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ANALYSIS OF RADIATION EXPOSURE FOR PERSONNEL ON THE RESIDENCE ISLANDS OF ENEWETAK ATOLL AFTER OPERATION GREENHOUSE, 1951 - 1952

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The radiological environments are reconstructed for the residence islands of Enewetak Atoll following the roll-up phase of Operation GREENHOUSE in May 1951. The residence islands received fallout during Operation GREENHOUSE (April/May 1951) as a result of Shots DOG, EASY, and ITEM. From the reconstructed radiological environments and assumed personnel activity scenarios, equivalent personnel film badge doses are calculated, by month, from June 1951 to June 1952. For an individual assigned to Enewetak Atoll during this period, a mean dose of 1.5-2.0 rem would have been accrued, depending on the residence island to which he was assigned. Keywords:

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SUMMARY

During the operational phase of Operation GREENHOUSE (April-May 1951), the residence islands of Enewetak Atoll received varying amounts of radioactive fallout following Shots DOG, EASY, and ITEM; fallout from Shot GEORGE did not affect the residence islands. The post-GREENHOUSE radiological environments are reconstructed for each of the three residence islands: Enewetak, Parry, and Japtan. Mean doses, with uncertainties, for personnel assigned to these islands between June 1951 and June 1952 are calculated. Dose accrual during this time period is calculated to be approximately 2.0 rem, 1.8 rem, and 1.5 rem, if assigned to Enewetak, Parry, or Japtan Islands, respectively. The dose calculations assume that an individual spends approximately 14½ hours of each day outside the permanent structures used for working, messing, and sleeping. While inside, it is assumed that the individual is exposed to one-half of the free-field intensity outside the structure. Adjustment factors are provided that allow the mean dose to be adjusted to account for more (or less) time spent outside than assumed in this analysis.

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INTRODUCTION

Following the roll-up phase of Operation GREENHOUSE during late May and early June of 1951, the only personnel remaining on Enewetak Atoll were a small military garrison and H&N (AEC contractor) personnel. Radiation doses were previously calculated for DoD personnel assigned to the residence islands of Enewetak during the operational phase of Operation GREENHOUSE in April and May of 1951 (Reference 1). The purpose of this report is to provide an addendum to Reference 1 in which dose estimates are extended to include the military personnel who remained on Enewetak Atoll subsequent to the roll-up phase of Operation GREENHOUSE.

1.1 BACKGROUND

Operation GREENHOUSE was a series of four atmospheric nuclear tests performed by the United States in April and May of 1951 at Enewetak Atoll in the Pacific Proving Grounds (PPG). By the direction of the Joint Chiefs of Staff, Joint Task Force Three (JTF 3) was formed to conduct these nuclear tests. The tests were code named Shots DOG, EASY, GEORGE, and ITEM; specific shot data are tabulated in Table 1 and their locations on Enewetak Atoll are depicted in Figure 1. Of the four nuclear tests, Shots DOG and ITEM resulted in significant fallout on the residence islands (Enewetak, Parry, and Japtan Islands) of Enewetak Atoll. Fallout from Shot EASY was a minor contributor to the total exposure of the task force personnel, and no fallout occurred on the residence islands as a result of Shot GEORGE.

Table 1. Operation GREENHOUSE shot data.

	DOG	EASY	GEORGE	ITEM
DATE	8 April 1951	21 April 1951	9 May 1951	25 May 1951
TIME (Local)*	0634	0627	0930	0617
HEIGHT OF BURST	300 ft.	300 ft.	200 ft.	200 ft.
TYPE	TOWER	TOWER	TOWER	TOWER
YIELD	**	47 KT	**	**

