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Operation
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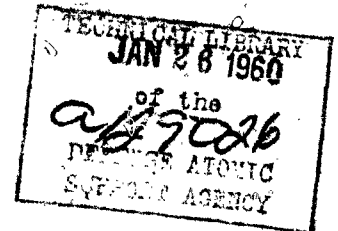
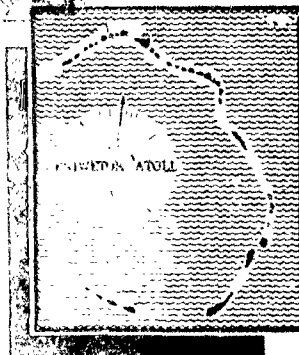
PACIFIC PROVING GROUNDS

May - July 1956

Project 2.9

STANDARD RECOVERY PROCEDURE FOR
TACTICAL DECONTAMINATION OF SHIPS

Issuance Date: March 20, 1959



~~Act of 1950~~

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HEADQUARTERS FIELD COMMAND, ARMED FORCES SPECIAL WEAPONS PROJECT
SANDIA BASE, ALBUQUERQUE, NEW MEXICO

FOREWORD

This report presents the preliminary results of one of the projects participating in the military-effect programs of Operation Redwing. Overall information about this and the other military-effect projects can be obtained from WT-1344, the "Summary Report of the Commander, Task Unit 3." This technical summary includes: (1) tables listing each detonation with its yield, type, environment, meteorological conditions, etc.; (2) maps showing shot locations; (3) discussions of results by programs; (4) summaries of objectives, procedures, results, etc., for all projects; and (5) a listing of project reports for the military-effect programs.





ABSTRACT

The objectives of this project were (1) to proof test a proposed standard recovery procedure for the tactical decontamination of Navy ships and (2) to perform, as required, an operational decontamination of each of three test ships to enable them to make their next scheduled participation.

Three washdown-equipped test ships, the YAG-39, the YAG-40, and the LST-611, served as fallout-collection stations and test platforms for other Program 2 projects. These ships were successively contaminated by radioactive fallout from Shots Zuni, Flathead, Navajo, and Tewa.

Because of insufficient contamination aboard the ships on their arrival at Eniwetok Lagoon following their several missions, the primary objective was not fulfilled. Therefore, the function of Project 2.9 was generally restricted to operational decontamination between shots. The proof-testing of the standard recovery procedure, which consisted of fire-hosing, hand-scrubbing, and fire-hosing again, which was planned for execution aboard the YAG-39, was therefore not attempted until after Shot Tewa. A shipboard gamma-radiation dose rate of 2 to 5 r/hr, considered to represent a minimum tactical situation, was not obtained. The measured average dose rate aboard the YAG-39 in the nonwashdown area at the start of decontamination after Shot Tewa was about 230 mr/hr.

In this test, the standard recovery procedure proved to be practicable for the conditions encountered; however, in order to determine the absolute satisfactoriness of this procedure for the tactical situation, a further evaluation will be required. 

A second procedure, hot-liquid-jet cleaning, was also investigated under like conditions and was found to be equally as effective as the standard recovery procedure at approximately twice the rate of surface coverage; however, insufficient evidence was obtained for a conclusion that the greater operating rate (and presumable reduced dosage of personnel involved) would justify the expenditure of large sums for the special equipment required. 

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Chapter 1 **INTRODUCTION**

1.1 OBJECTIVES

The objectives of this project were to (1) proof-test a standard recovery procedure for the tactical decontamination of Navy ships, and (2) support Project 2.10 by operational decontamination of the George Eastman (YAG-39), Granville S. Hall (YAG-40) and U. S. S. Crook County (LST-611) to permit their participation in successive shots in Operation Redwing.

1.2 BACKGROUND

Studies of various decontamination methods during Operation Castle indicated that a procedure consisting of fire-hosing, hand-scrubbing in the presence of a sea-water-soluble detergent, all followed by a second fire-hosing, was the most useful from the standpoints of decontamination effectiveness, rate of area coverage, economy of personnel dosage and simplicity of the equipment and materials required. Also, there were definite indications that hot-liquid-jet cleaning was a promising candidate procedure.

Proof-testing of these procedures in an approximate tactical situation was required and such testing was planned for Operation Wigwam. However, the tests were not performed because underwater shock damage to the YAG-39 prevented entry into the radioactively contaminated sea area. Therefore, the test was conducted during Operation Redwing.

Chapter 2 PROCEDURE

2.1 OPERATIONS

The YAG-39, YAG-40, and LST-611, each equipped with a washdown system, participated in Shots Cherokee, Zuni, Flathead, Navajo, and Tewa. In each of the above shots, these ships were positioned in the predicted area of fallout and served as fallout-collection stations for Project 2.63. On both the YAG-39 and YAG-40, the main weather deck forward of the superstructure was deprived of washdown so that the fallout could be sampled and other desired radiation information obtained. Further division of the ships into specific zones and areas is shown in Figure 2.1.

Because of conflicting space and time requirements between Project 2.8 ("Shipboard Radiological-Countermeasure Methods") and Project 2.9, it was impracticable to attempt parallel operations aboard any one ship. The YAG-40 was made available to Project 2.8 and the YAG-39 was utilized for the Project 2.9 technical operations. After each event, the ships returned to the Elmer anchorage in Eniwetok Lagoon for decontamination.

2.1.1 Shot Cherokee. Because of the negligible contamination received by the ships, no decontamination was required.

2.1.2 Shot Zuni. After Zuni, operational decontamination of the YAG-40 was begun on D + 3 and completed on D + 5 days.

In the nonwashdown area forward of the superstructure, all weather surfaces except the face of the superstructure and the experimental areas in Zones 2 and 3 (see Figure 2.1) reserved by Project 2.8, were decontaminated by the procedure of fire-hosing, hand-scrubbing with detergent, and fire-hosing again. A hot liquid jet consisting of sea water and detergent delivered at 180 F and 180 psi through a two-man lance was used on the forward face of the superstructure and for a final cleanup of the Project 2.8 experimental areas.

The remainder of the superstructure and the aft deck house were fire-hosed and hand-scrubbed. A hot-liquid-jet turret and the Sellers injector were used to decontaminate the top of No. 5 hatch and to strip a removable radiological protective coating (Project 2.8) from the deck on the starboard side of Zone 5. The two-man hot-liquid-jet lance was used on all other stern section areas. These items of equipment are described in Section 2.2.2.

The YAG-39 was decontaminated on D + 5. All weather surfaces were thoroughly fire-hosed to remove remaining loose contaminant which was being tracked into the ship's interior. No decontamination operations were required on the LST-611. An operational log of the decontamination of the test ships after Shots Zuni, Flathead, Navajo, and Tewa is contained in Appendix A.

2.1.3 Shot Flathead. The YAG-39 and YAG-40 were decontaminated simultaneously on D + 3. All weather surfaces of the YAG-39 were fire-hosed. Upon completion of the

procedure, the main deck between the flight deck and the superstructure was fire-hosed, hand-scrubbed with detergent, and fire-hosed.

On the YAG-40, the nonwashdown area forward of the superstructure, with the exception of the port side of the main deck, was fire-hosed, hand-scrubbed with detergent,

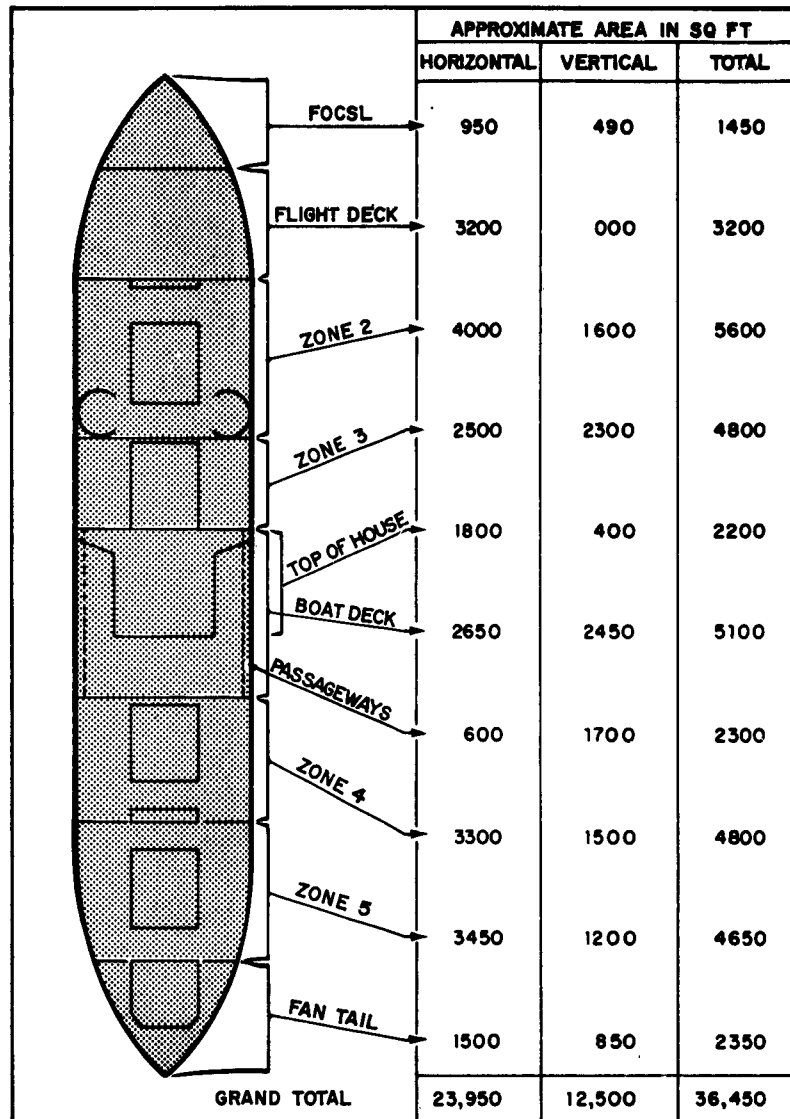


Figure 2.1 Zoning and area of weather surfaces of YAG-39 and YAG-40.

and fire-hosed. The port main deck, two sections of which were covered with a removable, radiological protective coating, was decontaminated as directed by Project 2.8. Two hot-liquid-jet lances (described in Section 2.2.2) were used for this operation. Decontamination of the superstructure and all other areas aft to the fantail was limited to fire hosing. No decontamination of the LST-611 was required.

2.1.4 Shot Navajo. Aboard both the YAG-39 and the YAG-40, ship-decontamination procedures were limited to fire-hosing, hand-scrubbing and fire-hosing in the nonwash-

down areas and the superstructure, and to fire hosing alone in the washdown areas aft of the superstructure. No decontamination of the LST-611 was necessary.

2.1.5 Shot Tewa. The LST-611 was decontaminated on D + 2 by the ship's force. The fire-hosing, hand-scrubbing, fire-hosing procedure was used.

The YAG-40 was decontaminated on D + 2 and D + 3. Manpower was supplied by the ship's force. Two hot-liquid-jet lances were used on the superstructure and the nonwash-down area forward. The remainder of the ship was decontaminated by fire-hosing, hand-scrubbing with detergent, and fire-hosing.



Figure 2.2 The standard recovery procedure.

The aft section of the YAG-39 was decontaminated on D + 3, but no work was done on the superstructure and forward area until D + 5. The interruption was occasioned by technical requirements of Project 2.71 ("Ship Shielding Studies"), which precluded decontamination of the nonwashdown area prior to D + 5. Fire-hosing, hand-scrubbing and fire-hosing as a standard recovery procedure was used exclusively. All work was done by the ship's force.

2.2 INSTRUMENTATION AND EQUIPMENT

2.2.1 Radiac Instrumentation. All instrumentation was furnished and maintained by Project 2.8 and is fully described in Reference 2. The AN/PDR-T1B was used for gamma measurement. Beta measurements were made with the RBI-13 survey meter developed by the U. S. Naval Radiological Defense Laboratory (NRDL).

2.2.2 Decontamination Equipment. The equipment employed for fire-hosing and hand-scrubbing (Figure 2.2) consisted of 1½-inch, rubber-lined, cotton-canvas-covered firehose;

1½-inch standard-play pipe nozzles; and deck brushes having 10-inch heads with 3-inch medium palmyra bristles. These were all Navy Standard Stock items.

Two salt-water-soluble detergents were used: (1) Cleaning Compound, Bureau of Aeronautics Specification C-120 and (2) Cleaning Compound, Decontamination, Bureau of Aeronautics Specification C-7907.

The Sellers injector, Figure 2.3, was a hand-truck-mounted venturi that mixed steam and sea water and delivered a 6,000-gal/hr jet of water at temperatures and pressures up to 200 F and 200 psig. It is manufactured by Sellers Injector Corporation, 1600 Hamilton Street, Philadelphia and identified by Drawing No. 48640. Detergent solutions can be educted through this unit. At both Operations Castle and Redwing, the 6,000-gal/hr injector was observed to operate satisfactorily, but because it was originally designed for use at dockside from a fixed location, the unit's shipboard mobility was found to be quite limited. Because of the excessive weight and dimensions, transport of the unit to various deck levels and along narrow passageways was extremely difficult. However, this unit has since become obsolete and is being replaced by a smaller, lighter and more flexible unit, Model FX-4000.

