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ANALYSIS OF RADIATION EXPOSURE
SERVICE PERSONNEL ON RONGERIK ATOLL
OPERATION CASTLE, SHOT BRAVO

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External and internal doses are reconstructed for the 28 American servicemen stationed on Rongerik Atoll, Marshall Islands, who were exposed to fallout on 1-2 March 1954 from Shot Bravo of Operation CASTLE. External doses are determined from limited radiation survey and film badge information. Internal dose commitments are derived from urinalysis data. The magnitude of the calculated activity intake suggests the principal pathways.

Reconstructed film badge doses are approximately 40 rem, with adjustments from individual activity scenarios, as available. Internal dose commitments to the thyroid and large intestine (nearly all first-year dose) provide the only significant increments to the external dose. Total doses are approximately 230 rem to the thyroid, 115 rem to the lower large intestine, 85 rem to the upper large intestine, and about 40 to 50 rem to all other organs.

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SECTION 1
INTRODUCTION AND SUMMARY

During the period 1-2 March 1954, twenty-eight Army and Air Force personnel stationed at Rongerik Atoll in the Marshall Islands were exposed to radioactive fallout from Shot Bravo of Operation CASTLE. The purpose of this report is to determine the whole body gamma radiation dose received by these personnel prior to their evacuation from the atoll, plus their organ dose commitments from internal emitters.

The gamma radiation dose is reconstructed as follows. The radiological environment resulting from Shot Bravo fallout is determined from time-of-arrival data on Rongerik, modeled deposition, measured decay rates, and a later reading on Rongerik. Personnel activity scenarios are considered in conjunction with radiation shielding factors to arrive at film badge doses on an individual basis. Although film badge readings are available, they relate inadequately to personnel dose. Readings that reflect well-specified exposures indicate good agreement with corresponding calculated doses. A small, but systematic, difference indicates an adjustment to the calculated personnel doses, which are in the vicinity of 40 rem.

Organ-specific 50-year dose commitments resulting from the large-particle inhalation and ingestion of Bravo fallout radionuclides are calculated. Intake of iodine-131 is determined from the body metabolism of iodine that led to a measured activity of I-131 in a pooled urine sample taken 17 days after Bravo. The radionuclide inventory for the time of intake is normalized to the level of I-131 activity, thereby indicating the full intake of radioactivity. Large-particle dose conversion factors for each radionuclide are developed for calculation of internal dose commitments to each organ. The calculated thyroid dose is 190 rem, and intestinal dose is as great as 76 rem. Other organ doses do not add significantly to the external gamma dose.

SECTION 2
BACKGROUND AND AVAILABLE DATA

2.1 BACKGROUND

Shot Bravo was detonated on Bikini Atoll at 0645 hours (local time) on 1 March 1954. The total yield of the thermonuclear explosion was approximately 15-megatons TNT equivalent. The nuclear device was mounted on a barge in shallow water, about seven feet above the surface of a coral reef. The radioactive fallout from Shot Bravo contaminated an area extending from about 20 statute miles upwind to over 330 miles downwind and varying in width to over 60 miles. Included within the area of major contamination were Bikini Atoll and three downwind atolls: Ailinginae Atoll, Rongelap Atoll, and Rongerik Atoll (References 1, 2). Among these atolls, Marshallese were present on Ailinginae and Rongelap, and American servicemen only on Rongerik.

Twenty-eight servicemen (25 Air Force personnel and 3 Army personnel) operated a weather station on Rongerik Atoll, about 150 miles east of Bikini. At approximately 1407 hours (almost 7½ hours after the Bravo detonation) the deposition of fallout on Rongerik was detected by a low-level gamma radiation monitoring instrument and subsequently observed visually.

At 1500 hours, a message was sent to Joint Task Force (JTF) Headquarters on Enewetak Atoll (Reference 3) notifying them of the fallout on Rongerik. Approximately one-half hour later, a reply came back from Enewetak instructing the military personnel on Rongerik to put on long-sleeved shirts, trousers, hats, and GI shoes, and to remain inside as much as possible, consistent with their normal work routine. At about 2330 hours, another message was received directing all personnel to cease operations and move inside permanent buildings.

At 1245 hours on 2 March 1954, eight men, the first eight on the alphabetical detachment roster, were evacuated from Rongerik to Kwajalein Atoll by airplane; the remaining twenty men were evacuated by airplane at approximately 1800 hours (Reference 3).

Upon arrival at Kwajalein Atoll, the personnel evacuated from Rongerik were monitored for personal contamination and decontaminated. The decontamination program, consisting of repeated showers and radiation monitoring, continued from 2 March through 6 March. While at Kwajalein, the film badges that had originally been issued to the Rongerik detachment were collected and processed. In addition, urine samples, both pooled and individual, were collected and sent to laboratories in the United States for analysis. Late in April, the servicemen from Rongerik were transferred from Kwajalein to Tripler Army Hospital (Honolulu, Hawaii) for further observation and subsequent return to duty (References 3, 4).

2.2 AVAILABLE DATA AND ASSUMPTIONS

Just prior to the first evacuation on 2 March, a gamma intensity reading was obtained with an uncalibrated AN/PDR-39 radiation survey meter. Because the operating condition of the instrument was not known at the time of its use, this reading (2000 mR/hr @ H+28.5 hours--Reference 5) is used only to indicate the general magnitude of the fallout intensity at the time of the first evacuation. The first radiological survey with calibrated instruments on the atoll was conducted on 10 March 1954, nine days after the shot. At this time the rad-safe survey team encountered average radiation intensity readings of 280 mR/hr on the island where the military personnel had been stationed.

The only other radiation intensity data available from Rongerik were obtained on 1 March when a low-level gamma background monitoring instrument at the weather station began to register at 1407 hours and then went off scale (100 mR/hr) at 1437 (H+7.9 hr). The data from this instrument establish the time of arrival of the fallout.

After Shot Bravo, analyses of fallout samples were made to determine the decay of gamma intensity with time. Unfortunately, the only data complete enough to be utilized were from Bikini Atoll and may not be completely representative of the fallout decay on Rongerik Atoll. Radiation intensity readings obtained from the Bikini lagoon (How Island) indicated decay rates that varied considerably from the traditional $t^{-1.2}$ rule. Average values for the decay exponent, obtained with several gamma ionization time-intensity meters on Bikini (Reference 6), are as follows:

$3 \leq t < 10$ hrs $k = -1.19$

$10 \leq t < 48$ hrs $k = -0.815$

$48 \leq t < 480$ hrs $k = -1.50$

Figure 1 depicts this decay in comparison to $t^{-1.2}$ decay. A variable decay of this type is consistent with the presence of Np-239 ($t_{1/2}$=56 hr) and U-240 ($t_{1/2}$=14 hr), significant neutron-activation products of the U-238 in a thermonuclear device.