*Local time was 12 hours behind GMT. Source: Reference 1

**Yield is classified.

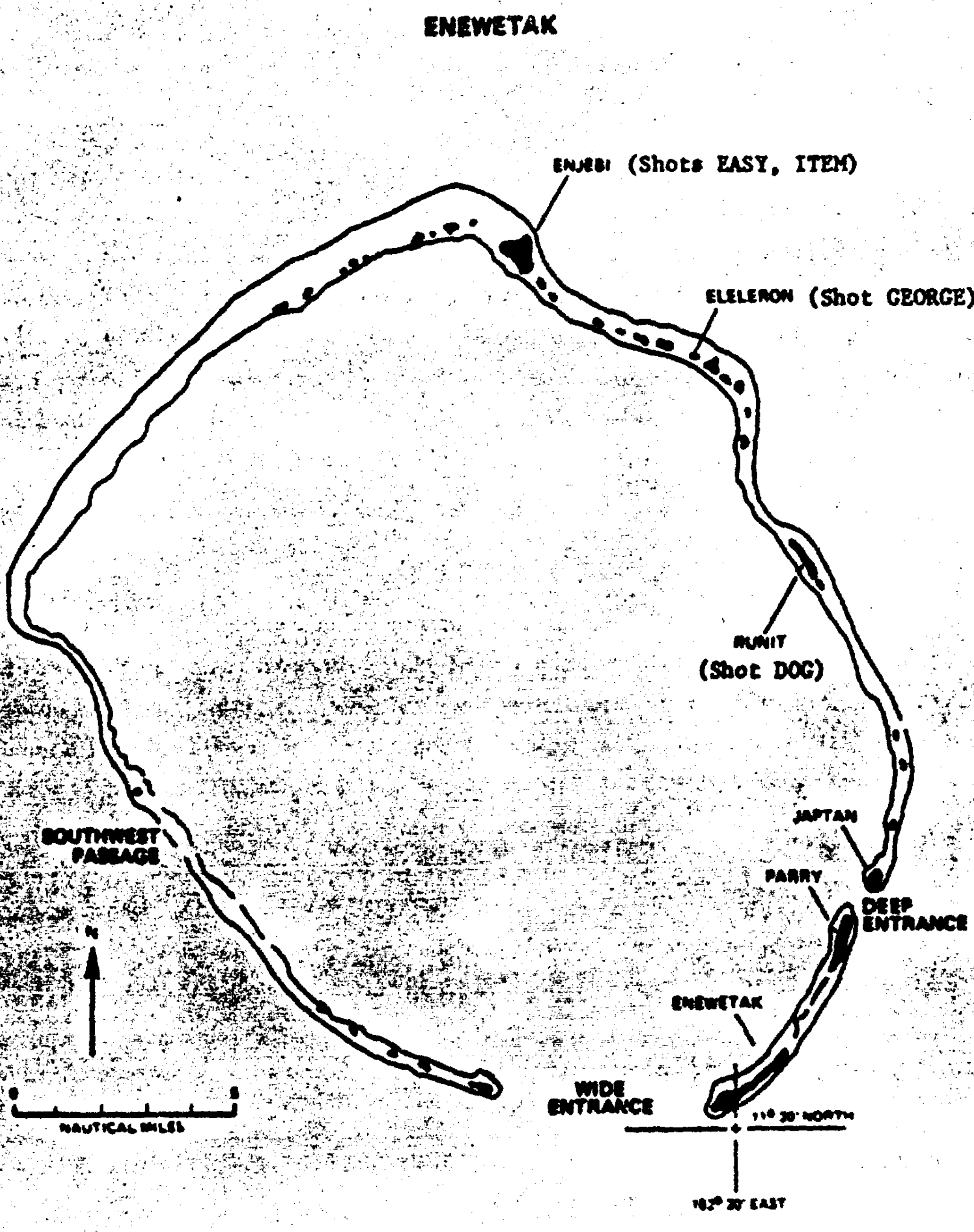

Figure 1. Enewetak Atoll, Operation GREENHOUSE shot locations.

Doses for personnel assigned to Enewetak Atoll were previously calculated through the end of May 1951, when the roll-up phase was virtually complete and most JTF 3 personnel had departed the PPG. At the time Reference 1 was published, the roll-up phase appeared to be the logical point at which to terminate the Operation GREENHOUSE dose calculations. In addition to the fact that most personnel had departed the atoll by the end of May, statements from several sources indicated that heavy rains set in (on Enewetak Atoll) at the end of May and early June 1951, which reduced the fallout dose rate from Shot ITEM (the last shot) to background values (References 2, 3). This information was used to justify terminating all dose calculations as of 31 May 1951. A subsequent detailed analysis of the hourly weather observations obtained on Enewetak Island during the period of interest (Reference 4a) and a number of interviews with radiation safety personnel at Greenhouse (Reference 4b) revealed that the statements in References 2 and 3 were unsubstantiated, and that there was a potential for additional radiation exposure to personnel remaining on the islands after the roll-up phase. Therefore, all assertions in Reference 1 concerning the heavy rains that set in at the end of May and early June, which allegedly reduced intensity levels on the residence islands to background, should be disregarded.

