DNA 4747F

ANALYSIS OF RADIATION EXPOSURE FOR TASK FORCE WARRIOR SHOT SMOKY

EXERCISE DESERT ROCK VII-VIII OPERATION PLUMBBOB

Science Applications, Inc.
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Radiation Exposure		

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The radiation exposures to Task Force WARRIOR troops who participated in Shot SMOKY are determined and compared with film badge data gathered during Exercise Desert Rock VII-VIII. Fallout contours and decay rates are established and used to calculate total exposure, based on estimated stay time for various troop activities. Uncertainties are calculated for each parameter. Exposures are corrected to a film badge equivalent environment to permit

20. ABSTRACT (Continued)

comparison with actual film badge readings. Total equivalent exposure is calculated to be 480 mrem as compared with a 575 mrem mean film badge reading for the entire operation.

TABLE OF CONTENTS

APPENDICES

LIST OF FIGURES

LIST OF TABLES

Section 1

INTRODUCTION AND SUMMARY

The story of Shot SMOKY is more than a chronology of events on 31 August 1957. SMOKY planning began in the spring of 1957 and evolved into a complex troop operation intended to test and, more importantly, to demonstrate the ability of the U.S. Army to operate on the atomic battlefield. In late July, Camp Desert Rock, Nevada, became the "home away from home" for most of the troops who participated in the exercises that were planned around the SMOKY event, scheduled for 19 August. The briefings, orientations, planning, preparations, and staging were accomplished at the "Rock," over 35 miles from the SMOKY tower where the shot was to be detonated (see Figure 1). The major troop element was Task Force WARRIOR, a reinforced infantry company from the 1st Battle Group, 12th Infantry, 4th Infantry Division. Leading up to the actual test, Task Force WARRIOR and supporting units engaged in several activities that would prepare them for the operation. Due to the shot postponements, other activities were added while some scheduled post-shot activities were deleted. Contingency planning proved crucial to the completion of the operation.

The thrust of this report centers on the determination of Task Force WARRIOR radiation exposure from its activities in contaminated areas of the Nevada Test Site and the comparison of exposure estimates with dosimetry data. A discussion of task force objectives and the troop maneuvers planned to attain them provides background for the events that transpired. Task force activities are traced from rehearsals in early August through the operation on 31 August and follow-up tasks in order to provide the time-dependent position data required for an exposure analysis. Initial and residual radiation exposures from SMOKY and preceding shots are then calculated using both measured and derived intensities. The synthesis of decay rate and intensity data for fallout fields permits the dose rate at any position and time to

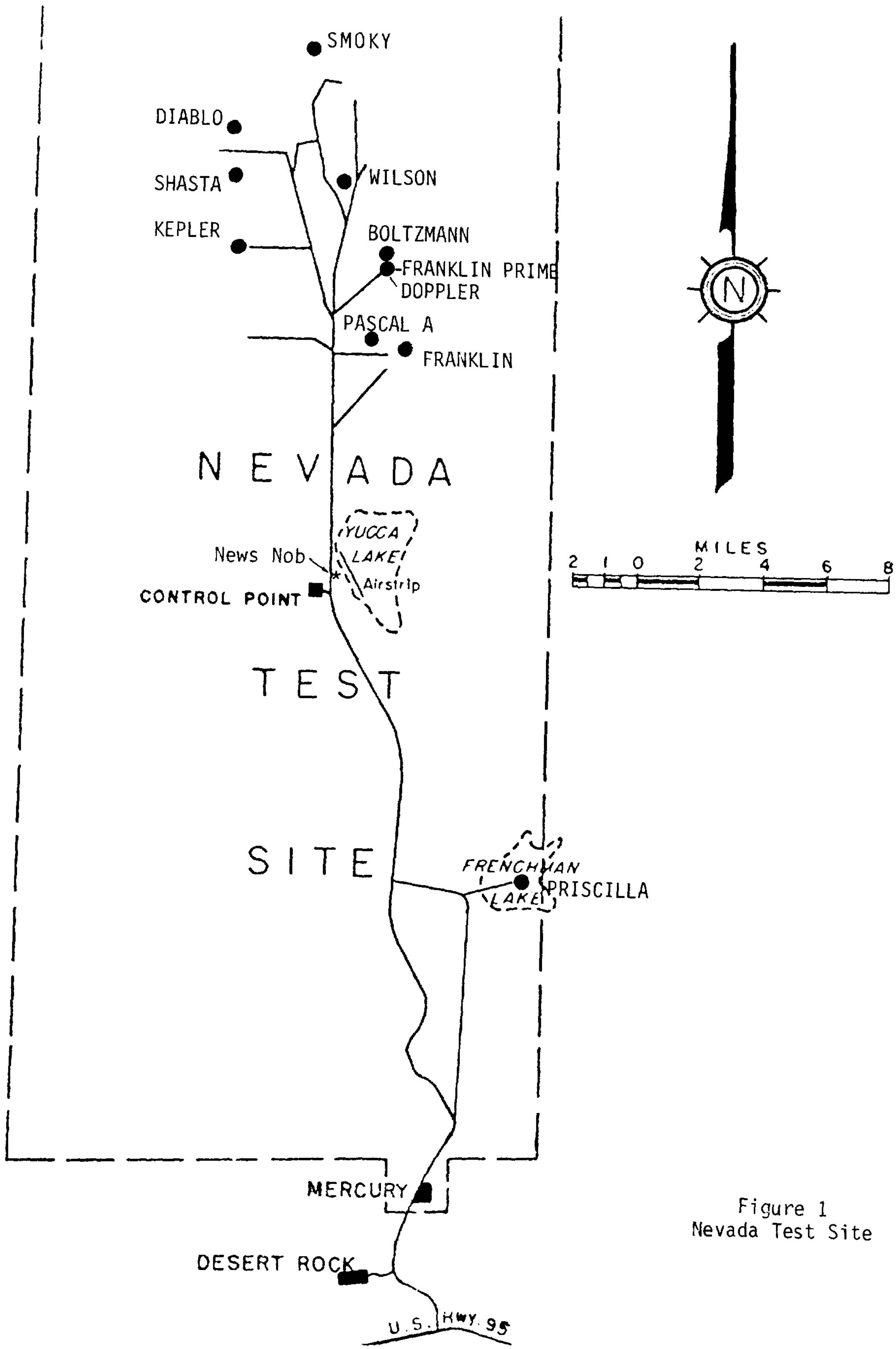

Figure 1
Nevada Test Site

be determined. An uncertainty analysis for all parameters not only provides confidence limits for the dose estimates, but also is necessary for the correct summation of the doses from each activity. The free-field dose is then corrected to the reading a film badge, as worn, would register in the same environment. This involves computer modeling of the attenuation and scatter of radiation in a human. Finally, the film-badge-equivalent estimates are compared with the actual data for the major periods of badge issue. These badge data are statistically analyzed to develop the optimal basis for this comparison.

Major findings presented in this report are:

- The sources of radiation exposure to Task Force WARRIOR were primarily the shots of Operation Plumbbob preceding SMOKY (Section 4.2).

- Fallout field gamma radiation intensities have been determined with improved accuracy for Plumbbob shots through the use of actual intensity data in conjunction with measured decay rates. Time-normalized intensities permit the utilization of all available data in an algorithm to generate composite fallout intensity plots (Appendices I, II).

- The total mean free-in-air tissue dose calculated for Task Force WARRIOR troops was 970 ± 270 mrem. This value is larger than film badge readings because the film badges did not record the neutron dose from the initial radiation of Shot DOPPLER and because a film badge is partially shielded by the body. The unit of neutron dose (rem) as used in this report is not correlated with specific biological effects (Section 5.3).

- The mean film badge dose as calculated from the Task Force WARRIOR integrated exposure was 480 ± 135 mrem (with 90 percent confidence), consistent with the actual mean total film badge reading of 575 mrem as determined from the complete original data (Section 7).

- The upper limit for a specific individual's film badge dose was calculated to be 1100 mrem. This limit resulted from an evaluation of the differences in locations and times at those locations for the individuals making up the task force. This calculated limit exceeds the highest recorded film badge readings, except for the readings of a small group. That group's film badge readings, 1100 ± 300 mrem over a short duration, indicate that the group engaged in an activity separate from the main body of the task force (Section 7).

The dose estimates for Task Force WARRIOR were derived, for the most part, from data provided in the references. Some troop activities, however, are unsubstantiated or uncorroborated and were therefore inferred from the limited data, to establish a logical scenario. In spite of the limited information, substantial agreement with film badge exposures resulted. The draft report was reviewed by the Nuclear Test Personnel Review Staff of the Office of the Chief of Staff, U.S. Army; the assumptions made were held to be reasonable and in essential agreement with standard Army practice. Efforts are being made to corroborate these assumptions through interviews with participants who can be contacted.

Section 2

OPERATIONS

2.1 SHOT DATA

Date: 31 August 1957, 0530 hours (Scheduled date 19 August 1957)

Location: Area 8 (T2c). Coordinates 828159, Nevada Test Site

Yield: 44 Kt

HOB: 700' (steel tower)

2.2 PARTICIPANTS

	Personnel		Source
Project 50.1 - Infantry Troop Test			
Task Force WARRIOR Troops		391	*
Co. C (Reinf), 1st BG, 12th Inf.			
Company Headquarters	12		*
4 Rifle Platoons	188		*
1 Weapons Platoon	36		*
1 Canadian Army Platoon	40		*
(7th Plt., Co. C, 2nd Bn Queen's Own Rifles)			film badge data
1 Reconnaissance Platoon	21		*
1 Mortar Platoon	54		*
1 Medical Detachment	17		*
1 Communications Detachment	16		*
1 Engineer Squad	7		*
Other Battle Group Personnel		212	
		603	total film badges

* Reference 4

2.3 TROOP MANEUVER PLAN

There were several facets to the overall plan for the troop test. The general objective was to train an infantry battle group and supporting elements to operate on an atomic battlefield, both defensively and offensively (Reference 5). To meet this objective, the troop test was developed with several specific tasks, as follows:

A. Preparation of a battle group defensive position to determine the time required to prepare the position in accordance with existing doctrine, and the effects of an atomic burst on the position.

> This was designated as Phase I of the troop test. Approximately 115 emplacements were to be prepared, ranging from 800 to 1900 meters W and NW of SMOKY GZ (Reference 4). Equipment and weapons were also to be emplaced in several positions. None of the positions were to be occupied for the test. The entire array was to be inspected before the shot to determine that the positions were properly prepared, and to document their condition and state of completion. After the shot, the positions would be inspected again to determine the effects of the shot. Damage would be assessed for each position to determine the vulnerability of each position as a function of configuration and distance from GZ.

B. Observation of an atomic explosion from trenches located at or near the minimum safe distance established by the Continental Army Command for friendly troops.

> This task was not to be integrated with other maneuver plans; thus, sufficient flexibility would be maintained to accommodate changes in shot schedules or predicted fallout patterns.