Because fallout decay rate data on Rongerik Atoll are not available, dose calculations for the military personnel on Rongerik are made using the measured decay rates on Bikini and the measured radiation intensity on Rongerik Atoll (280 mR/hr at D+9 days). In addition, the radiation environment during fallout deposition must be more explicitly defined. From the gamma background monitoring instrument on Rongerik, the time of arrival of measurable fallout from Bravo has been determined to be 1407 hours, or 7.4 hours after the shot. The radiation time-intensity recordings on Bikini indicated that, once fallout began, a period of 1-2 hours elapsed while fallout was occurring before the radiation levels reached a maximum and began to decay, even though fallout was still continuing (Reference 7). Other data were obtained aboard three Task Force 7.3 ships that were positioned at various distances downwind from the Bravo GZ. On one of these ships--the GYPSY--fallout commenced approximately 7 hours after detonation, about the time of arrival on Rongerik. The GYPSY data indicated that at least 4 hours of significant fallout occurred. The exact duration cannot be determined because ship washdown procedures were initiated while the intensity was still increasing. The data indicate, however, that at locations downwind from Bikini, the time to maximum intensity was somewhat longer than it was on Bikini. Based on these data, a five-hour period of significant fallout deposition is used to characterize the radiation environment on Rongerik. It is assumed that 90 percent of the fallout, by mass, was deposited during this interval.

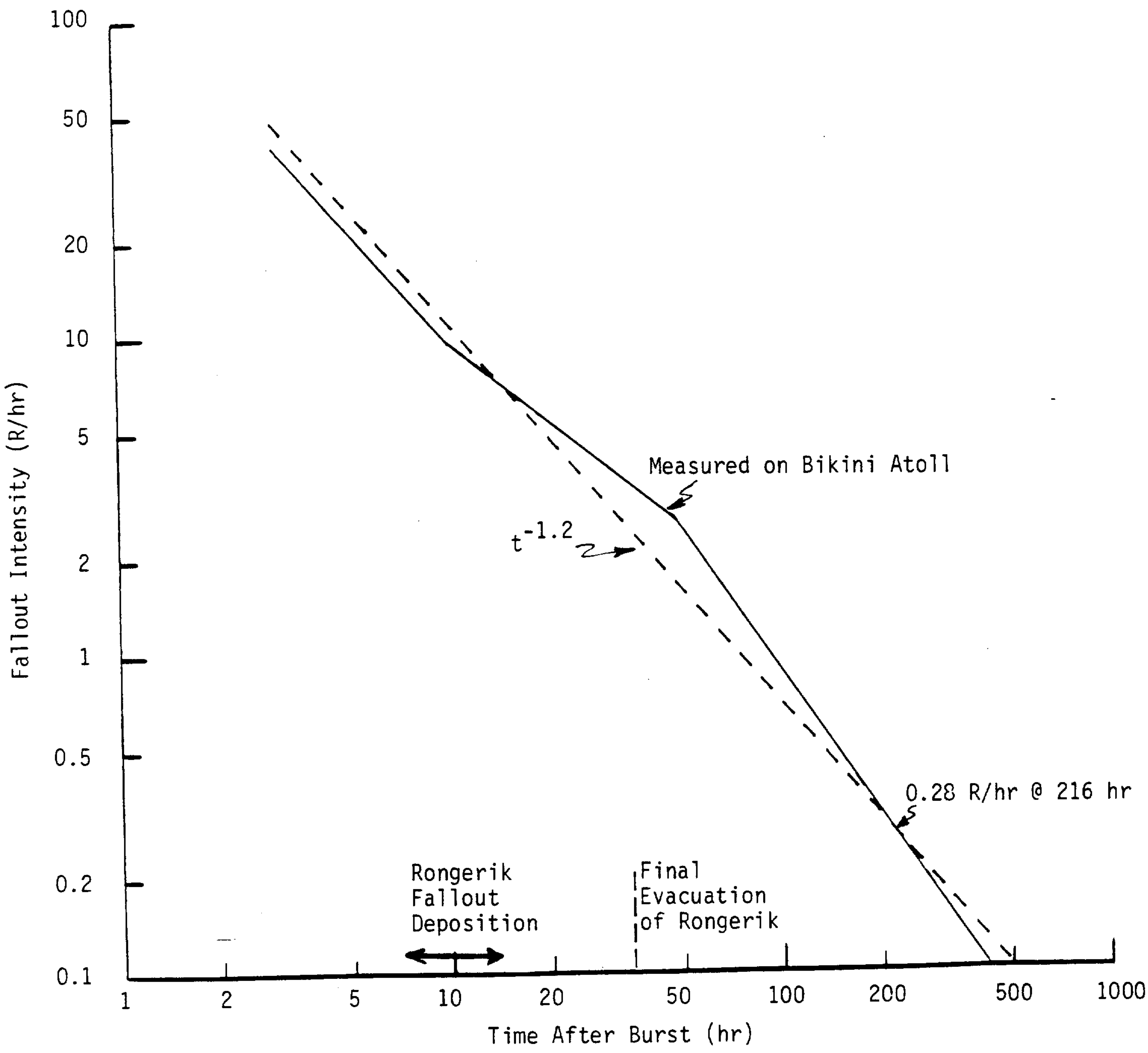

Figure 1. Fallout intensity versus time after burst (Shot Bravo) normalized to intensity reading on Rongerik.

SECTION 3
TECHNICAL APPROACH--EXTERNAL DOSE

3.1 DOSE CALCULATIONS

In order to calculate the radiation doses to personnel on Rongerik from the Shot Bravo fallout, the free-field radiation environment must be specified mathematically. Further, the calculated doses are dependent on any protection or shielding that was provided by buildings in which they stayed until they were evacuated.

(1) Free-Field Radiation on Rongerik

Based on the available data, the free-field radiation environment on Rongerik is estimated as follows:

For times greater than 48 hours after burst, the radiation decay followed a $t^{-1.5}$ decay rate. From the radiation intensity of .28 R/hr measured on Rongerik on 10 March (about 216 hours after burst), the intensity at 48 hours after burst (I_{48}) is:

$$I_{48} = I_{216}\,(216/48)^{1.5} = 2.67 \text{ R/hr}$$

Similarly, from I_{48} and the radiation decay according to $t^{-.815}$ between 10 and 48 hours after detonation, the intensity after cessation of fallout through the time of evacuation is:

$$I_t = I_{48}\,(48/t)^{.815} = 2.67\,(48/t)^{.815} = 62.7\ t^{-.815}$$

During fallout deposition, this decay applies to landed fallout particles (the change in decay exponent at 10 hours is too early in the deposition to noticeably affect the calculations). Thus, it is necessary to determine the fraction of time-normalized activity (or mass, for constant specific activity) deposited with time. This deposition is assumed to occur as a Gaussian (normal) distribution in time, reflecting a similar spatial (horizontal) distribution in the nuclear cloud. A correction is applied for lateral diffusion of the cloud. For an increase in cloud area in direct proportion to time, the concentration of fallout particles is inversely proportional to time. The rate of deposition with time (T) is of the form:

$$cT^{-1}e^{-a(T-b)^2}$$

Parameters a and b are chosen to match the meter reading of 100 mR/hr at 7.9 hours and for the central 90 percent of the deposition to occur in 5 hours. The normalization to total deposition is provided by c. Fallout accumulated through time t is represented by the time integral of the above expression. The choice of the lower limit of integration is not crucial; the observed time of fallout onset is satisfactory. The complete expression for intensity with time is then:

$$I_t = 62.7t^{-.815} \cdot 3.09 \int_{7.4}^{t} T^{-1}e^{-.23(T-11.6)^2}dT$$

Figure 2 depicts this relationship, which serves as the basis for the dose calculations. The peak intensity of 7 R/hr occurs at the end of the estimated interval of significant fallout (9 to 14 hours).