1.2 POST-GREENHOUSE MANNING ON ENEWETAK

By 20 June 1951, approximately 330 military personnel remained on Enewetak Atoll in a caretaker status. Comprised of personnel from all three services, with Army personnel in the majority, the garrison retained the designation of Task Group 3.2, the Army task group during Operation GREENHOUSE (Reference 5). The Air Force contingent, comprising approximately 80 personnel, remained on Enewetak to operate the airfield, while approximately 20 Navy personnel operated the boat pool. During the period following Operation GREENHOUSE, most work accomplished by the Army contingent (the 7126th Army Unit) was done on Enewetak Island; however, every 4 days or so, military police from this unit conducted ground security sweeps of the islands on the atoll. The boat pool was used extensively to support these security patrols (Reference 5). The Air Force unit (the 4931st Test Support Squadron) provided air transportation within Enewetak Atoll with six L-13 aircraft. Most of the air traffic was generated by H&N personnel to support their construction activities (for the upcoming Operation IVY) on the northern islands of the atoll.

During the early summer of 1951, when it became clear that Operation IVY would be conducted in the fall of 1952, JTF 132 was activated to replace the JTF 3 organization that had supported Operation GREENHOUSE. On 1 August 1951, TG 3.2 was deactivated and reactivated as TG 132.2 with the Air Force and Navy contingents on Enewetak remaining under the operational control of CTG 132.2 (Reference 5). The strength of TG 132.2 remained relatively constant until the spring of 1952, when preparations for Operation IVY began in earnest. Table 2 gives the personnel strength of TG 132.2 on Enewetak during the post-GREENHOUSE, pre-IVY period.

1.3 METHODOLOGY

The reconstructed free-field radiation environments presented in Reference 1 for each of the residence islands of Enewetak Atoll are time integrated, by month and by shot, from 1 June 1951 through 30 June 1952, by which time natural radioactive decay had reduced the free-field exposures to approximately 1 mR per day (essentially background levels). Because no radiological survey data are available for the residence islands following the last survey on 28 May 1951, radioactive decay after 31 May is assumed to be proportional to $t^{-1.2}$ for approximately 6 months after each shot, and proportional to $t^{-2.2}$ thereafter, as suggested in Reference 6. These decay rates do not consider weathering, which has a tendency to accelerate the natural decay process. Monthly contributions to the integrated free-field intensity from each shot resulting in fallout (Shots DOG, EASY, and ITEM) are summed for each of the residence islands and are presented in Section 2 of this addendum report.

In Section 3, the monthly integrated intensities are adjusted to account for shielding provided by structures on the islands utilized for working, messing, and sleeping. The adjusted free-field exposures are then converted to an equivalent film badge dose using the conversion factor 0.7 rem/R as derived in Reference 7. Calculated doses are tabulated, by month, for each of the residence islands. The calculated doses represent exposures for activities performed only on the residence islands; if an individual's activities required him to enter areas of higher contamination, such as the northern islands of the atoll, a film badge would have been issued to document this additional exposure. An uncertainty analysis is also provided in Section 3, with doses summarized, by month, in Table 6.

Table 2. Monthly personnel totals for Task Group 132.2.

