CASTLE 86

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MEMORANDUM

From: R. R. Hammond, Code 1603B, and W. W. Perkins, Code 5221
To: Captain Andrew G. Nelson, Commonwealth Bldg., Room 772
1300 Wilson Boulevard, Arlington, VA 22209

Subj: Gamma Dose Estimates for PATAPSCO Crew

Ref: (a) NNTPR ltr Ser 981TA/1238 of 28 Dec 78

Encl: (1) Estimation of Dosage Received by Personnel of USS PATAPSCO (AOG-1) following the BRAVO Shot of Operation CASTLE.

1. Enclosure (1) contains the estimates you requested (ref. a). The copy you requested for SAI is also enclosed in its addressed envelope. Your review and approval of the classification of appendix A extracted from the San Bruno Archives would be appreciated before mailing in this manner. We believe appendix A is now definitely unclassified if it indeed ever required security classcation above official use only. Another letter will follow shortly covering the many items which we have pending. Please call if you have any questions.

Bob Hammond
R. R. Hammond
W. W. Perkins
W. W. Perkins

Statement A
Approved for public release;
Distribution unlimited
Paul Brown
for Chief/SCM/DNA
5/15/85

Estimation of Dosage Reveived by Personnel of USS PATAPSCO (AOG-1) following the BRAVO shot of Operation CASTLE.

A. Introduction

Problem: In response to the Navy Nuclear Test Personnel Review office request (ref. 1) the following analysis of personnel exposures was undertaken. During a transit of the USS PATAPSCO from Eniwetok Atoll to Pearl Harbor Hawaii, the personnel of the PATAPSCO encountered an unknown amount of radioactive fallout that resulted from the Castle-Bravo shot (ref. 1). The captain of the ship had been alerted to the possibility of radioactive material contaminating the ship and so made attempts to measure the radioactivity but because of inadequate equipment only uncertain readings were obtained (ref. 2). When PATAPSCO arrived at Pearl Harbor the ship and personnel were monitored and the ship was found to have been contaminated (ref. 2). The following analysis will provide estimates of the range of possible external gamma radiation doses received by the crew from this fallout.

Approach: Two primary sources of radiation data for dose estimation are used in this analysis: (1) published unit reference (H+1) dose rate contours (ref. 3) and, (2) radiological survey data obtained on arrival at Pearl Harbor. Extrapolations of these data are then utilized to estimate the range of dose variations caused by environmental conditions, exposures situations and times. Valuable information contained in the PATAPSCO captains recollections (ref. 2), the ship's logs (ref. 4) and notes describing the survey and decontamination procedures employed at Pearl Harbor (ref. 4) was used in the preparation of this analysis. The time interval for the dose estimates undertaken here will be form fallout arrival at the ship to the time of crew evacuation as reported in the PATAPSCO deck log for 10 March 1954.

In order to estimate the cumulative gamma dose (D) over various time intervals (t_1, t_2) as expressed by equation (1),

$$(1) \qquad D = \int_{t_1}^{t_2} R_t \, dt$$

it is first necessary to evaluate the dose rate (R_t) as a function of time. This is usually accomplished by defining a set of "unit reference dose rate" fallout deposition contours so that subsequent decay corrected dose rates can be expressed relative to these unit hour (t = H + 1) reference rates, (R_1) according to the equation

$$(2) \qquad R_t = R_1 \, t^{-1.2}.$$

Actually since the fallout is seldom if ever all down at H+1 hour at any location, and since the R_1 values must be based on the total cumulative deposition, R_1 is a ficticious quantity defined and used to simplify computations. In practice R_1 is calculated from dose rate measurements made at various locations and times from the relationship.

$$(3) \qquad R_1 = R_t \, t^{1.2}$$

This is approximately valid, assuming 100% retention of bomb debris deposited on an infinite plane surface. All these gamma dose rates are defined for a point three feet above the surface and are proportionally reduced if some fraction of the radioactivity is removed by wind, rain or other decontamination, or if the surface deviates from an infinite plane.

In the following, the process of dose estimation will be broken down in five sections which cover ship movement, fallout dose deposition, radiological survey, dose rate variations and cumulative dose estimates. This will then be followed by an overall summary.