The hot-liquid-jet turret used in conjunction with the Sellers injector was originally developed for use in Operation Castle and is a sled-mounted nozzle incorporating an anti-



Figure 2.3 The 6,000-gal/hr Sellers injector.

torque delivery tube and a universal coupling providing a 360-degree horizontal traverse and approximately 90 degrees in the vertical plane. This turret is awkward and cumbersome and lacks the utility and flexibility of the two-man lance.

The two-man lance (Figure 2.4) was designed for use in Operation Redwing. It was

a 3-foot length of 1 $\frac{1}{4}$ -inch pipe tipped with a short, $\frac{3}{8}$ -inch-orifice nozzle and had two full-length pipe handles.

2.3 DESCRIPTION OF DATA

The reported data is intended primarily to indicate the ability of the decontamination procedures to reduce the overall gamma-radiation field and to indicate the time and man-power required. The results do not necessarily represent the ultimate reduction that could have been obtained, since the test areas were decontaminated only once after each shot. The data was obtained from detailed radiological surveys made by Project 2.8 as a support service.

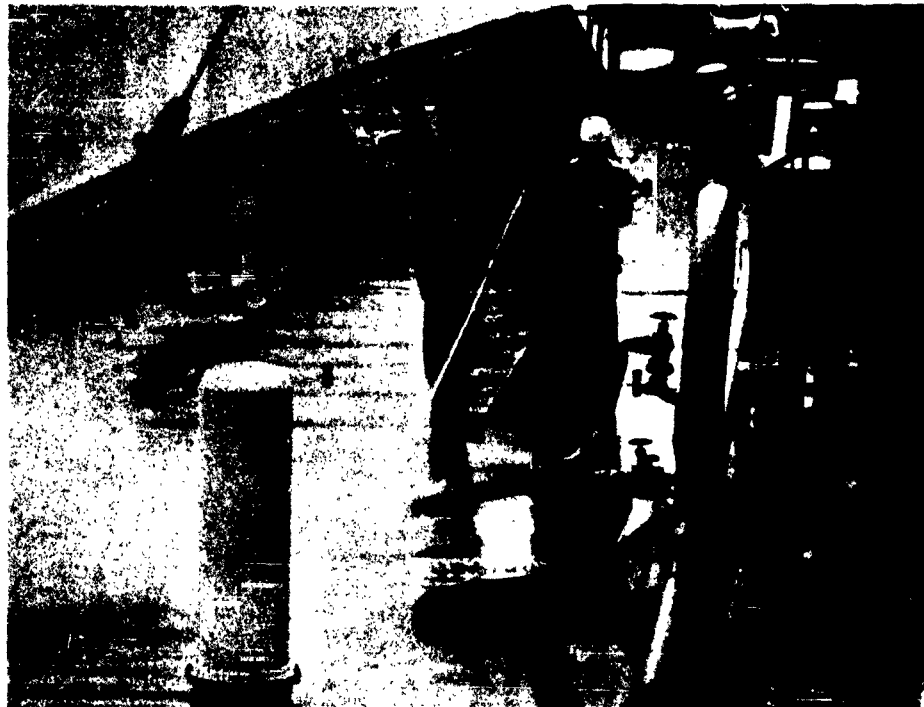


Figure 2.4 Decontaminating with the two-man, hot-liquid-jet lance.

2.3.1 Gamma Measurements. Readings were taken before and after decontamination at predetermined weather-deck stations on each ship. There were 174 stations on the YAG-39, 174 on the YAG-40, and 24 on the LST-611. The locations of 160 of these stations as used by Project 2.9 on the YAG's 39 and 40 are shown in Figure 2.5. Measurements were made over each station at 1 inch and 3 feet.

2.3.2 Beta Measurements. Beta readings were taken on the surface at each station. These data are presented in the beta dose-rate charts contained in Appendix B.

2.3.3 Radiation Decay Constant Determination. To determine an experimental decay constant, special decay panels were exposed to the fallout resulting from Zuni and Tewa on the nonwashdown-protected flight decks of YAG's. These panels were recovered upon return of the test ships on D + 2. Gamma and beta measurements were made daily over

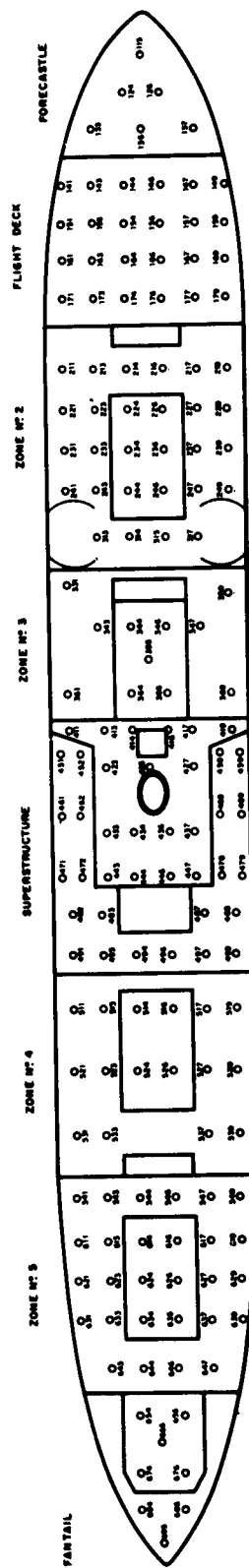


Figure 2.5 Location of 160 permanent radiological survey stations, YAG-39 and YAG-40.

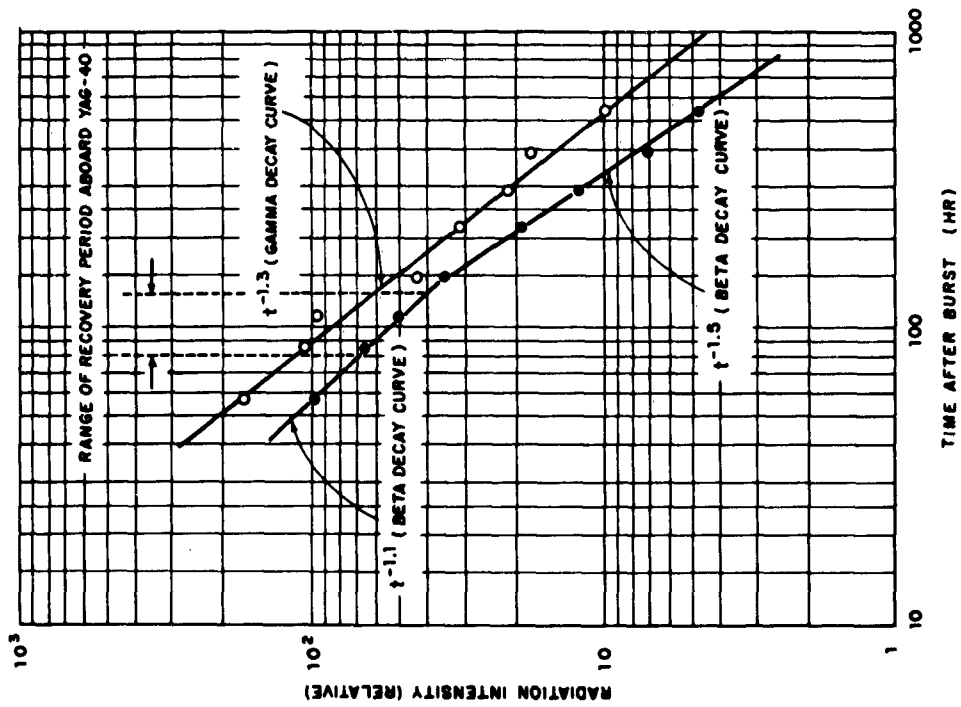


Figure 2.6 Decay curves from YAG-40 test panel, Shot Zuni, as determined by AN/PDR-T1B and RBI-13.

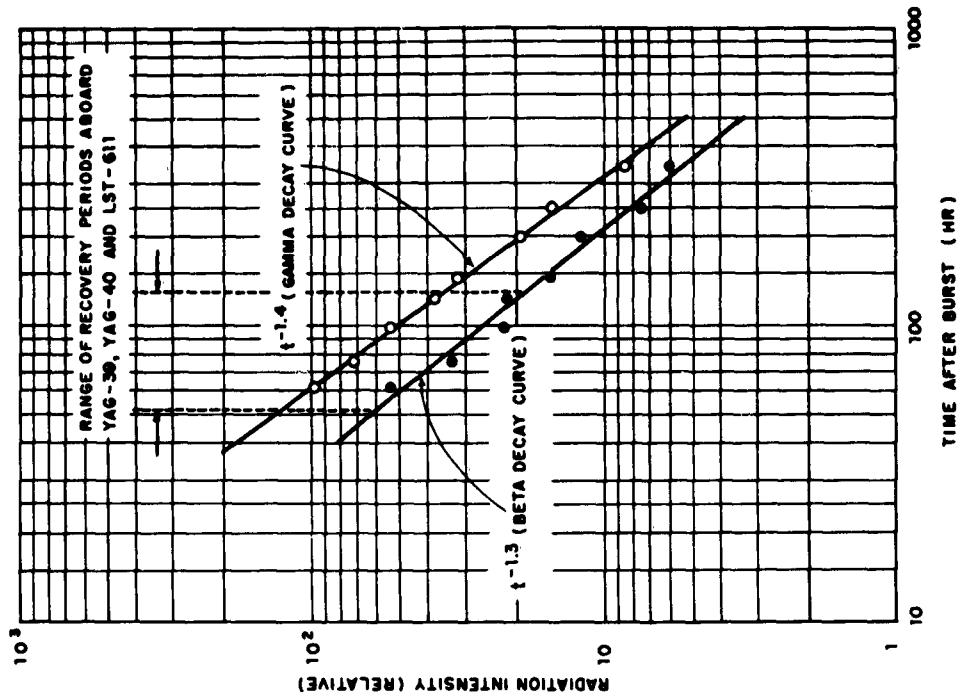


Figure 2.7 Decay curves from YAG-39 test panel, Shot Tewa, as determined by AN/PDR-T1B and RBI-13.

the time interval covering the period of ship recovery. The resultant decay curves appear in Figures 2.6 and 2.7.

2.3.4 Reduction of Data. The decrease in the gamma-radiation level aboard ship was computed from gamma measurements at 3 feet (waist level) above each of the permanent

TABLE 2.1 VALUES FOR DECAY CONSTANT EXPONENT n

	Zuni	Flathead	Navajo	Tewa
Gamma	1.3	1.1	1.25	1.4
Beta	1.1	1.0	1.25	1.3

radiological-survey stations. The surface—beta-measurement data, as presented in Appendix B, was used to indicate the effectiveness of the procedures in removing surface contamination. Estimates of recovery effectiveness based on 1-inch gamma observations

TABLE 2.2 DETERMINATION OF FRACTIONS REMAINING, ZONE 2; STANDARD RECOVERY PROCEDURE, YAG-39, SHOT TEWA

Station Number	Prerecovery Observation	Postrecovery Observation
	(3-foot gamma at H + 123 hours)	(3-foot gamma at H + 147 hours)
	mr/hr	mr/hr
211	100	21
214	180	50
216	200	50
219	240	24
223	100	23
227	160	30
231	120	21
234	80	14
236	80	14
239	140	19
243	180	24
247	260	50
313	140	28
314	180	20
316	200	30
317	120	25
Total 16	2,480	443

$$DCF = (147/123)^{1.4} = 1.28$$

Average Prerecovery observation (3-foot gamma): $2,480/16 = 155$ mr/hr

Average Postrecovery observation (3-foot gamma): $443/16 = 27.7$ mr/hr

Fraction Remaining: $(1.28)(27.7/155) = 0.23$

proved to be essentially the same as estimates computed from 3-foot observations (Tables 7.1 and 7.2, Reference 2). Data from the 1-inch surveys was therefore judged superfluous and deleted from this report.

It is customary to indicate the effectiveness of recovery procedures by reporting the fraction of original contaminant remaining. The fraction remaining is found by computing

the decay-corrected ratio of the average radiation level after recovery to the average radiation level before recovery:

$$\text{Fraction Remaining} = (\text{DCF}) \frac{\text{Postrecovery radiation level}}{\text{Prerecovery radiation level}} \quad (2.1)$$

Where: DCF is the decay correction factor.

Reduction of the data, therefore, involved the determination of the fraction remaining for any given weather surface and recovery procedure of interest.

In general, each fraction remaining resulted from a step-wise procedure involving: (1) computation of the arithmetic means of the radiation measurements from prerecovery and postrecovery surveys as furnished by Project 2.8; (2) computation of the DCF from assumed radioactive decay behavior; (3) substitution of these values into Equation 2.1.