(2) Personnel Activities on Rongerik Atoll, 1-2 March 1954

After being evacuated to Kwajalein, each person who was on Rongerik was interviewed to determine his specific activities during the period 1 March until evacuation on 2 March. Other pertinent data concerning their exposure conditions were also obtained such as clothing worn, food and drink consumed, and their recollection of what the fallout resembled. A synopsis of all of these interviews (Reference 3) is used in reconstructing the radiation exposure estimates in this memorandum. Seventeen of the interviews were in sufficient detail that the individuals' activities during the exposure period could be fairly well established on an hour-to-hour basis. For intervals without specified activities, reasonable assumptions are made that high-side the calculated radiation doses. The Appendix contains an example of the information available and the procedure employed in order to reconstruct the dose for one individual.

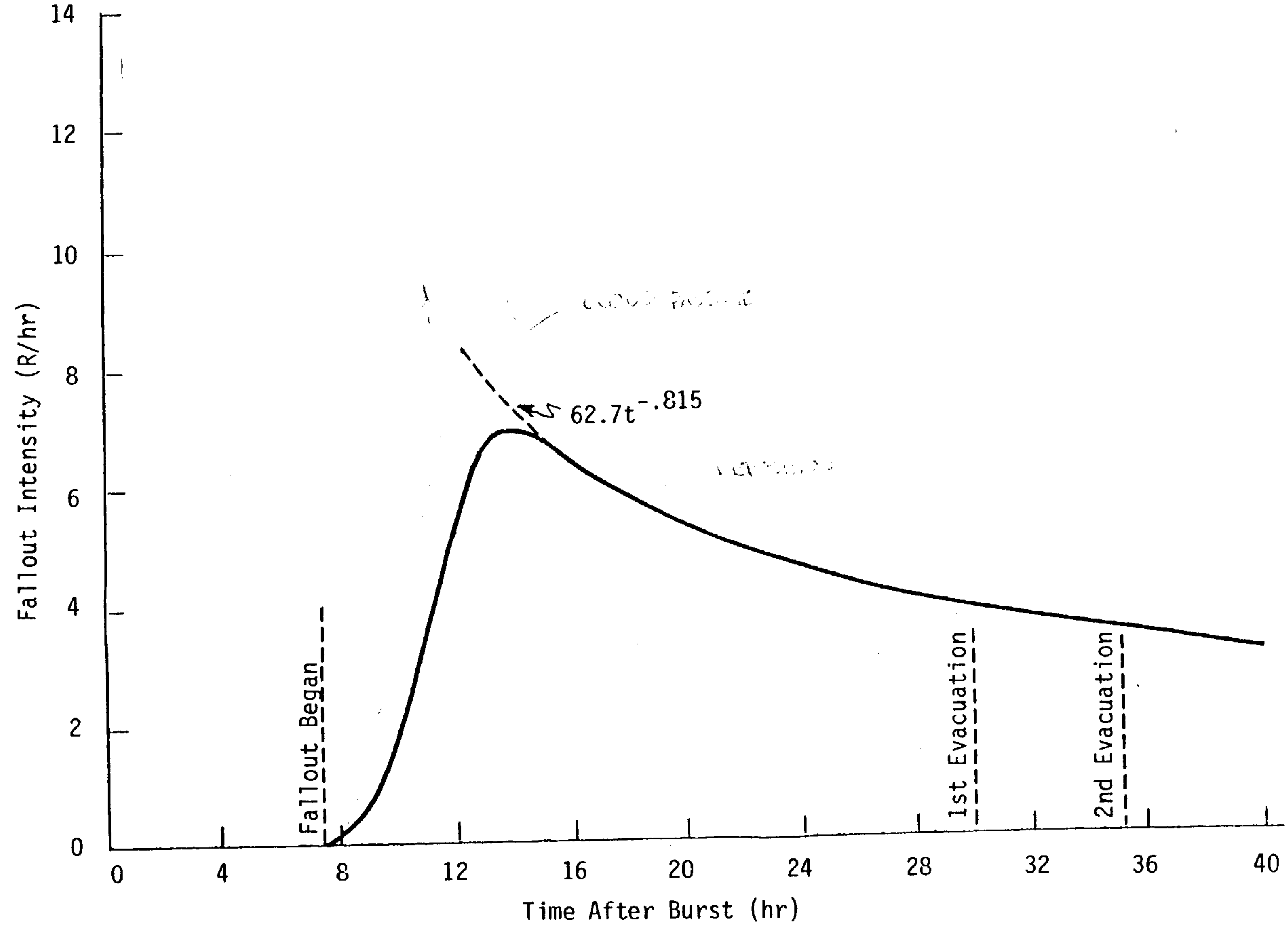

Figure 2. Rongerik fallout intensity versus time after burst (Shot Bravo).

(3) Protection Factors on Rongerik Atoll

During the initial radiological survey of Rongerik on 10 March 1954 (Reference 8), specific locations were surveyed with an AN/PDR-39 survey meters. In addition to the average reading of 280 mR/hr found at various locations on the island, the survey team also took intensity readings both inside and outside of the various structures utilized by the military personnel during their exposure period. The ratio of the intensity outside to the radiation intensity inside is defined as the protection factor and gives a measure of the radiation protection or shielding provided by the structure. From the 10 March survey data, each type of structure and its measured protection factor are as follows:

Structure	Protection Factor
Mess Hall	2.0
Tent	1.5
Latrine	1.6
Sleeping quarters	2.9
Dispensary	2.0
R-Section Bldg	2.5

(4) Film Badge Doses

With the free-field radiation intensity (I_t) as defined previously, film badge doses for the military personnel on Rongerik can be calculated for each time interval (t_1 to t_2) to which a protection factor (PF_i) applies, as follows:

$$D_{fb} = (0.7)(1/PF_i)\int_{t_1}^{t_2} I_t dt$$

where D_{fb} = Dose as would be recorded by a film badge worn on the chest

(0.7) = Factor to convert integrated free-field radiation intensity to film badge dose.

The maximum possible dose to a film badge worn continuously through the time of final evacuation is obtained by using PF=1 throughout, i.e., no radiation protection available on the island. The upper limit of integration in this case would be 35 1/4 hours after burst, which corresponds to final evacuation at 1800 hours, 2 March. A dose of 87 rem results. If a film badge was not worn, but instead left out in the open, the (0.7) factor would not enter into the calculations. As an example, one film badge was left hanging from a tent post (PF assumed to be 1) until H+28.75 hours (1130 hours, 2 March) at which time it was placed in the mess hall (PF=2) until the second group evacuated. The calculated dose is 112 rem.

All of the film badge dose calculations are dependent on the accuracy of integrated intensities derived from Figure 2. Uncertainty, especially concerning the duration of fallout deposition, is evidenced in a comparison with limited film badge dosimetry data (Section 3.3). Thus, film badge dose calculations in this section represent initial estimates.

For the seventeen individuals who provided sufficient information in their post-evacuation interviews to reconstruct their activities, the preliminary film badge dose estimates are given in Table 1. Because the individual activities used to derive these film badge doses were varied enough to encompass most reasonable activities, the calculations can be applied with confidence to all individuals, even those with insufficient information on their specific activities.

As would be expected, the second group of evacuees received a greater film badge dose than did the group evacuated approximately 5 hours earlier. Further, among the second group of evacuees, it appears that the Army troops who were manning the Project 6.6 station on Rongerik received a slightly larger dose than did the Air Force troops. This is not unexpected since the Army area on the island did not have any "permanent" structures, and the troops slept in a tent until approximately midnight, 1 March.