C. Helicopter movement of a landing force to an objective area and subsequent ground assault of a final objective immediately following the employment of a nuclear weapon (Phase II of the troop test).

To provide for various fallout contingencies, two plans were prepared, each with two alternate objective areas (Reference 6). Each plan provided for the assault troops to witness the shot from an observation point located 9000-13,000 meters from ground zero, to load into helicopters for airlift to an objective area about 5000-6000 meters from GZ, to secure an airhead, and lastly to conduct a ground assault on a final objective about 2500 meters from the airhead. For Plan A, the troop observation point was in the vicinity of Balloon Hill (coord. 881087) and the helicopter loading area was 800 meters farther east at coordinates 889089. For Plan B, the troop observation point was across Yucca Flat, north of Syncline Ridge at coordinates 757044, and the helicopter loading area was 2000 meters to the southwest at 740035. For both plans, the primary objective area was near Whiterock Spring, about 5000 meters W of SMOKY GZ. The alternate objective area, to be used if the direction of SMOKY fallout was to the north or west, was in the Rhyolite Hills, about 6000 meters NE of SMOKY GZ. Figure 2 depicts the general scheme of the air movement. Ultimately, because of expected fallout patterns, Plan B was used to observe the shot and to load helicopters for airlift to the primary objective area. Further detailed discussion of the actual troop maneuver will be confined to the scenario built around Plan B. However, it can be reasonably assumed that all four variations were rehearsed; hence, some discussion of these activities is appropriate (Section 2.5).

D. Helicopter re-supply (Phase III of the test) of the task force previously landed.

Supplies would be picked up from an aerial supply distribution point, 20 miles to the south near News Nob, and delivered to the airhead.

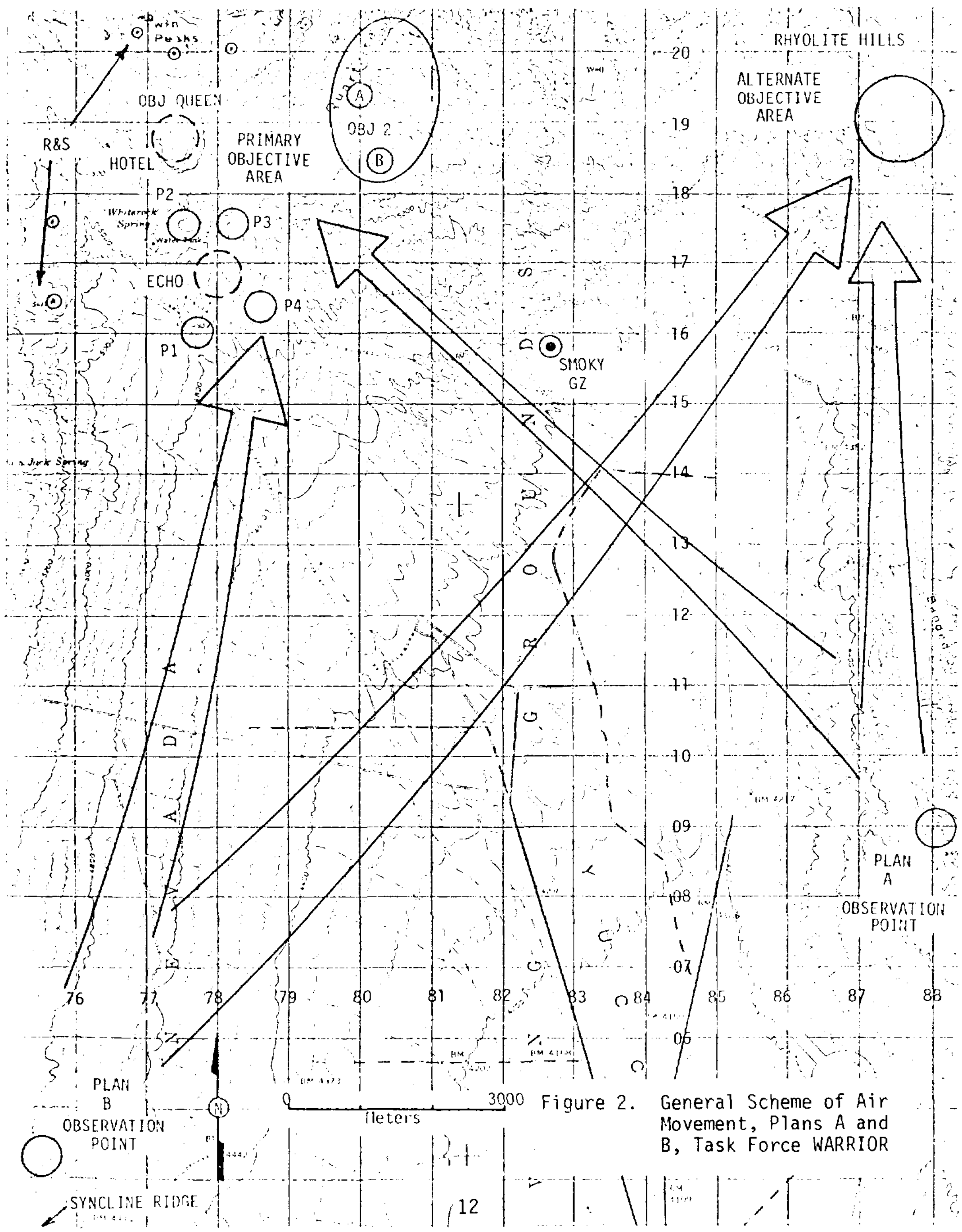

Figure 2. General Scheme of Air Movement, Plans A and B, Task Force WARRIOR

2.4 OTHER TROOP PLANS

Closely aligned with the Task Force WARRIOR plan was the Human Resources Research Office (HumRRO) troop test for Task Force BIG BANG. This test provided for a group of approximately 100 soldiers from the 82nd Airborne Division to observe Shot SMOKY, their first nuclear explosion, from trenches located 4400 meters from ground zero. Immediately thereafter they were to perform certain tasks, including rifle disassembly and reassembly. The other troops of the task force would act as assistants to the HumRRO monitors. In addition, the test troops would go through an infiltration course in which they would run and crawl over terrain containing barbed wire obstacles. The course would be marked as radioactive and perceived by the troops to be contaminated. All tasks would be timed and evaluated for comparison with the pre-shot performance of the same tasks.

The entire test was contingent upon the execution of Plan A by Task Force WARRIOR. If expected fallout contamination forced the adoption of Plan B, the contamination would also negate the use of the SMOKY trenches and the infiltration course. Ultimately, Task Force WARRIOR observed SMOKY from the Plan B location, while Task Force BIG BANG observed from News Nob (Reference 2). The SMOKY trenches were not used. The HumRRO tests were modified and conducted later in conjunction with the GALILEO shot. A complete description and analysis of the HumRRO test is provided in the GALILEO report (Reference 23).

2.5 PRE-SHOT OPERATIONS

2.5.1 Project 50.1 - Infantry Troop Test

The preparation of approximately 115 defensive positions (Phase I of the troop test) was accomplished on 12 and 13 August. This was in accordance with the scheduled shot date of 19 August. The prepared positions were inspected on 14 August, at which time communications equipment and weapons were installed in and around the positions. Figure 3 shows the locations of these positions, ranging from 820 to about 1850 meters to the west and north of ground zero. Reference 3

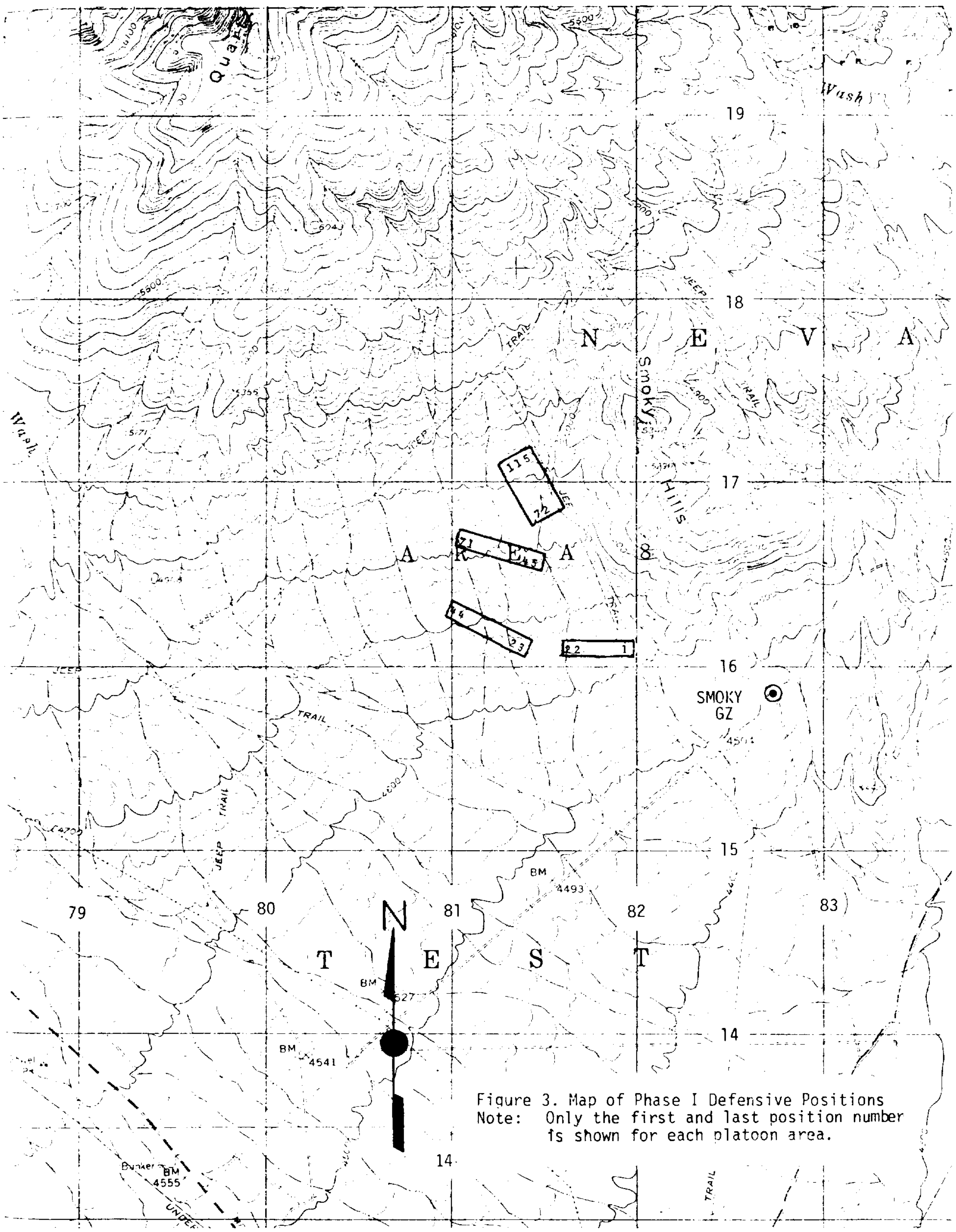

Figure 3. Map of Phase I Defensive Positions
Note: Only the first and last position number is shown for each platoon area.

states that a total of 7½ hours was devoted to digging the positions, and that only hand tools were used. Because the soil was quite rocky, as can be seen in Figure 4, the overall completion of the array was on the order of only 60 percent (Reference 4). The reference describes the digging as difficult, and the progress as slow. The reference also mentions that a "small quantity of sandbags were (sic) used." Two of the positions made use of sandbags, as shown for position #82 in Figure 4.