Over periods of several days, radioactive decay of undisturbed contaminant obeys a t^{-n} relation, where t is the time after detonation and n is a constant decay exponent. The decay curves of Figures 2.6 and 2.7 are typical examples of this relation. However, during recovery operations the decay rate may be altered due to fractionation of the contaminant. Because there is no convenient way to readily determine the degree of fractionation, a normal (t^{-n}) decay must be assumed and the available curves used.

The decay exponents for Shots Zuni and Tewa, as determined from Figures 2.6 and 2.7, are given in Table 2.1. For Flathead and Navajo, approximate values of n based on information furnished by Project 2.63 are also tabulated.

A typical example of data reduction is presented in Table 2.2. It gives the procedure for averaging the individual gamma readings before and after decontamination and computing the resultant residual numbers.

Chapter 3

RESULTS

The test data obtained from participation in the five shots were neither as comprehensive nor as useful as had been expected. The radiation levels remaining aboard the test ships after completion of their missions were insufficient for a determination of decontamination effectiveness under realistic tactical conditions. In addition, the imposed delay of decontamination operations until the ships returned to Eniwetok compromised the data to an extent that extrapolation to time of cessation of fallout was impossible. This information is still needed to determine the actual value of tactical decontamination. These conditions of insufficient contamination limited the project function to little more than operational decontamination of the ships between shots.

3.1 OPERATIONAL DECONTAMINATION

The successive operational decontaminations of the test ships were completed within the allotted turn-around periods and sufficiently reduced the gamma-radiation levels to permit shipboard personnel to remain within the total permissible radiation exposure limit of 3.9 r prescribed by the Task Force.

A graphical representation of the recovery effectiveness aboard the test ships is given in Figures 3.1 through 3.5. The points plotted on these charts represent discrete, average values for the respective test areas shown in each figure.

Lines connecting these points are not meant to imply a continuous relation between values but are merely intended to join and identify prerecovery and postrecovery dose rates, respectively.

All values for dose rates, both before and after recovery, have been decay corrected to the time recovery operations were first initiated. This time is shown in the ship's silhouette on each chart.

The following is a legend of the abbreviations used on the charts for the various recovery procedures: SRP, standard recovery procedure; HLJ, hot-liquid-jet cleaning; MS, machine scrubbing; MISC, miscellaneous recovery procedures; and STRIPPING, removal of special protective coating by Project 2.8.

3.1.1 Shot Cherokee. No results were obtained, since the ships required no decontamination.

3.1.2 Shot Zuni. On YAG-40 at the beginning of decontamination, H + 80 hours, the points in Figure 3.1 show that the average initial dose rates ranged from 50 mr/hr on the washdown area to 320 mr/hr in the nonwashdown area. With the exception of the flight deck, decontamination reduced each of these average levels to less than 30 mr/hr. Although the average final level on the flight deck remained at 55 mr/hr, this represented a 75-percent reduction from the initial level.

The contaminant was in the form of a nontenacious coral dust and in many areas, particularly in the nonwashdown forward section of the ship, was visible in deposits having a depth of several particle diameters. Final levels in the test zones after re-

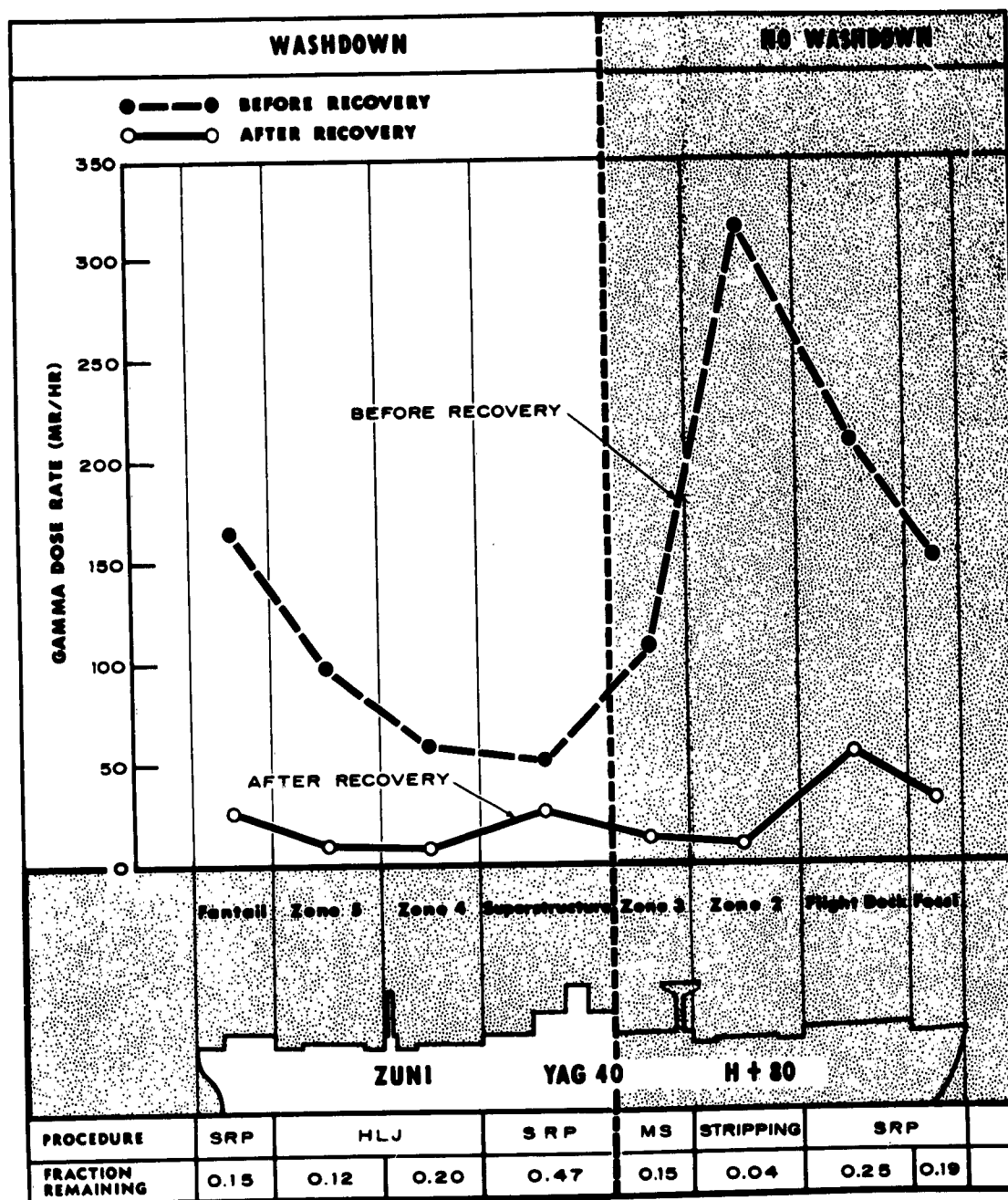


Figure 3.1 Average gamma dose rate in the test areas, Shot Zuni, YAG-40.

covery tended to be independent of the initial dose rate, the recovery procedure, or the type of surface.

It is emphasized that the contaminant, being particulate in form, was not of the type to be expected from a nuclear detonation in the open sea (on or below the surface) but may have been similar to that of a shallow underwater harbor burst. The results obtained by ship decontamination, therefore, are applicable only to the particular situation and are not generally applicable to planning for ship recovery at sea, particularly with regard to estimates of decontamination-procedure effectiveness.

Since contamination of the YAG-39 by fallout had been minor, no radiological surveys were made; however, as a precautionary measure all weather surfaces were fire-hosed.

The working party of 45 men was divided into 5- and 6-man teams and expended approximately 355 man-hours in the decontamination of the two ships. A breakdown of working time on the YAG-40 is given in Appendix A. In lieu of time-and-motion data, man-power estimates indicated that two 3-man fire-hose teams were adequate for decontamination of the YAG-39 and that four 6-man teams were all that could be used efficiently on the YAG-40 because of limitations of working space.

3.1.3 Shot Flathead. Negligible contamination was received by the YAG-39, and although a routine operational decontamination was performed, no data were obtained.

Decontamination aboard YAG-40 was initiated at H + 75 hours. Because of the low average initial dose rates, 6 mr/hr or less in the washdown portion of the ship, the recovery procedures were ineffective. This is demonstrated by Figure 3.2 where the average final dose rate was practically the same as the average initial rate. The four entries after "fraction remaining," all equal to unity, are a further indication of zero effectiveness in this region.

In the nonwashdown region of YAG-40, the average initial levels were reduced between 60 and 78 percent to an average final level of 13 mr/hr and lower. This effectiveness is unusual considering the low levels at the start of decontamination, the largest being just under 50 mr/hr on the flight deck.

A work party of 24 men was employed on each ship and a total of 170 man-hours was expended. A breakdown of the man-power effort aboard the YAG-40 is given in Appendix A. It was possible to utilize the available personnel more effectively than was done after Shot Zuni, but 24 men were more than adequate to perform a complete decontamination of either ship.

The contaminant was different from that of Zuni, having less mass and arriving as liquid droplets approximately 100 to 200 microns in size, instead of solid individual or agglomerated particles (Reference 3). The fallout material appeared to consist of small, relatively insoluble, radioactive particles (all less than 30 microns) in an aqueous solution having a high salt content. This material was not tenacious and responded readily to the decontamination procedures. It did not resemble any of the difficult-to-remove contaminant received by the YAG-39 and YAG-40 during their participation in Operation Castle.

3.1.4 Shot Navajo. Prior to decontamination, the indicated peak radiation levels in the nonwashdown regions of both the YAG-39 and YAG-40 were reduced approximately 65 percent by decay and by a series of heavy rain squalls. At the start of decontamination aboard the YAG-40 at H + 54 hours, the radiation levels were too low to provide any useful data.

The results of decontamination on the nonwashdown region of YAG-39 are indicated in Figure 3.3. Zone 2 was the only test area that exhibited a marked reduction in average

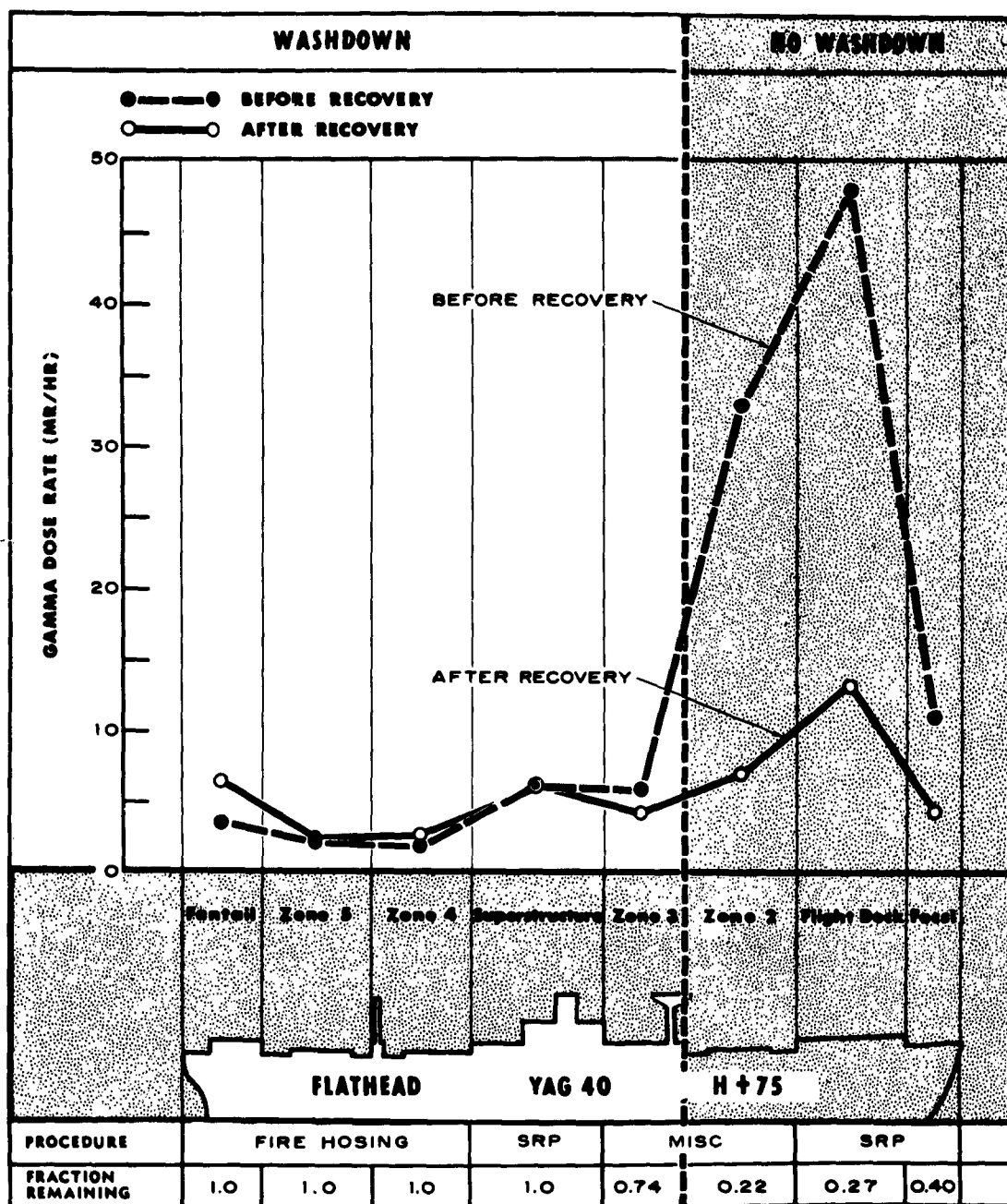


Figure 3.2 Average gamma dose rate in the test areas, Shot Flathead, YAG-40.