Table 1. Preliminary dose estimates for personnel on Rongerik Atoll, 1-2 March 1954.

Clinical No. (CN) Assigned**	Film Badge Dose (rem) Air Force	Army
First Group to Evacuate		
401	*	
402	*	
403	*	
404	39	
405	*	
406	35	
407	35	
408	*	
Second Group to Evacuate		
409	46	
410	*	
411	46	
412	38	
413	*	
414		51
415	43	
416	43	
417	44	
418	41	
419	*	
420	42	
421	*	
422	40	
423		48
424	*	
425		45
426	38	
427	44	
428	*	

*Film badge dose is assumed comparable to that dose received by other personnel in the evacuation group.

**For this analysis, clinical numbers are used instead of actual names.

3.2 AVAILABLE FILM BADGE DATA

Film badge data pertaining to the radiation exposure on Rongerik are reported in several references; however, the readings require interpretation. Because the allotted badges were not worn continuously by each individual, the data do not necessarily reflect the doses accrued by the servicemen. Moreover, there are inconsistencies among the references regarding the assignation of badges and in some of the reported readings.

Either twelve (Reference 9) or fourteen (Reference 3) film badges were received at the Rongerik weather station on 19 February 1954. One of these (#314) was distributed to the Army group. It was positioned seven feet above the floor of a tent in the Army area and was not worn. Two badges (#310/311) were assigned to the radio-weather station and were worn by a member of each shift (CN 408/CN 416) until approximately 1130 hours, 2 March. One badge (#312) was to be worn in the housing area by one of the Air Force personnel (CN 411) and another badge (#313), was worn by the NCOIC of the camp (CN 419). One other badge (#315) was placed on the side of a building in the housing area. This one was located shoulder high and moved occasionally each day to avoid direct sunlight. The remaining six badges (#309, #316-#320) were placed in a refrigerator in the mess hall. According to Reference 3, there were eight film badges placed in the refrigerator, but the reference does not cite badge numbers as does Reference 9.

Of the six badges that were issued, five (all but #313) were collected at 1130 hours, 2 March, and placed in a manila envelope and set on a table in the mess hall. The film badges that had been in the refrigerator remained there until 1700, at which time they too were placed in the manila envelope in preparation for the final evacuation. CN 419 continued to wear badge #313 until he arrived at Kwajalein at 1900, 2 March 1954.

The first written report of the film badge doses accrued on Rongerik came in Dispatch No. 240 431A from CTG 7.1, Enewetak and COMNAVSTA, Kwajalein, received 25 April 1954, which stated (documents of the period reported doses in r (i.e., R), not the modern rem):

Film Badge Readings are as follows:

CN401	40 r	CN416	40 r
CN403	40 r	CN417	40 r
CN404	40 r	CN419	52 r
CN408	40 r	Unknown	40 r
CN410	44 r	CN414	98 r
CN411	40 r	CN423	98 r
CN415	40 r	CN425	98 r

Film badges presently in custody of TU 7, TG 7.1 until completion of operation, at which time they will be forwarded to AFSWP.

This dispatch reportedly (Reference 3) contains the distribution list for the badges as originally planned; however, because only six of the badges were actually distributed, and only four were actually worn, many of the 40 R readings attributed to personnel may have actually been from the film badges that were placed in the refrigerator. One individual with whom a badge reading is associated was not stationed on Rongerik during the period 1-2 March 1954.

Reference 10 states that: "Several badges worn both outdoors and inside buildings on the island read 50-65 r, and one badge which remained outdoors over the 28.5 hr period read 98 r. Another group kept indoors inside a refrigerator read 38 r." The inference is that the troops received a film badge dose ranging from 50-65 R, while the badges in the refrigerator and the one that remained outside provide a lower and upper bound dose, respectively.

Reference 5, which cites a Hq JTF-7 Memo for Record: "Rad Safe Narrative Sequence of Events", BRAVO Shot, Operation CASTLE, as a reference, states that "film badge readings were obtained covering a range of values which varied with exposure conditions. Several badges were worn both outdoors and indoors (and covered the range 44-52 r). One badge which remained outdoors over the 28.5 hour exposure reached the upper limit of 98 r. Several other badges kept inside a refrigerator indoors gave the lowest value of 38 r." Thus, although References 5 and 10 agree on the maximum and minimum readings, they differ on the range of doses to personnel.

Dr. Payne S. Harris of Los Alamos National Laboratory (then LASL) listed film badge numbers and their respective doses (Reference 9). These data, in Table 2, approximate those film badge readings quoted in References 1 and 2, with a range in personnel dose of 40-52 R and maximum and minimum doses of 98 R and 37.5 R, respectively, depending on whether the badge remained outside or inside for the exposure period. For comparison with calculated doses, the Reference 9 doses are used.

Table 2. Film badge dosimetry results, Rongerik Atoll, 1-2 March 1954.

Badge#	Location	Dose (R)
309	Refrigerator	37.5
310	CN 408	40.0
311	CN 416	40.0
312	CN 411	44.0
313	CN 419	52.0
314	On tent pole	98.0
315	On barracks	82.0
316	Refrigerator	38.0
317	Refrigerator	38.5
318	Refrigerator	37.5
319	Refrigerator	37.5
320	Refrigerator	37.5

3.3 COMPARISON OF ESTIMATED FILM BADGE DOSES WITH FILM BADGE DATA

All film badges except badge # 313 were turned in and placed in the mess hall at approximately 1130 hours, 2 March (H+28.75), where they remained until evacuation at 1800 hours (H+35.25). Therefore, the estimated film badge doses in Table 1, which are based on personnel movements on the island until evacuation, cannot be compared directly with those film badge readings in Table 2. In order to make this comparison for a specific badge, the exposure of the film badge during the period it was in the mess hall (H+28.75 to H+35.25) must be added to the calculated film badge dose as of H+28.75 hours. This "mess hall dose" is approximately 12 rem.

From the personnel interviews it is possible to calculate the H+28.75 film badge dose for two of the film badges whose readings are given in Table 2 (badge #311 and #312). In addition, it is possible to calculate the H+28.75 hour dose for the badge that was hung on the tent post in the Army area (badge #314). Table 3 compares the calculated film badge dose at H+35.25 hours (the calculated dose at H+28.75 hours plus the "mess hall dose") and the corresponding film badge reading (from Table 2) for these three film badges. The activity scenarios or protection factors pertinent to the other badges are insufficiently known to permit meaningful comparisons.

Table 3. Comparison of dosimetry results with doses calculated to film badges.

Film Badge	CN	Calculated Dose @H+28.75 hrs	Calculated Dose @H+35.25 hrs	Film Badge Reading (Table 2)	Ratio
311	416	32 rem	44 rem	40 rem	1.10
312	411	38	50	44	1.14
314	N/A	100	112	98	1.14

From Table 3, the calculated dose to a specific film badge at H+35.25 hours is approximately 10-14 percent higher than the actual film badge reading. This difference between the calculated doses and the film badge readings could easily be accounted for in the uncertainties associated with defining the free-field radiation environment and protection factors on Rongerik. Thus, the estimated doses in Table 1 are conservatively reduced by 10 percent in order to be consistent with the dosimetry results. This adjustment in the Table 1 doses yields the best estimates of film badge doses received by the personnel on Rongerik. Results are presented in Section 5.