Date	Army	Air Force	Navy	Total
1 Sep 51	263	79	19	361
1 Oct 51	267	75	19	361
1 Nov 51	234	79	26	339
1 Dec 51	219	80	41	340
1 Jan 52	264	95	40	399
1 Feb 52	295	130	23	448
1 Mar 52	273	87	26	386
1 Apr 52	548	81	27	656
1 May 52	536	128	28	692
1 Jun 52	716	149	28	893
1 Jul 52	812	168	27	1,007
1 Aug 52	1,076	223	24	1,323
1 Sep 52	1,119	216	27	1,362
1 Oct 52	1,114	225	25	1,364
1 Nov 52	1,114	336	25	1,475

Source: Reference 5

SECTION 2
RESIDENCE ISLAND RADIATION ENVIRONMENTS

This section describes the post-GREENHOUSE radiation environment on the residence islands of Enewetak Atoll. In Reference 1, island radiation environments were reconstructed based on numerous survey readings obtained during the operational phase of GREENHOUSE. Radiological decay rates used in dose reconstructions for the operational phase were generally dictated by actual surveys and were approximately proportional to $t^{-1.1}$. It was assumed that these measured rates persisted from after the last survey through 31 May 1951, when the calculations were terminated. For the post-operational analysis, however, radiological survey data are not available and possible variations in the late-time (after 31 May) decay rates must be considered.

Table 3 gives the reconstructed intensity (from Reference 1) on each of the residence islands on 31 May 1951, resulting from fallout from Shots DOG, EASY and ITEM. Also given in the table is the number of hours after each shot that corresponds to the intensity at 2400 hours, 31 May. These times and intensities are used as the starting point for reconstructing the post-operational radiological environments on the islands.

Table 3. Reconstructed island intensities on 31 May 1951.

	Intensity (mR/hr) on			Hours after Shot
Shot	Enewetak	Parry	Japtan	(2400, 31 May 1951)
DOG	0.08	0.11	0.11	1290
EASY	0.02	0.02	0.02	978
ITEM	7.8	6.6	5.3	162
TOTAL	7.9	6.7	5.4	

The post-GREENHOUSE radiological environment on each of the islands is approximated using late-time decay rates suggested in Reference 6. For the first six months after each shot, radiological decay is proportional to $t^{-1.2}$; thereafter, an accelerated rate proportional to $t^{-2.2}$ is considered appropriate. The intensities, depicted in Figure 2, are extended out to 1 Nov 1952, when Shot MIKE of Operation IVY was detonated on Enewetak Atoll. It is evident that even when "weathering" is neglected, natural radioactive decay alone reduces the intensities to background levels (0.04 mR/hr or less) by May or June of 1952.

Each of the intensity curves in Figure 2 represents the total island intensity as a function of time, and is actually the sum of the intensity contributions from Shots DOG, EASY, and ITEM. Integrated intensities, by month, are calculated by time-integrating the incremental contribution from each shot on each island and then summing. Monthly contributions to the total integrated intensity on each of the three islands, through June 1952, are presented in Table 4.

Table 4. Integrated free-field intensity (mR) on the residence islands of Enewetak Atoll.

	Integrated Intensity on		
Month-Year	Enewetak	Parry	Japtan
June 1951	1868	1595	1308
July	552	480	398
August	314	275	229
September	209	184	154
October	163	144	121
November	125	111	93
December	106	93	78
January 1952	83	73	61
February	58	51	43
March	51	45	38
April	40	35	30
May	34	30	25
June 1952	28	24	20