B. Ship and Fallout Movement

Ship position data was obtained from the PATAPSCO deck log (ref. 4) and plotted on an HO chart #81007 with an open water extention to include the track of interest. Figure 1 illustrates the time-based track of the ship together with the track of fallout "hot line." The position and speed of advance of the fallout "hot line" up to BIKAR Atoll were obtained from reference 3 and superimposed on the ships track. Past BIKAR, available BRAVO reports do not agree on the "hot line" location (ref.5)and data to extend this line are not available. For this reason the extremely conservative assumption that the "hot line" coincides with the PATAPSCO track after 011200, was made. Figure 2 shows the advance of the leading edge of the fallout cloud along the "hot line" as extracted from reference 3 along with the calculated and extrapolated 18 knot downwind speed. Table 1 combines the time based locational data for the ship and fallout cloud and shows the intercept distance of 586 nmi down range at H + 32.5 hours. These values were obtained from the large scale plot as illustrated in figure 1.

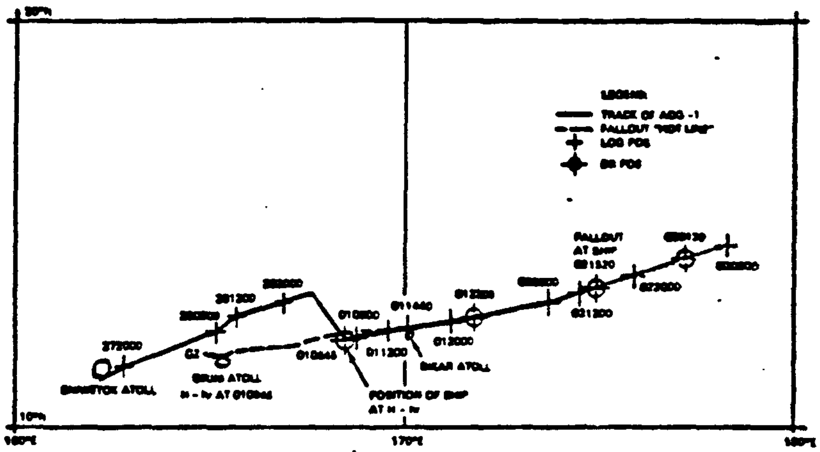

Figure 1. PATAPSCO Track and Fallout "Hot Line".

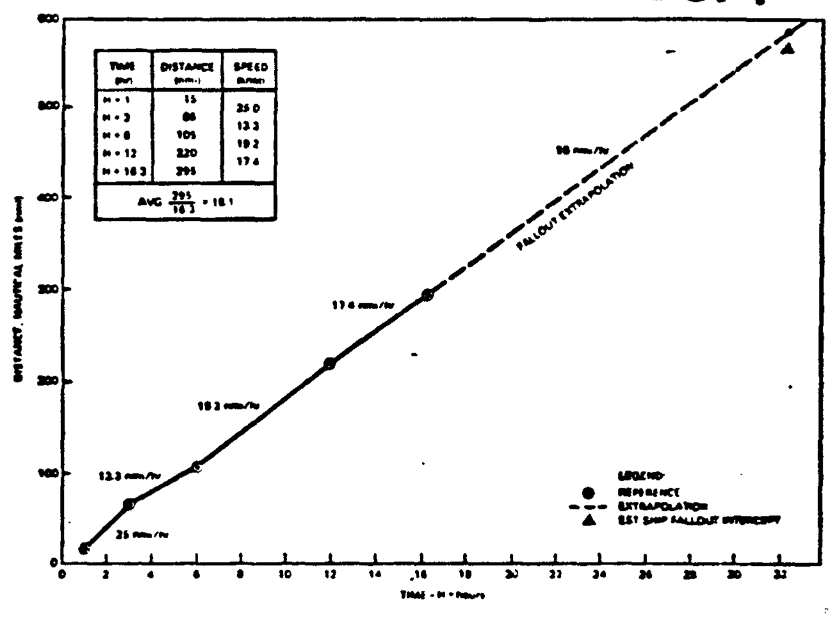

Figure 2. Advance of Leading Edge of Fallout Cloud vs Time.

