumed that the units of Task Group 132.3 adhered to the operation plans as promulgated by Commander Task Group 132.3; therefore, these operation plans serve as guides to ship activities. References 2 and 3 comprise the official reports of the tests. Supporting documents and reports prepared by the Naval Radiological Defense Laboratory and the Los Alamos Scientific Laboratory (References 8 and 9) also contain data pertinent to this dose reconstruction.

Radiological data are used to reconstruct the time-dependent radiation environment on each of the eighteen ships and three atolls manned by Naval personnel while at Operation IVY. Characterization of the radiation environment starts with the determination of free-field intensities from correlations made between shipboard fallout activity and limited radiation intensity data. The periodic shipboard surveys, in conjunction with fallout time-of-arrival data and nearby island surveys, serve to define the free-field intensity as a function of time. For interpolation between readings and for extrapolation beyond the last reading, the intensity is assumed to be a power law function of time after burst, determined from fallout decay rates. Specific data

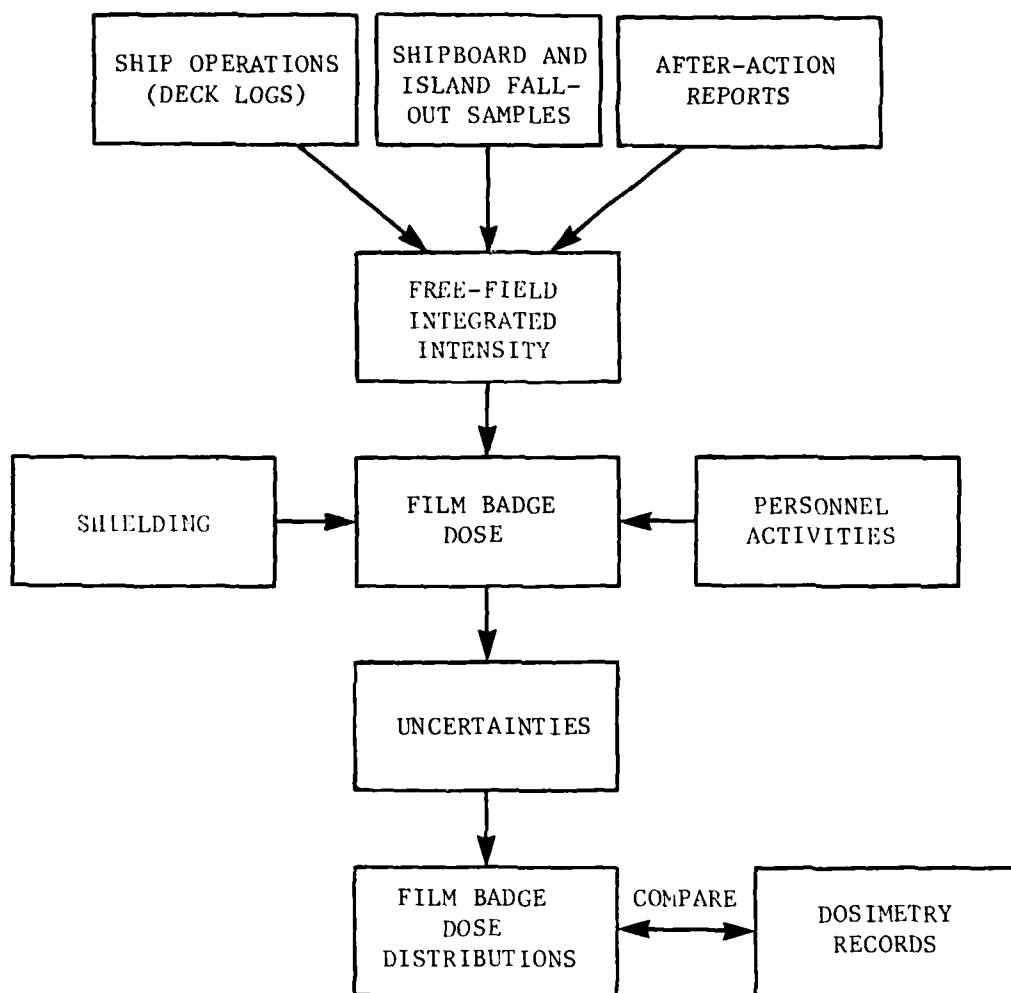


Figure 1-3. Operation IVY Dose Reconstruction Methodology

regarding the development of intensity curves for the ships and islands are presented in Section 2.

Shipboard radiation surveys indicated a considerable variation in topside intensities because of ship geometry, redistribution of fallout during washdown and decontamination, and non-uniform adherence of fallout particles to ship materials. If only an average survey reading was reported, this value is used. On some ships, readings were taken at several predetermined positions on the ship's exposed surfaces. These readings, taken three feet above the surface, are judged to provide an unbiased representation of the topside radiation field. The ship's crew is presumed to have been located at random positions when on deck; thus, the mean survey readings, appropriately decayed, are used to determine the mean intensities encountered by the crew when topside. The distribution of survey readings suggest a distribution in radiation exposure to the crew; this matter is considered in the uncertainty analysis (Section 4).

The analysis of radiation exposure to the crew also requires estimation of radiation intensities below deck and the apportionment of crew activities with time below and topside. A ship-shielding factor is defined as the ratio of intensity below to the intensity topside. This factor, determined for each type of ship in Section 2.4, is approximately 0.1 and is nearly constant over the usual crew locations within a ship. Thus, the radiation dose to the crew is dominated by the topside exposure. Specific durations of topside exposure are given in ship logs for shot day (rarely thereafter) when the radiological situation altered the normal pattern of duties. For other days, and when unspecified, the on-deck intervals are taken to be 0800-1200, 1330-1700, and 1800-2000 hours, which amount to 40 percent of a day. To facilitate the calculation, the daily fractional topside duration, rather than the specified intervals, is used when the slackening intensity lessens the need for more precision in timing. Because the specified intervals are nearly centered around midday, this approximation is suitable by the third day.

The mean film badge dose to the crew is obtained from time integration of intensity for all intervals below (including the shielding factor) and topside. A conversion factor of 0.7 is used to account for body shielding by the badge wearer (Reference 10).

Cumulative film badge doses to the average crewman of each ship are calculated and presented in Section 3. Calculations are continued through 18 November when the roll-up phase of the operation was nearly complete; subsequent dose accrual is negligible compared to that previously accrued. An uncertainty analysis of the dose calculations is provided in Section 4. In Section 5, the available dosimetry records are analyzed, and their comparability to the calculated doses is assessed.

Section 2

SHIP OPERATIONS AND RADIATION ENVIRONMENTS

This section details the individual TG 132.3 ship operations for the period just prior to Shot MIKE on 1 November 1952 through the roll-up phase of Operation IVY following Shot KING on 16 November 1952. In addition, radiological environments for each ship resulting from MIKE and KING fallout are reconstructed based on shipboard fallout samples and radiological survey data. For those ships where there are insufficient shipboard data to reconstruct the specific radiological environment, it is based on the ship's proximity to other ships with known environments. For instance, no radiological data are available for the USS ELDER or USS LEO following Shot MIKE; hence, their radiological situation is based on the reconstructed environment for the USS ESTES, which was anchored near these ships off Parry Island when Shot MIKE fallout was encountered. Because of the large number of ships comprising TG 132.3, ships are grouped, where possible, according to their positions at the times that Shot MIKE and Shot KING fallout were encountered. Similar radiation environments are reconstructed for the residence islands of Kwajalein, Bikini, and Enewetak Atolls. These environments are then time-integrated to determine the daily integrated free-field intensities on each of the ships and islands.

2.1 GENERAL SITUATION FOLLOWING SHOTS MIKE AND KING

Prior to the MIKE detonation at 0715 hours on 1 November 1952, all of the TG 132.3 ships present at Enewetak departed the lagoon and steamed to their respective shot positions. With the exception of the M/V HORIZON, which was 65 miles northeast of surface zero (SZ) at shot time, all of the ships were at least 25 miles to the south and east of the lagoon. From this distance, no initial nuclear radiation was received by any personnel aboard the ships.

As the MIKE radioactive cloud rose, the low-level winds deposited the primary (early-time) fallout in an area generally to the north and west of the MIKE SZ. Within four minutes after the detonation, the cloud stabilized with its base at 60,000 feet and

the top at 100,000 feet. Easterly winds between 60,000 and 80,000 feet were pushing the lower half of the cloud west while westerly winds between 80,000 and 100,000 feet were pushing the upper part the cloud to the east (Reference 1). As the cloud top drifted to the east, radioactive particles were continuously falling from the cloud back into the troposphere where, for several days, the prevailing easterly winds apparently took them on a course back toward Enewetak Lagoon. This secondary (late-time) fallout was the source of radioactive contamination aboard the majority of the ships participating in Operation IVY. Only the HORIZON, which was on station northeast of the MIKE SZ at shot time, received any primary fallout.

Analysis of lagoon water samples obtained on 1 and 2 November indicated that the water in the southern anchorage area of the lagoon was not contaminated by MIKE fallout and the TG 132.3 ships began reentering the lagoon at approximately 0930 hours on 2 November. The USS ESTES (AGC-12), USS LEO (AKA-60), USS ELDER (AN-20) and the USS AGAWAM (AOG-6) anchored off Parry Island while the USS OAK HILL (LSD-7), USS ARIKARA (ATF-98), USS LIPAN (ATF-85), USS RENDOVA (CVE-114), USNS GENERAL E.T. COLLINS (TAP-147) and the USNS DAVID C. SHANKS (TAP-180) anchored off Enewetak Island (see Figure 2-1). All ships were anchored in their respective berths by approximately 1900 hours on 2 November.

The USS CURTISS (AV-4) and USS YUMA (ATF-94) had also entered the lagoon but then departed for Kwajalein during the afternoon of 2 November. The USS FLETCHER (DDE-445), which had been patrolling the waters west of the lagoon during the morning of 2 November, provided screen for the CURTISS during its trip to Kwajalein and returned to Enewetak on 4 November. The YUMA did not return to Enewetak until 7 November, and the CURTISS remained at Kwajalein during the remainder of the operation.

The USS CARPENTER (DDE-825) and USS RADFORD (DDE-446) provided antisubmarine warfare patrols in the vicinity of Enewetak and did not reenter the lagoon until 8 and 9 November, respectively. The USS O'BANNON (DDE-450), after picking up Dan buoys in support of a Naval Radiological Defense Laboratory (NRDL) fallout experiment, reentered the lagoon during the evening of 6 November.

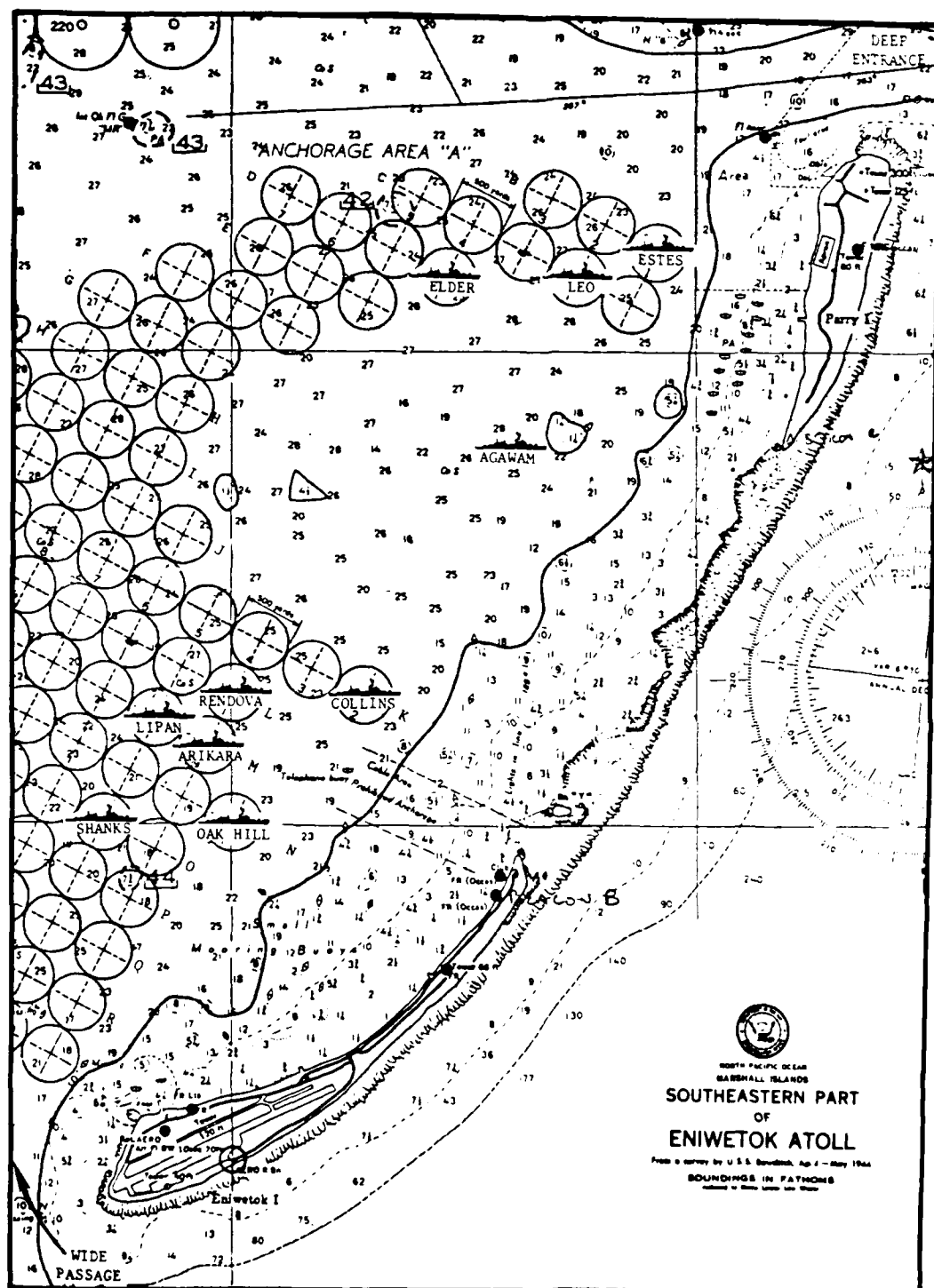


Figure 2-1. Eniwetok Lagoon Anchorage Areas for Task Group 132.3
Ships Following Shot MIKE - Operation IVY

The M/V HORIZON continued its operations in the area northeast of the lagoon, recovering instruments and equipment that had been laid out prior to the test. On 4 November, it steamed toward Bikini and arrived there the following morning. The HORIZON did not return to Enewetak until 6 November.