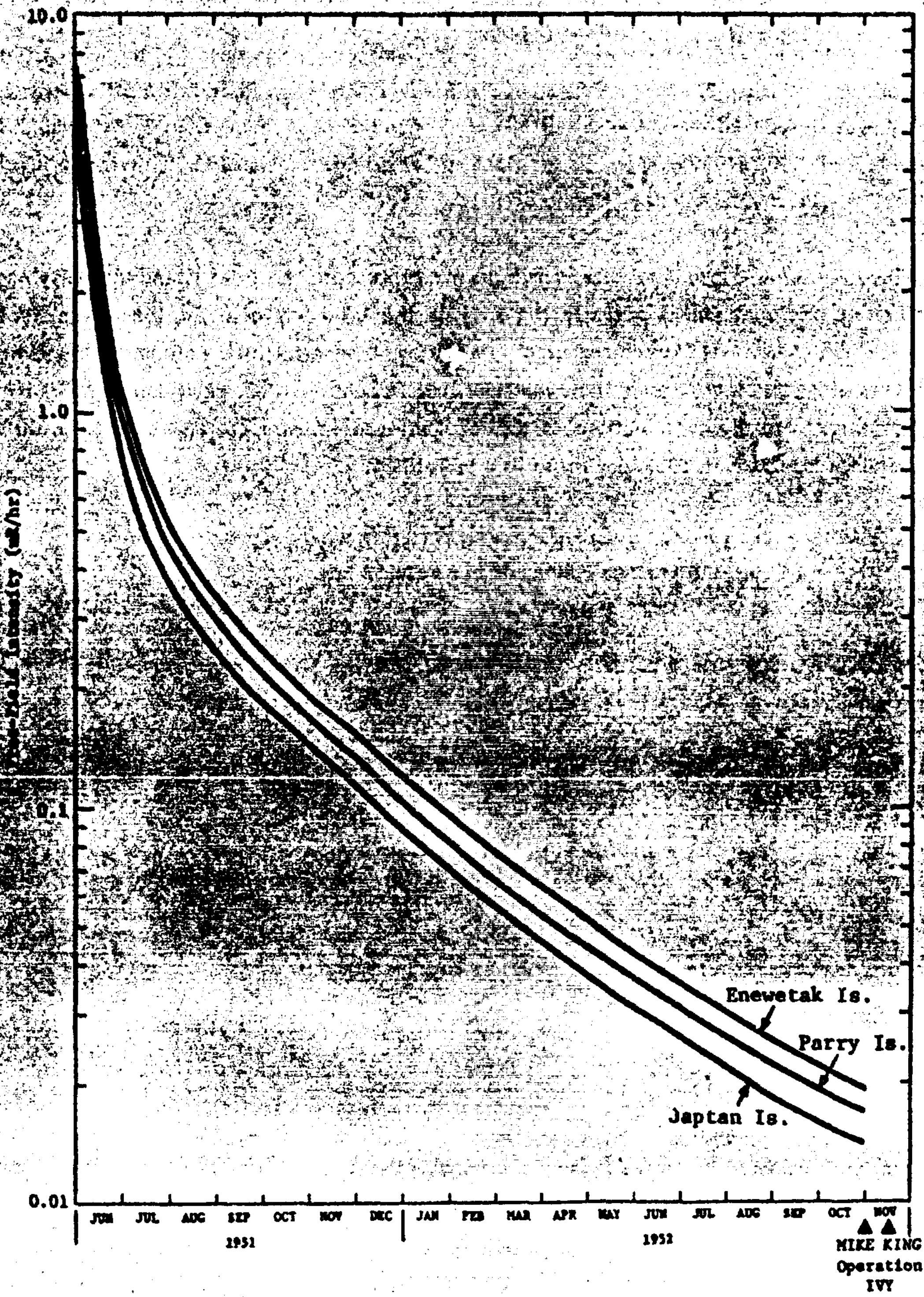

Figure 2. Post-GREENHOUSE radiation environments on the residence islands of Enewetak Atoll.

SECTION 3
DOSE CALCULATIONS

To determine the dose to personnel, consideration must be given to the time spent outside and inside and the radiation protection afforded by a building while inside. The monthly integrated free-field intensities from Section 2 are adjusted to account for personnel activities. The adjusted exposures (R) are then multiplied by a film badge conversion factor (rem/R) to determine a film badge dose (rem). Uncertainties in the calculated doses due to varying late-time decay rates (after the last radiological survey on the islands) are also considered. Results are presented as a cumulative film badge dose on each of the residence islands through 30 June 1952, when island intensities were essentially down to background levels.

3.1 PERSONNEL ACTIVITIES

An estimate of personnel activities must be considered in estimating an individual's dose while assigned to Enewetak. While detailed personnel activities are not known, it is assumed that individuals assigned to the residence islands spent at least a portion of each day inside the permanent structures on the islands for working, messing, and sleeping. While inside buildings, some protection was provided by the structure against the free-field radiation environment. Typically, a protection factor of two (PF=2) has been measured for the permanent structures such as those erected on tropical atolls. This protection factor is largely geometrical; that is, the structure offers little or no mass attenuation, but does provide for some stand-off from contamination on the island soil.