TABLE 1 Time Based Locational Data For Ship and Leading Edge of Fallout

Time H +	USS PATAPSCO, AOG-1: Ship Position	Incremental Distance (nmi)	Av. Speed Made Good (knots)	Distance From SZ (nmi)	FALLOUT: Distance From SZ (nmi)	FALLOUT: Speed of Advance (knots)
0 (Shot Time)	010645 DR 12-07N, 168-29E			195	0	
		16.8	13.4			17.0
+1.3	010800 LOG 12-10N, 168-45E			212	21.3	
		46.0	11.5			18.4
+5.3	011200 LOG 12-19N, 169-30E			258	94.9	
		37.0	13.7			17.5
+8.0 (Ship @ BIKAR)	011440 LOG 12-25N, 170-08E			295	143	
		61.0	11.5			18.9
+13.3	012000 LOG 12-36N, 171-10E			356	242	
		37.0	21.3			17.4
+16.3 (Fallout @ BIKAR)	012305 DR 12-43N, 171-48E			393	295	
		111.	12.3			18.0
+25.3	020800 LOG 13-02N, 173-38E			504	456	
		45.0	11.3			18.0
+29.3	021200 LOG 13-14N, 174-22E			549	528	
		36.8	11.5			18.0
+32.5 (Fallout @ Ship)	021520 DR 13-27N, 174-58E			586	586	
		55.2	11.5			18.0
+37.3	022000 LOG 13-44N, 175-52E			641	672	
		67.6	13.0			18.0
+42.5	030120 DR 14-08N, 177-13E			709	750	
		88.4	13.0			18.0
+49.3	030800 LOG 14-37N, 178-19E			797	887	
		1423	11.3			18.0
+175. (Pearl Harbor)	071550 LOG 21-16N, 157-58W			2220		

Fallout Deposition

The calculation of the shipboard (H+1) r/hr dose rate contour distances along the hot line was accomplished after the location of the fallout intercept had been determined. Table 2 shows the H+1 hr (unit reference) dose rate values obtained from ref. 3 together with the calculated values of the H+1 dose rates extrapolated down range to the ship. Various functional forms were investigated for this extrapolation. A power law curve of the form $y=ax^b$ provided the closest fit over the reference 3 distance and was used to obtain the extrapolated unit reference value of 12.2 r/hr for the ship at its intercept location. Making the conservative assumption that fallout with an 18 knot downwind speed could persist for roughly 10 hours at a specific geographic location (ref. 6), deposition on the deck of PATAPSCO (12 knots) moving relative to fallout cloud at only 6 knots might persist for 30 hours or 360 additional nautical miles wnwind. For the purposes of the conservative dose calculations presented here the maximum unit-reference dose rate of 12.2 r/hr at the initial intercept point will be used with the all-down time of 021520 or H + 32.5 hours.

Table 2 Unit Reference (H+1) Dose Rate Contour Curve Fitting and Extrapolation

Dose Rate Contour (y)	Reference 3 Distance (x)	Calculated * Distance (x)
3000	94.8	91
2000	107.0	105
1000	127.0	132
500	160.1	167
100	296.7	288
50	-	364
35	-	411
12.2	-	586
10	-	627
1	-	1365

* $y = (1.92 \times 10^9)x^{-2.96}$ with coefficient of determination, $r^2 = .99$

D. Pearl Harbor Radiological Survey

After arrival at Pearl Harbor Naval Shipyard at 071550 (H+175), the Atomic Defense Officer discovered radiation levels as high as 40 mr/hr (ref. 7) and the crew was "evacuated to the receiving station" (100200) except for special details. Subsequent radiological survey (appendix A) revealed the following general gamma backgrounds adopted here to a reference time of 120900 March, (H + 288 hrs).

- Weather decks $R_{288} \leq 5$ mr/hr
- Ship interior $R_{288} \leq 1$ mr/hr

While appendix A lists specific items scattered throughout the ship which exceeded these levels, the average dose rates were probably below these levels. Converting these dose rates to H+1 unit reference rates (R_1) gives;

$$R_1 \text{ (Deck)} = 4.5 \text{ r/hr}$$

$$R_1 \text{ (Interior)} = 0.9 \text{ r/hr.}$$

E. Variation of Dose Rate With Time

Two primary factors can change the dose rate at a given location. First, radioactive decay which will be estimated by use of equation (2) for each of the times of interest (see Table 5 below) and; second accumulation or depletion of activity by physical processes. Of specific interest here is the effect of the weather in removing some of the fallout which is assumed to have been deposited on PATAPSCO at H+32.5 hours. Table 3 extracted from the PATAPSCO deck log summarizes appropriate wind and rain periods during the return trip to Pearl Harbor.