Because picks and shovels were used for digging, many of the large rocks could have been removed from the emplacement only by hand. Moreover, the larger rocks in the spoil would have required removal by hand in order to use the material to fill approximately 60 sandbags.

Based on the above, it is reasonable to conclude that the total time spent in the Phase I defensive area was approximately 12 hours, 7½ of which were spent in actual digging over a two-day period, while the remainder of the time was spent in moving to and from the transport vehicles (30 minutes each way from and to a central vehicle parking area) and for inspection and installation of communications equipment on the third day (1½ hours, plus 30 minutes each way for movement to/from the transport vehicles).

Other operations which would have preceded the actual maneuver most certainly included several practice exercises and terrain familiarization exercises, at least one of which would have included the entire task force. The likelihood of such practice is apparent when the anticipated press coverage of the event is considered. The week of 5-9 August was available for rehearsing. Prior to that time, the task force received training at Camp Desert Rock. In the week before the scheduled shot date (19 August), rehearsals were precluded by the Phase I activities and planned helicopter maintenance (References 3 and 4).

Reference 4 states that the task force participated in four rehearsals of alternate plans for the exercise. From this it can be inferred that both Plan A and Plan B were rehearsed for both the primary

Figure 4. Typical Phase I Defensive Positions
(U.S. Army Photographs)

and the alternate objective areas. Figures 5 and 6 show helicopter troop landing exercises conducted on 8 August 1957. These pictures were taken at landing zone ECHO (coordinates 779169) looking north and west, respectively. It is thus reasonable to conclude that the task force conducted a full-scale practice on 8 August in the vicinity of the primary objective area. Using the actual maneuver scenario in Reference 4 to determine the time required to air-land the entire task force (approximately one hour), it can be concluded that the task force occupied the primary objective area, where it rehearsed the airlanding and conducted a full-scale field exercise of the ground assault maneuver, for approximately four hours on 8 August, and again one other day in the week 5-9 August. It would hold that the task force occupied the alternate objective area in the Rhyolite Hills, where only the airlanding portion of the exercise would have been rehearsed, for approximately two hours on each of two other days that week. The stay times were based on the shot day scenario duration of some three hours. Less extensive rehearsing would have sufficed at the alternate objective area, where less news coverage was anticipated.

2.5.2 Other Pre-Shot Operations

All pre-shot operations were concluded by 16 August, the Friday before the scheduled Monday shot date of 19 August. SMOKY was then postponed to a date at least ten days subsequent to SHASTA, fired on 18 August. The delay did not afford the opportunity for any meaningful operations in the forward area, however. Additional rehearsals in the northern sector of Yucca Flat would have been severely restricted by the fallout from SHASTA. On 23 August, the task force witnessed Shot DOPPLER from trenches, but no troop maneuvers were conducted in conjunction with any other shot. The troops had observed other shots from News Nob, including STOKES on 7 August (as evidenced by U.S. Army photographs), in likely coordination with a rehearsal.

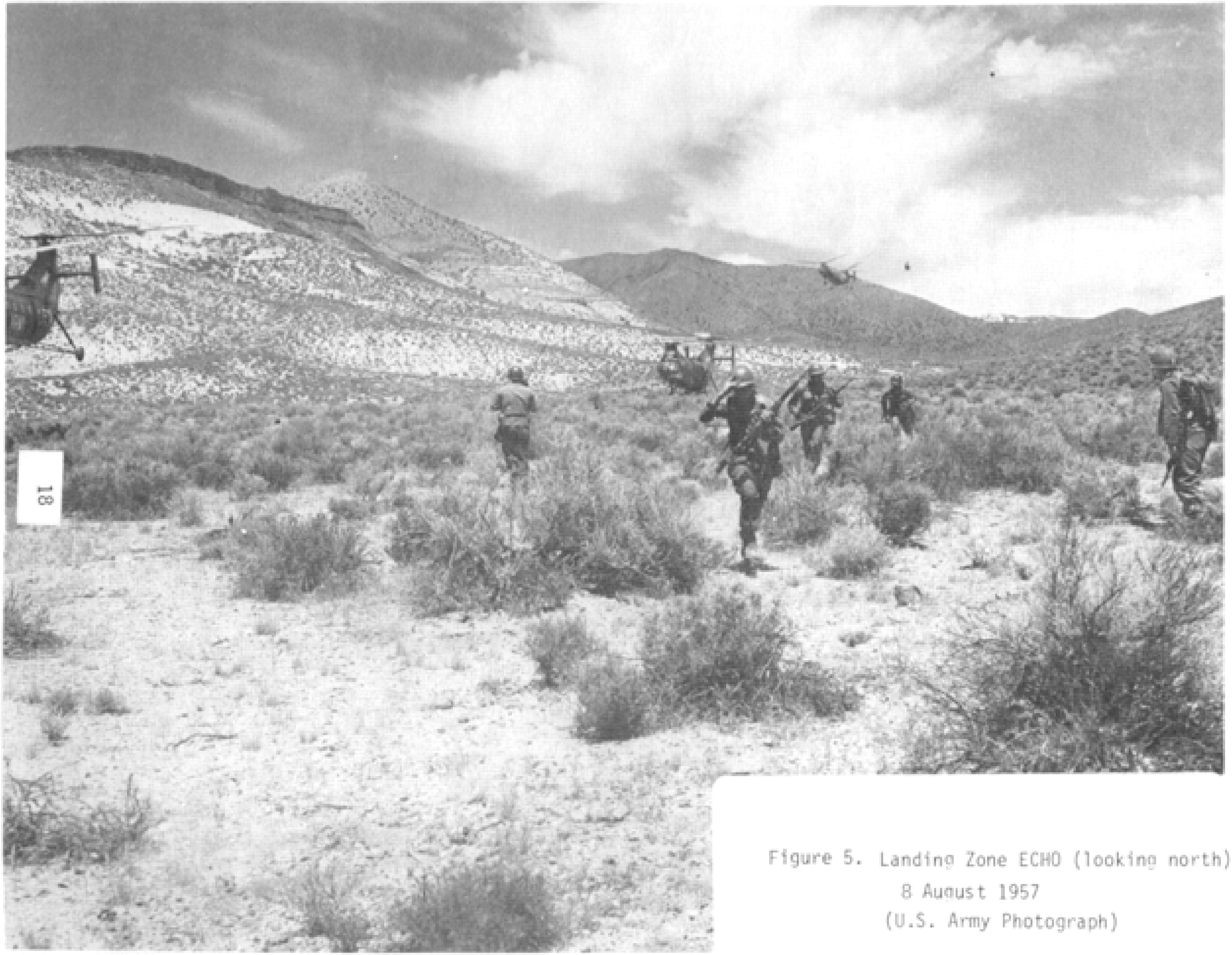

Figure 5. Landing Zone ECHO (looking north)
8 August 1957
(U.S. Army Photograph)

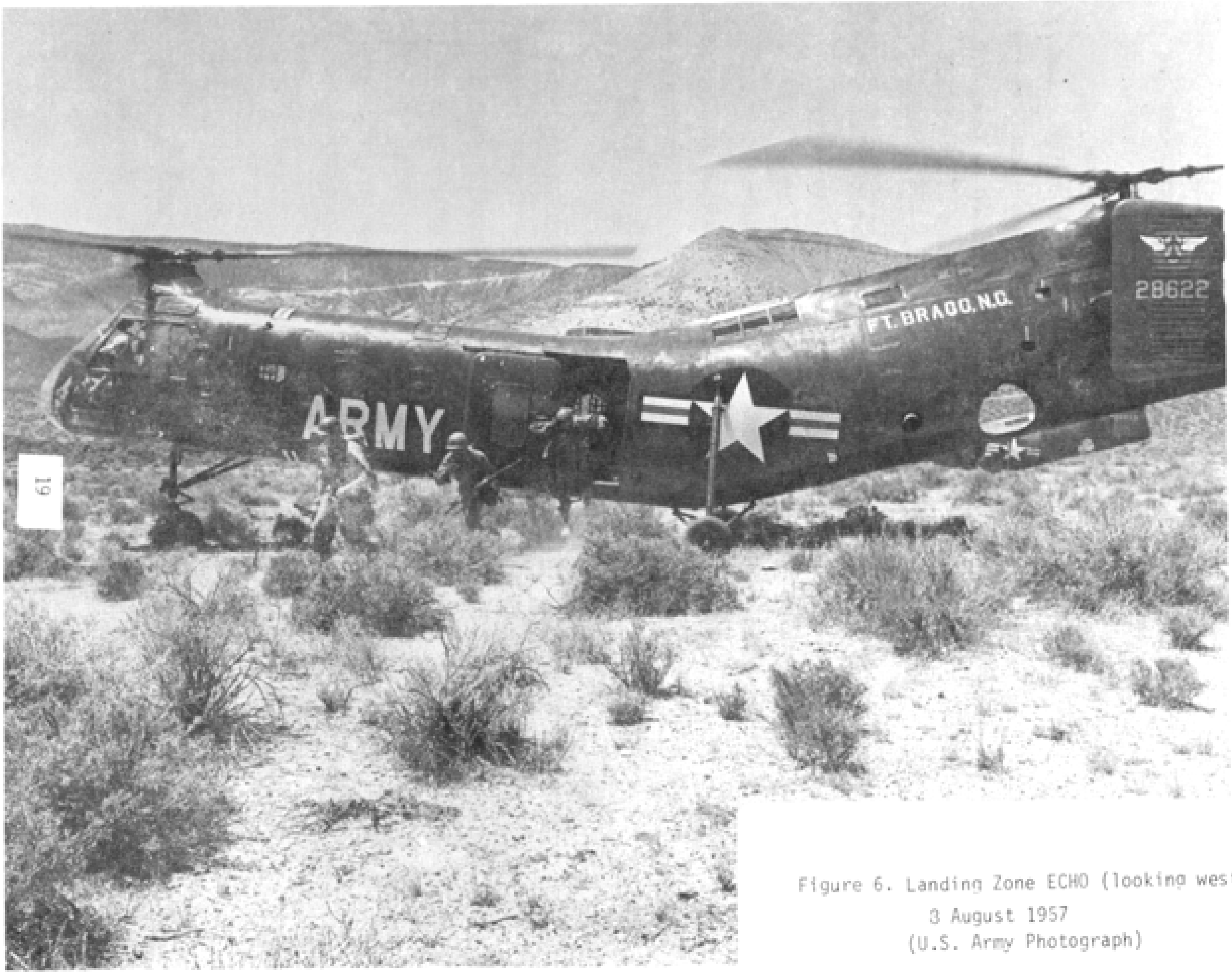

Figure 6. Landing Zone ECHO (looking west)
3 August 1957
(U.S. Army Photograph)

2.6 SHOT SCENARIO (References 3 and 4)

After several postponements, SMOKY was fired at 0530 on 31 August 1957. Due to the expected fallout direction, Task Force WARRIOR and observers witnessed the shot from the vicinity of coordinates 757044, approximately 7.5 miles SSW of ground zero, in accordance with exercise Plan B. The main body of troops had left Camp Desert Rock by 0100 hours and were in the observer area by 0330. During this pre-shot period, Pathfinders and all helicopters were positioned in the helicopter assembly area on the south side of the saddle between Yucca Flat and Frenchman Flat, approximately 20 miles south of GZ and about two miles south of News Nob. Task Force BIG BANG, consisting of the Provisional Company of the 82nd Airborne Division, observed the shot from News Nob.