In the dose calculations that follow, a time-averaged shielding factor is used to account for time spent inside/outside buildings and shielding provided by the structure while inside. The time-averaged shielding factor used in this analysis is 0.8, derived by assuming that personnel spent 60 percent of the day outside and 40 percent inside. While inside, personnel are afforded a protection factor of 2, i.e., a shielding factor of 0.5. Thus, the time-averaged shielding factor is computed as:

$$(0.6)(1) + (0.4)(0.5) = 0.8$$

The monthly integrated intensities in Section 2 are multiplied by 0.8 to account for times spent inside and outside of the permanent structures on Enewetak. The adjusted exposures are then converted to an equivalent film badge dose using the conversion factor 0.7 rem/R as derived in Reference 7.

In order to provide some flexibility in dose assignments for personnel whose documented activities required them to be inside or outside for greater periods of time than assumed in this analysis, Table 5 provides factors that can be used to adjust the calculated mean doses to account for actual exposure conditions, if known. The table assumes a protection factor of 2 while inside. For example, if it is known that an individual spent an average of 12 hours per day outside (rather than the assumed 60 percent or 14.4 hours), his calculated dose should be adjusted by a factor of 0.94.

Table 5. Adjustment factors for documented exposure conditions.

Number of Hours Outside	6	9	12	14.4	18
Multiply Mean Dose by	0.78	0.86	0.94	1.0	1.09

3.2 UNCERTAINTIES AND TOTAL DOSE DETERMINATION

For personnel remaining on residence islands after the conclusion of Operation GREENHOUSE, the uncertainties in dose are largely of different origin than during the operation. Because post-operational radiation intensity information is unavailable, the decay rate of the island fallout is assumed to be according to $t^{-1.2}$, the common power law relationship with time generally held to be most representative of fission product decay (up to 6 months, when $t^{-2.2}$ better applies). For extended durations of exposure, the potential uncertainty in dose from uncertainty in the decay exponent is appreciable. Early decay data after Shot ITEM suggest exponents of about -1.0 and -1.1. While -1.0 is taken as leading to an upper limit in dose, it is likely that an early deviation from $t^{-1.2}$ in this direction was compensated by a faster decay after May 1951. Given the additional tendency for fallout to partially leach into the ground surface, resulting in lesser measured gamma intensities, decay corresponding to $t^{-1.4}$ is considered as leading to a lower limit on dose. A similar uncertainty of $\pm$ 0.2 in the decay exponent after six months is also used. These uncertainties are taken to apply systematically throughout the post-operational phase.

For personnel who remained on the residence islands at least several months (the typical situation), the uncertainty in decay rate dominates the uncertainty in post-operational dose. Differences in duty would have affected the dose through the time spent indoors and the degree of radiation protection afforded by the buildings. The indoor protection factor of 2 used in the dose determination is fairly representative of residence quarters as well as work buildings (Reference 2); indoor protection was afforded more by the geometrical displacement from the ground source of fallout than by building mass.

Two treatments are available for the fraction of time spent outdoors. This fraction may be considered not as an uncertainty, but rather as a free variable. Accordingly, cumulative mean film badge doses are presented, by month, from June 1951 to June 1952, in Table 6. Upper and lower bounds are reported at the 90-percent level, i.e., 5th to 95th percentile, by considering uncertainties in late-time decay rates as described above. The nominal value of outdoor fraction (more than 14 hours) likely tends toward the high side in dose, but adjustment factors for other partitions of the daily exposure are presented in Table 5. Thus, the variations in dose resulting from non-standard duties can be accommodated. If, instead, the outdoor time fraction is considered as an uncertainty, it applies to both the operational and post-operational doses. The extremes of outside hours per day in Table 5 are taken to represent the 90-percent confidence limits.

The mean doses may be added to the operational doses of 2.93 rem on Enewetak Island, 3.10 rem on Parry Island, and 2.57 rem on Japtan Island (Reference 1). The combination of the predicted dose distributions of Reference 1 with the uncertainties herein does not lead to uncertainty in total mean dose; it is to be avoided on a collective basis. However, the specific circumstances of an individual's exposure can permit uncertainties to be combined as in Table 7. It should be noted that the simple addition of the upper bounds would result in a total dose far above the 95th percentile.