Table 3 PATAPSCO Deck Log Weather Summary
(Numbers in parenthesis are reference time zones)

Fallout Deposition Initiation 031530 (-12)
2 Mar (-12) No rain; winds 11-22 knots.
3 Mar (-12) Slight imtermittant rain (2100-2300); wind 10-12 knots.
3 Mar (+12) No rain; winds less than 20 knots.
4 Mar (+11)Moderate thunderstorms (2000-2300); winds 12-24 knots.
5 Mar (+11)Moderate thundershowers (0800-1000); winds 22-35 knots.
6 Mar (+11)No rain; winds 17-28 knots.
Arrive Pearl Harbor Naval Shipyard 071550 (+10).

During these intervals of rain and relatively high winds some portion of the fallout was undoubtly removed, the question is how much? At Operation CASTLE it was observed that moderate rain reduced ship (YAG) deck contamination to approximately 50% (ref. 8). Applying this 50% reduction to the PATAPSCO R_1 (deposition) value of 12.2 r/hr gives a post storm R_1 (deck) value of 6.1 r/hr which is in remarkable agreement with the R_1 (deck) value of 4.5 r/hr estimated from the radiological survey when the ship reached Pearl Harbor. While this decrease continues as long as the rain persists, the first rain removes the most actively and an effective time of decrease in the estimated weather deck dose rate from the 12.2 to 6.1 r/hr at 042100 (+11) or H + 109 will be assumed here.

Another important factor is the departure of the ships decks from idealized deposition surfaces. For a person moving about, these departures inject variable shielding which can considerably reduce the effective dose rate. It is also possible for a person to consistently occupy positions which increase his effective dose rate. For these reasons, combined with the difficulty and uncertainty in computation, no attempt will be made here to compensate for complex exposure geometries.

Within the interior of the ship, dose rates can also vary appreciably. This gamma field can result from deck deposition altered by complex shielding and variable distances to multiple surfaces, or more directly from activity tracked inside the ship. While the deck deposition component is reduced by weather, the interior contribution is constantly increasing as activity is tracked in and spread throughout the ship. Shielding factors from exterior contamination are reported to vary between 0.0001 and 0.2 for various ships and locations within the ship (ref. 9). A 10% transmittance giving an R_1 = 1.2 r/hr (interior) is a high (max dose) estimate which will be assumed for the interior gamma field between fallout deposition (H + 32.5) and partial fallout reduction at storm arrival (H + 109). After this time the R_1 = 0.9 r/hr value determined from the Pearl Harbor (survey) measurement is thought the best characterization of the interior gamma field for the remainder of the time interval.

Figure 3 show the estimated variation of dose rate with time as it relates to input data for four hypothetical cases for which total accumulated doses will be presented in the next section. These include an estimated "maximum" case which assumes no reductions in the gamma field after fallout deposition; two more realistic cases where minimal reductions have been applied to both the deck (A) and ship interior (B) gamma fields; and a "best estimate" for a hypothetical individual who spends eight hours per day outside on the weather decks (C). This later case (C) is a simple combination of cases (A) and (B). The unit references dose rates (R_1) applicable to these cases are summarized in Table 4.

Table 4 Unit Reference Dose Rates r/hr for Dose Calculations

	Weather Dose	Ship Interior	Hypothetical Crewman
. to Storm	12.2	1.2	4.8
After Storm	6.1	0.9	2.6