After the shot, the Pathfinders boarded the helicopters for airlift to the primary objective area. Radiological safety (Rad-safe) personnel accompanied the Pathfinders, arriving at landing zone (LZ) ECHO at 0617, approximately 5000 meters WNW of GZ (see Figure 2). From the landing zone, the Pathfinders and accompanying Rad-safe personnel fanned out to sweep the landing zone. Within 12 minutes, the sweep was complete and the airhead area was declared safe (radiation intensity less than 100 mr/hr) for the landing of TF WARRIOR.

During this period, the task force personnel boarded their vehicles and moved to the helicopter loading area, some 2000 meters SW, where they met the aircraft as they arrived from the helicopter assembly area. The first serial, consisting of the 2nd Platoon, loaded and departed, arriving at LZ ECHO at 0715. Upon landing, the platoon immediately secured the high ground (Elev. 5055 ft) of Objective P4, where it then prepared for the final ground assault on Objective 2B, a shoulder of Quartzite Ridge. At objective P4, the platoon was approximately 4100 meters (2.5 miles) west of SMOKY GZ.

The second serial, consisting of the 3rd Platoon, landed at 0716, one minute after the first serial. It secured the high ground (Elev. 5303 ft) of Objective P3 at 0740, where it then prepared for the final ground assault on Objective 2A, the southern end of Quartzite Ridge. At Objective P3, the platoon was approximately 4700 meters (2.9 miles) northwest of ground zero.

Both the 2nd and 3rd Platoons remained on Objectives P4 and P3 until they were relieved by the 4th Platoon. The platoons then began the ground assault of Objective 2.

The third serial, consisting of the 1st Platoon, arrived at the airhead at 0718. It landed in two elements on high ground of Objective P2, overlooking Whiterock Spring, at the approximate elevation of 5100 feet, and the high ground of Objective P1, 1200 meters to the south, at elevation 4955 feet. The platoon remained at these locations, 5200-5600 meters west of ground zero, until exercise termination at 0945.

The fourth serial, the Weapons Platoon, arrived at LZ ECHO in two increments. The first increment landed at 0723 and the second increment landed at 0732. It may have moved slightly eastward after landing to support the assault of Objective 2, but likely remained in the general vicinity of LZ ECHO, 4600 meters from ground zero, until exercise termination.

The Canadian Army Platoon arrived in the fifth serial. It landed on LZ HOTEL at 0740, 6000 meters WNW of ground zero. It then occupied Objective QUEEN, about 500 meters to the north, and the reconnaissance and security (R&S) positions on or near Twin Peaks, 1000-1500 meters to the north, at 0800. It remained in these positions, 6000-6600 meters NW of ground zero, until exercise termination.

The sixth serial, consisting of the Reconnaissance Platoon, an engineer squad, and Patrols #6 and #7, landed some elements on or near the road west of Whiterock Spring at 0745. These units secured the road and occupied two southern R&S points overlooking the road, 6500 meters west of ground zero, until exercise termination.

The seventh serial, consisting of the 4th Platoon and the medical detachment, landed at LZ ECHO at 0746. The medical detachment may have remained in this vicinity, while the 4th Platoon split into two segments to relieve the 3rd Platoon on Objective P3 and the 2nd Platoon on Objective P4. The relief was complete by 0818. The platoon remained at these positions while the 2nd and 3rd Platoons assaulted Objective 2 on Quartzite Ridge.

The eighth serial, the Mortar Platoon, arrived at LZ ECHO at 0757. Three aircraft from this serial did not arrive until 0815, having landed initially at LZ HOTEL. It is unlikely that this platoon moved any significant distance from the landing site. Rather, it probably remained in the general vicinity of task force headquarters near LZ ECHO, where it emplaced its 4.2" mortars for the general support of the final assault on Objective 2.

The ninth and last serial brought in the task force headquarters and the communications detachment. It landed at ECHO at 0814. Task force operations were controlled from this command post, established on the northern side of the landing zone, 5000 meters from ground zero, until exercise termination at 0945.

It should be noted that several VIP observers were with TF WARRIOR at shot time and flew to the objective area early in the airlift to observe the landing operations and the securing of the airhead. Figures 7 and 8 show the observer area as being established near Objective P1, where subsequent operations in LZ ECHO could be observed. Although there is no documentation to verify their arrival or their stay in the objective area, as many as 40 VIP observers may have observed the entire operation from this point, arriving with the first serial at 0715 and departing after exercise termination.

The final assault on Quartzite Ridge (Objective 2) began at 0830 after the 4th Platoon relieved the 2nd and 3rd Platoons on Objectives P4 and P3, respectively. The assault would have taken the platoons on a northeast azimuth that would have been no closer than 3500 meters to ground zero for the 2nd Platoon, and 4500 meters for the 3rd Platoon. The references state that the assault was halted at 0915 by the authority of accompanying rad-safe personnel before the

Figure 7. VIP Observers in Objective Area
31 August 1957
(U.S. Army Photograph)

Figure 8. VIP Observer Area on Objective P1
31 August 1957
(U.S. Army Photograph)

objective was fully secured. The extent of fallout patterns, however, (Figure I-9) indicates that rad-safe criterion should not have been a factor in halting the advance, if the path of the assault was as planned. Because the planned path of direct assault would have encountered some very steep slopes, the assault may have deviated to the south and east. This excursion could have led the 2nd Platoon toward the SMOKY fallout field where residual radiation levels were sufficient to cause rad-safe to halt the attack. The significance of this is discussed in Section 6.3.1.

Immediately after transporting the task force to the objective area, the H-34 helicopters engaged in an aerial resupply mission from the aerial supply distribution point to the objective area. Three sling loads, totaling about 2½ tons of water and simulated ammunition, were delivered between 0757 and 0818 hours on an automatic basis. An additional six tons were delivered at the request of the task force commander between 0829 and 0940, at which time all requests for additional supplies were denied in anticipation of the termination of the exercise.

The exercise terminated at 0945 on order of the battle group commander. Although there is no documentation of the post-termination activities, the troops likely returned to the same points at which they were landed. Return to Camp Desert Rock could have been by helicopter to the truck loading area near the observation point, or the trucks could have been brought up to the landing zone. In either case, the VIP observers could have been evacuated by helicopter while the main elements of the task force reassembled in LZ ECHO and LZ HOTEL. Most of the task could have been evacuated by 1100 hours. It is likely that the headquarters, commo detachment, and medical detachment remained at LZ ECHO until the 2nd and 3rd Platoons returned from Objective 2. Their return was probably between 1100 and 1115, at which time muster and equipment inventory would have been conducted. The entire area could have been evacuated by 1130 hours, although some of the supplies and slings may have been left for subsequent recovery on D+1.

2.7 POST D-DAY OPERATIONS

On D+1, a recovery party consisting of Camp Desert Rock personnel and helicopter battalion personnel flew into the objective area for the purpose of obtaining the slings and water cans that had been delivered to the task force during Phase III of the troop exercise. This effort would have required three helicopters and their crews, plus about 15 troops, to search the objective area, to load the slings, and to accomplish the hook-up. Approximately three hours would have been devoted to this exercise, two of which would have been in the objective area.

A necessary element of the exercise was the inspection of the Phase I defensive positions to determine the effects of the shot. This inspection was scheduled for D-Day or D+1 (Reference 4). There is no time or date record of this activity. Because of the possible high levels of contamination on these positions, a minimum one-day delay would have been required to permit the fallout contamination to decay to safe levels. On SMOKY D+2, Shot GALILEO was fired. Its northerly fallout would have restricted movement in the northern sector of Yucca Flat on 2 September. Film badges were turned in on 2 September. Hence, inspection of the defensive positions is assumed to have occurred on 1 September. The inspecting party, consisting of selected personnel from Task Force WARRIOR, likely flew to the general area by helicopter and remained on the ground for approximately two hours to record the damage to the positions and to recover weapons and equipment. Two helicopters and about 15 personnel would have been necessary for this effort.

Section 3

INITIAL RADIATION

3.1 SMOKY INITIAL RADIATION

Because the expected fallout necessitated the execution of Plan B, no observers were in the SMOKY trenches. Observers for Plan A would have consisted of the Provisional Company, 82nd Airborne Division (TF BIG BANG), plus approximately 50 VIP observers. For Plan B, TF BIG BANG witnessed the SMOKY event from News Nob while the VIP observers witnessed from the TF WARRIOR area, approximately eight miles from ground zero. The limit of 1 roentgen exposure extended to less than two miles (Reference 7). Thus, no initial radiation, defined as that radiation occurring within the first minute after burst, was received by any of the participants in the SMOKY event.

3.2 DOPPLER INITIAL RADIATION

Neither observation of SMOKY, nor of other Plumbbob shots from News Nob, resulted in accrual of initial radiation exposure. However, on 23 August, Task Force WARRIOR observed Shot DOPPLER from a trench system constructed on a line normal to a radius from ground zero at horizontal ranges between 2800 and 2900 meters. Figure 9 shows the shot area as well as the trench area used by the troops. Personnel of Task Force WARRIOR were exposed to both neutron and gamma initial radiation. This occurred in spite of the protection afforded by the trenches and was due primarily to the scattering of the radiation in the air above the trenches.

Estimation of personnel exposure in the trench system has been accomplished in two parts. First, the intensity and angular and energy-differential character of the neutron and gamma radiation immediately above the trench system were determined. Second, the radiation field above the trench system was used as a source to determine the exposure within the trenches themselves.