SECTION 4
TECHNICAL APPROACH — INTERNAL DOSE

The technical approach used to estimate the organ-specific radiation dose commitments for the American military personnel exposed on Rongerik Atoll is based on the following data:

- o Radionuclide inventory data for Shot Bravo calculated by Lawrence Livermore National Laboratory.
- o Urinalysis data for the exposed Americans obtained by Los Alamos National Laboratory.

The basic approach used to calculate the dose commitments has four steps.

- o The calculated radionuclide inventory provides the time-dependent relative activity of the radionuclides present in the fallout.
- o The inventory is normalized to the actual activity intake by relying on post-shot urinalysis to determine the amount of I-131 activity intake.
- o The internal dose pathways are examined to determine that doses are high-sided through use of large-particle inhalation dose conversion factors (rem/μCi), which are developed by modifying published ingestion dose conversion factors.
- o Organ-specific dose commitments (rem) are calculated by combining the normalized activity inventory data with the large particle inhalation dose conversion factors.

A description of each of the above steps is provided in the subsections below.

4.1 RELATIVE ACTIVITY

The basic fallout radiological data calculated for Shot Bravo was provided by Lawrence Livermore National Laboratory (LLNL) (Reference 11). The calculations were performed using the isotope generation and depletion code ORIGEN (Reference 12). Modifications to the ORIGEN-calculated results were made based on radiation chemistry data for Bravo available to LLNL. The LLNL-calculated data for Bravo thus reflect the device-specific characteristics (such as fissile nuclides, neutron energy, and light/heavy element production) that are necessary to correctly specify the radionuclide content of the fallout material. The unfractionated inventory is used because it high-sides organ doses derived from an iodine-based bioassay and because no specific level of fractionation can be substantiated. Plutonium nuclide information does not explicitly appear in Reference 11, but has been derived based on guidance from the author.

4.2 INVENTORY NORMALIZATION

As previously mentioned, urine samples were collected from the exposed American servicemen and sent to US laboratories for analysis. These afford the opportunity for a more accurate dose calculation than possible from first-principle physical considerations. On-site radiation surveys were late (D+9 days) and did not facilitate an internal exposure analysis (Reference 8). The urinalysis data collected by Dr. Payne S. Harris of the Los Alamos National Laboratory are the most useful for this dose calculation because they are based on a comparatively early (D+17 days) sample collection and are well documented (Reference 9). The urinalysis results reported by the Naval Radiological Defense Laboratory involved samples collected much later (D+44 days and after), for which the available documentation is weak (Reference 13). It is understood that urinalysis results were also reported by medical personnel at Tripler Army Hospital; however, apparently the sample collection times were so late that meaningful results were not reported (Reference 4).

The urinalysis data reported by Dr. Harris for the American servicemen were based on a 10-man, pooled urine sample collected on 18 March 1954. The urine samples were analyzed for plutonium, calcium-45, strontium-89, ruthenium-103, iodine-131, and barium-140. The I-131 analyses of the pooled urine samples of the servicemen and Marshallese provided the basis for thyroid dose estimates by Dr. Harris and later researchers. Dr. Harris judged that I-131 analysis was the most accurate; it also led to the highest doses to the servicemen (Reference 9).

The basic finding of the I-131 analysis of the pooled urine sample was the determination that, for an average individual, the amount of I-131 excreted in urine over a 24-hour period at the time of the urine sample collection (D+17 days) was 4.0 nanocuries. That result is used to determine the amount of I-131 intake.

The amount of a radionuclide excreted in a 24-hour urine sample is related to the amount of the radionuclide initially intaken (that is, inhaled and/or ingested) by

$$A_u(t) = Q_I \cdot f_1 \cdot Y(t) \cdot F_u$$

where

$A_u(t)$ = the amount (μCi) of the radionuclide in a 24-hour urine sample taken at time t,

Q_I = the amount (μCi) of the radionuclide intake,

f_1 = the fractional amount of the radionuclide intake that is transferred to the blood,

$Y(t)$ = the ratio of the amount (μCi) of the radionuclide excreted with a 24-hour period to the amount (μCi) of the radionuclide uptaken by the blood, and

F_u = the fraction of the total daily excretion that is present in the urine.

To apply this equation, not only must the time t of excretion relative to that of intake be known, but also, for a radionuclide mixture, the time after detonation/release. In addition, the pathway may influence the body absorption fraction f_1 and Y(t) may be influenced by the presence of parent radionuclides.

As mentioned above, the value of A_u (D+17) is 4.0 nCi or 0.004 μCi for I-131. For iodine, the biological parameters f_1 = 1.0 and F_u = .86 (References 14, 15). The value of Y(t) is derived from Reference 16, which contains a recent retention model. The value of Y(D+17) used is for an effectively instantaneous (relative to 17 days) intake: Y(D+17) = 2.87×10^{-4} μCi/day per μCi uptake. This value reflects excreted I-131 that entered the body as I-131. However, at an early (shot-day) time of intake, the parent radionuclide Te-131m (half-life of 30 hours) exists in modest abundance--about 10 percent as much as I-131, by mass (Reference 11). Although tellurium is only partially absorbed into the body, at least half of the Te-131m decays prior to elimination from the body, and the iodine produced is fully absorbed. Therefore, up to about 7 percent of the excreted I-131 on D+17 could be from intake of Te-131m. With this adjustment, Y (D+17) = 3.07×10^{-4}.

Using the values of A_u (D+17), f_1, Y(D+17), and F_u cited above, the amount of the I-131 intake, Q_I, is 15 μCi. This value of Q_I is used to normalize the radionuclide inventory. Based on I-131 representing 0.2-0.3 percent of the total fission product activity (Reference 11) at the estimated time of intake (discussed subsequently), the total activity intake of fission products was about 5 to 7 mCi.

4.3 PATHWAYS AND DOSE CONVERSION FACTORS

Researchers have arrived at various conclusions as to the dominant pathways for exposure to the Bravo contamination. The assumption of an inhalation pathway was made by Cole based on a comparison of the internal and external radiation dose estimates for the Americans on Rongerik and the natives on Rongelap (Reference 4). Cole's basic logic was that since the ratio of the internal and external doses was practically the same for both the Americans and the natives, the exposure pathways must have been similar (i.e., inhalation) and not related to the personal hygiene or consumption habits that were dissimilar. However, the latest determination of internal dose for the Marshallese (Reference 19) considers ingestion to be the dominant pathway and arrives at significantly greater thyroid doses than previously calculated. Dr. Harris considers that ingestion through food or drinking water also contributed to the internal dose of the servicemen on Rongerik (Reference 9).

Scoping calculations suggest that both inhalation and ingestion pathways could have contributed significantly to internal dose at Rongerik, but that inhalation could not have dominated. As derived in Reference 20, the inhaled activity (curies) from full exposure to descending fallout is roughly 10^{-5} x peak gamma intensity (R/hr) x time of fallout after detonation (hr). The values of these parameters obtained in Sections 2 and 3 imply an inhaled activity on the order of 1 mCi. Ingestion could have resulted in virtually all of the activity intake, if, for example, food on a plate exposed to 15 minutes of significant fallout deposition were entirely ingested. At the time of the peak intensity, the areal concentration of activity exceeded 1 Ci/m^2 (Reference 11). With a plate size of 0.1 m^2 and exposure for 5 percent of the estimated duration of significant fallout, an intake of 5 mCi is implied.

Later pathways are less likely to have contributed significantly to internal dose. Fallout, which had accumulated to a noticeable depth, would have been brushed or washed off of objects pertinent to ingestibles; at lower levels of contamination, an unrealistically large surface area would have to be involved for ingestion at the mCi level. Inhalation during the following day of contaminants resuspended by wind or personal agitation would have been minor.