Table 6. Calculated film badge doses (rem) for the residence islands of Enewetak Atoll (June 1951 - June 1952)

For Continuous Exposure from 1 Jun 51 thru:	Enewetak Island			Parry Island			Japtan Island		
	Lower Bound	Mean	Upper Bound	Lower Bound	Mean	Upper Bound	Lower Bound	Mean	Upper Bound
June 1951	0.90	1.05	1.22	0.77	0.89	1.04	0.63	0.73	0.85
July	1.11	1.36	1.67	0.95	1.16	1.43	0.78	0.96	1.18
August	1.22	1.53	1.95	1.05	1.32	1.68	0.86	1.08	1.38
September	1.29	1.65	2.15	1.11	1.42	1.85	0.91	1.17	1.53
October	1.34	1.74	2.31	1.15	1.50	2.00	0.95	1.24	1.65
November	1.38	1.81	2.44	1.19	1.56	2.11	0.98	1.29	1.74
December	1.41	1.87	2.55	1.21	1.61	2.21	1.00	1.33	1.83
January 1952	1.43	1.92	2.64	1.24	1.65	2.29	1.02	1.37	1.89
February	1.45	1.95	2.71	1.25	1.68	2.35	1.03	1.39	1.94
March	1.46	1.98	2.77	1.26	1.71	2.40	1.04	1.41	1.99
April	1.47	2.00	2.82	1.27	1.73	2.44	1.05	1.43	2.02
May	1.48	2.02	2.86	1.28	1.75	2.48	1.06	1.44	2.05
June	1.49	2.03	2.89	1.29	1.76	2.51	1.06	1.45	2.08

Table 7. Calculated film badge doses (rem) for the residence islands of Enewetak Atoll, April 1951 to June 1952.

a. For fraction of outdoor time = 0.6:

For Continuous Exposure from April 1951 through:	Enewetak Island	Parry Island	Japtan Island
June 1951	3.98 ± 0.61	3.99 + 0.59 - 0.58	3.30 ± 0.49
July	4.29 + 0.67 - 0.64	4.26 + 0.63 - 0.61	3.53 + 0.53 - 0.51
August	4.46 + 0.72 - 0.67	4.42 + 0.67 - 0.63	3.65 + 0.57 - 0.53
September	4.58 + 0.77 - 0.69	4.52 + 0.71 - 0.65	3.74 + 0.60 - 0.55
October	4.67 + 0.82 - 0.71	4.60 + 0.76 - 0.67	3.81 + 0.63 - 0.56
November	4.74 + 0.86 - 0.73	4.66 + 0.79 - 0.68	3.86 + 0.66 - 0.57
December	4.80 + 0.90 - 0.75	4.71 + 0.83 - 0.70	3.90 + 0.69 - 0.58
January 1952	4.85 + 0.93 - 0.77	4.75 + 0.86 - 0.70	3.94 + 0.71 - 0.59
February	4.88 + 0.96 - 0.77	4.78 + 0.88 - 0.71	3.96 + 0.73 - 0.60
March	4.91 + 0.99 - 0.79	4.81 + 0.89 - 0.73	3.98 + 0.75 - 0.61
April	4.93 + 1.01 - 0.79	4.83 + 0.91 - 0.73	4.00 + 0.76 - 0.61
May	4.95 + 1.03 - 0.80	4.85 + 0.93 - 0.74	4.01 + 0.78 - 0.61
June	4.96 + 1.04 - 0.80	4.86 + 0.94 - 0.74	4.02 + 0.79 - 0.62

Example: Derivation for Enewetak Island through June 1952, upper bound, is as follows. Upper uncertainty = 0.59 during operation (Reference 1); = 0.86 post-operation (Table 6). Upper uncertainty in total dose = $\sqrt{(0.59)^2 + (0.86)^2}$ = 1.04.