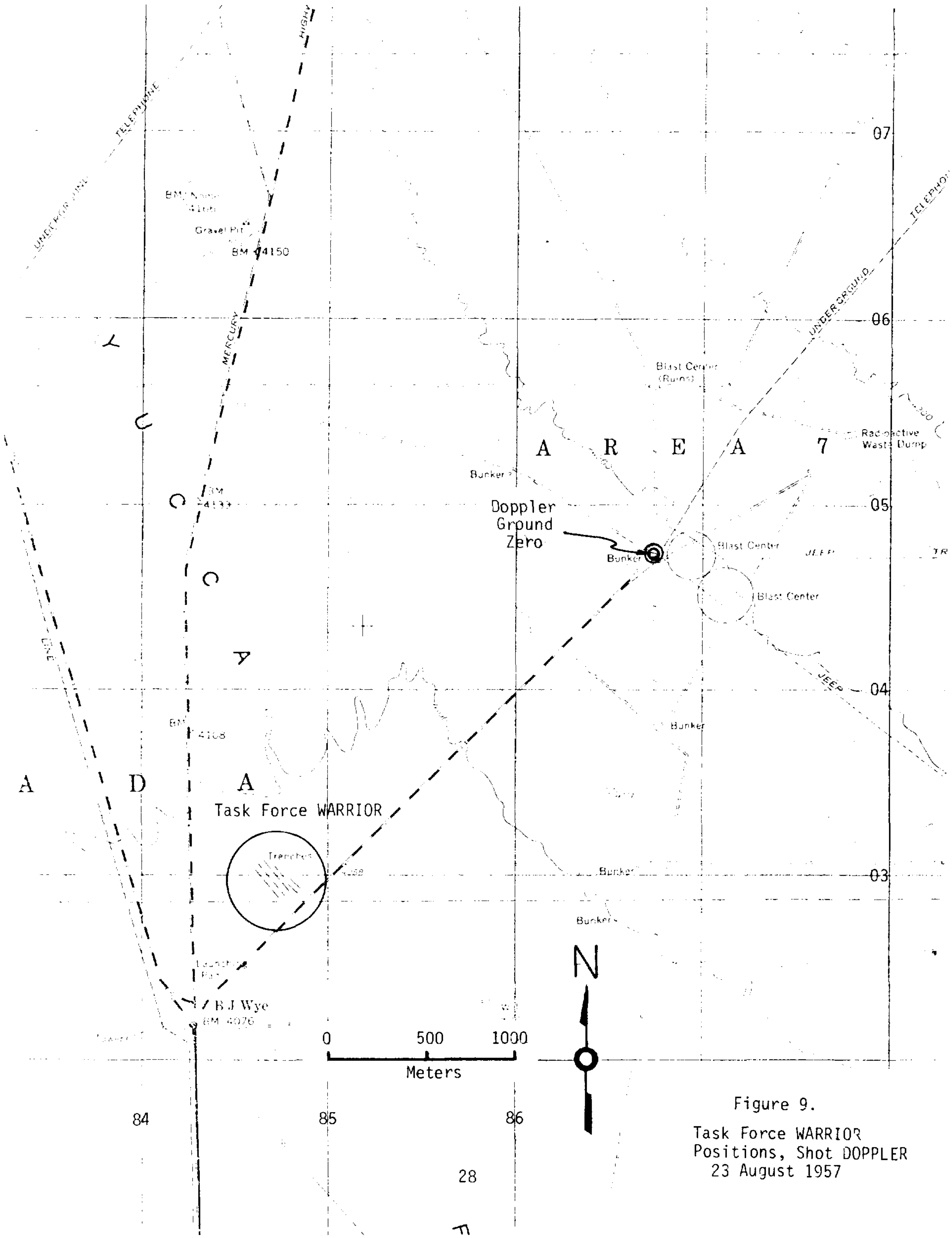

Figure 9.

Task Force WARRIOR
Positions, Shot DOPPLER
23 August 1957

The character of the neutron and gamma radiation fields produced by Shot DOPPLER was affected by the following parameters:

Blast Yield	11 kt
Height of Burst	457 m
Delta Elevation (GZ-Trench)	30 m
Effective Air Density	1.009×10^{-3} g/cc (Reference 9, 24)
Hydrogen Content of Dry Area 7 Soil	1.00×10^{-2} atom/b·cm (Reference 25)
Humidity (Relative)	48% at 22^{o}C (Reference 28)

Radiation field intensity and other characteristics were determined from these parameters for a location immediately above the trenches, using measured radiation fluence and dose data (Reference 8, 9) and the computer codes ATR4 (Reference 20) and ATR4.1 (Reference 26). These codes are data handling routines which contain the results of state-of-the-art calculations of neutron and gamma ray transport through infinite homogeneous dry air. They also contain factors for the adjustment of integral quantities, such as free-in-air tissue dose*, to correct for the presence of the ground. Gritzner et al. (Reference 27) have shown that the ground's hydrogen content has a significant effect on the propagation of neutron and neutron-induced gamma free-in-air dose. The data base used to prepare the ground correction factors for ATR4 has been generated using the hydrogen content of average Nevada soil (9.77×10^{-3} atom/b·cm), which is very similar to that of Area 7. Therefore, ATR4 was used to calculate the neutron and neutron-induced dose components for DOPPLER. An adjustment for the small remaining difference in soil hydrogen content was made according to the method and data presented by Gritzner, et al. (Reference 27). No similar

* The term free-in-air (FIA) tissue dose refers to the amount of energy absorption (in rads) in a small sample of tissue located at the point of interest. One rad is the deposition of 100 ergs of energy in one gram of the material of interest (tissue in this case).

compendium exists for adjusting transported neutron free-in-air dose values for variations in relative humidity. Omission of such adjustment will cause ATR4 to overpredict such dose values to an undetermined, but probably small degree. Prompt gamma ray and debris gamma ray fields are not sensitive to soil hydrogen content. Therefore, ATR4.1, which contains fully energy differential ground correction factors calculated for drier ground (1.75×10^{-3} atom/b·cm hydrogen), was used to calculate these components.

Calculated neutron and gamma ray integral intensities for Shot DOPPLER are shown in Figure 10, along with the results of neutron and gamma ray field measurements made at that event. Qualitatively, the agreement between calculated and measured values is quite good. In particular the slopes of calculated and measured neutron FIA dose values are well matched, indicating that the source spectra and ground hydrogen content used in the calculation are appropriate. However, the calculated neutron FIA dose consistently exceeds the measured value by approximately 35%. Since the probable uncertainty in the total neutron output of the device as used in the calculation probably exceeds that of the fluence field measurements, a best estimate of the FIA dose distribution for Shot DOPPLER has been obtained by normalizing the calculated neutron and neutron-induced gamma ray FIA dose using the neutron FIA dose values as interpreted from the measured fluences. The best estimate values are shown in Figure 11. Both the gamma ray and neutron calculated FIA dose values agree very well with the measured data. The good agreement between measured and calculated gamma ray FIA dose lends extra credence to the adjustment of neutron values.

The fully adjusted calculated values for FIA dose 1 meter above the trench locations are shown in the following table.

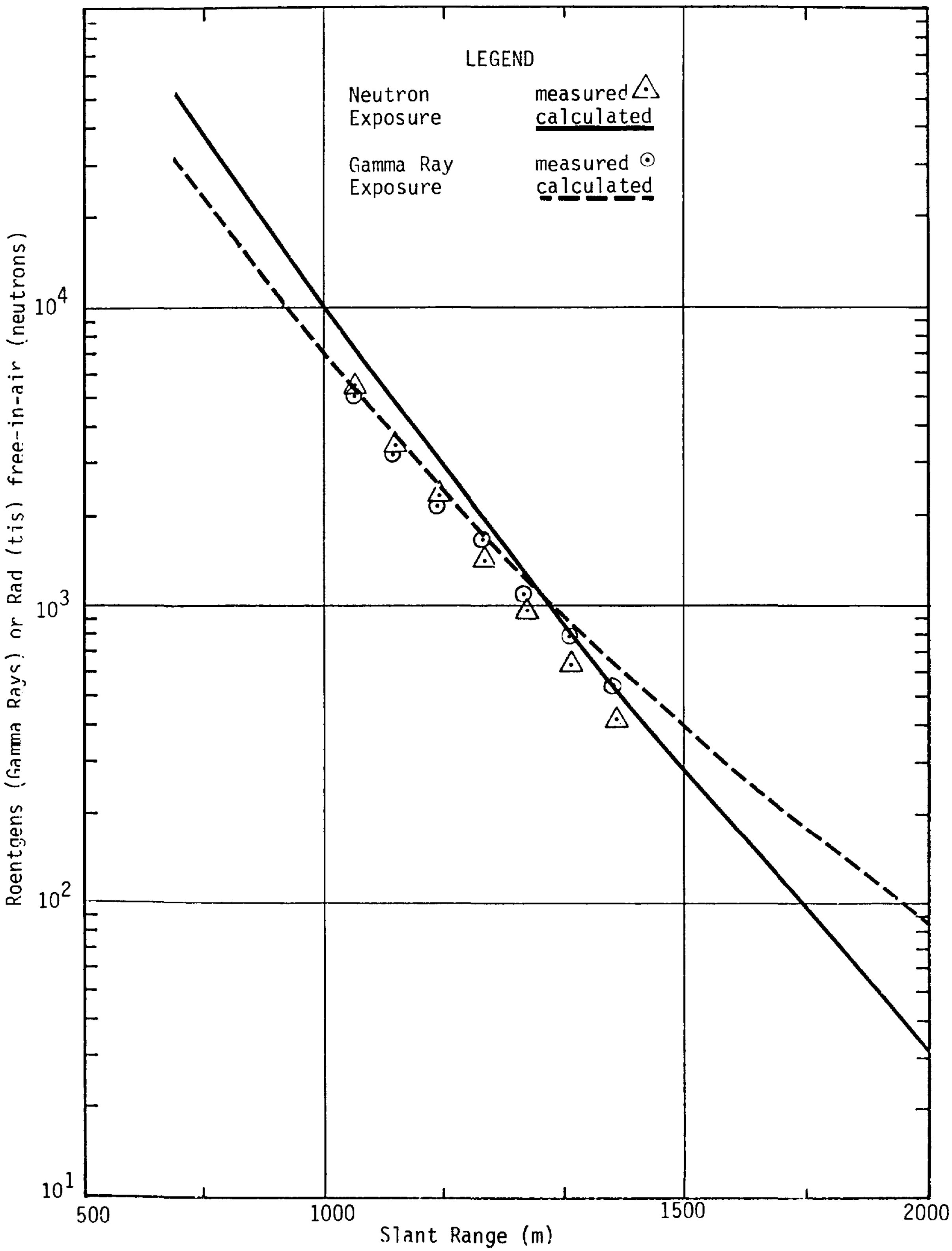

Figure 10. Measured and Calculated Neutron and Gamma Ray Exposure as a Function of Slant Range from Plumbbob Shot DOPPLER.