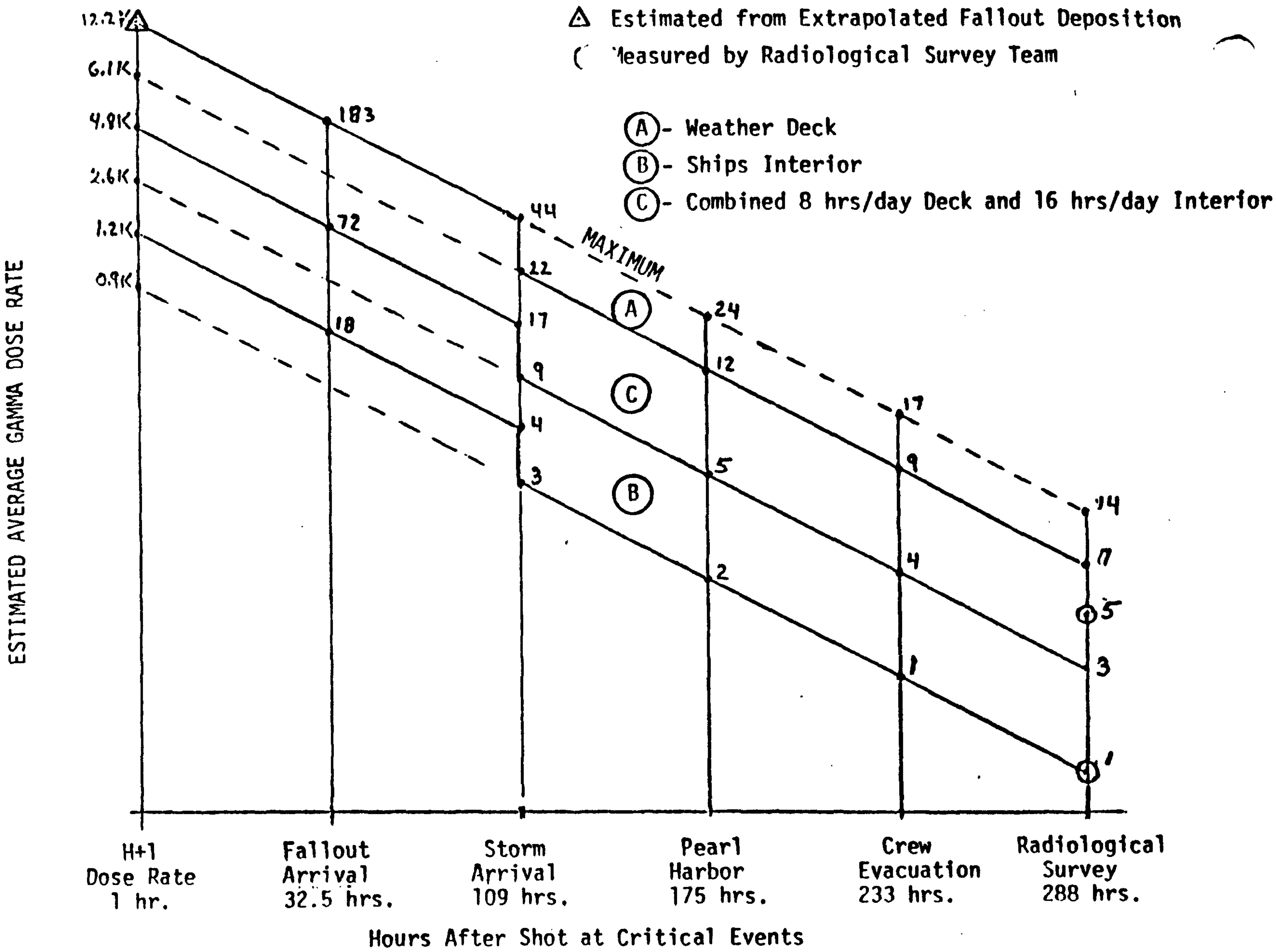

Figure 3 Conceptual Dose Rate (mr/hr) vs Time for Cumulative Dose Calculations (not drawn to scale).

F. Gamma Dose Estimates

The gamma dose for each interval of the cases specified above is calculated from equation (4)

$$(4)\quad D = R_1 \times \int_{t_1}^{t_2} t^{-1.2}dt = R_1 \times I$$

by multiplication of the approximate unit reference dose rate (R_1) from Table 4 by the time integral (I) from Table 5.

Table 5 Time Parameters of Interest for Dose Calculation

Event	Time (t)	$t^{-1.2}$	$I = \int_{t_1}^{t_2} t^{-1.2}dt$
Shipboard Deposition	H + 32.5	.0153	
			0.54
Thundershowers	+109	.0036	
			0.18
Pearl Harbor Arrival	+175	.0020	
			0.10
Crew Evacuation	+233	.0014	
			0.07
Radiological Survey	+288	.0011	

The total cumulative dose for each case is then computed by summing of appropriate intervals covering the desired time period. For the time interval of interest here, from fallout depostion on PATAPSCO on 2 March (H+32.5) to crew evacuation at Pearl Harbor on 10 March (H+233), the total cumulative doses estimated for each case are shown below.

° Maximum — Estimated from extrapolation fallout deposition for a crewman on deck 24 hours a day with 100% retention of all radioactivity on deck.

Time Interval	R_1 x I = D
Deposition to Storm	12.2 x .54 = 6.6 r
Storm to Pearl Harbor Arr.	12.2 x .18 = 2.2
Pearl Harbor Arr. to Crew Evacuation	12.2 x .10 = 1.2
	10.0 r

° (A) Deck Dose w/weather — Estimated from extrapolated fallout deposition for a crewman on deck 24 hours a day with 50% removal of activity by weather enroute.