The particle-size characteristics of the airborne fallout material are adequately known. Based on considerations of particle fall rate, Bravo cloud height, and time after detonation, it is estimated that the deposited fallout particles were in the size range of 55 to 120 μm diameter. Analysis of soil samples on Rongerik indicated that most of the radioactivity in soil was associated with particles in the size range of 60 to 200 μm diameter (Reference 13). In the context of aerosols, the deposited material consisted of large particles (greater than 10 μm in diameter). For dosimetric purposes, differentiation among large particle sizes is unnecessary, as shown below.

For most typical radiological contamination situations involving the inhalation of radioactive material, organ dose commitments are calculated using published inhalation dose conversion factors. Inhalation dose conversion factors are available for activity on particles of less than 10 µm in diameter; however, inhalation dose conversion factors for large particles are not available in the published literature. Accordingly, for the purpose of this dose calculation a set of large-particle inhalation dose conversion factors is developed.

For particles greater than 10 µm diameter, essentially all of the inhaled material is initially deposited in the nasal or nasopharyngeal region of the respiratory tract (Reference 17). This material is removed by chemical (absorption) and mechanical processes, and goes either to the blood, with subsequent transfer to other body organs, or to the gastrointestinal (GI) tract, with subsequent transfer to the blood and further transfer to other body organs or bodily elimination by excretion. The "pulmonary clearance classification" of the inhaled material (roughly analogous to the solubility of the material) determines the amount of the material that is initially transferred to the blood or the GI tract; for example, 99 percent of an "insoluble" material will go to the the GI tract with only 1 percent going to the blood, whereas a "very soluble" material will be divided evenly between the GI tract and the blood (Reference 16).

As ingestion plays a major role in the fate of an inhaled large particle, the large-particle inhalation dose conversion factors used for the present dose calculation are obtained by modifying ingestion dose conversion factors. This modification is necessary to properly account for that portion of the inhaled material that is initially transferred to the blood, rather than to the GI tract. The metabolic data needed to construct inhalation/ingestion dose conversion factors are given in ORNL/NUREG/TM-190 (Reference 16) for the most radiologically significant radionuclides. The TM-190 dose conversion factors, based on the most current dosimetry information, are used in conjunction with these. For those radionuclides not addressed in TM-190, unmodified ingestion dose conversion factors are taken from NUREG-0172 (Reference 18).

Large-particle inhalation dose conversion factors (where derivable) are used to high-side estimates of internal dose, despite the apparent dominance of the ingestion pathway. For some radionuclides, the original deposition of inhaled particles in the nasopharyngeal region affords a significantly greater absorption into the body than occurs in the GI tract. A minor contribution to GI tract doses is depleted through this pathway, but lung dose is greatly increased. For iodine, absorption is essentially complete with either pathway. Thus, the iodine-dominated thyroid dose is insensitive to the mix of ingestion and large-particle inhalation contributions to the total activity intake (so long as these occur at about the same time). Moreover, the use of the calculated I-131 intake to normalize the radionuclide inventory is independent of this mix.

Dose calculations are made for intake at 9 hours after detonation. In the early portion of significant fallout deposition, this high-sides organ doses by including greater activities of fast-decaying radionuclides. The large-particle dose conversion factors used in the calculation are listed in Reference 21.

4.4 ORGAN-SPECIFIC DOSE COMMITMENTS

The 50-year dose commitment to organ j, D_j, resulting from the intake of a mixture of radionuclides is given by

$$D_j = \sum_i Q_I^i \cdot DCF_i^j$$

Q_I^i, the amount of intake of radionuclide i, is determined from the radionuclide inventory as normalized by the I-131 activity intake developed from the urinalysis data. The dose conversion factor, DCF_i^j, for organ j due to the intake of radionuclide i is as discussed previously.

SECTION 5
RESULTS AND COMPARATIVE ANALYSIS

5.1 RESULTS

EXTERNAL DOSE

The gamma radiation dose to the servicemen on Rongerik Atoll is reconstructed as follows. The radiological environment resulting from Shot Bravo fallout is determined from time-of-arrival data on Rongerik, modeled deposition, measured decay rates, and a late reading on Rongerik. Personnel activity scenarios are considered in conjunction with radiation shielding factors to arrive at film badge doses on an individual basis. Although film badge readings are available, they inadequately relate to personnel dose. Readings that reflect well-specified exposures indicate good agreement with corresponding calculated doses. A small, but systematic, difference indicates an adjustment to the calculated personnel doses. Average doses to the identifiable subgroups of Rongerik personnel are as follows:

Group	Number of People	Average Dose (rem)
First Evacuation	8	33^{+2}_{-1}
Second Evacuation		
Air Force	17	38^{+3}_{-4}
Army	3	43^{+3}_{-2}

Reconstructed doses are presented by case number in Table 4, with individual scenario information included as available.

INTERNAL DOSE

Organ-specific 50-year dose commitments resulting from the large-particle inhalation and ingestion of Bravo fallout radionuclides are given in Table 5. The

Table 4. Reconstructed gamma radiation doses for military personnel stationed on Rongerik Atoll, 1 and 2 March 1954.

Air Force	Army	Clinical Number Assigned	Film Badge Number* (Reading)	Reconstructed Dose (rem)
		FIRST EVACUATION		
X		401		33**
X		402		33**
X		403		33**
X		404		35
X		405		33**
X		406		32
X		407		32
X		408	#00310 (40R)	33**
		SECOND EVACUATION		
X		409		41
X		410		38**
X		411	#00312 (44R)	41
X		412		34
X		413		38**
	X	414		46
X		415		39
X		416	#00311 (40R)	39
X		417		40
X		418		37
X		419	#00313 (52R)	52***
X		420		38
X		421		38**
X		422		36
	X	423		43
X		424		38**
	X	425		43
X		426		34
X		427		40
X		428		38**

*Reference 9
**Mean dose for group
***Actual film badge reading is given because it represents entire exposure.

Table 5. Fifty-year internal dose commitments for military personnel stationed on Rongerik Atoll, 1 and 2 March 1954.

Organ	Dose Commitment (rem)
Thyroid	190
Lower large intestine wall	76
Upper large intestine wall	44
Small intestine wall	13
Lung	13
Stomach wall	6.4
Endosteum (bone surfaces)	3.4
Liver	1.6
Bone	1.4
Red marrow	1.3
Kidney	1.2
Pancreas	0.9
Testes	0.6

calculation of internal dose commitments is based on an intake at 9 hours after Shot Bravo, with large-particle dose conversion factors applied to the radionuclide inventory to that time. The inventory, which is based on radiochemical analysis of Bravo, is normalized to the activity level of iodine-131. Intake of this radionuclide is determined from the body metabolism of iodine that led to a measured activity of I-131 in urine samples taken 17 days after Bravo.

The calculated thyroid dose commitment of 190 rem is by far the largest organ dose commitment, and the dose is accrued comparatively rapidly. Short-lived radionuclides dominate the thyroid dose, which is seven times that from I-131 alone. If the intake had been at 13 hours after Bravo, the thyroid dose would be six times that from I-131 (based on the Reference 11 radionuclide inventory). Thus, the thyroid dose is not sensitive to actual time of intake within the fallout deposition period.