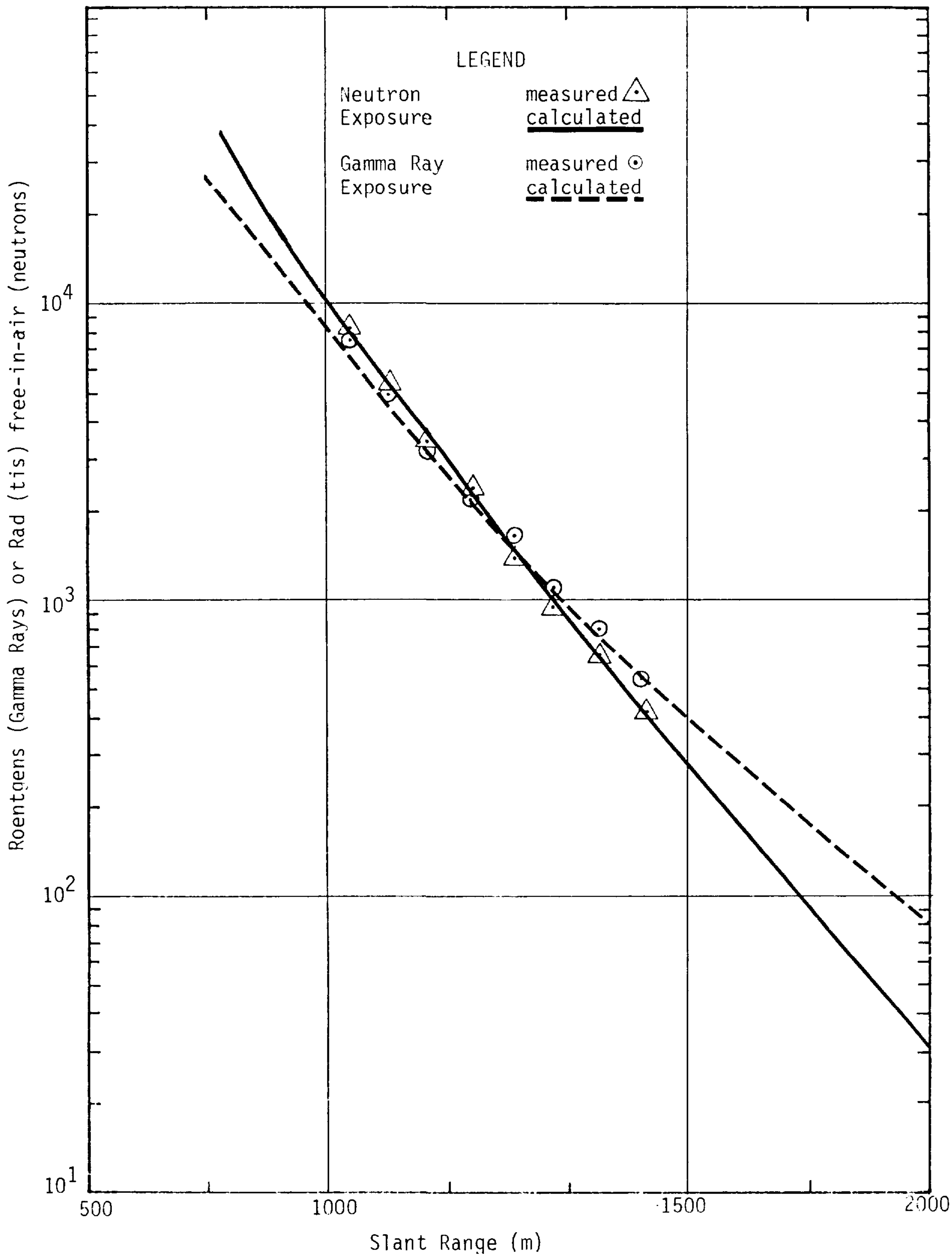

Figure 11. Best Estimate of Neutron and Gamma Ray Exposure as a Function of Slant Range from Plumbbob Shot DOPPLER with Comparison to Measurement

	Mean (Middle Trench)	Front Trench	Back Trench
Slant range (m)	2891	2842	2941
Neutron Rad (FIA)	.099	.125	.078
Gamma Rad (FIA)	1.24	1.40	1.12

As a check on the neutron values the measured neutron fluences were extrapolated using a semi-log fit to the r^2 fluence. The dose obtained by the approximation is .091 rad, which is in good agreement with the calculated value. The calculated value has been chosen as the FIA dose of record because it is considered to be the result of a more physically realistic method of extrapolation than the simple semi-log fit. However, the close agreement of the two values indicates that the uncertainty in the calculated value is probably on the same order as that of the measured data to which it is normalized (±25%).

The same test cannot be applied to gamma ray dose FIA values since it is well known that in the presence of neutrons such values do not behave as described by a strict semi-log fit. However, at the trench location the dominant gamma ray component is that generated by the neutrons. Therefore, it is unlikely that the uncertainty in the gamma ray FIA dose value exceeds ±50%, i.e., twice the neutron component uncertainty.

The energy and angle dependence of neutron fluence and gamma ray exposure have been estimated using a number of sources. First the energy dependence of the neutron fluence was estimated by extrapolating the measured fluences and normalizing the result using the integral FIA dose value (.099 rad(tis) @ 2891 m). The spectrum thus obtained is:

Neutron Energy Range		Neutron fluence (n/cm^2) at slant range = 2891 m
Thermal	(10^{-11} to 3.00×10^{-1} eV)	2.22×10^7
Epithermal	(3.00×10^{-1} eV to 10 keV)	6.80×10^7
Fast	(.010 to .63 MeV)	1.56×10^7
	(.63 to 1.5 MeV)	8.05×10^6
	(1.5 to 3.0 MeV)	5.03×10^6
	> 3.0 MeV	1.19×10^7
	TOTAL	1.31×10^8

The epithermal component was taken to be 52% of the total fluence as suggested by R. J. Smith et al. (Reference 9). Angular dependence of the neutron fluence was estimated using data reported by Straker (Reference 30). These indicate that, 1500 m from a bare fission source placed at 15 m above the ground, the downward directed components of the neutron fluence 1 meter above the ground are

Energy	% Downward Directed Fluence
Thermal	35
Epithermal	50
Fast (>.63 MeV)	71

The gamma ray spectrum was approximated by that of the combined prompt and neutron-induced components, transported through infinite homogeneous air.

Gamma Ray Energy Range (MeV)	Gamma Ray Fluence (γ/cm^2) at slant range = 2891 m
2×10^{-2} to 1×10^{-1}	1.08×10^9
1×10^{-1} to 2×10^{-1}	6.26×10^8
2×10^{-1} to 4×10^{-1}	3.18×10^8
4×10^{-1} to 8×10^{-1}	2.40×10^8
8×10^{-1} to 1.0	5.55×10^7
1.0 to 2.0	1.79×10^8
2.0 to 4.0	2.19×10^8
4.0 to 10.0	3.50×10^8

The gamma ray fluence angular dependence has been estimated using the DOPPLER geometry and the directional gamma ray dose calculated in infinite homogeneous air. Directional dose was used in order to weight most heavily that portion of the fluence producing the greatest dose. On this basis, approximately 54% of the total fluence was downward-directed.

All the above energy spectra and downward-directed components are merely estimates. No specific differential measurements or calculations have ever been performed for the combination of source characteristics and geometry of interest here. Consequently it was postulated that for both gamma rays and neutrons, the downward-directed component was spread uniformly over the lower 2π steradians. This treatment provides an upper limit for the dose in the trench. Any distribution of radiation peaked in the direction away from the shot would reduce the fluence into the trench.

Two methods have been chosen to characterize the radiation intensity within the trench. First, film badge reading equivalent values were calculated, using the response (energy differential sensitivity) of the Sn/Pb shielded DuPont Type 502 film badge in use at the time (References 13, 15). Calculations were performed using the MORSE Monte Carlo radiation transport code (Reference 22) together with a man phantom model developed previously for the Defense Nuclear Agency (see Appendix III). Troops in trenches are assumed to have remained at least 2 ft below the surface, in accordance with the SOP outlined in Reference 3. Thus, for the purpose of establishing a representative film badge equivalent reading for personnel within the trench the man phantom was positioned in a crouching position with its back 2 ft below the lip of the trench. This corresponds to a man of the size of the phantom bent 90° at the waist and standing in a 5 ft deep trench. This depth is consistent with the minimum trench depth cited in Reference 3. In order to gain some appreciation for the effect of position on the calculated badge reading equivalent value, calculations were also performed for the phantom upright, facing the length of the trench. In that case the phantom's head extends to within 14 in. of the trench lip, which violates the SOP. However, this position does allow the badge on the phantom's chest to remain at the same depth relative to the lip of the trench (2.6 ft), thereby permitting direct comparison of badge readings for body orientation effects. The average torso depth within the trench is expected to have been within six inches of that specified. Calculated film badge reading equivalents are:

	Representative Film Badge Reading (rem) for Personnel Following SOP	Badge Reading (rem) for Upright Phantom
Gamma Ray	.130(.12)*	.158(.12)
Neutron-Induced Gamma Ray	.003(.30)	.002(.35)
TOTAL	.133	.160

* Values in parentheses are fractional deviations of Monte Carlo Calculations.

Neutron-induced gamma radiation includes that produced in the walls of the trench and in the man himself. The contribution from direct neutron interaction with the badge is on the order of 10 percent of the neutron-induced gamma ray component and is hence neglected. The total value of 133 mrem has been chosen as the best estimate of the film badge reading equivalent of the Task Force WARRIOR exposure to initial radiation while observing Shot DOPPLER.

Actual exposure to individuals is difficult to characterize because of variations in protection afforded by increasing trench depth. Therefore, in addition to the film badge reading equivalent data presented above, exposure in terms of rad free-in-air for both neutrons and gamma rays have been calculated as a function of depth in an empty trench (L = 10 ft, W = 2 ft, D = 5 ft). These values are:

	Dose (Rad FIA)		
Depth (ft)	Neutron	Neutron-Induced Gamma	Gamma
1.0	.050 (.09)*	.004 (.40)	.430 (.07)
2.33	.020 (.10)	.003 (.40)	.225 (.09)
4.0	.012 (.17)	.002 (.50)	.115 (.12)

* Values in parentheses are fractional standard deviations of Monte Carlo Calculations.

The 2.33 ft location corresponds to that of the midline of the torso of the man phantom in the representative personnel position described above. Therefore, the dose at this depth has been chosen to represent the actual exposure of Task Force WARRIOR personnel. Of course extremities extending above this depth would receive a higher dose while the lower extremities would receive less.

Available data, such as those summarized in the report, "Radiobiological Factors in Manned Space Flight" (Reference 29) and the later "Biological Effects of Ionizing Radiation (BEIR) Report" (Reference 31), indicate that there is a difference in the biological consequences between radiation with high energy transfer per unit path length (LET)* and that with low LET. The heavy charged particles set in motion by neutron interactions are attributed a high LET. The gamma rays and the electrons that the neutrons set in motion have relatively low LET value. The measure of this overall effect is the relative biological effectiveness (RBE) of the radiation, which uses as a standard X-rays of approximately 250 keV energy. The RBE for gamma rays is commonly accepted as unity.