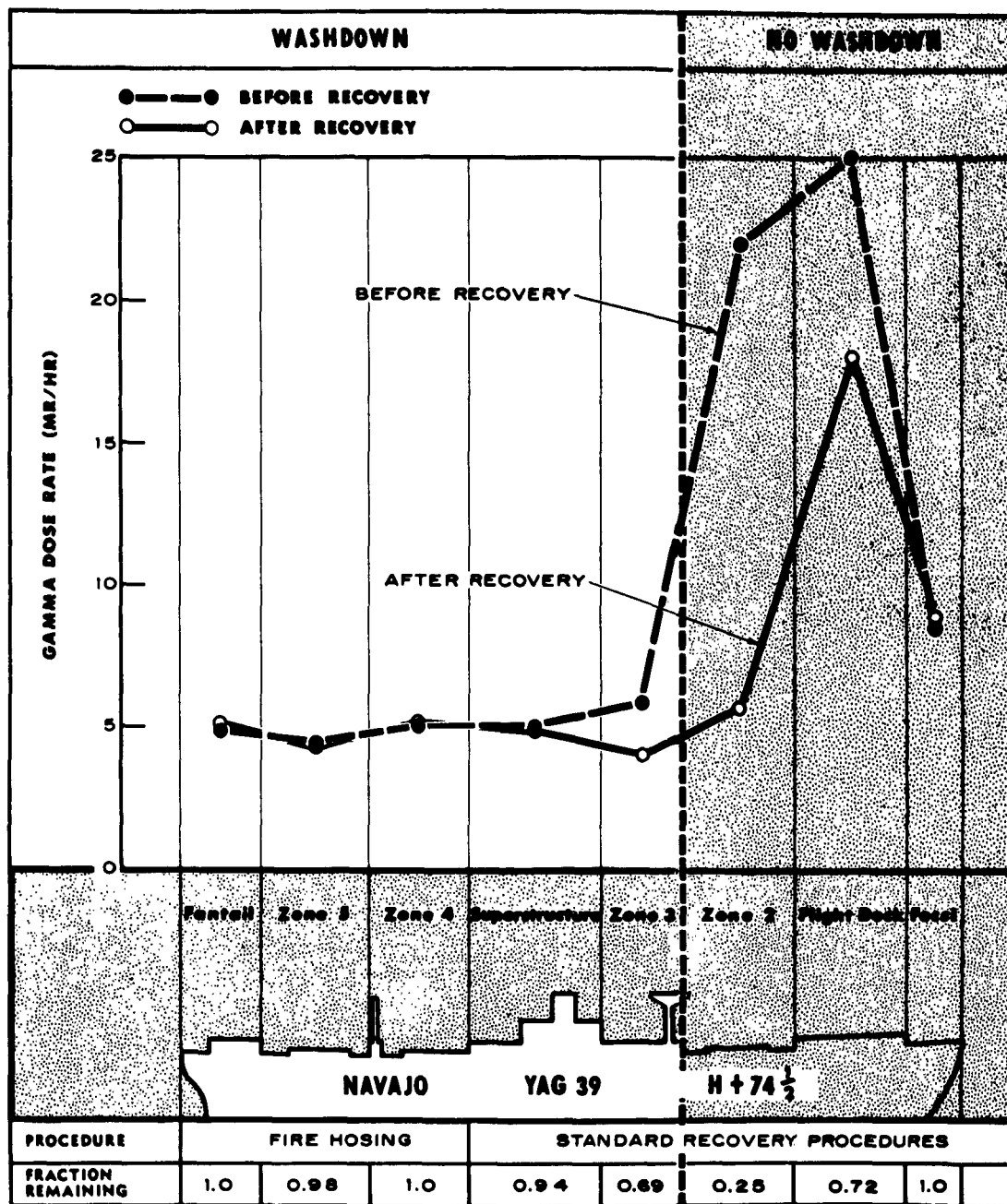


Figure 3.3 Average gamma dose rate in the test areas, Shot Navajo, YAG-39.

dose rate, 75 percent. The flight deck, which was beginning to show the effects of weathering, was reduced from 25 mr/hr to 18 mr/hr, a reduction of 28 percent. The forecastle, together with the washdown section aft, showed little or no reduction because of the extremely small initial radiation levels.

One work party of 24 men was used successively on the YAG-40 and the YAG-39. A total of 150 man-hours was expended.

The contaminant was similar to that of Flathead, and its ready removability was demonstrated by the rapid drop in radiation level as recorded by the fixed detector stations during the previously mentioned rain squalls.

3.1.5 Shot Tewa. All three ships received fallout from Tewa, but only the YAG-39 and YAG-40 retained significant radiation levels.

The operational decontamination of YAG-40 (Figure 3.4) reduced the dose rates in the nonwashdown region over a range varying from 25 percent in the forecastle to 79 percent in Zone 2. The ineffectiveness of decontamination was largely due to the cramped, complex configuration of the forecastle and the exposure of bare wood planking on the flight deck. The poor surface condition of the flight deck resulted from weathering, previous recovery operations, and abrasion from daily traffic.

Dose-rate reduction in the washdown region was negligible. For the most part, the recovery procedures redistributed the contaminant without removing it.

Results of decontamination of YAG-39 are given in Figure 3.5. Recovery effectiveness in the nonwashdown region ranged from 30 to 77 percent. The flight deck displayed the highest average final dose rate, 150 mr/hr. Zone 2 responded the most readily to the recovery procedure, when considered from the standpoint of residual numbers.

In the washdown region, recovery effectiveness ranged from 30 to 63 percent, even though the average final dose rates approximated those observed in the corresponding region aboard YAG-40.

For these operations, the decontamination work parties were selected from the ships' forces. The enthusiasm of these persons, induced no doubt by a desire to finish and go home, made it difficult if not impossible to hold the procedures to the desired rate of coverage. There is little doubt that this had a detrimental effect on the effectiveness of the decontamination. However, in all other respects the performance of these personnel was superior to that previously obtained from Task Group work parties. It was again demonstrated that the working force is most effective when kept to a minimum commensurate with the extent of the areas to be decontaminated. Size of work parties varied between 10 and 16 men. A total of 40 man-hours was expended on YAG-40 and 82 man-hours on YAG-39.

A second decontamination effort, directed by Task Group 7.3 Radiological Safety Personnel, was made over the aft sections of the ships in an attempt to further remove loose contaminant which could have been tracked into the interior of the ship. This operation decreased the surface beta contamination level on certain limited deck areas without significantly lowering the overall residual gamma level measured at 3 feet. Such a paradox would be possible if this second effort succeeded in only removing the contaminant from traffic lanes and redepositing it under and along-side the hatch combing, deck machinery, etc.

Tewa contaminant was observed at time of fallout to arrive on both ships in the form of a white coral dust, similar in appearance to that from Shot Zuni. However, after the ship's arrival in Eniwetok Lagoon, only the forward section of YAG-39 retained any

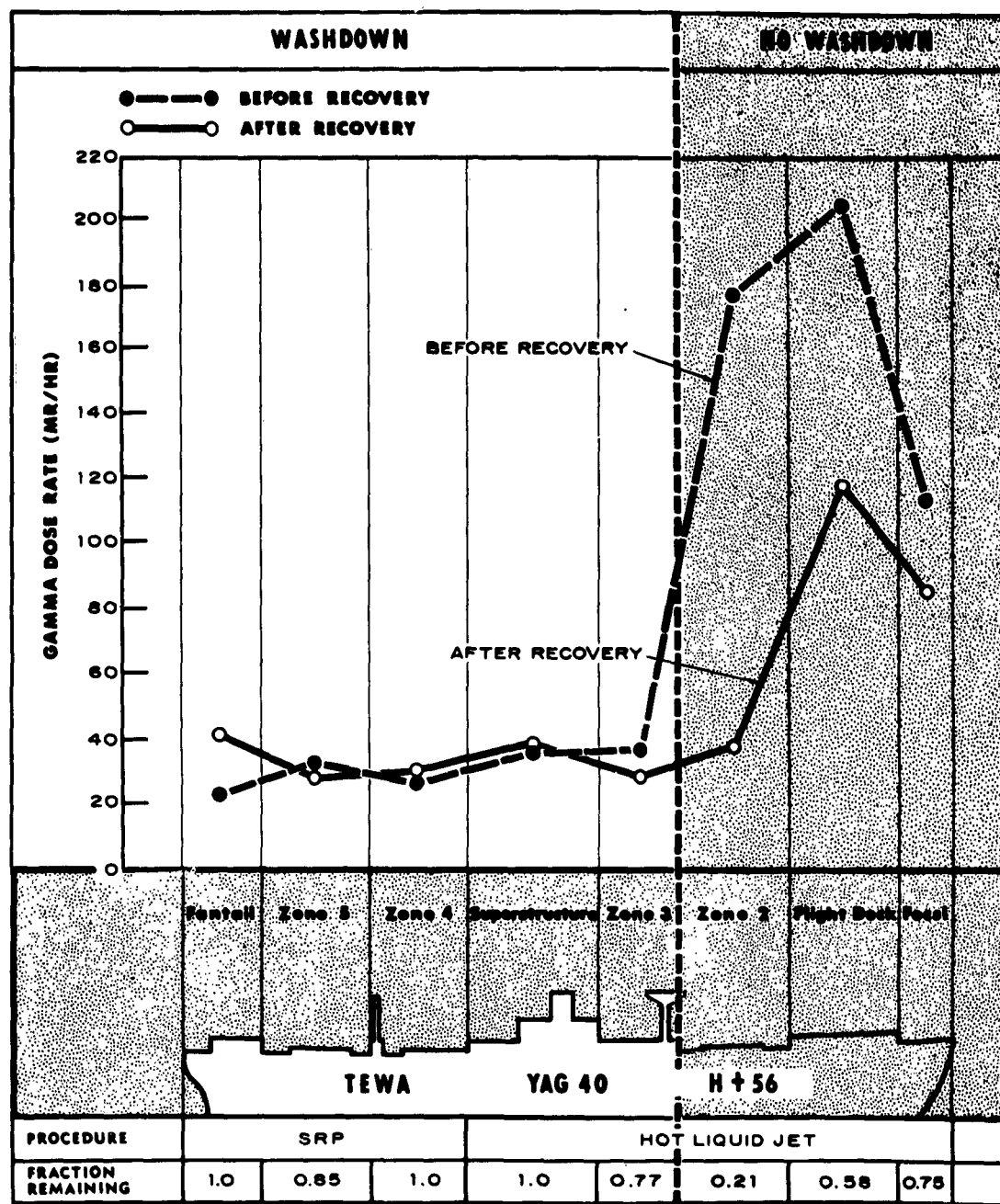


Figure 3.4 Average gamma dose rate in the test areas, Shot Tewa, YAG-40.