The only other dose commitments that exceed the dose from external gamma radiation are for the sections of the large intestine. Actinide emitters, produced by the neutron activation of U-238 during the detonation, are significant to these doses. Because GI tract doses are dominated by the ingested contents in transit rather than by absorbed radionuclides, these doses are also accrued rapidly.

Caution is advised in interpreting these calculated internal doses for specific individuals. Based on a pooled urine sample, the calculated doses represent an average or nominal dose estimate and do not necessarily pertain to a specific individual. However, limited individual urine sampling reported by Dr. Harris (Reference 9) indicated only a modest spread of results. The counts of the individual samples were consistent to within 40 percent of their mean. Also, the implied intake of I-131 agreed well with that from the pooled sample.

5.2 COMPARISON WITH PREVIOUS DOSE DETERMINATIONS

Dose determinations for personnel on atolls downwind of CASTLE Bravo have been principally of two types: the initial estimates developed in the mid-1950s, shortly after the event, and the long-term, continuing followup by Brookhaven

National Laboratory on the affected Marshallese. While the servicemen on Rongerik Atoll do not fall under the Brookhaven charter, they do obtain limited mention in Brookhaven reports with respect to the consistency of external dose estimates. Moreover, the internal dose methodologies for the two groups are perforce similar, as the underlying data are related. Consequently, as the current Brookhaven report (Reference 19) provides the best synthesis of earlier work, it affords a sufficient comparison with this analysis.

EXTERNAL DOSE

Previous studies have the following features in common for dose estimates to the servicemen on Rongerik: doses are based on free-field intensities, are reported as air exposure (R), and thus are non-specific as to individual's activities. These estimates have recently been referred to in terms of rad or rem, which further blurs the distinction between them and the calculated film badge doses that are presented in this report. Thus, the previous estimates, which are generally in the range of 70-100 R, would correspond to about 50-70 rem with the use of the 0.7 rem/R film badge conversion factor. With the inclusion of the protection factor of about 2 for time indoors, the estimates would be reduced further and adequately correspond to the present results. Earlier reports displayed no interest in arriving at individualized estimates; it is not even clear that the 1950's researchers had access to the full range of then-classified information that would have been required for such estimates.

Brookhaven lists along with its current estimates of whole body external doses to the Marshallese a corresponding value for Rongerik personnel, 81 rad. This value is treated as if it were the whole body dose and thus additive, without adjustment, to an internal dose in rem. This is the treatment afforded the corresponding external dose estimates for the Marshallese, to arrive at total thyroid doses. Actually, 81 rad is arrived at by application of a Marshallese living-style factor to an estimate of integrated intensity in free air. No consideration was given to the substantially greater shielding of the servicemen. Thus, the Brookhaven estimate is not germane to the Rongerik servicemen (Reference 22).

A previous estimate of Rongerik external whole-body dose is listed by Brookhaven as 78 rad, from WT-939 (Reference 5). This value came through the use of a secondary reference (Reference 22); WT-939 actually provides a range of possible air doses (R), from which it selected a value of 86 R. While WT-939 did report final results in terms of R, it contains a discussion of corresponding depth doses in tissue. The magnitude of depth doses, relative to the air dose, are consistent with the aim of a film badge reading to adequately reflect depth dose. These relationships should have been noted by researchers who obtained a whole body dose from use of WT-939.

Even after conversion to depth dose/film badge dose, the WT-939 dose estimate remains greater than the present value for two reasons: how it considered shielding and how it arrived at an integrated intensity in air. Without the benefit of WT-938 (Reference 3), published later, WT-939 incorporated no specifics on personnel movement; an estimate was used of one-half of the time outdoors with no protection and one-half of the time indoors with a protection factor of 2. Based on the personnel-scenarios in WT-938, however, it is deduced that a considerably greater fraction of the time was spent indoors, and more of that was in buildings with a PF > 2 than PF < 2. In fact, for the lowest dose case (CN406), detailed in the Appendix, the time-averaged PF was greater than 2. Thus, the calculated film badge dose for this case is less than two-thirds of what WT-939 would suggest -- 0.65 x 0.7 x 86 = 39 rem, close to the present value of 32 rem.

The WT-939 estimate of integrated intensity in air relies on an assumed duration of fallout deposition. While the present analysis initially follows this approach, the results are adjusted for actual film badge readings. Both indoor and outdoor badges, when shielding and duration of exposure are properly accounted for, imply a consistent adjustment factor. Lacking any known systematic error in the film badge readings, the normalization to badge readings provides the most credible personnel dose determination. The implied integrated intensity in air is about 15 percent less than in WT-939. This resolves the remnant difference in personnel dose estimates.

One other estimate of Rongerik external dose is displayed by Brookhaven. A computerized theoretical treatment of Bravo fallout deposition leads to dose estimates at odds with other analyses for all atolls studied. The wind data needed for this approach are too sparse, leading to results that are not credible (Reference 22).

INTERNAL DOSE

The current Brookhaven report has a number of features that make it useful for comparison with internal dose estimates for the Rongerik servicemen: closely related urinalysis data for the Marshallese and the servicemen are utilized in similar internal dose methodologies; the latest thyroid dose estimates (to the Marshallese) exceed any of the referenced previous estimates; and use is made of ICRP-30 (Reference 14), a likely foundation for the present analysis had all of the metabolic and dosimetric information for specific radionuclides been published when this work was initiated.

Both the Brookhaven and the present assessments utilize I-131 counts from urinalyses to arrive at initial body burdens of I-131. From this, Brookhaven determines the levels of other iodine isotopes that lead to thyroid dose. The present analysis goes beyond, with use of Reference 11, to determine the levels of radionuclides generally, and from them and References 16-18, the doses to all relevant organs. Thus, the central comparison is afforded by the specifications of iodine metabolism and how they influence the estimates of initial I-131 body burden.

The common basis for the ORNL-TM-190 (Reference 16) and ICRP-30 (References 14, 15) treatments of iodine metabolism is Reference 23. TM-190 has applied the Reference 23 prescription numerically as a function of time for various body compartments; ICRP-30 gives approximated time constants for these compartments, from which the user can develop functional relationships. When this is done, the agreement between I-131 body burdens deduced from ICRP-30 and TM-190 is good, especially with the approximations taken into account. However, this agreement exists only for the latest version of iodine metabolism expressed in ICRP-30, Part 3 (Reference 15). Unfortunately, Brookhaven referenced ICRP-30, Part 1 (Reference 14) as its source of metabolic information, which has since been acknowledged as incorrectly stating the iodine parameters (References 15, 24). Whereas the difference has a minimal impact on the principal ICRP-30 mission of determining annual limit intakes, the implication on excretion fraction on D+17 is considerable. For stable iodine, 6.4×10^{-4} is excreted on D+17, as deduced from ICRP-30, Part 1, and as used by Brookhaven. Application of the revision in Part 3 leads to a 9.3×10^{-4} excretion on D+17. As the implied initial body burden is inversely proportional to this excretion fraction, the Brookhaven estimate is consequently overstated by 44 percent. Thus is explained the dominant difference between the Brookhaven and the present determinations of initial I-131 body burden, per unit of activity excreted on D+17.

5.3 TOTAL DOSE

The total dose to each organ is the sum of the external and internal dose contributions. For consideration of risk assessment, the long-term aspect of certain dose commitments must be included. However, the important contributions of internal dose to the total dose of the Rongerik personnel were only for organs in which the internal dose is rapidly accrued. Approximate total values are 230 rem to the thyroid, 115 rem to the lower large intestine wall, 85 rem to the upper large intestine wall, and about 40 to 50 rem to all other organs.