Table 7. Calculated film badge doses (rem) for the residence islands of Enewetak Atoll, April 1951 to June 1952 (concluded).

b. With fraction of outdoor time as an uncertainty:

For Continuous Exposure from April 1951 through:	Enewetak Island	Parry Island	Japtan Island
June 1951	$3.98^{+0.67}_{-0.82}$	$3.99^{+0.67}_{-0.88}$	$3.30^{+0.56}_{-0.73}$
July	$4.29^{+0.72}_{-0.90}$	$4.26^{+0.71}_{-0.91}$	$3.53^{+0.59}_{-0.76}$
August	$4.46^{+0.78}_{-0.93}$	$4.42^{+0.76}_{-0.93}$	$3.65^{+0.63}_{-0.77}$
September	$4.58^{+0.83}_{-0.95}$	$4.52^{+0.79}_{-0.95}$	$3.74^{+0.66}_{-0.79}$
October	$4.67^{+0.88}_{-0.97}$	$4.60^{+0.84}_{-0.97}$	$3.81^{+0.69}_{-0.80}$
November	$4.74^{+0.92}_{-0.99}$	$4.66^{+0.87}_{-0.98}$	$3.86^{+0.72}_{-0.81}$
December	$4.80^{+0.96}_{-1.01}$	$4.71^{+0.90}_{-0.99}$	$3.90^{+0.75}_{-0.82}$
January 1952	$4.85^{+0.99}_{-1.02}$	$4.75^{+0.93}_{-1.00}$	$3.94^{+0.77}_{-0.83}$
February	$4.88^{+1.02}_{-1.03}$	$4.78^{+0.95}_{-1.01}$	$3.96^{+0.79}_{-0.84}$
March	$4.91^{+1.04}_{-1.04}$	$4.81^{+0.97}_{-1.02}$	$3.98^{+0.81}_{-0.84}$
April	$4.93^{+1.06}_{-1.05}$	$4.83^{+0.98}_{-1.02}$	$4.00^{+0.82}_{-0.85}$
May	$4.95^{+1.08}_{-1.05}$	$4.85^{+1.00}_{-1.03}$	$4.01^{+0.83}_{-0.85}$
June	$4.96^{+1.10}_{-1.06}$	$4.86^{+1.01}_{-1.03}$	$4.02^{+0.85}_{-0.86}$

Example: Derivation for Enewetak Island through June 1952, upper bound, is as follows. Determine upper bound error factors for each source of error. For outdoor fraction, it is 1.09 (Table 5); otherwise during operation, it is $(2.93 + 0.59)/2.93 = 1.20$ (Reference 1); for post-operational decay, it is $2.89/2.03 = 1.42$ (Table 6). Combined error factor during operation is antilog $\sqrt{(\log 1.09)^2 + (\log 1.20)^2} = 1.225$, leading to uncertainty in dose of $(2.93)(1.225)-2.93 = 0.66$; for post-operation, it is antilog $\sqrt{(\log 1.09)^2 + (\log 1.42)^2} = 1.435$, leading to $(2.03)(1.435)-2.03 = 0.88$. Upper uncertainty in total dose is $\sqrt{(0.66)^2 + (0.88)^2} = 1.10$.

SECTION 4
LIST OF REFERENCES

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3. "Information on GREENHOUSE," letter from Payne Harris, M.D. (JAYCOR), to Navy NTPR, 11 June 1981. **

4a. Surface Weather Observations, Pacific/Enewetak, 1 April-30 June 1951, provided by the National Climatic Data Center, Asheville, NC. **

4b. Phone Conversations and Correspondence from Paul Boren (Defense Nuclear Agency) to: MGEN James Cooney, USA Ret; COL Meredith Mowery, USA Ret; Dr. Payne Harris; and Mr. Jack Aeby: January-March 1985. ***

5. "Operation IVY-1952," DNA 6036F, Defense Nuclear Agency, 1 December 1982. AD/A152 190 */**.

6. "The Effects of Nuclear Weapons," Glasstone, S. and Dolan, P., DOD/DOE, 1977. ADA 087568 */**.

7. "Analysis of Radiation Exposure for Task Force WARRIOR, Shot Smoky," Exercise Desert Rock VII-VIII, Operation PLUMBBOB, DNA 4747F, Defense Nuclear Agency, May 1979. *(AD/A 070239)/**.

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