The available data on RBE for neutrons are sparse. However, they indicate that RBE values vary with radiation intensity and type of effect of interest as well as with LET. Because of this the term RBE has come to possess a large degree of ambiguity and even when properly defined has an uncertain value. Therefore, for the purpose

* LET is the abbreviation for "linear energy transfer."

of radiation protection, the neutron RBE has been replaced with the quality factor (QF). The National Committee for Radiation Protection (NCRP) (Reference 21) defines the QF as follows:

> quality factor (QF): A factor which is used in radiation protection to weight the absorbed dose with regard to its presumed biological effectiveness insofar as it depends on the LET of the charged particles. The quality factor is a function of the LET of the charged particles that deliver the absorbed dose. The charged particles traversing irradiated matter usually have a range of values of LET in which case the term then refers to the weighted average quality factor.

The QF has been calculated as a function of neutron energy and is presented in Table 1. Note that for the energies of interest, the QF can vary from 2 to 11. For the purpose of this study these point energy data have been converted into the energy group average data in Figure 12 and collapsed further into the energy groups as follows:

QF	Energy Range
2.0	Thermal (<.3eV)
2.1	Epithermal (.3eV $\leq$ E <10 keV)
8.0	Fast (.010 $\leq$ E < 0.63 MeV)
10.7	(0.63 $\leq$ E < 1.5 MeV)
9.7	(1.5 $\leq$ E < 3.0 MeV)
7.9	($\geq$ 3.0 MeV)

Dose equivalent values (in rem) given in this report have been calculated as recommended by NCRP, using the above quality factor data as follows:

$$\text{rem} = \sum_i \phi_i \times K_i \times QF_i$$

Table 1. Neutron Quality Factors As A Function of Energy

Neutron Energy	$\overline{QF}$
MeV	
2.5×10^{-8}	2
1×10^{-7}	2
1×10^{-6}	2
1×10^{-5}	2
1×10^{-4}	2
1×10^{-3}	2
1×10^{-3}	2
1×10^{-2}	2.5
1×10^{-1}	7.5
5×10^{-1}	11
1	11
2.5	9
5	8
7	7
10	6.5
14	7.5
20	8
40	7
60	5.5
1×10^{2}	4
2×10^{2}	3.5
3×10^{2}	3.5
4×10^{2}	3.5

Source: Reference 21

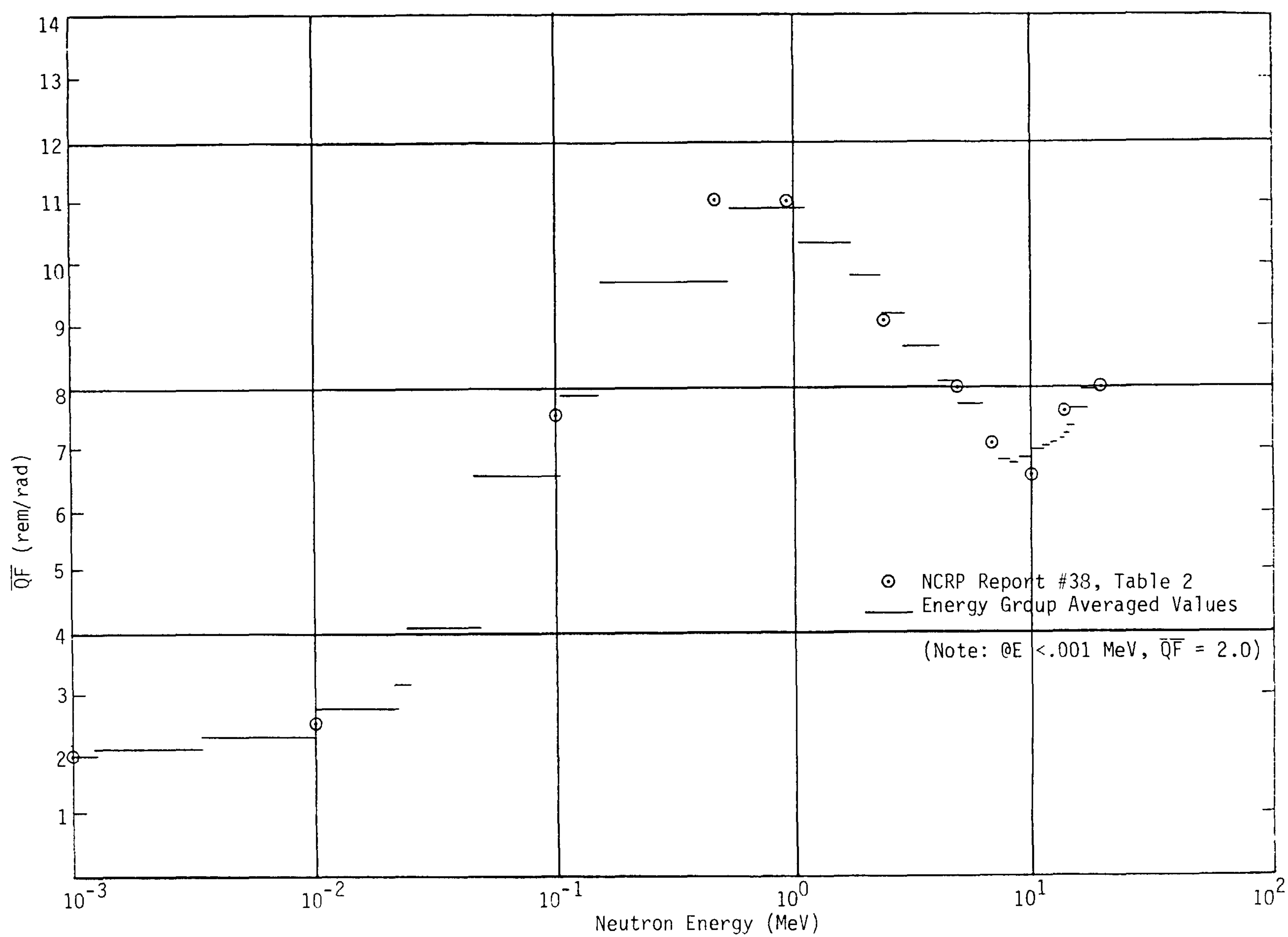

Figure 12. Energy Distribution of Quality Factor (QF)

where the dose in rem is equal to the sum over all energy groups i of the product of the fluence ϕ (n/cm^2), the Kerma factor K (rads/(n/cm^2)) and the Quality Factor QF (rem/rad) for each energy group. The overall average quality factor may be determined as follows:

$$\overline{QF} = \frac{rem}{rad} = \frac{\sum_i \phi_i \times K_i \times QF_i}{\sum_i \phi_i \times K_i}$$

For the neutron environment immediately above the mean DOPPLER trench location, $\overline{QF}$ = 8.6. At a depth of 2.33 feet in the trench, the quality factor is close to the maximum. These values may be compared with the value of 5 given by the BEIR committee as an estimate of the RBE for neutron-induced leukemia based on the Japanese atomic bomb survivors.

The BEIR RBE estimate is based on relatively high neutron doses, i.e., between 1 and 100 rads, and reasonably uniform exposure across the extremities. In the case of DOPPLER personnel the neutron exposure was low, in the range of 10^{-2} to 10^{-1} rad and extremely nonuniform. At these low dose levels the studies of Katz (Reference 32) indicate that the neutron RBE for any specific biological effect may be an order of magnitude or more greater than it is in the high dose range. However, this is postulated on the basis of an apparent decrease in the effectiveness of the gamma rays relative to that of neutrons with decreasing dose levels. On the other hand, the nonuniform nature of the exposure may serve to reduce the total neutron interactions in the body by a large amount, thus offsetting the increase in RBE. Given this uncertainty as well as the interest in many radiation effects attendant to the WARRIOR exposure, results reported here are limited to exposure values in rad(tis) free-in-air and rem free-in-air, the latter being based on the uniquely definable, dose level independent, LET dependent approach set forth by NCRP. The in-trench dose in rem is as follows:

	Dose (rem-FIA)			
Depth (ft)	Neutron	Neutron-Induced Gamma	Gamma	Total
1	.411(.09)*	.004(.40)	.430(.07)	.845
2.33	.227(.10)	.003(.40)	.225(.09)	.455
4.0	.122(.17)	.002(.50)	.115(.12)	.239

*Values in parentheses are fractional standard deviation of Monte Carlo Calculations.

Note that the film badge reading equivalent value of 133 mrem calculated earlier accounts for less than one-third of the 455 mrem exposure at nominal trench depth. This is because of body shielding and the fact that the film badge is insensitive to direct neutron exposure.

Section 4

RESIDUAL RADIATION

4.1 SMOKY RESIDUAL RADIATION

The SMOKY fallout pattern generally followed the meteorological predictions. Lower segments of the cloud were seen to drift slowly to the southeast while the cloud top rose to above 35,000 feet and drifted due east at about 48 knots. Both the on-site (close-in) and off-site radiological measurements confirmed the visual observations. The Plan A observer area, the trench line and the infiltration course, none of which were used due to the expected fallout drift, were directly in the path of the cloud (Figure I-9). The levels of contamination at the infiltration course, 3400 meters SSE of ground zero, and the trenches, 4400 meters from ground zero, were on the order of 100 r/hr at H+1. Obviously, any occupation of the trench or infiltration course areas would have resulted in extremely high exposures. Thus, the decision not to use Plan A and the SMOKY trenches was indeed a sound one.

4.2 ESTIMATED RESIDUAL RADIATION EXPOSURE

The 14 shots prior to SMOKY, as well as SMOKY itself, are listed in Appendix I, Table I-1. The table notes that five shots produced insignificant fallout and one (Priscilla) resulted in fallout in the Air Force Gunnery Range to the east. Fallout from all others is depicted in the appropriate figures referenced in the table. Ground zeros for these shots are shown in Figure 1. It can be assumed that virtually any entry into the forward area, particularly the northern end of Yucca Flat, would have resulted in residual radiation exposure from previous shots. Accordingly, every Task Force WARRIOR activity conducted in the forward area is examined. For ease of analysis, the activities related to SMOKY are grouped as follows:

- Rehearsals of Phase II and Phase II Operational Plans, 5-9 August

- Preparation and inspection of Phase I Defensive Positions, 12-14 August
- Observation of Shot SMOKY, 31 August
- Execution of Phase II and Phase III exercises, 31 August
- Resupply equipment recovery, 1 September
- Post-shot inspection of Phase I Defensive Positions, 1 September

For each of the above activities, the radiation fields encountered during the activity are now examined.

4.2.1 Rehearsals

The rehearsals of operational plans for Phase II and Phase III of the Infantry Troop Test were accomplished during the week of 5-9 August 1957 (discussed in Section 2.5). The loading areas for both Plan A and Plan B were used in the airlift of Task Force WARRIOR to both the primary and alternate objective areas. Of the four possible variations of the airlift maneuver, two would have included the ground assault field exercise in the primary objective area. The Phase III resupply rehearsals were conducted in conjunction with the first two troop operation rehearsals. For the rehearsals, Task Force WARRIOR would have spent one to two hours (depending on the serial) in each helicopter loading area before boarding the helicopters for the lift to the objective area. Some four hours would have been required for a full-scale rehearsal in the primary objective area before evacuation back to the loading area, where ground transportation was waiting. Two hours in the alternate objective area for each rehearsal would have sufficed for this variation.