On 2 November, secondary fallout from the MIKE radioactive cloud began to contaminate the ships anchored in the lagoon, the destroyers on patrol outside of the lagoon, and the three ships steaming towards Kwajalein. Particle sizes in the fallout were quite small ($\leq 25 \mu\text{m}$); precipitation was the mechanism for depositing the debris on the task group ships (Reference 3). This secondary fallout continued intermittently for several days with average intensities onboard the ships anchored in the lagoon reaching a maximum on 4 November. Another "wave" of secondary fallout arrived during the evening of 7 November and continued for approximately 12 hours. It is assumed that this fallout was so widespread that any ship in the vicinity of Enewetak encountered it. This second wave of fallout apparently did not affect Bikini or Kwajalein Atolls.

On completion of the MIKE event, some ships were no longer required and were released from TG 132.3. The first ships released were the ELDER and the ARIKARA, which departed Enewetak on 8 November for Pearl Harbor. The YUMA was released and steamed back to Kwajalein on the same day. The DAVID C. SHANKS was reported ready for release on 8 November but did not depart Enewetak until 11 November. Although not released from the task group, the LEO also departed Enewetak on 8 November enroute to Kwajalein, where it remained until 21 November, when it returned to Enewetak.

The remaining ships comprising TG 132.3 stayed in the vicinity of Enewetak preparing for Shot KING. On 14 November, the O'BANNON departed the lagoon enroute to the Control Destroyer Station approximately 145 miles southeast of Enewetak. Early in the morning of 16 November, all of the task group ships, with the exception of the ESTES and the HORIZON, departed Enewetak Lagoon to take up their shot positions. The CARPENTER, FLETCHER, AGAWAM, COLLINS and LIPAN took up stations 19 miles south-southeast of the lagoon while the RENDOVA and RADFORD took up stations approximately 24 miles southeast of the lagoon. The OAK HILL was

approximately 19 miles east of Enewetak. Of the two ships that remained in the lagoon, the ESTES was approximately 9.5 miles south of the KING SZ, while the HORIZON was assigned an anchorage near the southern entrance (Wide Passage) of the lagoon, off Enewetak Island.

Shot KING was detonated at 1130 hours, 16 November 1952. Reentry had been set for 1550 hours on 16 November and all TG 132.3 ships that returned to Enewetak on shot day were anchored in the lagoon by 1800 hours. The COLLINS and LIPAN anchored off Enewetak Island while the ESTES, OAK HILL, RENDOVA, RADFORD, CARPENTER, FLETCHER and AGAWAM anchored off Parry Island. The O'BANNON left its shot station at 1705 hours and steamed toward Kwajalein. The M/V SPENCER F. BAIRD, which had remained at Bikini Atoll throughout most of Operation IVY, departed Bikini after Shot KING and arrived at Enewetak at approximately 0700 hours, 17 November.

Being an air burst, Shot KING produced very little local fallout. Some ships reported a trace of fallout and measured a maximum intensity of 0.6 mR/hr (beta) approximately 24 hours after the shot (Reference 3). It is assumed that all ships in the vicinity of Enewetak were contaminated by this fallout. Bikini and Kwajalein Atolls did not report any fallout following Shot KING.

2.2 RADIATION ENVIRONMENTS

Four main sources of fallout data are used in reconstructing the shipboard radiation environments resulting from Shots MIKE and KING:

- For ten ships that participated in a NRDL fallout experiment, fallout samples were obtained on two-foot square "sticky-paper" fallout collectors. These collectors were placed on a platform high on the main mast of each ship to insure they were above any spray from the ship's washdown system. Exposure periods were generally 12 hours, but this varied from ship to ship. Measurements made on these fallout samples with a proportional counter (counts per minute of beta plus gamma) are given in Reference 8. The

REDOVA continued taking fallout samples for several days after the other ships, and it is assumed that this fallout was so widespread that any ship in the vicinity of Enewetak received it. Fallout samples were also obtained on Kwajalein and Bikini Atolls.

- A second source of fallout data consists of survey measurements taken aboard the ESTES. Hourly gamma intensity readings (mR/hr) were obtained from eight representative locations on the weather decks from 31 October through 4 November, and approximately every six hours on 5, 6 and 7 November (Reference 11). Corresponding intensity readings were also obtained on a helicopter landing platform that had become contaminated by helicopters returning from the shot island on 1 November. These readings are not included in determining the average topside intensity. This particular reference also indicates that average beta plus gamma intensities on the ESTES were 4-5 times the average gamma intensity.
- The third major source of data is the activity (counts per minute of beta plus gamma) outside the counting laboratory on the hangar deck of the REDOVA (Reference 12).
- The last source of fallout data used in this analysis are beta plus gamma intensities (mR/hr) measured on the REDOVA's weather surfaces on 4, 5, and 6 November (Reference 12).

Between 1 and 7 November, the fallout samples obtained from the collectors aboard ten of the task group ships provide the majority of shipboard intensity data used in this analysis. Comparable fallout samples were also obtained on Bikini and Kwajalein Atolls. The activity measurements, in counts per minute, were normalized to 21 November 1952, apparently because the main purpose of the fallout sampling was to determine the time of arrival and the time of maximum intensity of the secondary fallout (Reference 8). Alone, the samples would be of little use in reconstructing the magnitude of the gamma intensity on the ships and atolls where they were collected.

Fortunately, on two ships--the ESTES and RENDOVA--free-field (topside) gamma intensity readings were obtained during the period 1-7 November, which could be correlated with the fallout sample data obtained onboard these ships during the same time period. Figure 2-2 is a plot of the average topside gamma intensity on the ESTES (minus background) along with the cumulative activity inferred (by $t^{-1.2}$ from 21 November back to the time of deposition) from the fallout samples. The cumulative activity is plotted at times corresponding to the end of exposure for each sample. The cumulative curve is obtained by summing the activity contribution from all previous sampling periods, appropriately decayed. The cumulative counts through the end of any sampling period should thus correlate with the measured intensity at that end time, barring any intervening decontamination. Reference 13 indicates that the ratio of beta activity to gamma intensity is nearly constant over the interval in question (3 days to 3 weeks after burst). The "spikes" in the topside gamma intensity curve prior to 1200 hours on 3 November, correlate quite well with periods of light rainfall.

The correlation of activity with intensity is derived from comparisons at two times on the ESTES and one on the RENDOVA. Intensity readings on the ESTES through the morning of 3 November are insufficiently distinguishable from background to aid in the correlation. Useful comparisons are made at 1900 hours, 3 November, and at 0700 hours, 4 November (denoted by solid squares in Figure 2-2), resulting in ratios of 0.069 and 0.025 mR/hr per Mcpm, respectively. Because of the much higher intensities at the latter time, the two comparisons are essentially independent. Attempts to decontaminate the ship were begun at approximately 0800 hours on 4 November, therefore, correlations at later times are not possible. A subsequent rise in intensity late on 4 November (at 1300 and 1700 hours) is not associated with a substantial increase in activity counts. Curiously, the Roll-Up Phase Report from the ESTES (Reference 11) does not mention fallout deposition for the interval of these ostensibly highest intensity readings onboard the ship. Perhaps the monitors reported peak readings during this interval, rather than the usual average readings. Regardless, these two data points are considered inappropriate for use in the correlation. For the RENDOVA, the only useful comparison leads to a ratio of 0.066 mR/hr per Mcpm at 1100 hours on 5 November. The average of the three ratios is about 0.05 mR/hr per Mcpm. This value is used to derive intensity curves for all ships where fallout sample data are the only basis for determining activity levels.

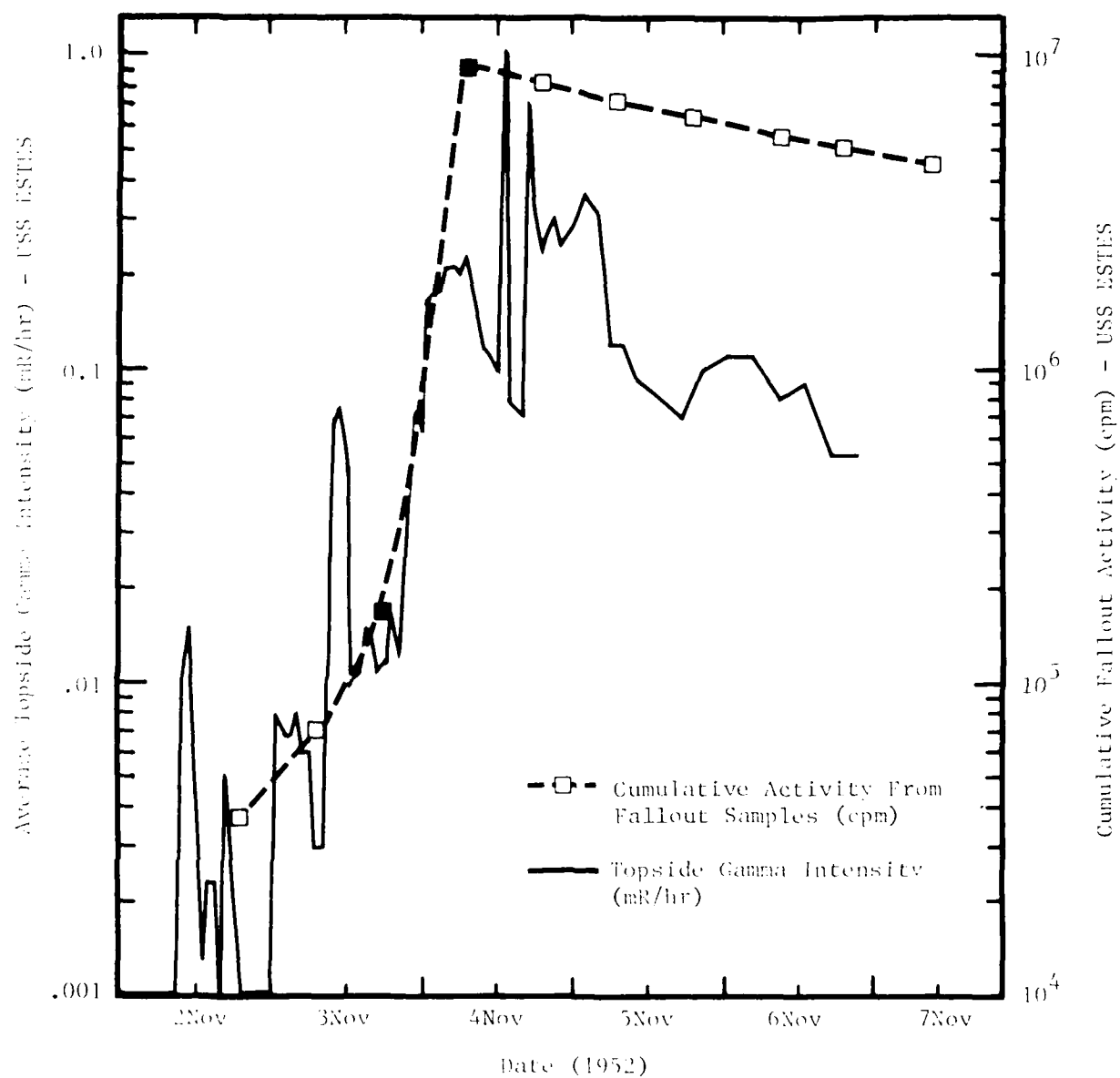


Figure 2-2. Cumulative Fallout Activity and Average Gamma Intensity vs. Time on the USS ESTES

Reconstructing the ship intensity curves past 7 November requires further correlations to be made between the derived topside intensity on the RENDOVA for the period 4-7 November and activity measurements obtained on the RENDOVA's hangar deck during the same period. This activity was continuously monitored from before Shot MIKE until 42 hours after Shot KING. Because the detector was below the weather decks (it was located on the side of a laboratory wall approximately six feet above the hangar deck), it is fair to assume that the activity monitored was due to gamma radiation only and that the activity measured was proportional to the gamma intensity on the flight deck directly over the detector. Figure 2-3 is a plot of the activity as measured on the RENDOVA's hangar deck from 1-18 November 1952, and the average topside gamma intensity derived from the cumulative fallout sample correlations described in the preceeding paragraph. With the exception of one data point on the hangar deck activity curve (1200 hours on 5 November), it appears that the hangar deck intensity is proportional to the topside gamma intensity during the period 5 November to 7 November. Assuming the proportionality remained constant through 18 November, it possible to reconstruct the average topside gamma intensity onboard the RENDOVA through its departure from Enewetak on 20 November 1952. It is also possible to subtract out the intensity contribution from Shot MIKE fallout on 3-6 November in order to quantify the magnitude of the MIKE fallout that occurred on 7-8 November and the trace of fallout following Shot KING on 16 November. For the task force ships remaining at Enewetak during these two subsequent periods of fallout, the gamma intensity contribution from each source is simply added to each ship's intensity curve (derived from the fallout sampling data).

2.2.1 USS ESTES (AGC-12)

The ESTES reentered the lagoon at 1051 hours on 2 November and anchored in berth B-1 off Parry Island, where it remained until its departure from the lagoon on 19 November enroute to Pearl Harbor. The radiological contamination on the ESTES resulting from Shot MIKE and Shot KING fallout is depicted in Figure 2-4. It is based on fallout samples obtained on the ship through 7 November and correlations with the RENDOVA hangar deck activity through 21 November. Although some shipboard decontamination had taken place, it is not apparent in the intensity curve since the