Time Interval	R_1 x I = D
Deposition to Storm	12.2 x .54 = 6.6 r
Storm to Pearl Harbor Arr.	6.1 x .18 = 1.1
Pearl Harbor Arr. to Crew Evacuation	6.1 x .10 = .6
	8.3 r

° (B) Below Deck Dose — Estimated for external fallout plus internal ship contamination for a crewman spending 24 hours per day inside the ship structure.

Time Interval	R_1 x I = D
Deposition to Storm	1.2 x .54 = 0.65 r
Storm to Pearl Harbor Arr.	.9 x .18 = .016
Pearl Harbor Arr. to Crew Evacuation	.9 x .10 = 0.09
	0.90 r

° (C) Best Estimate — Estimated for a crewman who spends 8 hours per day on deck and 16 hours per day inside using conservative storm decontamination estimates.

Time Interval	R_1 x I = D
Deposition to Storm	4.8 x .54 = 2.59 r
Storm to Pearl Harbor Arr.	2.6 x .18 = 0.47
Pearl Harbor Arr. to Crew Evacuation	2.6 x .10 = 0.26
	3.3 r

Summary and Conclusions

The range of dose estimates presented here for a "typical PATAPSCO crewman" vary between 0.9 to 10r depending on the exposure conditions. Our conservative "best estimate", that we believe is on the high side because of the nature of the worst case analysis used here, is 3.3r. This dose was accumulated between the estimated start of fallout deposition aboard ship at 011520 March and crew evacuation at 100200 March at Pearl Harbor.

So many assumptions were made in this analysis that confidence limits cannot be assigned to the values presented. All that can be done is to list those assumptions most crucial to the above estimates.

1. The fallout "hot line" coincides with the ship's track during the period of interest.

2. Extrapolation of a power curve fit to the H + 1 hr does rate contours provides an adequate description of fallout deposition.

3. The dose rate is adequately described by the $t^{-1.2}$ law.

4. The choice of an instantaneous storm decontamination time could significantly change the primary dose contribution.

In order for the fallout deposition to grossly exceed the estimated value something like a "catastrophic" high altitude rainout would have to have occurred. However "catastrophies" of this type are not predictable.

Action Suggested. It will be noticed that the subject of internal personnel doses was not discussed. It will also be noticed in the Appendix, that reference is made to a report covering the events leading to the ships contamination and possible dose to the crew. This report was to be prepared by then LCDR Royce K. Skow. Captain Skow (USN Ret*) was contacted and asked if the report was ever

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tten. He did not recall its preparation, but thought that since there must have been pressure to prepare it, it was probably done. A document search of the DDC reports authored by Skow was made, but no such title was found. This report, if published, would probably be worth the effort to find it, since all the details of the dose rate measurements and the contamination status of the crew would have been available to Skow. More importantly, this document might also describe any internal dose measurements that were made on the crew and thus provide the only source of information for determining internal radiation doses.

REFERENCES

1. Letter from Captain A. G. Nelson to Mr. Bob Hammond, NNTPR Ser 981TA/1238 of 28 Dec 1978.

2. Letter for Lt. James W. Downing (Ret) to Capt. A. G. Nelson, 14 Dec. 78, encl to ref 1 above.

3. Figure 149. Operation CASTLE - Shot 1 - BRAVO. Off-site dose rate contours in r/hr at H+1 hour (NRDL), encl to ref 1 above. See also Fallout Symposium, AFSWP, 895, Jan 55, pp.387-401, SECRET RD.

4. Pages extracted form the Deck Log of USS PATAPSCO dtd 27 Feb 54 to 23 April, encl to ref 1 above.

5. Fallout Computations and CASTLE-BRAVO A Case Study. (U) S. M. Greenfield and R. R. Rapp, USAF Proj. Rand Research Memorandum RM1855 16 Jan 1957, SECRET RD.

6. The Effects of Nuclear Weapons, 1977.

7. Memorandum report covering TAD at Pearl Harbor, 11 Mar to 10 Apr re: decontamination of the USS PATAPSCO AOG-1, H. N. Wellhouser to Scientific Director NRDL, 24 May 1954.

8. Operation CASTLE, Summary Report of Commander Task Unit 13, Military Effects Programs 1-9, 30 Jan 1959, WT934, SECRET RD.

9. Capabilities of Nuclear Weapons, OPNAVINST 03400.1C, DASA, 1 Jan 68, CONFIDENTIAL.