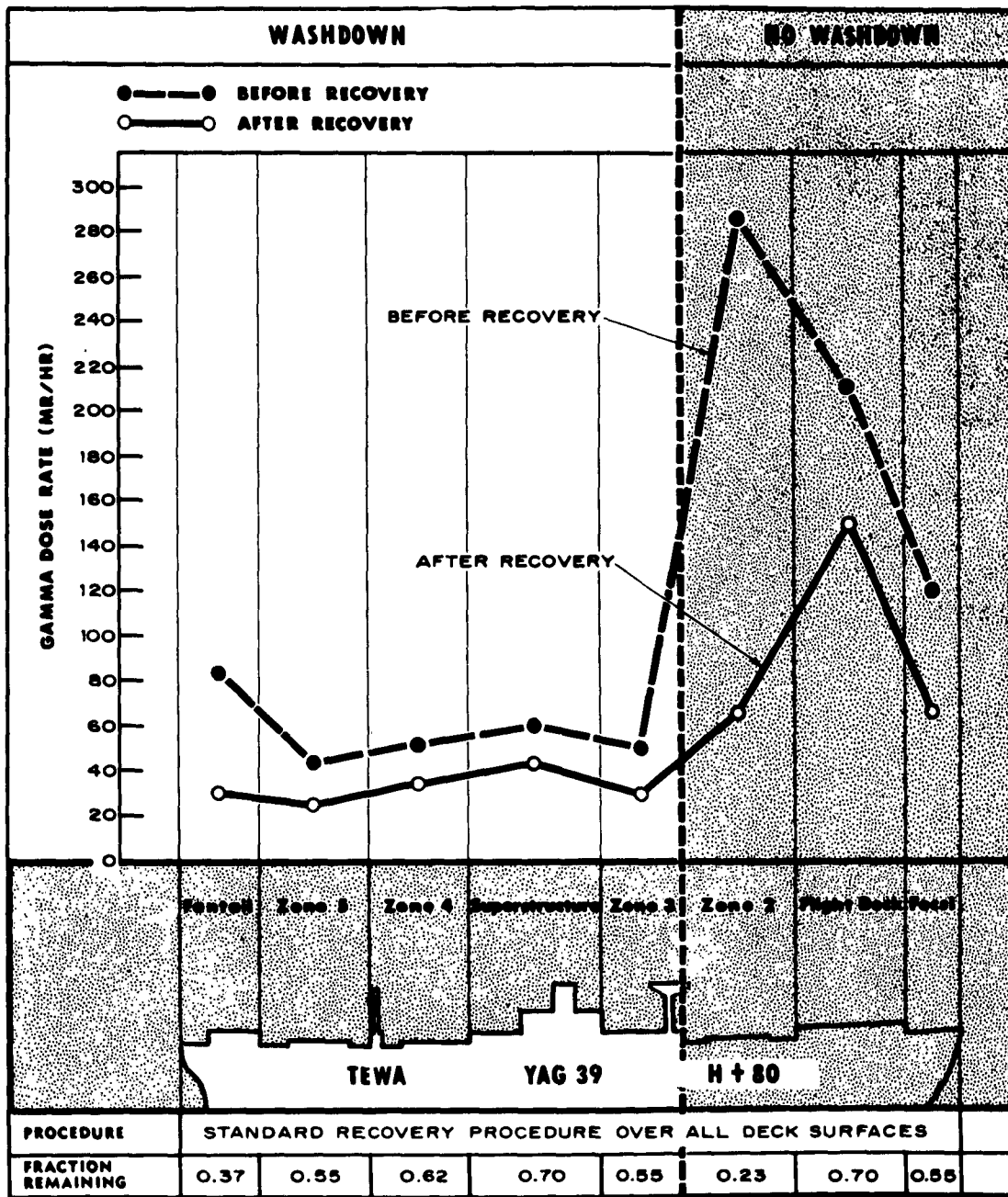


Figure 3.5 Average gamma dose rate in the test areas, Shot Tewa, YAG-39.

visible amounts of contaminant. This consisted largely of a thin film which gave the navy-gray surfaces a faded appearance.

After Zuni it was observed that the contaminant had little tendency to adhere to the ships' weather surfaces and that the visual disappearance of particulate matter was a direct index of the reduction in the gamma radiation level. This, however, did not occur after Shot Tewa. The fractions remaining indicate that the Tewa contaminant was more difficult to remove than the Zuni contaminant. Although the gamma dose rates were lowered considerably in the forward section of both ships, the film observed aboard YAG-39 withstood all removal efforts and was a visual reminder of the overall tenacious characteristic of the Tewa contaminant. Project 2.63 analyses (Reference 3) indicate that at arrival time, the Tewa fallout closely resembled that of Shot Zuni for the parameters measured. At present, there is no supportable explanation for the differences encountered in decontamination.

A routine fire-hosing, hand-scrubbing, fire-hosing operation was carried out aboard the LST-611 by the ship's force after Shot Tewa. Because of the minor radiation levels (about 7 mr/hr), no measurable reduction in gamma dose rate was observed at any of the 24 survey stations located on the main deck. However, a 50-percent decrease in the surface contact hazard was indicated by beta readings taken at these same stations.

3.2 RADIATION DOSE TO PERSONNEL

None of the enlisted personnel supplied by Task Group 7.3 for ship decontamination after Shots Zuni, Flathead, and Navajo received a total accumulated dose of more than 1 r, although some of the men participated in all three operations. Project personnel doses were higher, but even after Shot Tewa none exceeded the permissible maximum exposure of 3.9 r.

Chapter 4

DISCUSSION

4.1 DECONTAMINATION EFFECTIVENESS

The determination of decontamination effectiveness under tactical conditions, which was the principal objective of this project, was not achieved for the reasons stated in Chapter 3. Any attempt to extrapolate data to earlier times (immediately after cessation of fallout) would require a full knowledge of the fallout characteristics that influence the contamination-decontamination processes.

According to Miller (Reference 4), decontamination effectiveness is not only influenced by the properties of the surfaces but by the amount of fallout present, the solubility characteristics as related to adsorption-absorption, and the particle-size distribution.

Considerable information is available on the material encountered at Redwing (Reference 3); however, it appears that additional knowledge is required. For instance, Reference 3 indicates that the fallout samples collected at Shots Zuni and Tewa were quite similar as far as the characteristics observed were concerned. As reported in Chapter 3 of this report, the decontamination effectiveness varied considerably on the two shots. Whether this disparity is due to contaminant differences that were not determined, or operational factors not evaluated, is not known. It may be possible to provide a correlation between the results of the various experiments when additional information becomes available regarding the characteristics of these types of fallout and when the various contamination-decontamination processes are better understood.

4.1.1 Description of Data. Tables 4.1 and 4.2 present a detailed breakdown of the decontamination effectivenesses achieved at Shot Tewa aboard the two YAG's in terms of the fractions remaining computed from gamma and beta survey data, respectively. Fractions remaining for both the standard recovery procedure (SRP) and hot-liquid-jet cleaning (HLJ) are given for each test area. These in turn have been combined to give an average fraction remaining for each of three sections—forward, midships, and aft. This average has been weighted to allow for the varied number of observations taken in the individual test areas of any given section.

The contents of these tables are shown graphically in Figures 4.1 and 4.2. The bars extend over the range of fractions remaining entered in Tables 4.1 and 4.2 for each test area. The value for the weighted average residual number in each section is depicted by a horizontal line through each bar.

4.1.2 Gamma-Radiation Reduction in Nonwashdown Regions. In the nonwashdown region (forward section) of both ships, the graphs in Figure 4.1 indicate that the SRP and HLJ were equal in decontamination effectiveness. Not only are the lengths of the bars nearly the same but the average fractions remaining practically coincide at values of 0.42 for the HLJ and 0.43 for the SRP.

The influence of deck surface condition and configuration is reflected in the wide ranges which the two bars cover. The more-weathered or complicated surfaces of the flight deck and forecastle give larger fractions remaining, 0.55 and greater, in the upper half

of the bar graphs. In direct contrast, Zone 2 (which was repainted prior to Shot Navajo) permitted effectivenesses approaching fractions remaining of 0.2, evidenced at the lower ends of the bar graphs. Because of the varied structural geometry and the intermittent maintenance of weather surfaces aboard many ships, the expected average effectiveness of either the SRP or HLJ is not readily predictable.

4.1.3 Gamma-Radiation Reduction in Washdown Regions. In the washdown region aboard YAG-40, it is apparent that little or no decrease in dose rate was accomplished with either the SRP or HLJ, since the average fractions remaining in both midships and aft sections were very nearly equal to unity.

Theoretically, fractions remaining greater than 1.0 have no meaning, but the arrows in Figure 4.1 denote fractions existing beyond this limit. In reality, this means that,

TABLE 4.1 RECOVERY EFFECTIVENESS IN FRACTIONS REMAINING BASED ON REDUCTION OF GAMMA RADIATION AFTER SHOT TEWA

Condition	Section	Test Area	YAG-40	YAG-39
Nonwashdown	Forward	Forecastle	HLJ 0.75	SRP 0.55
		Flight Deck	HLJ 0.58	SRP 0.70
		Zone 2	HLJ 0.21	SRP 0.23
		Weighted Average	0.42	0.43
Washdown	Midships	Zone 3	HLJ 0.77	SRP 0.55
		Top O'House	HLJ 1.33	SRP 0.81
		Boat Deck	HLJ 0.96	SRP 0.61
		Weighted Average	0.99	0.67
Washdown	Aft	Zone 4	SRP 1.16	SRP 0.62
		Zone 5	SRP 0.85	SRP 0.55
		Fantail	SRP 1.85	SRP 0.37
		Weighted Average	1.10	0.52

because of redistribution of contaminant during recovery operations at many survey stations, the final readings were larger than the initial readings. Such was the case in three test areas, viz., the top of the wheel house, Zone 4, and the fantail (refer to Table 4.1).

In comparison to the negligible reduction effected on YAG-40, fractions remaining of 0.67 and 0.52 were obtained in the midships and aft sections, respectively, on board YAG-39. This marked difference in effectiveness was probably caused, in part, by the extended recovery effort of 2.1 man-hours on YAG-39 as against 1.2 man-hours on YAG-40 for every 1,000 ft² recovered. Referring to Figures 3.4 and 3.5, all other rates lie within an interval of 20 to 42 mr/hr with the exception of the dose rates on the YAG-39 before recovery. Because it is not likely that such an arrangement is merely due to coincidence, this narrow interval must represent the minimum band of average final dose rates producible under the test conditions. Thus, since the washdown system aboard the YAG-40 had held radiation intensities to an irreducible level within the minimum band, no additional decontamination was possible. The moderate decontamination aboard YAG-39, however, was due to subsequent removal of loose contaminant which had not been entirely eliminated by washdown.

4.1.4 Contaminant Removal in the Nonwashdown Regions. A comparison of fractions remaining as indicated by beta surveys (given in Table 4.2 and graphed in Figure 4.2) in

the nonwashdown regions shows an average value of 0.33 for the SRP and 0.41 for HLJ. It would appear that, when considering the entire region, the SRP was about 20-percent more effective than the HLJ in removing the surface contaminant, i. e., beta hazard. As noted previously for the washdown regions (see Section 4.1.3), the recovery effort in the nonwashdown region of YAG-39 was twice that expended in the corresponding region aboard the YAG-40. Ten men spent 3 hours performing the SRP aboard YAG-39, while an equal number of men took only 1½ hours for the YAG-40. Had HLJ been slowed to match the cleaning rate of the SRP, it might well have proven more effective than the latter procedure.

4.1.5 Contaminant Removal in the Washdown Region. Removal of surface contaminant was slightly effective in the washdown region aboard YAG-40. An average residual number of 0.79 was obtained in the midships section with HLJ while a value of 0.69 was

**TABLE 4.2 RECOVERY EFFECTIVENESS IN FRACTIONS REMAINING
BASED ON REMOVAL OF BETA CONTAMINANT AFTER
SHOT TEWA**

Condition	Section	Test Area	YAG-40	YAG-39
Nonwashdown	Forward	Forecastle	HLJ 0.49	SRP 0.77
		Flight Deck	HLJ 0.38	SRP 0.69
		Zone 2	HLJ 0.42	SRP 0.22
		Weighted Average	0.41	0.33
Washdown	Midships	Zone 3	HLJ 0.65	SRP 0.46
		Top O'House	HLJ 0.82	SRP 0.70
		Boat Deck	HLJ 0.81	SRP 0.79
		Weighted Average	0.79	0.68
Washdown	Aft	Zone 4	SRP 0.51	SRP 0.38
		Zone 5	SRP 0.78	SRP 0.38
		Fantail	SRP 0.70	SRP 0.22
		Weighted Average	0.69	0.28

achieved by the SRP in the aft section. By comparison, the fractions remaining resulting from the SRP conducted aboard YAG-39 were 0.68 and 0.28 in the midships and aft sections, respectively.

Again, this difference in effectiveness aboard the two ships may be related to the increased recovery effort expended aboard YAG-39 and the greater success of the washdown system aboard YAG-40. A minimum beta-dose-rate condition existed which parallels that discussed in Section 4.1.3 with respect to the gamma levels of Figures 3.4 and 3.5.