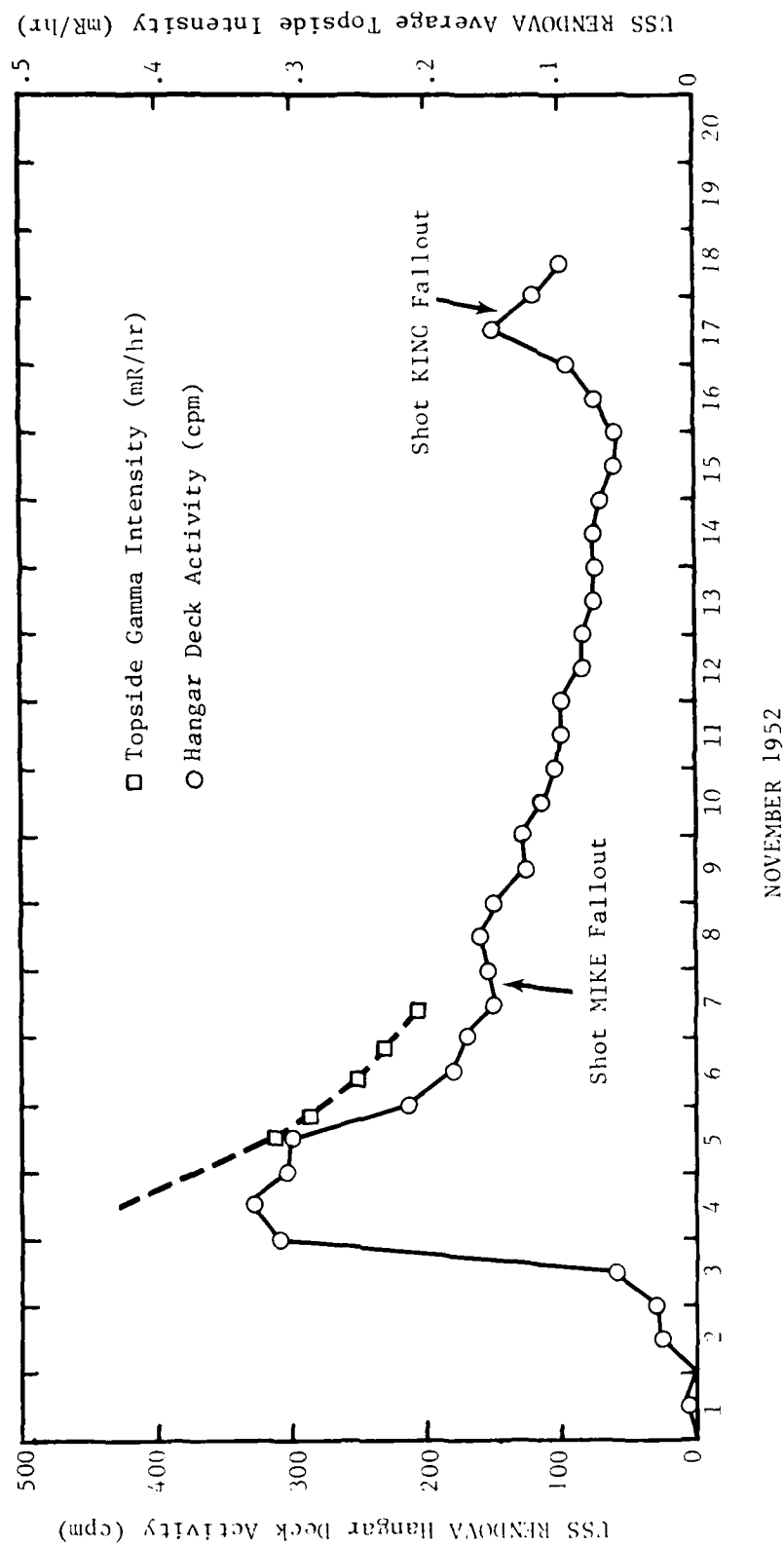


Figure 2-3. Gamma Intensity and Activity vs. Time on the USS RENDOVA

fallout samples were obtained above any weather surfaces that were decontaminated (Section 2.2). By neglecting the effects of decontamination in reconstructing a ship's topside intensity, subsequent dose calculations in Section 3 are high-sided. Radiological data available for the ESTES are contained in two messages to the RENDOVA, the latter (0715 hours on 3 November) stating that, at MIKE plus 48 hours, "maximum dosage received by personnel 0 mR" (Reference 14). This is in good agreement with Figure 2-4, which shows that only background intensities were encountered prior to 0700 hours on 3 November.

Because the ESTES remained in the lagoon for the remainder of the operation, it is assumed that it received the second "wave" of fallout on 7-8 November from Shot MIKE as well as the fallout on 17 November following Shot KING. Final radiological clearance was given to the ESTES on 19 November 1952.

Radiological surveys and fallout samples were not obtained on Parry Island, approximately 1500 yards east of the ESTES. Due to the lack of radiological data from this island, it is assumed that Parry received the same fallout that occurred onboard the ESTES, depicted in Figure 2-4.

2.2.2 USS LEO (AKA-60) and USS ELDER (AN-20)

Following Shot MIKE, the LEO entered the lagoon and anchored in berth C-2 off Parry Island at 1051 hours on 2 November; the ELDER anchored in berth D-3, also off Parry, at 1134 hours 2 November. Both ships were in close proximity to the ESTES, which was anchored in berth B-1 (see Figure 2-1). Except for a 7-hour excursion by the ELDER to a northern operating area on 3 November to search for instrument buoys, both ships remained anchored off Parry until 8 November. The ELDER, having received final radiological clearance on 7 November, was released from operational control of the Task Group and departed Enewetak at 0927 hours on 8 November enroute to Pearl Harbor. The LEO departed the lagoon at 1556 hours on 8 November enroute to Kwajalein and did not return to Enewetak until 21 November. The LEO was granted final radiological clearance at Kwajalein on 19 November.

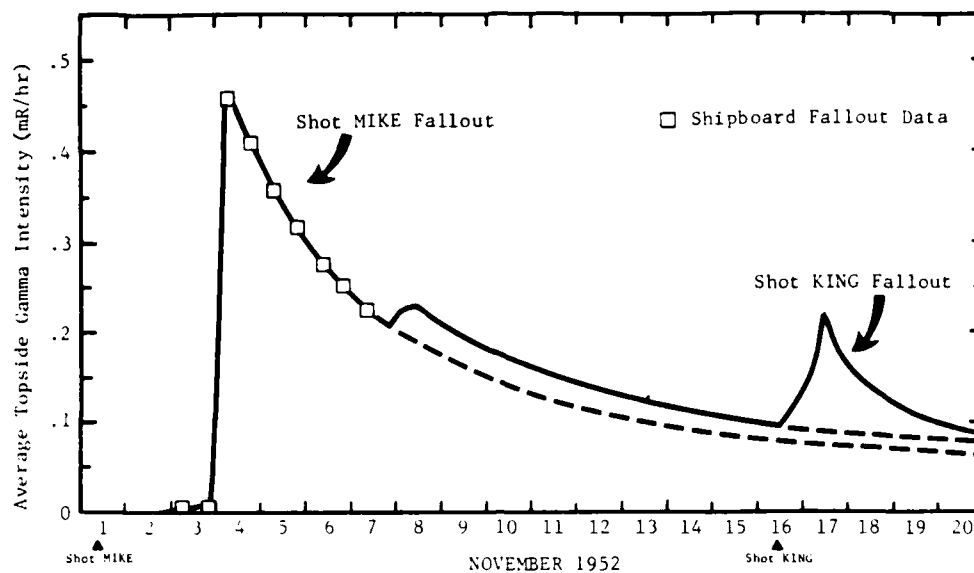


Figure 2-4. Average Intensity on the USS ESTES and Parry Island

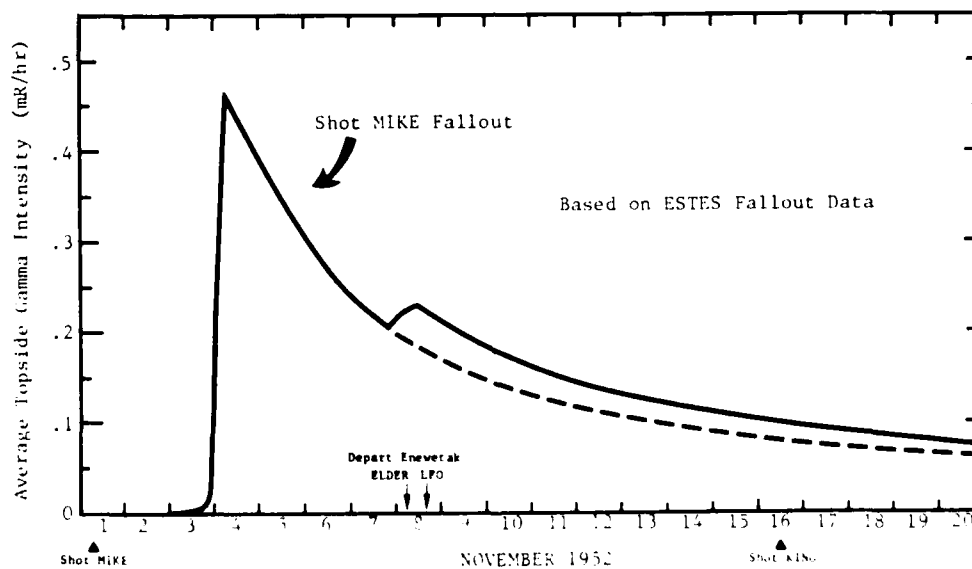


Figure 2-5. Average Intensity on the USS LEO and the USS ELDER

No radiological data from either ship have been located that would indicate the topside gamma intensities resulting from Shot MIKE. Fallout collectors were placed on the LEO from 1-5 November but an analysis of these samples indicated that no fallout occurred on the ship. This appears highly unlikely due to its close proximity to the ESTES during this time period. It is assumed that both the LEO and ELDER received the same fallout that occurred on the ESTES through 8 November when they departed the lagoon. Figure 2-5 depicts the average topside gamma intensity on the LEO and ELDER, as inferred from the ESTES data. The Shot KING contribution does not apply since neither ship was in the vicinity of Enewetak when the KING fallout occurred.

2.2.3 USS RENDOVA (CVE-114), USS OAK HILL (LSD-7), USS LIPAN (ATF-85) and USNS GENERAL E.T. COLLINS (TAP-147)

On 2 November, the day after Shot MIKE, the RENDOVA, OAK HILL, LIPAN, and COLLINS reentered the lagoon and anchored off Enewetak Island (see Figure 2-1). All four ships remained in this anchorage area until 5 November when the LIPAN began taking up various positions in the western and northern portions of the lagoon while aiding the HORIZON in conducting its seismic refraction studies. These studies continued through 15 November, during which time the LIPAN never left the lagoon.

On 6 November, the RENDOVA shifted berths to the anchorage area off Parry Island and departed the lagoon only twice on 12 and 13 November, to conduct aircraft operations. Both times it returned to the anchorage off Parry.

The OAK HILL remained anchored off Enewetak until 8 November when it departed the lagoon, returning to the same berth on 9 November. On 12 November, the OAK HILL shifted berths to the anchorage area off Parry where, except for nine hours at sea on 13 November, it remained until 16 November. The COLLINS did not shift berths following Shot MIKE and left the lagoon only once for approximately six hours on 13 November.

Early in the morning on 16 November, all four ships departed the lagoon to take up positions from where the crews would safely observe Shot KING at 1130 hours. Later that same afternoon, the RENDOVA and OAK HILL returned to anchorages off Parry, while the LIPAN and COLLINS anchored off Enewetak Island.

From the fallout samples obtained on the RENDOVA and OAK HILL it is possible to estimate the topside gamma intensity on all four ships while at Enewetak. Figure 2-6 is the derived topside intensity on the RENDOVA and Figure 2-7 is a similar curve for the OAK HILL. Since the LIPAN and COLLINS were anchored in close proximity to the OAK HILL following Shot MIKE, it is assumed they received the same fallout. It is further assumed that Enewetak Island, being only several thousand yards east of these ships, received similar fallout although its occurrence is not documented. Because all four of the ships remained in the vicinity of the lagoon for the remainder of the operation, it is assumed that each of the ships received similar fallout on 7-8 November as well as the fallout from Shot KING.

On 4, 5, and 6 November, intensity measurements obtained on the RENDOVA's flight deck indicated average beta plus gamma intensities of 2.1 mR/hr, 1.8 mR/hr and 0.7 mR/hr, respectively (Reference 12). Assuming a beta plus gamma to gamma ratio of 5 (Section 2.2), these survey readings imply gamma intensities of 0.42 mR/hr, 0.36 mR/hr and 0.14 mR/hr on these three successive days. These values are plotted in Figure 2-6 (solid circles on 4, 5, and 6 November) and, with the exception of the 6 November survey point, show good agreement with the average topside gamma intensity curve derived from the fallout samples.

On 8 November, following a radiation survey onboard the COLLINS, average intensities ranged from 1.5-2.5 mR/hr with a maximum of 6 mR/hr (all beta plus gamma). Negative results were obtained below decks (Reference 7). Assuming the same ratio as before, average gamma intensities would have been 0.3-0.5 mR/hr. The range in average intensities has been plotted in Figure 2-7 and tend to support the average curve derived from the OAK HILL fallout samples and RENDOVA hangar deck activities.

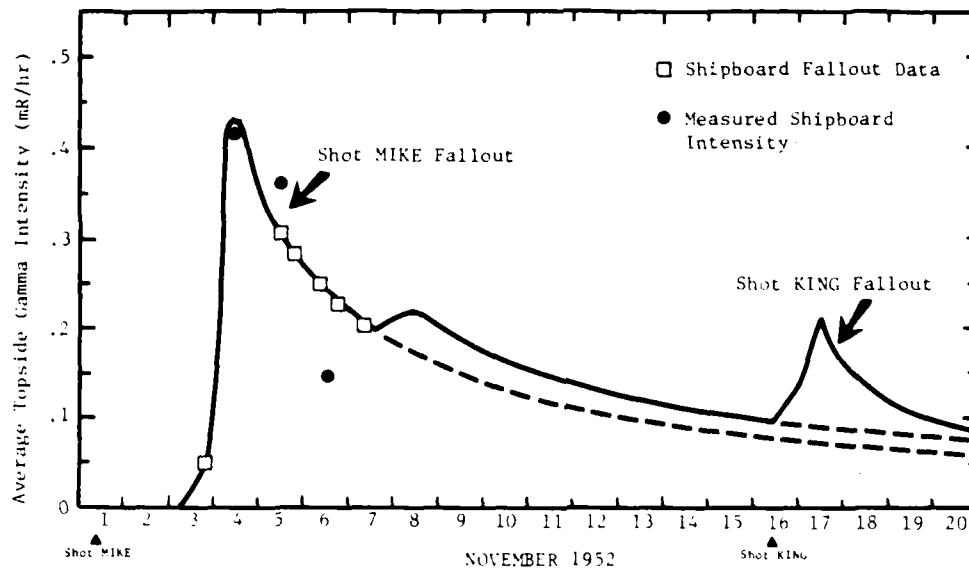


Figure 2-6. Average Intensity on the USS RENDOVA

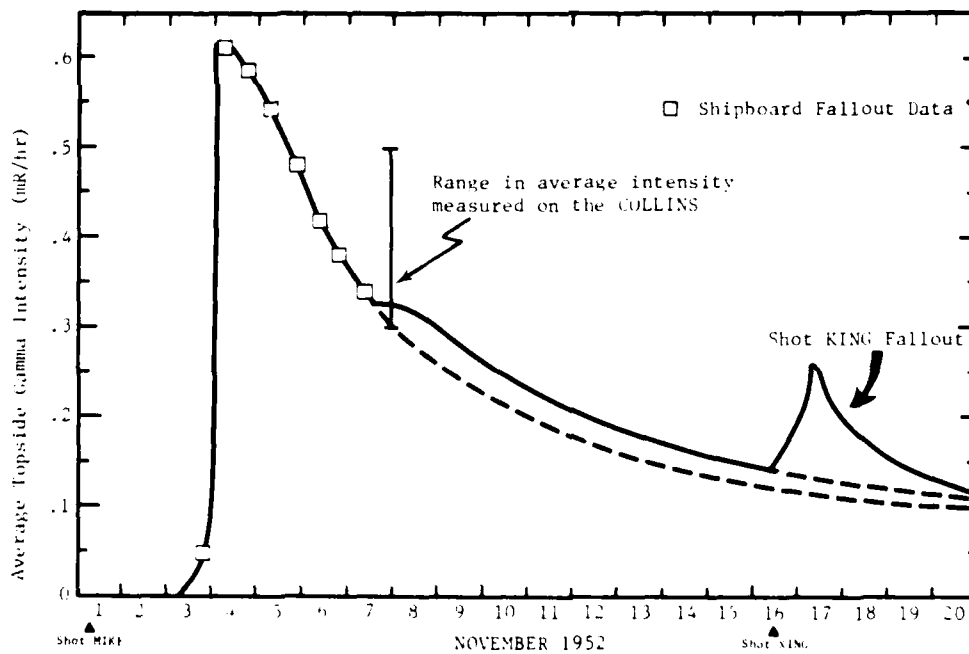


Figure 2-7. Average Intensity on the USS OAK HILL, USS LIPAN, USNS GENERAL E.T. COLLINS, and Enewetak Island

While helping the HORIZON perform seismic studies in the northern portion of the atoll following Shot MIKE, the LIPAN's evaporators became slightly contaminated from radioactive water. Although measurements of deposits (scale) obtained from the ship's evaporators indicated intensities above the permissible maximum for Operation IVY (0.6 mR/hr, beta plus gamma), it is reported to have been virtually all beta radiation (References 2 and 12) and the ship was given an operational radiological clearance on 17 November. The COLLINS and OAK HILL received their final radiological clearances on 19 November and the RENDOVA received its final clearance on 2 December 1952.