SECTION 6
LIST OF REFERENCES

1. The Effects of Nuclear Weapons, S. Glasstone and P.J. Dolan, US Department of Defense and US Department of Energy, Washington, DC, GPO, 1976.

2. "Environmental Radioactivity," M. Eisenbud, Second Edition, Academic Press, New York, 1973.

3. "Exposure of Marshall Islanders and American Military Personnel to Fallout," R. Sharp and W.H. Chapman, Naval Medical Research Institute, Operation CASTLE, WT-938-EX, February 1980. AD/A 995 077.*

4. "Inhalation of Radioiodine from Fallout: Hazards and Countermeasures," R. Cole, Defense Civil Preparedness Agency, August 1972, AD 761 638.*

5. "Physical Factors and Dosimetry in the Marshall Island Radiation Exposure," Addendum Report, Project 4.1, C.A. Sondhaus and V.P. Bond, Naval Radiological Defense Laboratory, Operation CASTLE, WT-939, December 1955, AD 338 337.*

6. "Distribution and Intensity of Fallout," R.L. Steton, Naval Radiological Defense Laboratory, Operation CASTLE, WT-915, January 1956, AD 361 836.*

7. Analysis of Fallout Data, Part II, "Decay Characteristics of Radioactive Fallout," C.F. Miller, Naval Radiological Defense Laboratory-TR-221, 1958.

8. Letter Report, Subject: Radiological Survey of Downwind Atolls Contaminated by BRAVO, Herbert Scoville, Jr., Hq. Task Unit 13, Task Group 7.1, TU-13-54-375, ~~12~~ March 1954.

9. Private Notes and Communications, Dr. P.S. Harris to SAIC Staff, 1982-1983.

*Available from NTIS; order number appears before the asterisk.
**Available at CIC.

10. "Study of Response of Human Beings Accidentally Exposed to Significant Fallout Radiation," Project 4.1, E.P. Cronkite et al., Naval Medical Research Institute, Operation CASTLE, WT-923, January 1954, AD 465 295.*

11. "Results of Calculations of External Gamma Radiation Exposure Rates from Local Fallout and the Related Radionuclide Compositions of Selected US Pacific Events," H.G. Hicks, Lawrence Livermore National Laboratory, UCRL-53505, 1984, (A10) DE 84 010 678.*

12. "ORIGEN - The ORNL Isotope Generation and Depletion Code," M.J. Bell, Oak Ridge National Laboratory, ORNL-4628, Oak Ridge, Tennessee, May 1973.

13. "Nature and Extent of Internal Radioactive Contamination of Human Beings, Plants and Animals Exposed to Fallout," S.H. Cohn et al., Naval Radiological Defense Laboratory and Naval Medical Research Institute, Operation CASTLE, WT-936, 1957, AD 617 134.*

14. "Limits for Intakes of Radionuclides by Workers," International Commission on Radiological Protection, ICRP Publication 30, Part 1, Pergamon Press, New York, 1978.

15. __________, ICRP Publication 30, Part 3, Pergamon Press, New York, 1981.

16. Estimates of Internal Dose Equivalent to 22 Target Organs for Radionuclides Occurring in Routine Releases from Nuclear Fuel-Cycle Facilities, 2 vols., G.G. Killough et al., ORNL/NUREG/TM-190, Jun 78 and Nov 79, NUREG/CR-0150* and NUREG/CR-0150-V-2.*

17. Task Group on Lung Dynamics, "Deposition and Retention Models for Internal Dosimetry of the Human Respiratory Tract," Health Physics, 12(1966), p. 173-207.

*Available from NTIS; order number appears before the asterisk.
**Available at CIC.

18. "Age Specific Radiation Dose Commitment Factors for a One Year Chronic Intake," G.R. Hoenes and J.K. Soldat, Battelle Pacific Northwest Laboratories, NUREG-0172, November 1977, PB-272 348.*

19. "Thyroid Absorbed Dose for People at Rongelap, Utirik, and Sifo on March 1, 1954," E. Lessard et al., Brookhaven National Laboratory, March 1985. BNL 51882.*

20. "Low Level Internal Dose Screen," Vol I: CONUS Tests, SAIC draft report, October 1985.

21. FIIDOS--A Computer Code for the Computation of Fallout Inhalation and Ingestion Dose to Organs, DNA-TR-84-375, December 1985. AD/A

22. Discussion with E. Lessard, Brookhaven National Laboratory, 25 March 1986.

23. "Quantitative Aspects of Iodine Metabolism in Man," D.S. Riggs, Pharmacological Reviews, Vol. 4 (1952), p. 284-370.

24. Discussion with K. Eckerman, member ICRP Committee 2, 11 March 1986.

*Available from NTIS; order number appears before the asterisk.
**Available at CIC.

APPENDIX

SAMPLE CASE INTERVIEW

After being evacuated to Kwajalein on 2 March 1954, all of the military personnel assigned to Rongerik Atoll were interviewed to determine their specific activities during the period 1 March until their subsequent evacuation on 2 March. Some of the interviews provided sufficient detail to determine an individual's activities, hence his whereabouts, on an hour-to-hour basis. Because the film badge dose estimates in this memorandum are based on seventeen such interviews, this appendix shows how these data are utilized in calculating the film badge doses.

Reference 3 contains a summary of the interviews obtained from the 28 military personnel after being evacuated to Kwajalein. The results of an interview with CN 406, extracted from Reference 3, is as follows:

CN406

Duty. Rawinsonde Operator.
Activities. 1 March: On duty day of 1 March until 1630. Took shower before chow. Attended movie in mess hall.
2 March: Worked outside, helping to wash outside of mess hall.
Clothing. Wore shorts until 1530. Changed to long clothing.
Food and Drink. Ate evening meal 1 March. Had coffee for breakfast, 2 March. No lunch.
Fallout. Observed fallout at about 1500. "White ashes; light, floated down."
Film Badge. None. CN408 wore badge for group.
Evacuated. In first group (1245, 2 March).
Note: High school education. Thirteen months remaining of present enlistment.

Based on the interview with CN406, it is possible to estimate where this individual was at a particular time and, hence, determine what radiation protection was provided by the particular building he was in. When a particular structure was not specified, ~~it~~ was assumed he was outdoors (PF=1.0). Table 6 details the activities of CN406 as inferred from his interview, and lists the calculated film badge dose for this individual during his stay on Rongerik.

Table 6. Calculated film badge dose for one airman (CN 406).

1-2 MARCH 1954 TIME (LOCAL)	TIME AFTER BURST (HRS)	ACTIVITY	PF	CUMULATIVE DOSE (rem)
1430-1630	7.75-9.75	Radiosonde bldg-on duty	2.5	0.3
1630-1700	9.75-10.25	Shower	1.0	0.9
1700-1800	10.25-11.25	Mess hall-chow	2.0	2.0
1800-2300	11.25-16.25	Mess hall-movies	2.0	13.0
2300-0700	16.25-24.25	Barracks	2.9	23.6
0700-0800	24.25-25.25	Mess hall-chow	2.0	25.2
0800-1000	25.25-27.25	Washing down mess hall	1.0	31.3
1000-1245	27.25-30.0	Mess hall until evacuation	2.0	35.2*

*This total is subsequently reduced by 10 percent as described in Section 3.3.