4.2 CRITICISM OF FRACTIONS REMAINING

On the basis of the fractions remaining entered in Table 4.2 for the flight deck, it might be concluded that HLJ was nearly twice as effective as the SRP when applied to painted wood decking (for a nonwashdown situation). However, an examination of Figures B.3 and B.4 of Appendix B shows that the final beta dose rate upon completion of HLJ was still higher than the initial dose rate prior to application of the SRP. Such a situation implies that the latter procedure essentially began at the level where the former ceased and under these circumstances appeared in an unfavorable light because of in-

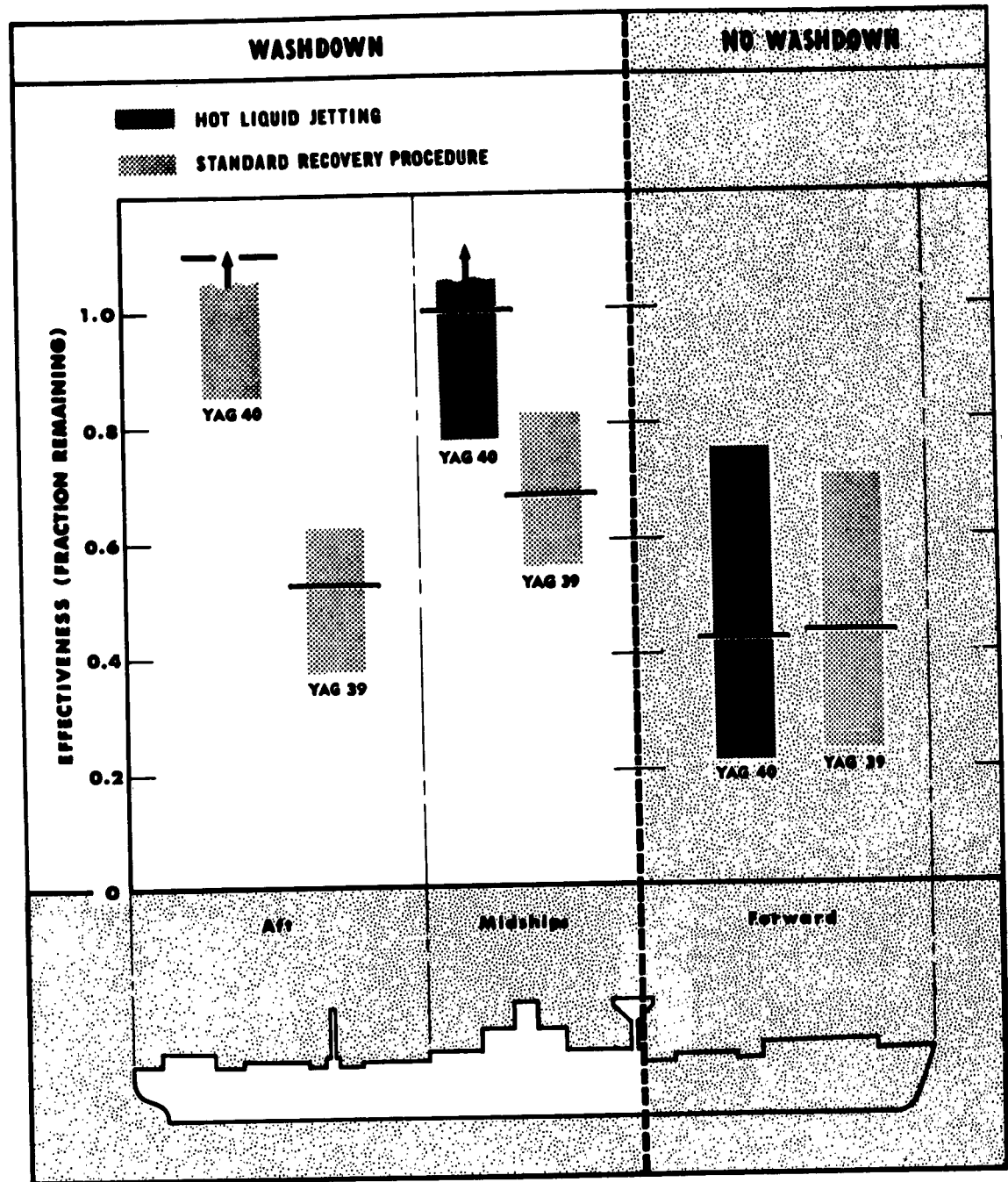


Figure 4.1 Recovery effectiveness, gamma, Shot Tewa.

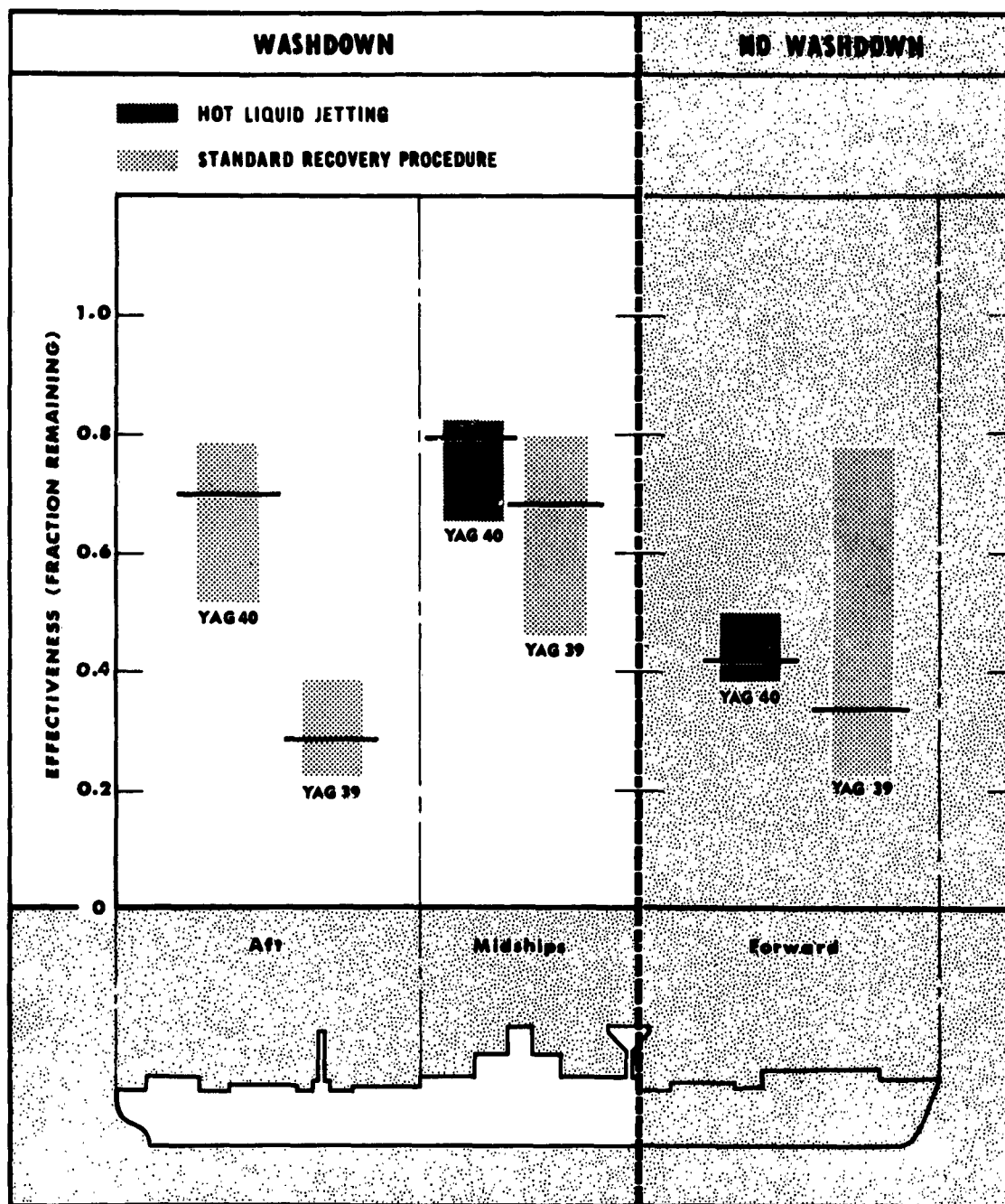


Figure 4.2 Recovery effectiveness, beta, Shot Tewa.

sufficient removable contaminant on the flight deck of YAG-39 at the start of recovery operations.

The above example points out why great care must be exercised in comparing fractions remaining. Due consideration should be given to the relative magnitudes of the dose rates involved before reaching a decision.

4.3 RECOVERY RATES AND EFFORT

Engineering scale studies at NRDL (Reference 5) in August 1954 showed that although a fire-hosing procedure progressing at 100 ft²/min presumably covered an entire test surface, not more than half was actually subjected to the full impact of the stream. It was found that by slowing the hosing rate to 25 ft²/min, the stream from a 1½-inch fire-hose effected complete contact coverage.

Because it was doubtful that 100-percent coverage would be either mandatory or physically obtainable in the urgency of a tactical situation, a rate of 50 ft²/min was

TABLE 4.3 SHIPBOARD RECOVERY RATES AND MANPOWER REQUIREMENTS

Contaminating Event	Ship	Procedure	Power Rate (ft ² /man-hr)	Recovery Effort (man-hr/10 ³ ft ²)	Team Rate* (ft ² /hr)
Zuni	YAG-40	SRP	280	3.6	1,680
		HLJ	570	1.8	3,420
Flathead	YAG-40	SRP	390	2.6	2,340
Navajo	YAG-39	SRP	450	2.2	2,700
Tewa	YAG-40	HLJ	740	1.4	4,400
Tewa	YAG-39	SRP	500	2.0	3,000
Estimated Range of Idealized Values		SRP	250-500	2-4	1,500-3,000
		HLJ	500-1,000	1-2	3,000-6,000

*Rate for basic 6-man team.

selected as a lower limit for hosing-type methods. This rate corresponded to a coverage of over 80 percent.

The results of ship decontamination tests at Operation Castle indicated that from the standpoint of reaching a balance between personnel fatigue, recovery effort, and accumulated dosage, a fire-hosing rate of 100 ft²/min was optimum. For this reason and because of the increased coverage resulting from the successive application of separate methods comprising a recovery procedure, the 100-ft²/min rate was chosen as the upper limit for most tactical situations.

With these limiting values as a guide, estimates were made of the overall recovery rates and the corresponding man-power requirements for the SRP and HLJ. These idealized estimates together with the more-representative findings from Operation Redwing are shown in Table 4.3. This information is given under three separate headings denoting the more-convenient expressions currently in use. When given the value of one expression, the remaining two can be computed immediately. For this reason, the figures under the heading "Team Rate" will be referred to exclusively as a means of simplifying the discussion that follows.

Team rates of 1,680 ft²/hr for the SRP and 3,420 ft²/hr for HLJ are noted in Table 4.3 following Shot Zuni. These rates approached the lower limits of the idealized ranges

shown at the bottom of the table. Such low values were a direct result of the plentiful quantities and, especially, the visible nature of the Zuni contaminant. That is, the progress of the two recovery procedures was paced to match the rate at which the contaminant was seen to be removed.

Because the contaminant from subsequent shots provided no visual indication of the speed of actual removal, the recovery rates were considerably greater than those measured following Shot Zuni. In particular, after Shot Tewa the SRP reached the estimated maximum rate of 3,000 ft²/hr aboard YAG-39. The HLJ, as employed on board YAG-40, performed at a team rate of 4,400 ft²/hr—approximately midway between the idealized limits set for that procedure. Although this is not as great a relative gain as that demonstrated by the SRP, it does represent an increase of nearly 1,000 ft²/hr over the HLJ rate observed following Shot Zuni.

It has been pointed out previously in Section 3.1.5 that, in addition to the tenacious nature of the Tewa contaminant, these high recovery rates may have been partially responsible for the resultant lower decontamination effectiveness. For this reason and in view of the complete coverage accomplished after Shot Zuni, the recovery rates should be held near the lower limits of the idealized ranges whenever it is tactically feasible; e.g., 1,700 ft²/hr for the SRP and 3,400 ft²/hr for HLJ. Relaxation of these restrictions will be a function of time, man power, and dosage limitations as dictated by each tactical situation.

4.3.1 Limit and Placement of Decontamination Teams. During the shipboard recovery operations at Operation Redwing, it was discovered that the number of decontamination personnel that can be used with maximum efficiency is limited by the size, orientation, and configuration of the contaminated weather surfaces. Thus, for each type of ship a different number of men will be required in providing for optimum recovery performance. For instance, aboard the YAG's, three teams of six men each would be ideal for instituting either HLJ or the SRP.

To minimize the possible interference of one team with another, it would be advisable to start one team working forward from the fantail, a second team working aft from the flight deck and forecastle, and a third team working down from the top of the wheel house. This placement also takes advantage of the natural drainage characteristics of the YAG's. Similar schemes can be worked out for other type ships in achieving the most-desirable placement of decontamination teams.

4.3.2 Consumption of Supplies. Instead of applying the detergent in the usual manner, i.e., as a 1-percent solution from GI cans (during the SRP operations) it was hand-cast directly onto the deck surfaces in its original solid form. For this reason, the detergent consumption was 10 to 20 times greater than reported at Operation Castle—ranging from 6 to 26 lb/10³ ft², depending upon how closely the procedure was supervised.

For the hand-casting technique, a consumption rate of 6 lb/10³ ft² is acceptable in light of the low cost of the detergent and the advantage gained by eliminating the drudgery of handling GI cans full of soap solutions. Rates in excess of 12 lb/10³ ft² are considered wasteful in most cases and are to be avoided.

4.4 PERSONNEL DOSAGE

In the event that a ship is subjected to radioactive fallout during a tactical situation, it will be highly desirable to effect the removal of the contaminant in the shortest time possible. To start these operations immediately upon cessation of fallout could result

in extremely high and possibly lethal doses to decontamination parties. However, to wait in shielded positions for sufficient reduction in radiation levels due to decay and weathering might be equally unacceptable from a tactical standpoint.