2.2.4 USS ARIKARA (ATF-98) and USNS DAVID C. SHANKS (TAP-180)

Following Shot MIKE, the ARIKARA entered the lagoon at 0925 hours on 2 November with three Navy barges in tow. After discharging its tow in berth D-1, the ARIKARA anchored in berth M-4 off Enewetak Island at 1543 hours. In this anchorage, the ship was approximately 500 yards from the RENDOVA, OAK HILL, and LIPAN, essentially surrounded by these three ships (see Figure 2-1). It remained in berth M-4 until 1544 hours on 5 November when it departed the lagoon enroute to a position 155 nmi northwest of Enewetak to recover some drifting buoys. It returned to the lagoon at 1035 hours on 6 November and anchored in berth M-4 at 1110 hours. The ARIKARA shifted berths on 7 November to an anchorage off Parry. The ship also received a radiological clearance and was released from operational control of the task group on this date. On 8 November, at 0915 hours, the ARIKARA departed Enewetak for Pearl Harbor in company with the ELDER. The ARIKARA did not participate at Shot KING.

The deck log from the SHANKS has not been located, hence its operational activities while at Enewetak cannot be detailed. It is known that the SHANKS departed the lagoon at 1720 hours, 31 October, to take up a position for Shot MIKE, and probably returned to the lagoon during the morning of 2 November with the other task group ships. It is not known where the SHANKS anchored, but several entries in the OAK HILL's deck log indicate that it was anchored off Enewetak Island near the five other ships in this anchorage area. The SHANKS received its final radiological

clearance on 10 November and, having been released from operational control of CTG 132.3 on the same day, departed Enewetak on 11 November. Like the ARIKARA, the SHANKS did not participate at Shot KING.

Shipboard radiological data have not been found to indicate that the ARIKARA and SHANKS received fallout from Shot MIKE, but because of their proximity to the RENDOVA and OAK HILL at the time these two ships received the MIKE fallout, it is likely the ARIKARA and SHANKS received similar fallout. Figure 2-8 is the average topside intensity on these two ships as inferred from the OAK HILL intensity data, minus the fallout following Shot KING.

Early in the morning on 6 November, while recovering the buoys northeast of the lagoon, 12 of the crewmen aboard the ARIKARA became contaminated when they brought aboard a buoy "which was found to be 80 mR/hr radioactive". At 0110 hours, 6 November, the crewmen were monitored and intensities ranged from .15-3.0 mR/hr. Personnel decontamination was carried out immediately and by 0135 hours "further monitoring found the above personnel to be clean of radioactive contamination. Above personnel were exposed one hour maximum" (Reference 7).

2.2.5 USS AGAWAM (AOG-6)

After observing Shot MIKE, the crew of the AGAWAM reentered the lagoon on 2 November and moored to POL buoys F1 and F2 off the southern tip of Parry Island at 1130 hours (see Figure 2-1). Except for a 6-hour period on 5 November when it moved to berth N-6, and a 5½-hour period on 13 November when it departed the lagoon, the AGAWAM remained moored to the POL buoys until 0801 hours on 16 November when it left the lagoon in preparation for Shot KING. Following Shot KING, the AGAWAM reentered the lagoon and again moored to POL buoys F1 and F2 at 1746 hours on 16 November. The ship remained in the southern anchorage area of the lagoon until 1307 hours on 18 November when it departed Enewetak enroute to Kwajalein.

The average topside gamma intensity onboard the AGAWAM is reconstructed in Figure 2-9 from fallout samples and RENDOVA hangar deck activity correlations.

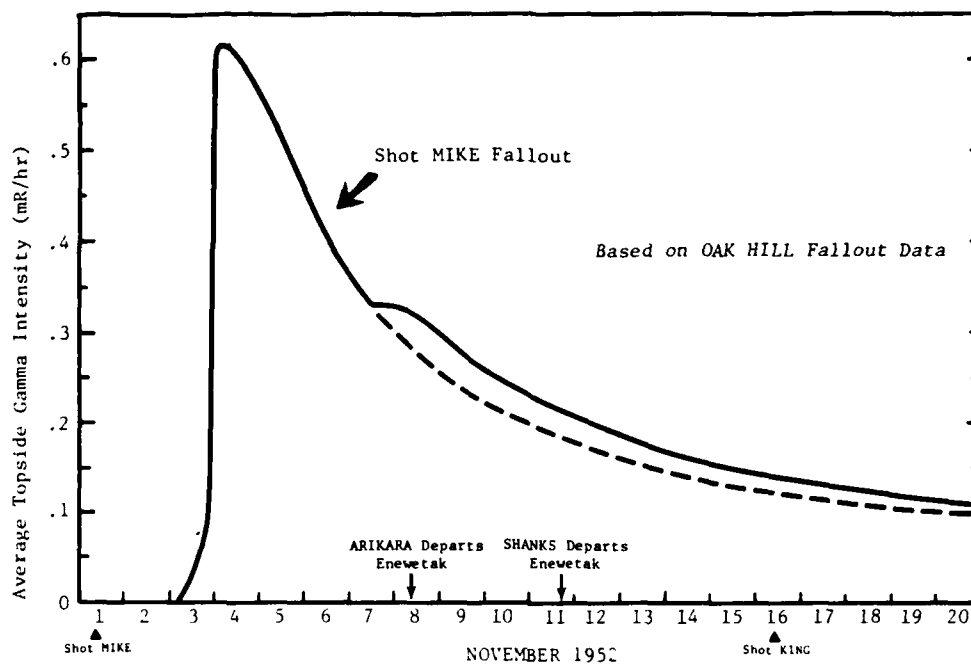


Figure 2-8. Average Intensity on the USS ARIKARA and USNS DAVID C. SHANKS

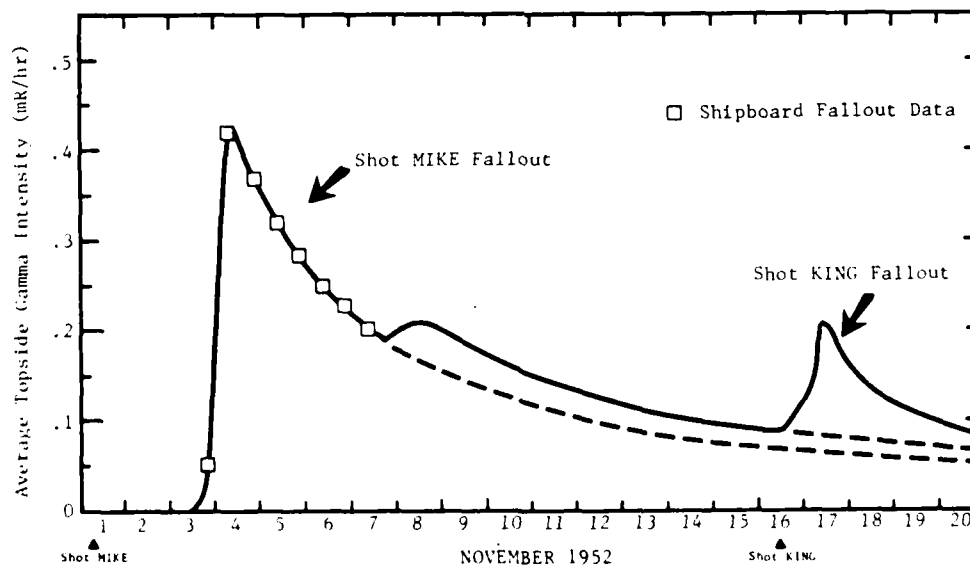


Figure 2-9. Average Intensity on the USS AGAWAM

Since the AGAWAM remained in the vicinity of Enewetak throughout the operation, it is assumed it received the 7-8 November fallout from Shot MIKE and also, the contamination following Shot KING. The only reference to any fallout onboard the AGAWAM is given in Reference 15, which states that "no contamination occurred except in isolated spots where water had collected and evaporated." Maximum readings were 5 mR/hr, beta plus gamma. Using a beta plus gamma to gamma ratio of 5 as was determined onboard the ESTES (See Section 2.2), this reading equates to a maximum reading of 1 mR/hr gamma on 18 November. No average readings were mentioned in this reference. Upon arrival at Kwajalein on 21 November, the ship was resurveyed, but no appreciable contamination was found. Readings of 2 mR/hr, all beta, were found in two isolated locations and measures were taken to remove the contaminants. Final radiological clearance was given to the AGAWAM on 22 November 1952.

2.2.6 USS O'BANNON (DDE-450)

The O'BANNON's crew observed Shot MIKE from the Control Destroyer Station approximately 155 miles southeast of Enewetak, midway between Enewetak and Kwajalein. For the next several days the O'BANNON searched for and recovered Dan buoys used in an experiment that had been laid out for NRDL on 31 October and 1 November by the YUMA. This search led them north to just off the western edge of Bikini and eventually in a wide arc which took them to the northeast and north of Enewetak during the period 3-5 November. At 0830 hours on 6 November, the search was terminated and the O'BANNON entered Enewetak Lagoon and anchored in berth D-7 at 1815 hours. It remained anchored in the lagoon until 9 November when it relieved the RADFORD and assumed patrol duties around Enewetak. The O'BANNON briefly reentered the lagoon on 12 and 14 November to refuel and at 0600 hours on 15 November it was on station for Shot KING approximately 145 miles southeast of Enewetak. At 1705 hours on 16 November, the O'BANNON was released from its duties and proceeded to Kwajalein. The O'BANNON did not return to Enewetak after Shot KING.

Figure 2-10 depicts the reconstructed topside gamma intensity on the O'BANNON resulting from Shot MIKE fallout. The fallout samples obtained from the O'BANNON from 2-7 November revealed much less activity than observed onboard the majority of the other ships participating at Operation IVY. This is probably attributable to the fact that the O'BANNON was well north of Enewetak when the major portion of MIKE secondary fallout was being deposited in the lagoon. The slight hump in the intensity curve on 6 November is due to fallout that was occurring at Enewetak when the ship reentered the lagoon. The O'BANNON was granted final radiological clearance on 18 November 1952 while at Kwajalein.

While recovering Dan buoys on 3 November, 14 crewmen of the O'BANNON were slightly contaminated when a radioactive buoy was brought onboard at 2204 hours. Maximum intensity readings on personnel were 1.0 mR/hr on shoes and 0.5 mR/hr on hands. The intensity readings on the main deck (port side aft of Frame 105) were 0.6-0.7 mR/hr. It is not stated if these readings are beta plus gamma or only gamma but all exposed personnel and shipboard areas were decontaminated to a level of .04 mR/hr by 2207 hours (Reference 7).

2.2.7 USS RADFORD (DDE-446) and USS CARPENTER (DDE-825)

After the Shot MIKE detonation on 1 November, the RADFORD began patrolling the waters east of Enewetak. It continued its anti-submarine patrol until 9 November, when it entered the lagoon to take on fuel. Between 10-15 November, the RADFORD again assumed patrol duties east and southeast of the atoll, breaking twice to act as plane guard for the RENDOVA on 12 and 13 November. With the detonation of Shot KING on 16 November, the RADFORD again acted as plane guard for the RENDOVA until 1600 hours, after which it entered the lagoon and anchored in berth D-5 at 1655 hours. After refueling on 17 November, the RADFORD departed Enewetak at approximately 1500 hours in company with the CARPENTER and FLETCHER enroute to Kwajalein.

Between 1 and 8 November, while the RADFORD was on patrol east of Enewetak, the CARPENTER was patrolling the waters to the south (off Wide Passage)

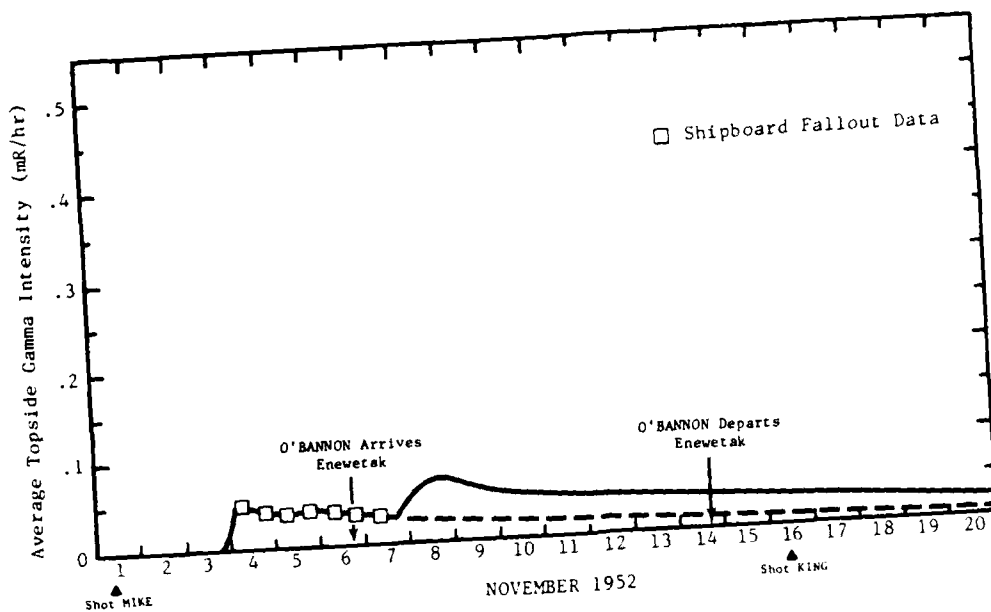


Figure 2-10. Average Intensity on the USS O'BANNON

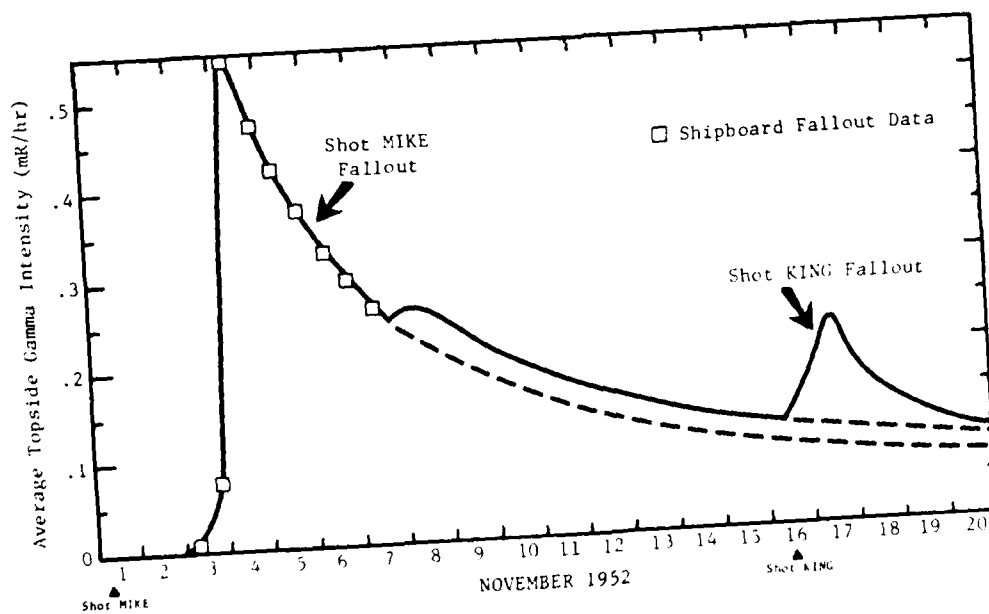


Figure 2-11. Average Intensity on the USS RADFORD

and west, occasionally serving as plane guard for the RENDOVA on 1 and 2 November. On 8 November, the CARPENTER entered the lagoon and anchored in berth D-5 at 1414 hours. It remained in the lagoon until 11 November, when it resumed patrolling the waters to the east and south of Enewetak. The CARPENTER reentered the lagoon briefly on 15 November to take on fuel and then began patrolling the waters to the west and south. After Shot KING was detonated on 16 November, the CARPENTER entered the lagoon and anchored in berth D-4 at 1733 hours. At approximately 1500 hours on 17 November, the CARPENTER departed Enewetak for Kwajalein in company with the RADFORD and FLETCHER.

The RADFORD and CARPENTER, while patrolling east and south of Enewetak, were the first task group ships to encounter the secondary fallout from Shot MIKE. The fallout samples indicate that both ships began receiving light fallout at approximately noon on 2 November and that it continued intermittently through 7 November. Figure 2-11 depicts the average topside gamma intensity onboard the RADFORD as inferred from the fallout samples through 7 November, and as calculated from RENDOVA correlations through 20 November. Figure 2-12 is a comparable intensity curve for the CARPENTER. The History of Operation IVY (Reference 3) states that, on 3 November, the RADFORD and FLETCHER*, while on patrol outside of the lagoon, encountered fallout with average intensities of 1 mR/hr (gamma) and maximum intensities of 4 mR/hr (gamma). Actual shipboard intensity measurements (from fallout samples), and messages from these two ships to CTG 132.3 do not support this statement. Both ships received a final radiological clearance from CTG 132.3 on 17 November, prior to their departure from Enewetak.

2.2.8 USS FLETCHER (DDE-445)

Following the MIKE detonation on 1 November, the FLETCHER remained outside of the lagoon to provide escort for the RENDOVA and to patrol the waters west of the

*Although Reference 3 states that the RADFORD and FLETCHER received this fallout, it was probably the RADFORD and CARPENTER since the FLETCHER was enroute to Kwajalein at this time.

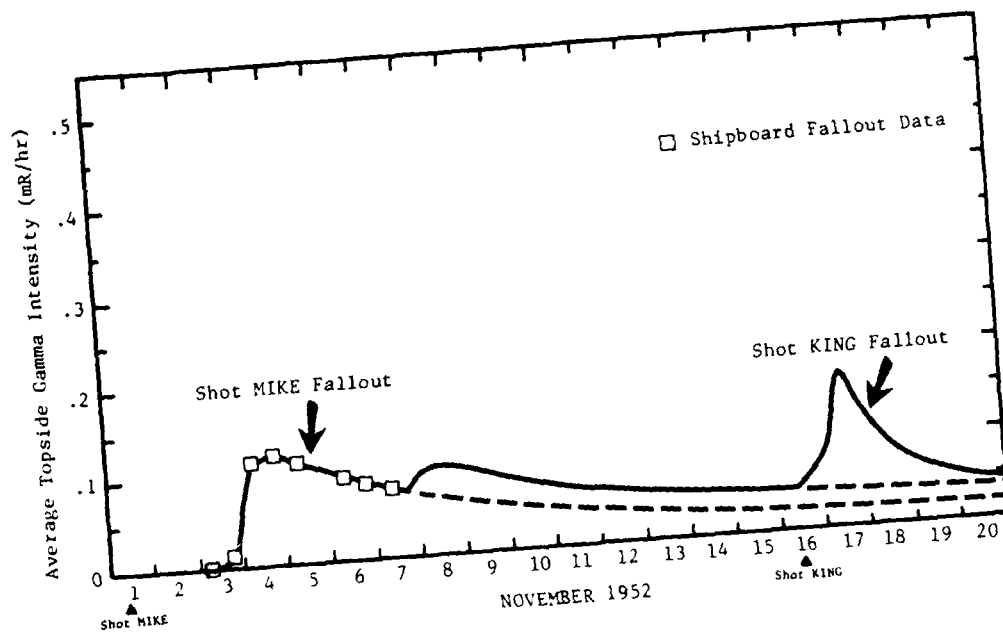


Figure 2-12. Average Intensity on the USS CARPENTER

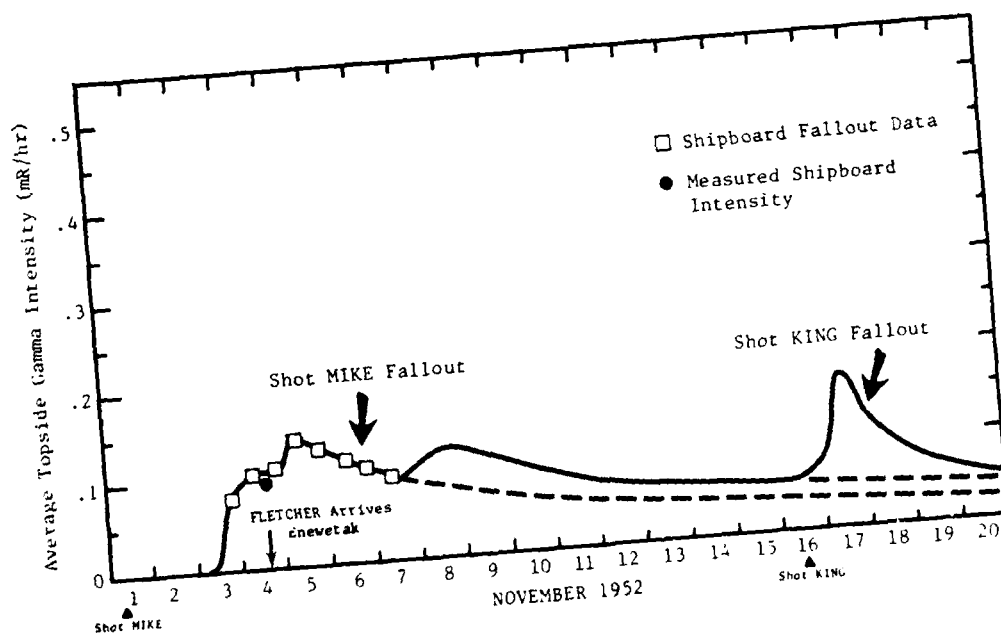


Figure 2-13. Average Intensity on the USS FLETCHER

lagoon. At 1645 hours on 2 November, the FLETCHER took station ahead of the CURTISS and provided screen for the weapons ship enroute to Kwajalein. Upon reaching Kwajalein on 3 November, the FLETCHER was released from screen duties at 1536 hours and returned to Enewetak, anchoring in the lagoon in berth D-5 at 1340 hours on 4 November. On 8 November, the FLETCHER relieved the CARPENTER of its patrol duties in the waters to the south, west, and north of Enewetak. The FLETCHER reentered the lagoon to refuel on 15 November and remained there until its departure at 0635 hours on 16 November for a position 19 miles south-southeast of the atoll from where the crew observed Shot KING at 1130 hours. At 1741 hours, the FLETCHER returned to the lagoon and anchored in berth D-6. The next day, the FLETCHER departed Enewetak at approximately 1500 hours in company with the RADFORD and CARPENTER enroute to Kwajalein.

The average topside gamma intensity reconstructed from the fallout data is depicted in Figure 2-13. The only shipboard readings available on the FLETCHER are contained in a 4 November message from the FLETCHER to CTG 132.3 (Reference 16) which states that, at 1300 hours, average intensities were .087 mR/hr gamma and maximum intensities were 0.1 mR/hr gamma. The message further states that there was an increase since 1000 hours and that they believed a trace of contamination was received just prior to entering the lagoon. Both the actual data and the reported trends of the data are in good agreement with Figure 2-13. On 17 November 1952, the FLETCHER received a final radiological clearance prior to steaming to Kwajalein.

2.2.9 USS CURTISS (AV-4)

In preparation for Shot MIKE, the CURTISS departed Enewetak at 0359 hours on 1 November and proceeded to its assigned station 35 miles southeast of the lagoon. After the detonation, the CURTISS reentered the lagoon and anchored in berth C-3 at 1010 hours on 2 November. At 1535 hours the same day, after off-loading equipment and AEC personnel, the CURTISS departed Enewetak Lagoon. After rendezvousing with the FLETCHER at 1645 hours, both ships steamed for Kwajalein. At approximately 1500 hours on 3 November, the CURTISS arrived at Kwajalein and by 1607 hours was anchored in berth K-14, Kwajalein Atoll. The CURTISS remained at Kwajalein until 18 November when it departed for San Francisco.

Figure 2-14 is the reconstructed average topside gamma intensity onboard the CURTISS resulting from Shot MIKE secondary fallout, based on fallout samples taken on the ship. It is assumed that the CURTISS received the same fallout after arrival at Kwajalein that was occurring on that atoll through 7 November. Since the CURTISS remained at Kwajalein until 18 November, it did not receive the fallout that occurred over Enewetak after 7 November. The CURTISS received a final radiological clearance on 18 November prior to its departure from Kwajalein.

2.2.10 USS YUMA (ATF-94) and Kwajalein Atoll

On 1 November, the crew of the YUMA observed Shot MIKE from a position 27 miles southeast of the MIKE SZ. The day after the detonation, the YUMA entered Enewetak lagoon and anchored off Enewetak Island at 1110 hours. At 1335 hours, the YUMA departed for Kwajalein, arriving at approximately 1500 hours on 3 November. About 24 hours later, the YUMA departed Kwajalein towing a fuel barge, arriving Enewetak at 0700 hours on 7 November. A radiological inspection team boarded at 1815 hours and gave the YUMA a final radiological clearance prior to its release from TG 132.3 operational control. At 1226 hours on 8 November, the YUMA got underway for Pearl Harbor via Kwajalein. The YUMA did not participate at Shot KING.

Shipboard radiological data has not been found for the YUMA; hence, the gamma intensity curve in Figure 2-15 is based in part on its proximity to Kwajalein on 2, 3, and 4 November and that the ship was at Enewetak when the 7-8 November fallout occurred. Fallout samples obtained on Kwajalein are used to reconstruct the island intensity curve depicted in Figure 2-16. The YUMA's topside intensity is identical except for the addition of the 7-8 November secondary fallout it received after reentering Enewetak Lagoon on 7 November. Maximum gamma intensities on Kwajalein were reported to range from 0.30-0.35 mR/hr on MIKE + 2 days (Reference 17). When one considers that maximum readings are often two or three times the average, there is good agreement with the fallout sample data.