Hopefully, an analysis based on the decontamination effectiveness indicated by this experiment and the ship-shielding effects documented by Project 2.71 can be made in the near future to determine the optimum time for initiating decontamination operations so that dosage to all personnel is held to a minimum.

Chapter 5

CONCLUSIONS and RECOMMENDATIONS

For reasons already discussed, the data from these tests did not permit the evaluation of the effectiveness of tactical decontamination, insofar as high radiation levels and early times are concerned. Therefore, the following conclusions reflect the results of an operational-type decontamination and are not to be interpreted in terms of tactical requirements without strict qualification.

5.1 CONCLUSIONS

The standard recovery procedure of fire-hosing, hand-scrubbing with detergent, and fire-hosing is a practicable means for the decontamination of ships at sea.

Hot-liquid-jet cleaning is equally effective at twice the operating rate, but requires special equipment to provide a high-volume jet of sea water at high temperature and high pressure.

The effectiveness of recovery operations was influenced to a great extent by the type of fallout encountered and to a lesser extent by surface characteristics, structural configuration, initial level, operational rate, recovery effort, etc.

The varied structural geometry and the intermittent maintenance of weather surfaces aboard ship prevent the accurate prediction of the expected average decontamination effectiveness of either a standard recovery procedure or a hot-liquid-jet cleaning.

Aside from its minor effects on gamma-radiation intensity, the major contribution of decontamination by the tested procedures in areas previously protected by the wash-down system is the reduction of the beta contact hazard on important surfaces.

As deduced previously from the data obtained at Operation Castle, the concerted effort of several decontamination teams working at once is more successful in effecting a major reduction in the radiation dose to exposed personnel than are piecemeal efforts of limited operations over a protracted period of time.

Holding the size and number of decontamination teams to a minimum commensurate with the extent of the areas to be cleaned prevents their interference with other working parties and each other.

Of the four separate fallout materials encountered at Operation Redwing, that resulting from Shot Tewa proved to be the most difficult to remove.

Even though additional ship-recovery procedures may be required, a washdown system is still the best available fallout countermeasure, whether the installation is permanent or interim.

Although the effects of decay and decontamination are additive, the possibility exists that at very-early times the contribution of decay to the decrease in dose rate may be so overwhelming that decontamination procedures should not be initiated until some later and optimum time.

5.2 RECOMMENDATIONS

The standard recovery procedure and hot-liquid-jet cleaning should be proof-tested

in the field under conditions approximating a tactical situation, that is, aboard a combatant type Navy ship soon after the cessation of fallout from a nuclear detonation at sea.

Further investigation should be undertaken at the laboratory level and in the field to determine the best operating rates for both procedures. Until such time, operational rates of approximately 1,700 ft²/hr for the SRP and 3,400 ft²/hr for HLJ should be observed to ensure maximum coverage and effectiveness.

The adoption and procurement of hot-liquid-jet equipment should not be undertaken without additional testing and evaluation.

The optimum time after burst for commencing recovery operations such that the net effects of decay and decontamination will be maximized should be determined, if possible, from the field test data now available.

Appendix A

LOG OF RECOVERY OPERATIONS

Following abbreviations are used: SRP, Standard Recovery Procedure, fire-hosing, hand-scrubbing*, fire-hosing; HLJL, Hot-Liquid-Jet Lance; FH, Firehose(ed/ing); RRPC, Removable Radiological Protective Coating.

Date	Time After Burst		Time of Day*	Number of Men	Action
	Days	Hours*			
YAG-40, Shot Zuni:					
May 28	Z + 0	H + 0	0600		Time of burst.
29	Z + 1				Ships not available, no action.
30	Z + 2	H + 56	1400		Initial survey.
31	Z + 3	H + 77	1100		Surveyed flite deck, Zones 4 and 5 and fantail.
Afternoon		H + 80	1400	19	SRP flite deck and fantail. Surveyed Zone 2.
		H + 81	1500	4	Project 2.8 FH Zone 2, starboard half only.
		H + 81½	1530		Stripped RRPC from top No. 5 hatch, for Project 2.8 with single 2-man HLJL.
		H + 83	1700		Surveyed flite deck and Zones 2 and 5.
June 1	Z + 4	H + 99	0900	13	Surveyed Zone 2. SRP forecastle with 1½-inch parabolic nozzle. Reworked top No. 5 hatch and stripped RRPC from starboard side Zone 5, for Project 2.8, with HLJ Turret.
		H + 100½	1030	10	Project 2.8 worked in Zones 2 and 3 all morning. SRP top of house, secured HLJ Turret and hooked up single 2-man HLJL.
Afternoon		H + 103½	1330	13	Worked Zone 4 and port and aft bulkhead on boat deck with single 2-man HLJL† followed by 2-man HLJL rinse. SRP port flying bridge, bridge deck ladders and engine space vent.
		H + 106	1600	9	Surveyed Zones 4 and 5. Project 2.8 worked Zones 2 and 3.
		H + 107	1700		Surveyed Zone 2.
June 2	Z + 5	H + 123	0900	22	Stripped RRPC from port side Zone 5, for Project 2.8, with single 2-man HLJL. SRP dish pan and whale boat. FH section aft of superstructure.
		H + 124½	1030		Moved Sellers Units into Zone 2 and hooked up double 2-man HLJL's. Reworked forward half Zone 2 with double 2-man HLJL's.
Afternoon		H + 127½	1330	22	SRP top No. 3 deck house, stripped RRPC from aft half Zone 2 including gun tube using double 2-man HLJL's. Worked face of superstructure with single 2-man HLJL† followed by 2-man HLJL rinse. FH Zones 2 and 3, both passageways and starboard bulkhead on boat deck. SRP boat deck (bulkheads excluded). Recovery completed.
		H + 129½	1530		
June 3	Z + 6	H + 148½	1030		Final survey.
YAG-40, Shot Flathead:					
June 12	F + 0	H + 0	0630		Time of burst.
13	F + 1				Ships not available, no action.
14	F + 2	H + 56	1430		Initial survey.
15	F + 3	H + 75	0930	19	SRP forecastle, top of house, boat deck and top after deck house. FH after section.
		H + 75½	1000	10	Project 2.8 began HLJL stripping of RRPC in port area beside No. 2 hatch and worked starboard deck beside No. 2 hatch with mechanical scrubber.

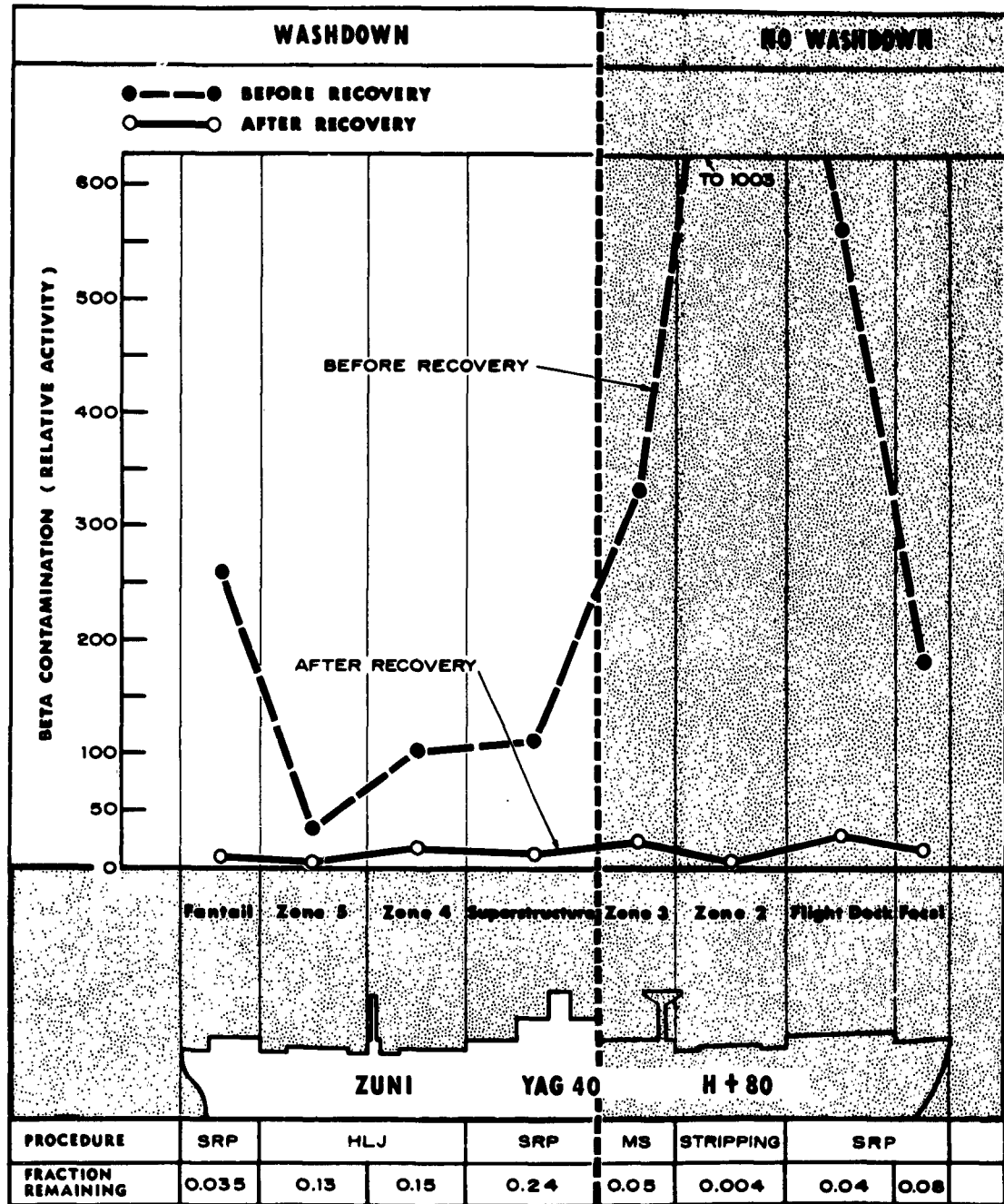


Figure B.1 Average beta contamination level in the test areas, Shot Zuni, YAG-40.

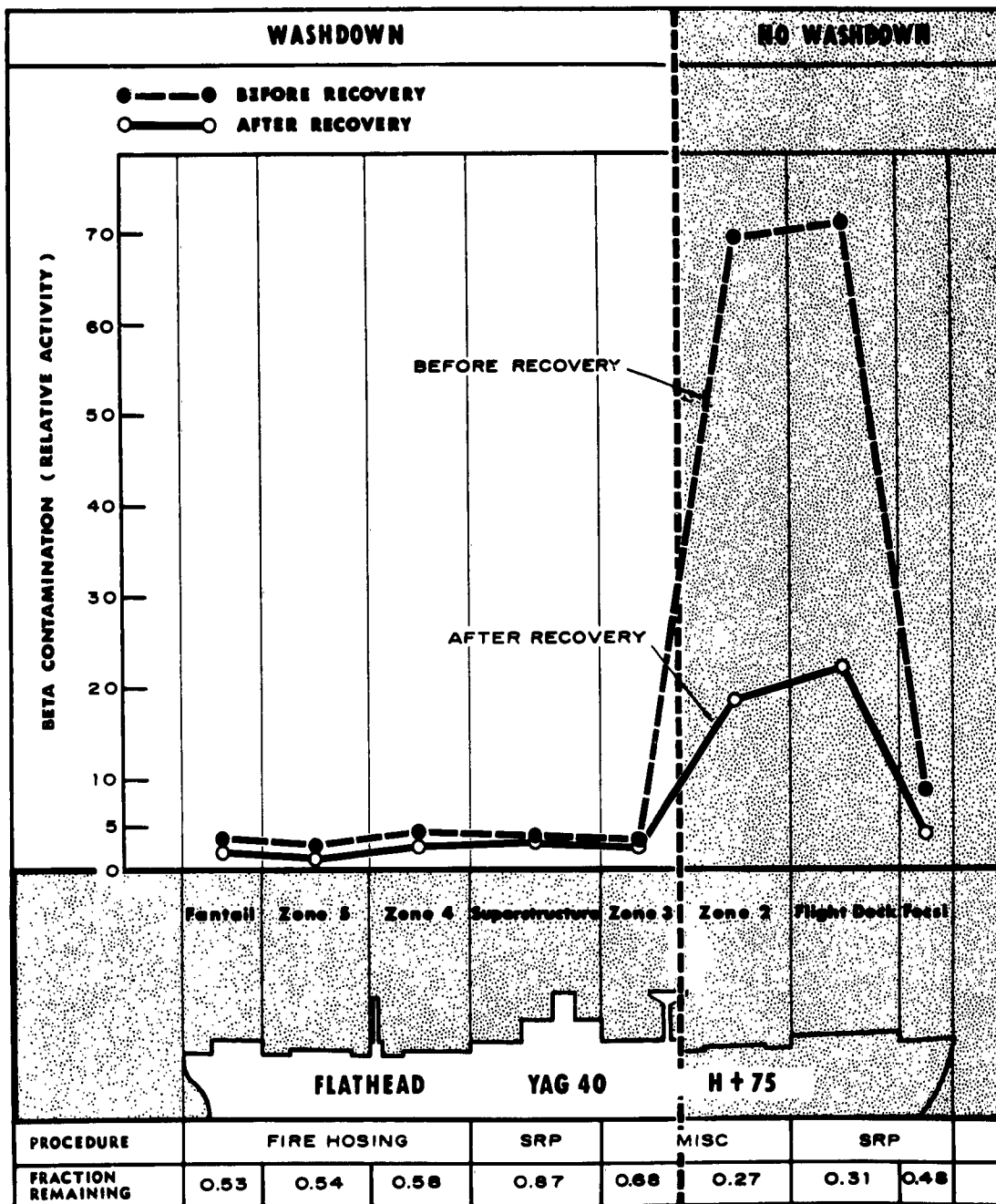


Figure B.2 Average beta contamination level in the test areas, Shot Flathead, YAG-40.