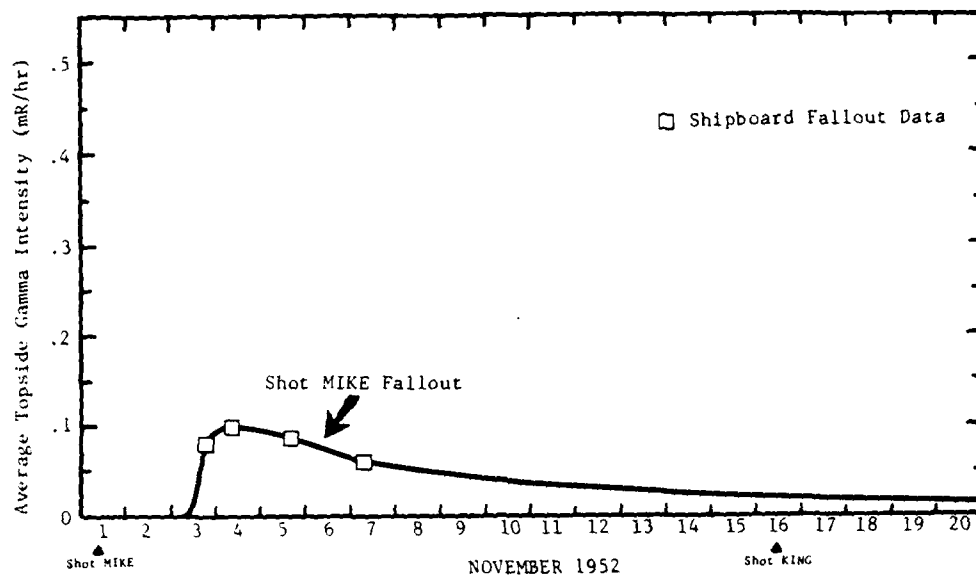


Figure 2-14. Average Intensity on the USS CURTISS

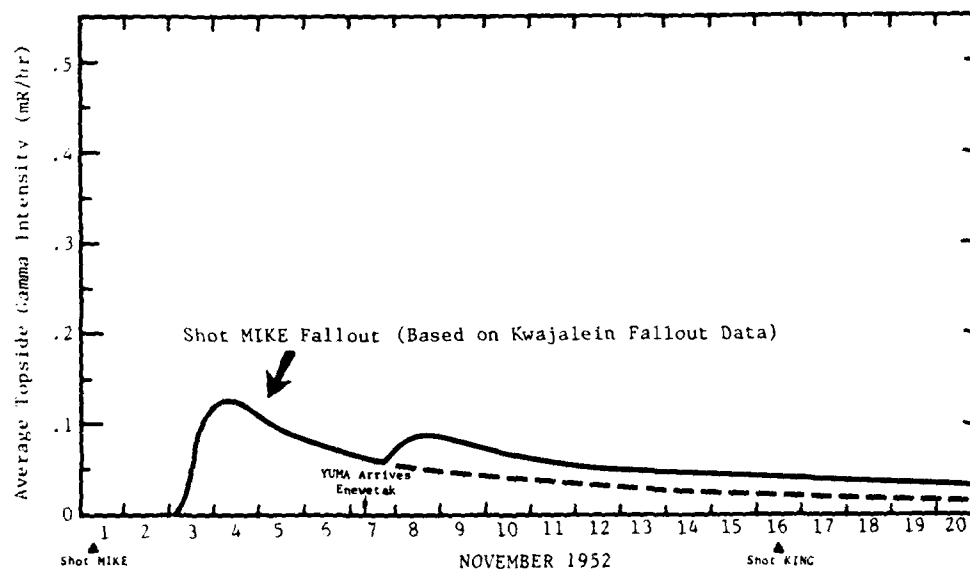


Figure 2-15. Average Intensity on the USS YUMA

2.2.11 M/V HORIZON (ex-ATA)

Primary fallout from Shot MIKE occurred on only one TG 132.3 ship, the USNS HORIZON, an ex-ATA being used for seismic refraction studies conducted by the Scripps Institute of Oceanography. At shot time, the HORIZON was on station approximately 65 miles northeast of SZ. At 0745 hours, the HORIZON was ordered to proceed to an area 110 miles north-northeast of SZ and, at 1240 hours, the ship encountered radioactive fallout in a moderate rainshower. Although the radiation levels were low (~ 1 mR/hr gamma), the ship was closed up, the ventilation system was secured, all personnel were ordered below decks, and the washdown system was placed in operation. By 1300 hours, the average topside intensity had increased to 5 mR/hr with maximum readings of 15 mR/hr being reported. Radiation levels gradually increased to 8 mR/hr by 1500 hours, with maximum intensities of 35 mR/hr. The washdown system remained on as the ship proceeded on a southerly course in an attempt to clear the fallout area. At 1630 hours the crew took two air samples which indicated no detectable activity in the air and a resurvey of the weather decks at 1700 hours indicated a slight drop in the intensity levels--average 6 mR/hr and a maximum of 30 mR/hr. The ventilation system was cut on and the ship was opened and washed down with high pressure hoses until 1930 hours. Only work parties were allowed on deck; all other personnel were ordered to remain below until decontamination was complete. A survey of the ship at 2000 hours indicated average gamma intensities of 3 mR/hr and maximum readings of 20 mR/hr. Only a trace of contamination had been tracked below decks. Decontamination operations were continued until the ship returned to Enewetak on 6 November, when average topside intensities of 0.5 mR/hr (with maximum readings of 3 mR/hr) were still being reported (References 3, 9, and 18).

The deck log of the HORIZON has not been located; therefore its activities after 6 November are not detailed. It is assumed that the HORIZON remained in the vicinity of Enewetak through the remainder of Operation IVY. Entries in the deck log of the OAK HILL indicate that the HORIZON was anchored in berths Q-3 or Q-5 (off Enewetak Island) on 6, 9, 10 and 11 November. It is known that at the time of Shot KING on 16 November, the HORIZON was anchored off Enewetak Island. It is also

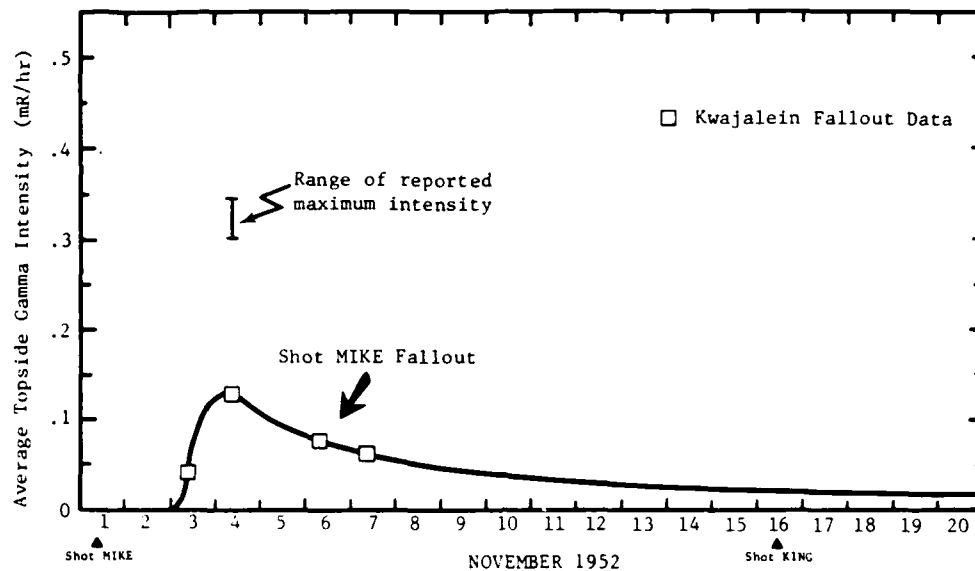


Figure 2-16. Average Intensity on Kwajalein Atoll

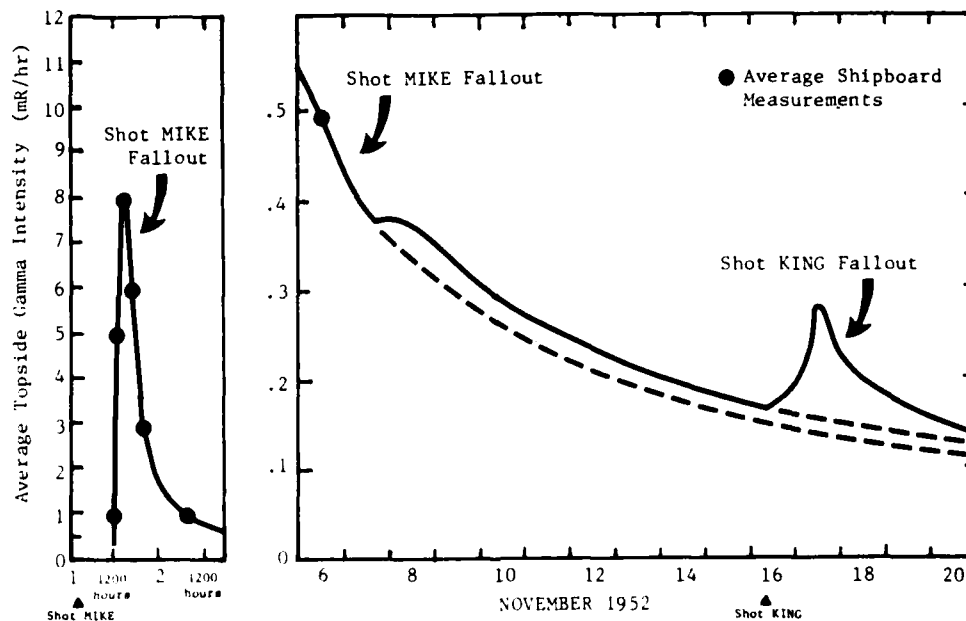


Figure 2-17. Average Intensity on the M/V HORIZON

known the HORIZON was in the lagoon on 22 November when it was released from operational control of CTG 132.3. The HORIZON probably departed Enewetak on 22 November enroute to Kwajalein where it received an operational radiological clearance on 23 or 24 November.

Figure 2-17 is the reconstructed topside gamma intensity on the HORIZON resulting from Shots MIKE and KING fallout. The solid circles plotted represent actual shipboard intensity readings obtained during these time periods. It is assumed that the HORIZON received both the 7-8 November fallout from Shot MIKE and the fallout from Shot KING on 16 November. Gamma intensity measurements taken on the HORIZON prior to its release from the task group on 22 November indicated an average intensity of 0.1 mR/hr and a maximum reading of 2 mR/hr (Reference 19). The 0.1 mR/hr average is in good agreement with the reconstructed intensity for that date.

2.2.12 M/V SPENCER F. BAIRD (ex-ATA) and Bikini Atoll

The BAIRD was another ship used for the seismic refraction studies conducted by the Scripps Institute of Oceanography during Operation IVY. The BAIRD had departed CONUS on 27 October 1952, enroute to Enewetak via Bikini Atoll. Upon arriving at Bikini on 14 November, it was ordered to remain there until Shot KING was detonated on 16 November; this step was taken to ensure that it would not be contaminated by KING fallout. On 16 November, the BAIRD departed Bikini enroute to Enewetak, arriving Enewetak at 0700 hours on 17 November -- just in time to encounter the trace of fallout following Shot KING. The BAIRD was released from operational control of the task group on 22 November, and probably steamed in company with the HORIZON from Enewetak to Kwajalein. On 23 or 24 November, while at Kwajalein, the BAIRD received a final radiological clearance.

Figure 2-18 depicts the reconstructed average gamma intensity on the BAIRD resulting from fallout while at Enewetak. Measurements obtained prior to its release from the task group on 22 November (probably on 18 or 19 November) indicated average readings of 0.05 mR/hr with maximum readings of 0.1 mR/hr (Reference 19).

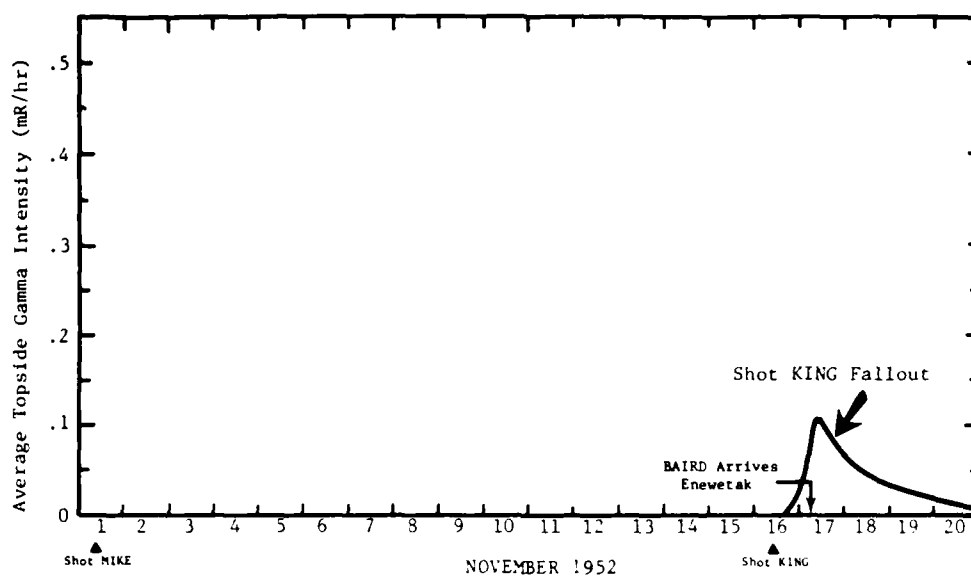


Figure 2-18. Average Intensity on the M/V SPENCER F. BAIRD

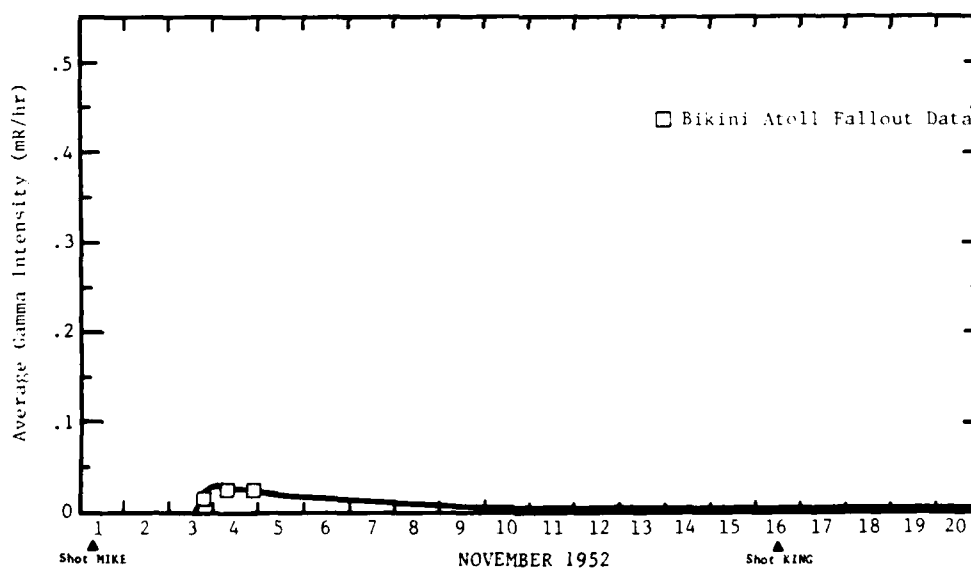


Figure 2-19. Average Intensity on Bikini Atoll

These readings are in excellent agreement with the reconstructed environment in Figure 2-18.

Fallout samples obtained on Bikini Atoll are used to reconstruct the island intensity depicted in Figure 2-19. The BAIRD did not arrive at Bikini until 14 November; hence, it was not contaminated by this fallout.

2.3 INTEGRATED FREE-FIELD INTENSITIES

The average free-field intensities on the ships and residence islands of the various atolls occupied by TG 132.3 personnel, as depicted in Figures 2-4 through 2-19, are integrated with respect to time from 1 November to 18 November 1952. Calculations are terminated on 18 November because the Operation IVY roll-up phase was virtually complete by this time and nearly all of the ships had departed Enewetak.

The basic expression used to calculate the integrated free-field intensities on the ships and islands is given by:

$$\int_{t_1}^t I(t)_{\text{MIKE 1}} dt + \int_{t_2}^t I(t)_{\text{MIKE 2}} dt + \int_{t_3}^t I(t)_{\text{KING}} dt$$

t_1, t_2 and t_3 = Fallout arrival times for Shots MIKE (t_1 and t_2) and KING (t_3) in hours after the shot.

$I(t)_{\text{MIKE 1}}, I(t)_{\text{MIKE 2}}$ = Average intensity with respect to time after Shot MIKE for fallout arriving between 1-6 November and 7-8 November, respectively.

$I(t)_{\text{KING}}$ = Average intensity with respect to time after Shot KING.

The upper limit of integration, t , is the time, in hours after the shot, at the end of the period for which is desired to calculate the average film badge dose, i.e., 18 November.

From the fallout activity/gamma intensity correlations inferred from the ESTES and RENDOVA data (Figure 2-2), and the continuous recording of activity on the RENDOVA's hangar deck (Figure 2-3), it is possible to quantify the incremental dose contributions on the RENDOVA from the 7-8 November fallout and the fallout from Shot KING. The second "wave" of Shot MIKE fallout on 7-8 November contributed approximately 7 mR to the free-field radiation dose on the RENDOVA through 18 November; Shot KING contributed only 3 mR.

The basic expression used to calculate the integrated intensity thus becomes:

$$\int_{t_1}^t I(t)_{\text{MIKE}} dt + 7 \text{ mR}^* + 3 \text{ mR}^{**}$$

This expression is used to calculate the *integrated intensity on each of the task group ships and the surrounding atolls during Operation IVY*. The results are given in Table 2-1.

2.4 SHIP SHIELDING

Dose estimates for crewmembers require consideration of the shielding provided by the ship structure for radioactive fallout deposited on the weather surfaces of the ships. A ship shielding factor, defined as the ratio of radiation intensity at an interior location to an intensity topside, depends on such variables as time after detonation, distribution of fallout on the weather surface, amount of intervening material (decking, bulkheads, piping, etc.) from weather surface to point of interest, and distance from weather surface. Consequently, while ship shielding effects have been experimentally and theoretically studied by the Navy since Operation CROSSROADS

*Applies only if the ship was in the vicinity of Enewetak on 7-8 November

**Applies only if the ship was in the vicinity of Enewetak on 16-17 November.

Table 2-1. Integrated Free-Field Intensities on Task Group 132.3 Ships and the Residence Islands of Surrounding Atolls.

<u>Ship</u>	Integrated Intensity (mR) from Fallout Occuring on			<u>Total</u>
	<u>1-6 November</u>	<u>7-8 November</u>	<u>16-17 November</u>	
USS RENDOVA	55.8	6.7	3.2	65.7
USS OAK HILL	87.3	6.7	3.2	97.2
USS ARIKARA	87.3	6.7	0	94.0
USS LIPAN	87.3	6.7	3.2	97.2
USNS DAVID C. SHANKS	87.3	6.7	0	94.0
USNS GEN. E.T. COLLINS	87.3	6.7	3.2	97.2
USS AGAWAM	55.3	6.7	3.2	65.2
USS ESTES	60.2	6.7	3.2	70.1
USS LEO	60.2	6.7	0	66.9
USS ELDER	60.2	6.7	0	66.9
USS CARPENTER	19.8	6.7	3.2	29.7
USS RADFORD	72.0	6.7	3.2	81.9
USS O'BANNON	7.8	6.7	0	14.5
USS FLETCHER	23.9	6.7	3.2	33.8
USS YUMA	17.8	6.7	0	24.5
USS CURTISS	16.6	0	0	16.6
M/V HORIZON	190.7	6.7	3.2	200.6
M/V SPENCER F. BAIRD	0	0	3.2	3.2
<u>Atoll</u>				
Enewetak Atoll*				
Enewetak Is.	87.3	6.7	3.2	97.2
Parry Is.	60.2	6.7	3.2	70.1
Kwajalein Atoll	17.8	0	0	17.8
Bikini Atoll	3.3	0	0	3.3

*Inferred from shipboard data

(1946), values of shielding factors remain uncertain. Readings taken on target ships during Operation CROSSROADS, and on two test ships (TAG-39 and YAG-40) during Operations CASTLE (1954) and REDWING (1956) gave preliminary estimates of shielding factors (References 20, 21 and 22). However, a significant fraction of the radiation penetrating to the interior of these ships, especially at the lower depths, apparently came from radioactive materials in the water and on the hulls of the ships. Thus, these shielding factors are not directly applicable to the present problem.

Experimental results reported by W.F. Waldorf (Reference 23) on radiation from Cobalt-60 and Cesium-137 sources on the flight deck penetrating the interior of a light aircraft carrier (USS COWPENS) indicated that an average shielding factor could be correlated with the thickness of deck plating directly above the point of interest in the ship. He further showed that the effects of bulkheads, piping, and other miscellaneous intervening material could be approximated (somewhat high-sided) by doubling the deck thickness in shielding calculations. Results from British experiments on a carrier, destroyer, and light cruiser, referenced by Waldorf, verified these conclusions and indicated that this factor of two may apply to most ship types. C.F. Ksanda (References 20 and 24) performed detailed calculations on an aircraft carrier (USS RANGER), presenting the shielding factors graphically as functions of deck plating thickness for various times after detonation. He also accounted for miscellaneous shielding materials by doubling the deck thickness when performing the calculations. The results of the Waldorf experiment and the geometric means of Ksanda's upper and lower limit shielding factors for unfractionated U-235 fission products at one day after detonation are displayed in Figure 2-20. Due to geometric attenuation, these curves approach values less than one as deck thickness becomes small. Comparison indicates that Ksanda's mean values represent a somewhat high-sided estimate of the shielding factor, since the average gamma energy for the times of interest (days to weeks after detonation) is similar to the 0.66 MeV from the cesium source. Because of the detailed nature of Ksanda's effort and the general agreement with experiment, the Ksanda mean value is used in the present calculations.

In the present analysis, it is assumed that, when topside, personnel experienced the average external topside intensity, and any shielding provided by the super-

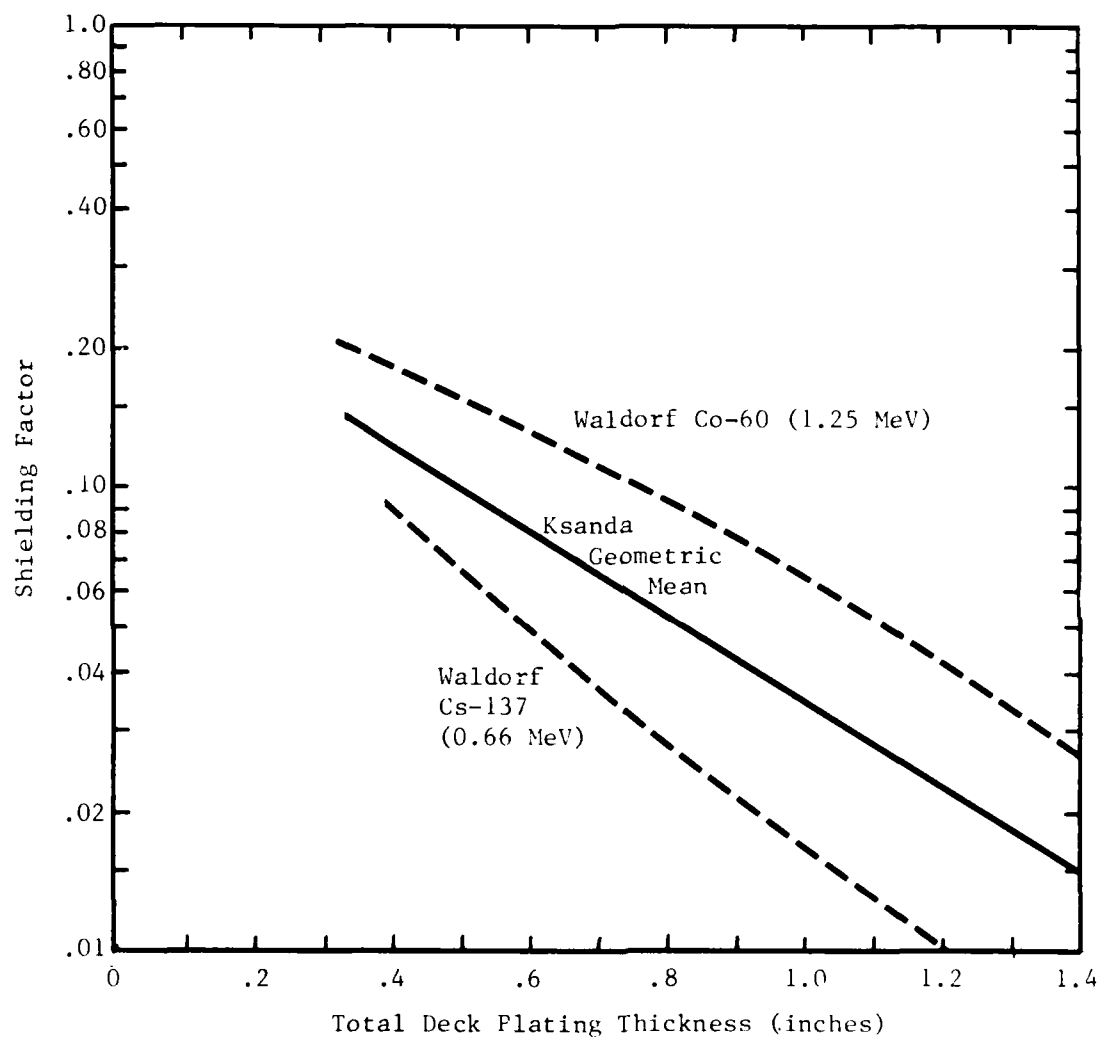


Figure 2-20. Ship Shielding Factor vs. Deck Plating Thickness

structure is neglected. Large variations in personnel activities and shielding factors preclude a more accurate assessment of this factor. It is further assumed that, when below decks, personnel were located on the second deck, with only the thickness of the main deck to provide radiation shielding. Personnel below the second deck, and in those portions of the second deck under the superstructure, were afforded additional radiation shielding not included in these calculations. The main deck thickness and the shielding factors used for the types of ships at Operation IVY are given in Table 2-2.

Table 2-2 Ship Shielding Factors

<u>Ship Type</u>	<u>Estimated Main Deck Thickness (inches)</u>	<u>Shielding Factor</u>
CVE	0.75	0.06
LSD, AV	0.60	0.08
AGC, AKA	0.55	0.09
AOG	0.53	0.09
TAP	0.50	0.10
DDE	0.35	0.14
ATA, ATF, AN	0.30	0.15

Section 3

DOSE CALCULATIONS

To determine the dose to personnel, consideration is given to the time spent topside (outside) and below decks (inside) and the radiation protection afforded by a ship or building. The free-field integrated intensities from Section 2 are adjusted to account for personnel activities, either documented or assumed. The adjusted exposures (mR) are then multiplied by a film badge conversion factor (0.7 mrem/mR) to determine film badge doses (mrem) as described in Reference 10. Results are presented as cumulative doses to personnel through 18 November 1952, when the IVY roll-up phase was nearly complete.

3.1 PERSONNEL ACTIVITIES

Normally, during fallout deposition and at early times when intensities are relatively high, an estimate of personnel movements onboard each ship is critical in determining the film badge dose. This is especially true for the crew of the M/V HORIZON, which encountered primary fallout from Shot MIKE shortly after the detonation (see Section 2.2.11). As soon as fallout was detected onboard the HORIZON, the ship was buttoned up, the ventilation system turned off and all personnel were ordered to remain below decks. While below, the crew was afforded a protection factor (PF) of approximately 7. Although decontamination of the ship was essentially completed at approximately 1930 hours on 1 November, the crew probably remained below until the normal crew routine was reestablished on 2 November. For the remaining ships participating at Operation IVY, the secondary fallout from Shots MIKE and KING was relatively minor and normal crew routines were not altered. For these ships, only an estimate of the amount of time spent topside and below decks during a typical work day is needed for determining film badge doses.

With the exception of 1-2 November, when the HORIZON received primary fallout from Shot MIKE for which actual times topside and below must be determined, the free-field integrated intensities are multiplied by a time-averaged shielding factor to account for the time spent topside (outside) and below (inside) during a "typical" work

day. It is estimated that the typical crew on each ship was on deck at the following times: 0800-1200, 1330-1700, and 1800-2000 hours. This amounts to 40 percent of the day (9½ hours) topside and 60 percent (14½ hours) below. While below, the crew was offered shielding provided by the ship's structure. In Section 2.4, it is estimated that ship-shielding factors vary from approximately 0.06 to 0.15, depending on the main deck thickness. A time-averaged shielding factor is computed as $0.4 + 0.6 \times \text{ship-shielding factor}$, where the 0.4 and 0.6 represent the fraction of the day spent above and below the deck, respectively. The time-averaged shielding factors vary from approximately 0.44 to 0.49. A similar argument is used to obtain a time-averaged shielding factor of 0.8 for the land-based personnel. This assumes that 60 percent of the day is spent outside and 40 percent inside. While inside, personnel are afforded a protection factor of 2, i.e., a shielding factor of 0.5.

3.2 CALCULATED PERSONNEL FILM BADGE DOSES

To demonstrate the effect of crew activities on the film badge dose, personnel dose calculations for the crew of the HORIZON on 1 and 2 November are detailed. First, a crew activity time-line is inferred from available references on the 1st and 2nd of November. This time-line, shown in Figure 3-1, indicates the periods during these two days that a typical crewman would have been topside and below. For

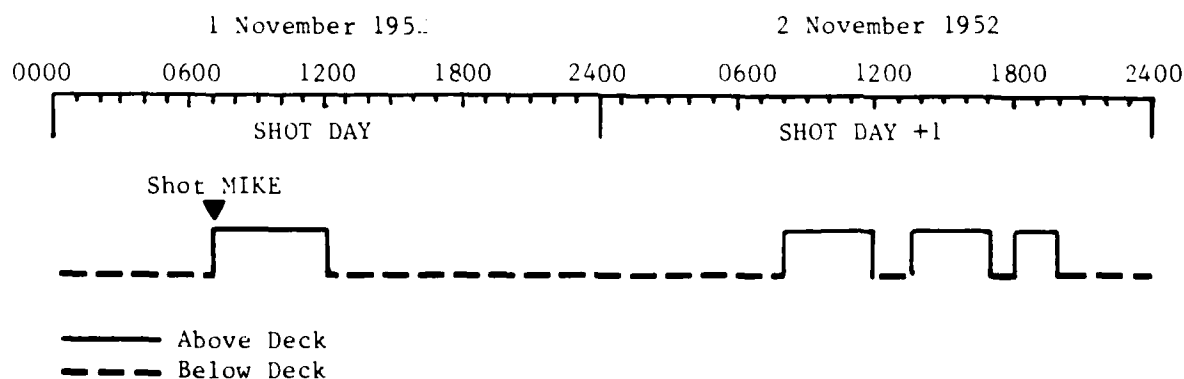


Figure 3-1. M/V HORIZON Crew Activity Time Line - Shot MIKE

those periods when the crew would have been topside, the average integrated intensity would have been received. For those periods spent below, the integrated intensity is adjusted to account for the shielding provided by the ship's structure (see Section 2.4). The doses for each period are then added to determine a daily dose for the crew. Starting on 3 November, the crew is estimated to have spent approximately 40 percent of the day (9.5 hours) above deck and 60 percent (14.5 hours) below; therefore, on 3 November and thereafter, the time-averaged shielding factor is $0.4 + (0.6)(.15) = 0.49$, where .15 is the ship-shielding factor for the HORIZON (Table 2-2). The dose calculations for the crew of the HORIZON are detailed in Table 3-1.