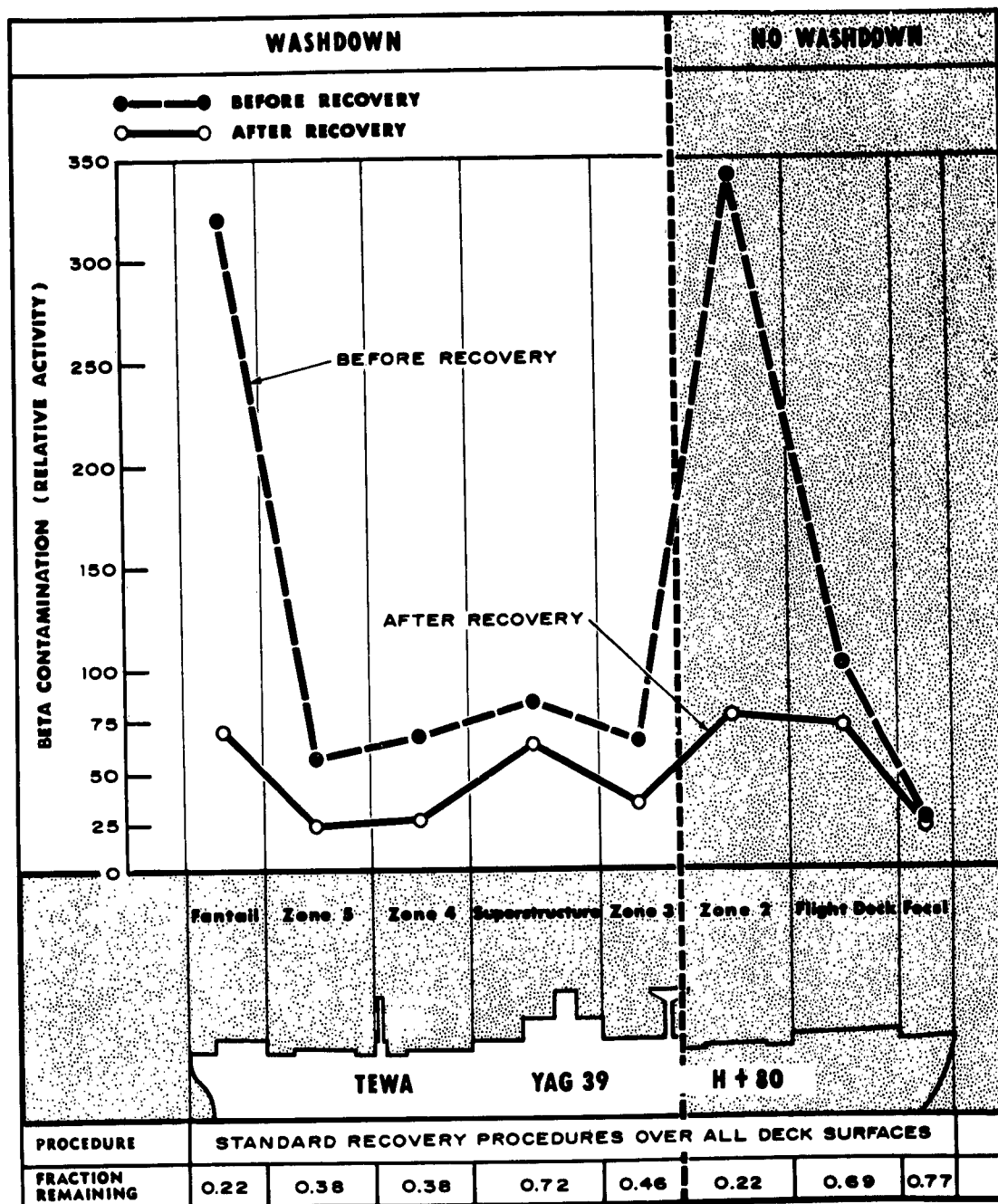


Figure B.3 Average beta contamination level in the test areas, Shot Tewa, YAG-39.

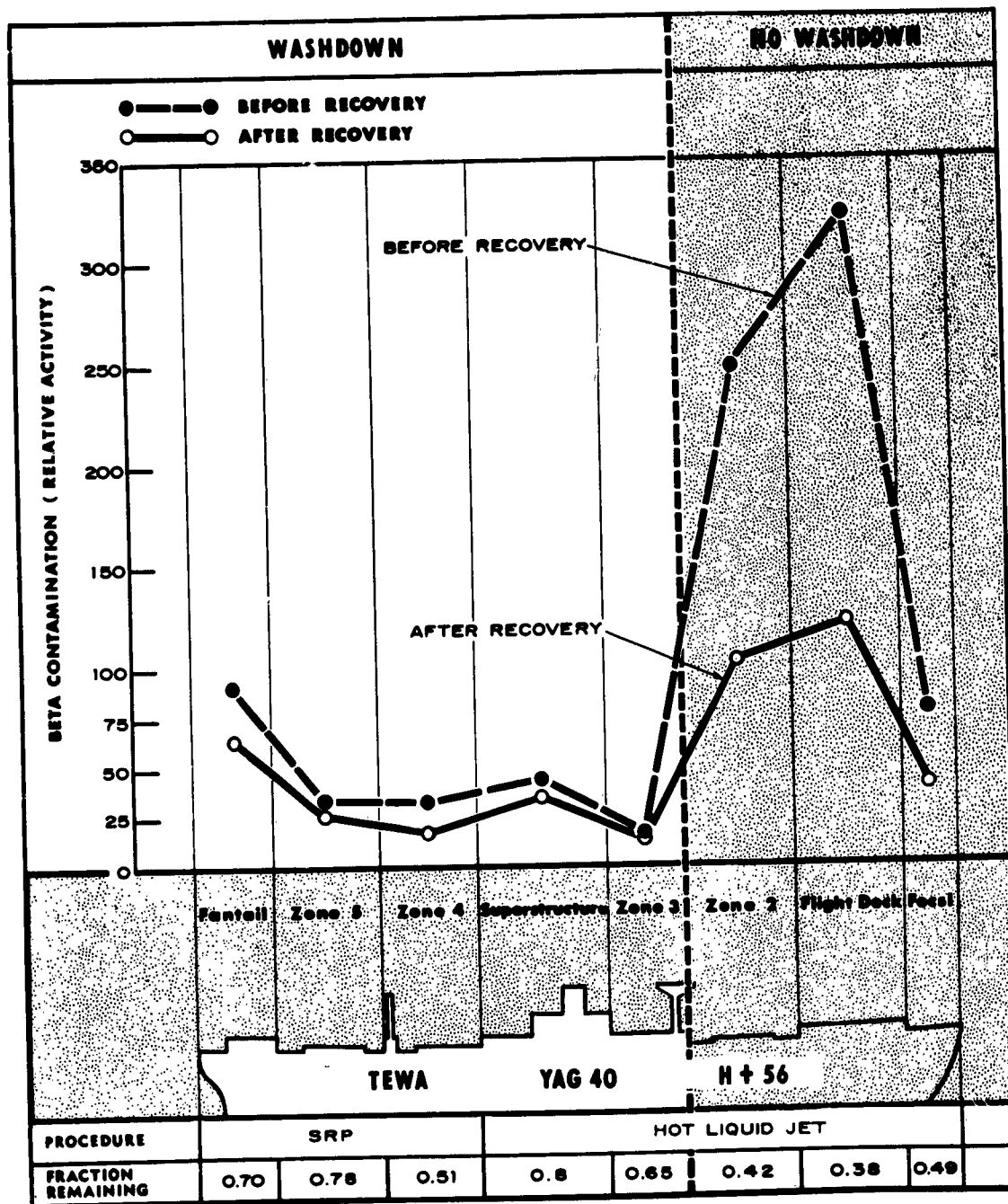


Figure B.4 Average beta contamination level in the test areas, Shot Tewa, YAG-40.

Date	Time After Burst		Time of Day*	Number of Men	Action
	Days	Hours*			
Afternoon		H + 79½	1400	16	SRP flite deck, dish pan, top No. 3 deck house and finished starboard areas Zones 2 and 3.
				8	Project 2.8 finished stripping RRPC from port areas on Zones 2 and 3.
		H + 81	1530	23	HLJL†, FH face of superstructure, aft bulkhead of No. 3 deck house and top No. 2 hatch. FH passageways. Stowed gear.
		H + 82	1630		Recovery completed.
June 16	F + 4	H + 100	1030		Final survey.
YAG-39/40, Shot Navajo:					
July 11	N + 0	H + 0	0600		Time of burst.
12	N + 1				Ships not available, no action.
13	N + 2	H + 51½	0930		YAG-40 arrived. Radsafe survey.
Noon		H + 54	1200	24	SRP nonwashdown area and superstructure. FH washdown area aft of superstructure.
		H + 56½	1430		Recovery completed. Radsafe survey.
July 14	N + 3	H + 75	0900		Final survey (Project 2.8).
July 13	N + 2	H + 55½	1330		YAG-39 arrived.
		H + 56½	1430		Initial survey (Project 2.8).
July 14	N + 3	H + 74½	0830	24	SRP nonwashdown area and superstructure. FH washdown area aft of superstructure.
Afternoon		H + 80	1400		Recovery completed. Radsafe survey.
		H + 80½	1430		Final survey (Project 2.8).
YAG-39/40, LST-611, Shot Tewa:					
July 21	T + 0	H + 0	0600		Time of burst.
22	T + 1	H + 28	1000		LST-611 arrived.
23	T + 2	H + 52	1000	19	SRP superstructure and fore-castle.
Afternoon		H + 55½	1330	9	Continued SRP of main deck.
		H + 56½	1430	9	Recovery completed.
July 23	T + 2	H + 50	0800		YAG-40 arrived.
		H + 56	1400		Initial survey.
Afternoon		H + 56½	1430	10	Double 2-man HLJL†, FH top of house, boat deck and face of superstructure.
		H + 58	1600		Completed recovery of above areas.
July 24	T + 3	H + 75	0900	10	SRP Zones 4 and 5, fantail and top of No. 3 deck house. Double 2-man HLJL†, FH fore-castle, flite deck and Zones 2 and 3. Stowed gear.
		H + 77	1100		Recovery completed.
July 25	T + 4	H + 99	0900		Final survey.
July 23	T + 2	H + 54	1200		YAG-39 arrived.
		H + 75	0900		Initial survey.
July 24	T + 3	H + 80	1400	10	SRP Zones 4 and 5 and fantail.
		H + 82	1600		Completed recovery of aft section.
		H + 98½	0830		Intermediate survey.
July 25	T + 4				Continuation of shielding studies (Project 2.71)
July 26	T + 5	H + 123	0900	15	SRP flite deck, fore-castle, top of house, star-board and aft bulkheads above boat deck.
Afternoon		H + 127½	1330	16	SRP boat deck and Zones 2 and 3. FH face superstructure and both passageways.
July 26	T + 6	H + 129½	1530		Recovery completed.
		H + 147	0900		Final survey.

* Times shown are averaged to nearest half hour.

† C-120 detergent added.

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2. R. H. Heiskell; "Shipboard Radiological-Countermeasure Methods"; Project 2.8, Operation Redwing, Final Report, draft manuscript; U. S. Naval Radiological Defense Laboratory, San Francisco 24, California; Confidential.
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4. C. F. Miller; "A Theory of Decontamination, Part I"; Draft manuscript; U. S. Naval Radiological Defense Laboratory, San Francisco 24, California; Confidential.
5. W. S. Kehrer and F. S. Vine; "Operational Feedback"; Memorandum to: Head, Technical Developments Branch, August 1954; U. S. Naval Radiological Defense Laboratory, San Francisco 24, California; Unclassified.

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