Table 3-1. M/V HORIZON (ex-ATA) - Personnel Dose Calculations

<u>1 Nov 52</u>	<u>Integrated Intensity (mR)</u>	x	<u>Ship-Shielding Factor</u>	=	<u>Adjusted Exposure (mR)</u>
0000-0700*	0		.15		0
0700-1200	0		1.0		0
1200-1240*	0		.15		0
1240-2400*	50.0		.15		7.5
<u>2 Nov 52</u>					
0000-0800*	10.4		.15		1.6
0800-1200	3.9		1.0		3.9
1200-1330*	1.4		.15		0.2
1330-1700	3.0		1.0		3.0
1700-1800*	0.9		.15		0.1
1800-2000	1.7		1.0		1.7
2000-2400*	1.6		.15		0.2
<u>3-18 Nov 52</u>	<u>127.7</u>		.49		<u>62.6</u>
Total	200.6 (Table 2-1)				80.8

1-18 Nov 52 film badge dose = $(80.8 \text{ mR})(0.7 \text{ mrem/mR}) = 57 \text{ mrem}$ (Table 3-2)

*Denotes time periods below deck (from Figure 3-1).

For the remaining personnel at Operation IVY, the normal work routine was not interrupted with the occurrence of fallout. The personnel film badge dose is calculated by multiplying the average integrated intensity on each ship (atoll) by the appropriate time-averaged shielding factor and the film badge correction factor. The results of these calculations, as well as those for the HORIZON developed in the preceding paragraph, are given in Table 3-2.

Table 3-2. Calculated Personnel Film Badge Doses on Task Group 132.3 Ships and the Residence Islands of Surrounding Atolls.

<u>Ship</u>	<u>Integrated Intensity (mR)</u> x	<u>Shielding Factor</u> x	<u>0.7 mrem/mR</u> =	<u>Film Badge Dose (mrem)</u>
USS RENDOVA	65.7	.44		20
USS OAK HILL	97.2	.45		31
USS ARIKARA	94.0	.49		32
USS LIPAN	97.2	.49		33
USNS DAVID C. SHANKS	94.0	.46		30
USNS GEN. E.T. COLLINS	97.2	.46		31
USS AGAWAM	65.2	.45		21
USS ESTES	70.1	.45		22
USS LEO	66.9	.45		21
USS ELDER	66.9	.49		23
USS CARPENTER	29.7	.48		10
USS RADFORD	81.9	.48		28
USS O'BANNON	14.5	.48		5
USS FLETCHER	33.8	.48		11
USS YUMA	24.5	.49		8
USS CURTISS	16.6	.45		5
M/V HORIZON	200.6	(Table 3-1)		57
M/V SPENCER F. BAIRD	3.2	.49		1
<u>Atoll</u>				
Enewetak Atoll				
Enewetak Is.	97.2	.80		54
Parry Is.	70.1	.80		39
Kwajalein Atoll	17.8	.80		10
Bikini Atoll	3.3	.80		2

Section 4

UNCERTAINTY ANALYSIS

The uncertainty in calculated film badge doses is estimated from the underlying parameters. The basic uncertainties include radiation intensities topside (outside), the time spent at various locations, and the shielding afforded to personnel below (inside).

Intensity levels topside are determined from limited shipboard radiological survey data, supplemented by fallout sample data from most of the ships and atolls. From the few instances in which more than one type of measurement was made of the radiation environment, a correlation is developed between topside intensity and other measurements. Together with ship log entries regarding proximity to other ships and the incidence of fallout, the derived intensities are sufficient to characterize the radiological environment on all ships and atolls under consideration. In the event of any unreported shipboard decontamination, the calculated intensities would be high-sided.

Several aspects of a topside intensity determination involve minimal uncertainty. Survey meter readings and sample counts are essentially accurate. Variation in intensity on the weather decks was generally small, as noted from the hourly readings at eight locations onboard one ship. Exceptions were of a transient nature (perhaps puddling that motivated localized decontamination) or from a contaminated helicopter pad--neither applicable to the typical crewmember. Average topside intensity as a function of time rests on a power law interpolation that closely approximates fission product decay for the intervals considered. The rise in intensity during fallout deposition is not well characterized, but the potential for dose accrual during those intervals as compared to other periods of exposure is small. For the only ship encountering primary fallout, the precise topside intensities are not at issue during deposition because the crew was then below, significantly shielded. Overall, error in on-deck intensity is small compared to the uncertainty associated with crew position in the non-uniform radiation environment.

The major source of error in shipboard intensity is the correlation between cumulative, normalized fallout sample counts and intensity readings. The three,

essentially independent comparisons that lead to this correlation provide ratios of .025, .066, and .069 mR/hr per Mcpm. These imply an error factor at the 90-percent level of 1.9.*

The value for the fraction of time spent topside is estimated to be accurate within a factor of 1.2 with 90-percent confidence. For the typical day, this corresponds to 8 to 11½ hours topside. The systematic uncertainty in the time topside is considered to be greater than its random variation from day to day and ship to ship. The uncertainty in total dose is thus reasonably high-sided by treating the uncertainty in time topside as a systematic error. The below-deck contribution introduces a small, ship-dependent perturbation to the factor of 1.2.

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

Overall, the error factor for calculated film badge doses is 2.0. For each ship, this value implies, for the associated lognormal distribution, a mean that is 9 percent greater than the best estimate derived in Section 3.

*Obtained from $10^{1.65\sigma/\sqrt{n-1}}$, where σ is the standard deviation of the log of the ratios, 1.65 σ provides the 90-percent level, and n is 3.

Section 5

FILM BADGE DOSIMETRY

Film badge data are available for 14 of the 18 ships for which doses have been reconstructed. Approximately 560 badges were issued to ships' personnel during Operation IVY. The periods of badged exposure vary from ship to ship; therefore, dose calculations are performed for these specific badged periods in order to provide a basis for comparison.

Figure 5-1 summarizes the shipboard film badge dosimetry and the corresponding film badge dose calculations. The number in parentheses following each ship is the number of film badges issued to the crew, while the badged period is annotated below each ship. The underlined numbers in the figure are the number of zero doses recorded by the issued film badges. Film badge dosimetry data are not available for crews on the COLLINS, LEO, RADFORD, and BAIRD. The calculated doses and uncertainties are indicated by the inverted solid triangles.

It is apparent from the figure that reasonably good agreement exists between the calculated doses and dosimetry data for crews on the RENDOVA, OAK HILL, ARIKARA, LIPAN, SHANKS, ESTES, ELDER, CURTISS, and HORIZON. Although the calculated dose for the crew of the RENDOVA appears to be significantly lower than the dosimetry data suggest, 142 badges, or 68 percent of those issued for the five-day exposure period, recorded a dose of zero. Similarly, calculated doses for the crew on the ESTES appear somewhat low. In Section 2, intensity readings obtained from the contaminated helicopter pad were not included when calculating the average topside intensity. The open triangle above the ESTES dosimetry data is the calculated dose for personnel who spent their apportioned time topside in the vicinity of this pad. This dose (72 mrem) may be more applicable to members of the helicopter unit assigned to the ESTES than the dose calculated for the average crew. The very high film badge readings on the RENDOVA, OAK HILL, and ESTES are probably obtained from "mission" badges, i.e., badges that were issued to personnel when they were expected to enter areas of radioactive contamination other than those routinely encountered onboard the ships.

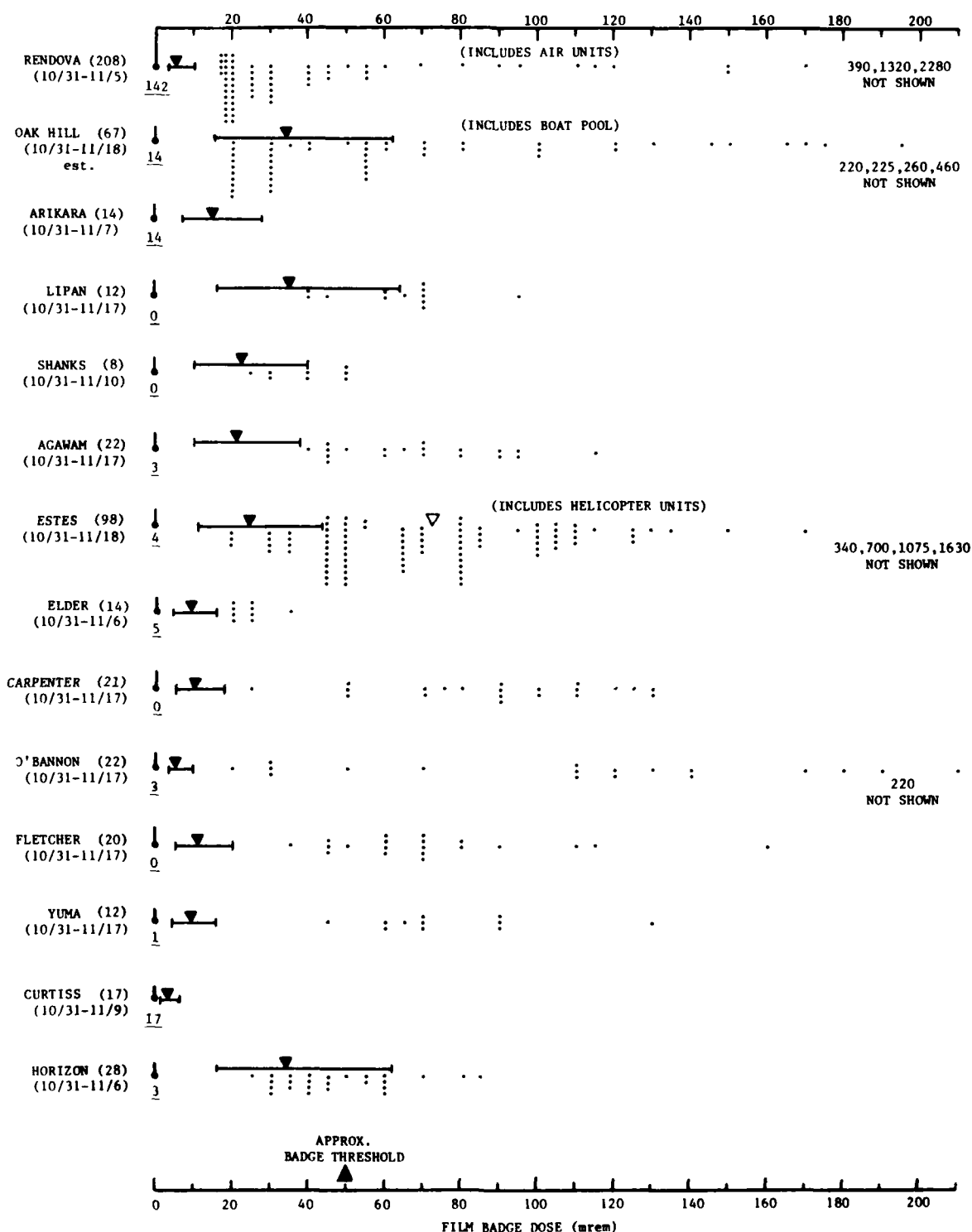


Figure 5-1. Operation IVY Dosimetry Data and Dose Calculations

Dose calculations are low for the crew of the AGAWAM when compared to the film badge data. This ship, like the RENDOVA, OAK HILL, LIPAN, and ESTES remained anchored in the lagoon throughout virtually all of the operation until its departure from Enewetak in mid-November (see Figure 2-1). Dosimetry data from the AGAWAM suggest exposures that are more in line with the calculated doses for the OAK HILL and LIPAN, which were anchored several miles southwest of the AGAWAM off Enewetak Island during the same badged period.

Calculated doses are also lower than the film badge readings for the three destroyers for which data are available--the CARPENTER, O'BANNON, and FLETCHER. Topside intensities on these three ships, as inferred from fallout samples obtained on them, do not support the film badge data. It is possible that the hulls of these ships became contaminated while patrolling the waters to the west and north of Enewetak after Shot MIKE where much of the fallout was deposited. It has been noted in previous dose reconstructions (Reference 5) that hull contamination can be a significant source of exposure to crews onboard these vessels. The extent to which these three ships may have been contaminated cannot be quantified since neither exposure times or water intensities, if encountered, were documented.

A reasonable comparison between the calculated dose for the crew of the YUMA and the dosimetry data from that ship cannot be made. Film badge readings for the YUMA indicate the badges were turned in and processed on 17 November. This is unlikely since the YUMA was enroute from Kwajalein to Pearl Harbor on this date. The film badges were probably turned in prior to the YUMA's departure from Enewetak on 8 November and, if they were not processed until 17 November, the recorded doses would not be applicable for the crew.

Section 6

CONCLUSIONS AND TOTAL DOSE SUMMARY

Secondary fallout from Shot MIKE was the major contributor to the shipboard and island radiological environments to which TG 132.3 personnel were exposed at Operation IVY. Only one ship, the M/V HORIZON, received primary fallout following this event. Fallout from Shot KING was insignificant.

A comparison between calculated film badge doses and available dosimetry data from the various ships indicates reasonably good agreement for most ships. Dosimetry data available for three of the destroyers (DDEs) indicate exposures significantly greater than the calculated doses. Shipboard radiological data do not support the dosimetry data for these ships, which suggests that their hulls may have become contaminated while steaming in radioactive water (from MIKE fallout), thus contributing to the crews' dose. This possible source of contamination was not documented by any of the destroyers.

The uncertainty analysis indicates an error factor of 2.0 in the calculated average film badge doses (from Section 3). This value implies a lognormal distribution of doses with a mean value 9 percent greater than the calculated average. Mean doses (through 18 November 1952), with 90-percent confidence limits, are presented in Table 6-1.

Table 6-1. Summary of Calculated Doses

<u>Shipboard Personnel</u>	<u>Mean Dose (mrem) With Bounds</u>	<u>Shipboard Personnel</u>	<u>Mean Dose (mrem) With Bounds</u>
USS RENDOVA	22 ⁺¹⁸ ₋₁₂	USS ELDER	25 ⁺²¹ ₋₁₃
USS OAK HILL	34 ⁺²⁸ ₋₁₈	USS CARPENTER	11 ⁺⁹ ₋₆
USS ARIKARA	35 ⁺²⁹ ₋₁₉	USS RADFORD	29 ⁺²⁵ ₋₁₅
USS LIPAN	36 ⁺³⁰ ₋₁₉	USS O'BANNON	5 ⁺⁵ ₋₂
USNS DAVID C. SHANKS	33 ⁺²⁷ ₋₁₈	USS FLETCHER	13 ⁺¹¹ ₋₇
USNS GENERAL E.T. COLLINS	34 ⁺²⁸ ₋₁₈	USS YUMA	9 ⁺⁷ ₋₅
USS AGAWAM	23 ⁺¹⁹ ₋₁₂	USS CURTISS	5 ⁺⁵ ₋₂
USS ESTES	24 ⁺²⁰ ₋₁₃	M/V HORIZON	62 ⁺⁵² ₋₃₃
USS LEO	23 ⁺¹⁹ ₋₁₂	M/V SPENCER F. BAIRD	1 ⁺¹ ₋₀
<u>Island-Based Personnel</u>			
Enewetak Atoll			
Enewetak Island	59 ⁺⁴⁹ ₋₃₂		
Parry Island	43 ⁺³⁵ ₋₂₃		
Kwajalein Atoll	13 ⁺¹¹ ₋₇		
Bikini Atoll	2 ⁺² ₋₁		

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