Fallout patterns from the following six shots could have impacted the rehearsal areas. They are now examined to determine their possible contribution to the radiation dose received during all the rehearsals of operational plans.

BOLTZMANN	(28 May)
FRANKLIN	(2 June)

WILSON	(18 June)
DIABLO	(15 July)
KEPLER	(24 July)
PASCAL "A"	(26 July)

The fallout patterns for these shots are shown in Figures I-1 through I-6, Appendix I.

The BOLTZMANN fallout (Figure I-1) impacted in the Plan A loading area, used for two task force rehearsals during 5 to 9 August. It also impacted on the primary objective area. From the decay conversion factors shown in Table II-6, the BOLTZMANN fallout intensities, adjusted to 7 August, were approximately .04 mr/hr (10 x .004) in the Plan A loading area and in the primary objective area. This is considered insignificant and need not be evaluated further.

The FRANKLIN fallout (Figure I-2) may have impacted on the Plan A loading area. Because this shot was a misfire, however, the H+12 intensity at Balloon Hill was probably no higher than 1 mr/hr. The decay conversion factor shown in Table II-6 is .004. The FRANKLIN fallout intensity at Balloon Hill, adjusted to 7 August, is insignificant and need not be considered further.

The WILSON fallout (Figure I-3) impacted on the helicopter loading areas for both Plan A and Plan B. From the decay conversion factors shown in Table II-6, the WILSON fallout intensities, adjusted to 7 August, were approximately .03 mr/hr (5 x .006) in the Plan A loading area and .06 mr/hr (10 x .006) in the Plan B loading area. These intensities are insignificant for the stay times involved and need not be considered further.

The DIABLO fallout pattern (Figure I-4) impacted on both the primary and alternate objective areas for the troop maneuver. From the decay conversion factors shown in Table II-6, the DIABLO intensities around 7 August were less than 1 mr/hr (<10 x .011) and about 3 mr/hr (300 x .011) in the primary and alternate objective areas, respectively, during exercise rehearsals. For the assumed stay time of two hours on each occasion in the alternate objective area, the estimated accrued exposure is 12 mrem.

KEPLER produced a fallout pattern (Figure I-5) that impacted on the troop loading area for Plan B, used for two rehearsals. From the decay conversion factors shown in Table II-6, the KEPLER fallout intensity, adjusted to 7 August, was approximately 5 mr/hr (200 x .027). Assuming a total stay time in the loading area of 2 hours for each rehearsal, the task force would have accrued an exposure of 20 mrem during 5 to 9 August in the KEPLER fallout field.

PASCAL "A" was a safety shot with some nuclear yield. The fallout was in the direction of Balloon Hill, but was sufficiently localized that it is extremely doubtful that any significant fallout reached the Plan A loading area. This is evidenced by inspection of Figure I-6. No further evaluation of this dose is necessary.

4.2.2 Defensive Positions

The Phase I defensive positions were prepared on 12 and 13 August, and inspected on 14 August. The task force spent 12 hours in the preparation and inspection of these positions, as well as in moving to and from the specific positions and the ground transport vehicles. The total exposure is determined by the technique described previously. Inspection of dose rate contours shows that Shots BOLTZMANN and DIABLO contributed to the fallout intensity in the defensive position area. The following chart shows the factor used to convert each intensity ($\dot{D}$ in mr/hr) to 13 August, as well as the estimated exposure of the task force for the period 12-14 August:

Shot	$\dot{D}_{12}$	f	$\dot{D}$ (13 August)	Dose (mrem)
BOLTZMANN	300	.004	1.2	14
DIABLO	2400*	.009	22	260

*For those positions prepared closer to the hot line, this rate could have been 30 percent higher. This would apply particularly to positions 1-22 (Figure 3).

4.2.3 Shot SMOKY

Task Force WARRIOR witnessed Shot SMOKY from the Plan B observation area on 31 August. They arrived at the observer area at approximately 0330. The stay time, until the troops boarded the helicopters for airlift to the objective area, was 3½ to 4½ hours. Inspection of all significant fallout contours shows that Shots WILSON and KEPLER contributed to the residual intensities in the observer area. The earlier discussion of the WILSON contribution showed it to be insignificant for the exercise rehearsals; hence, at times subsequent to the rehearsals, the intensity remains insignificant. The KEPLER fallout, shown in Figure I-5, had an H+12 intensity of 1000 mr/hr at the observation location on the north slope of the high ground, coordinates 760046. Using the conversion method described previously, the KEPLER H+12 intensity corresponds to an intensity of 8 mr/hr (1000 x .008) on 31 August. A stay time of approximately 4 hours yields a total estimated exposure of 32 mrem to Task Force WARRIOR personnel while observing Shot SMOKY. The troops received no radiation exposure from SMOKY itself during the observation phase.

4.2.4 Troop Maneuvers

The troop maneuver in the primary objective area on 31 August was discussed in detail in Section 2.6. The fallout from Shots BOLTZMANN, DIABLO, and SHASTA impacted on the primary objective area. The wind patterns on 31 August were such that fallout from SMOKY itself did not impact the maneuver area, as can be seen from Figure I-9. The fallout patterns from BOLTZMANN and DIABLO (Figures I-1 and I-4) were examined previously to determine the dose accumulated during the exercise rehearsals. SHASTA occurred on 18 August and FRANKLIN PRIME on 30 August, subsequent to the rehearsals. Their fallout plots are shown in Figures I-7 and I-8. Using the decay rates shown in Table II-6, the H+12 intensities are converted to 31 August. The following chart shows the conversion factors as well as the total estimated exposure of the maneuver elements for the period of the exercise.

Shot	$\dot{D}_{12}$	f	$\dot{D}$ (31 Aug)	Task Force Dose (mrem)
BOLTZMANN	10-100	.003	.3	Negl.
DIABLO	10	.005	.05	Negl.
SHASTA	1000	.033	33	116
FRANKLIN PRIME	Negl.	—	—	Negl.

The above exposures are based on an average stay time in the objective area of 3.5 hours for the task force. The calculations could be refined to provide exposures for each platoon-sized element, but such refinement is beyond the scope of the data reliability. The two platoons that assaulted Quartzite Ridge were moving toward the SHASTA hot line as well as that of the older DIABLO field. Their exposures could have been some 20 percent higher than the 116 mrem received by the main body of troops.

4.2.5 Equipment Recovery

The equipment recovery, assumed to have been accomplished on 1 September, is not documented. As discussed earlier, only a few helicopters and accompanying task force personnel would have been required to recover slings, water cans, and related matter. Because there is no way to identify the personnel involved in this activity, the exposure is not ascribed to the task force as a whole. The estimated exposure of 56 mrem is obtained from the H+12 SHASTA plot (Figure I-7), the conversion factor from Table II-6, and a stay time of two hours (1000 x .028 x 2). SMOKY itself did not contribute to this exposure.

4.2.6 Defensive Positions

The inspection of the Phase I defensive positions by selected personnel is assumed to have occurred on 1 September 1957, as described previously. The stay time of two hours is applied to the fallout fields of the four shots that contributed to the residual radiation in the area of the defensive positions, using the decay conversion factors from Table II-6. Of the four shots, SHASTA and SMOKY occurred subsequent to the preparation of the positions. Their H+12 intensities are 700 and 50 mr, respectively (Figures I-7 and I-9). The chart below shows the estimated exposure of selected task force personnel during this activity.

Shot	$\dot{D}_{12}$	f	$\dot{D}$ (1 Sept)	Dose (mrem)
BOLTZMANN	300	.003	1	2
DIABLO	2400	.005	12	24
SHASTA	700	.028	20	40
SMOKY	50	.50	25	50

Section 5

UNCERTAINTY ANALYSIS AND DETERMINATION OF TOTAL EXPOSURE

Because of the uncertainties of the parameters used in calculating the partial exposures in Sections 3.2 and 4.2, a rigorous treatment of all the sources of error is required. After the uncertainties are determined, the total exposure of Task Force WARRIOR can be assessed.

5.1 RESIDUAL RADIATION EXPOSURE

Determination of the residual radiation exposure for Task Force WARRIOR (made independently of film badge data) has the following sources of error: (1) fallout plot intensities, (2) location of a troop activity, (3) fallout decay rates, (4) troop arrival time at an activity, and (5) duration of an activity. These arise because residual radiation exposure, as calculated for each troop location or activity, is the product of the exposure rate (normalized to H+12) as a function of position; decay (since H+12) as a function of time; and duration (stay time) at a given position.

For purposes of comparison and calculation, errors are expressed as multiplicative factors which arise from the exponential character of decay rates and fallout field intensity variations. All are expressed in terms of a 90 percent confidence limit.

As discussed in Appendix I, the fallout plot intensities have an error factor of 1.46 in the region in which data was collected. Error in the interpolated region between on-site and off-site data points cannot be as precisely assessed. There, error estimates are based on what variation in fallout level would result from shifting the interpolated (dashed) contours to the estimated limit of consistency with on-site and Program 37 contours. Fallout intensities between contours are computed by logarithmic interpolation, except across the hot line, where the Gaussian fit of Appendix I is applied.

The position of an activity may be imprecisely known owing to a dearth of documentation or because of troop movement during the activity. For most activities, troop elements were located in a set of discrete positions. In these cases, a distribution of exposure around the mean exists, rather than an error of the mean. The exposure is computed for troops in the hottest positions as well as that for the "average" troops.

The decay curve for a particular shot may be treated as exact to the extent that the measured fallout decay is representative of the entire fallout field for that shot. Because insufficient information exists to evaluate the assumed independence of decay rate with position and the accuracy of the decay plots of Reference 11, the presumably small errors associated with these will be neglected. All decay curves except for Shot SHASTA have at least partial reliance on Plumbbob Composite decay. Therefore, all other shots have an associated decay error that arises from that mean decay. An assessment of the variation in decay of the shots comprising Plumbbob Composite, together with the observation that the variation is minimally dependent on the duration of Plumbbob Composite decay utilization, yields an error factor of 1.3. This applies to all shots except SHASTA for the fallout intensity on the dates of troop activities.

Error resulting from impreciseness of troop arrival time in a fallout field is minimal. Because the activities were conducted some two weeks or more after shots yielding the fallout, even the day-to-day decay during extended exercises never exceeded 10 percent. Consequently, error from this source can be disregarded.

The error in duration of an activity can range from zero for precisely logged events to a substantial value for inferred activities. When durations are not precisely known, their uncertainties are estimated in accordance with sound military judgment.

As may be seen from Section 4.2, exercises in the DIABLO fallout field on 12-14 August and in the SHASTA field on 31 August resulted in nearly all the residual gamma exposure of the troops. The error factors for each are displayed below:

	Fallout Field on Dates	
Source of Error	DIABLO 12-14 Aug	SHASTA 31 Aug
Fallout plot intensities	1.46	1.46
Fallout plot interpolation	1.3	1.3
Mean troop position	1.0	1.0
Decay rate	1.3	1.0
Duration of activity	1.25	1.15
COMBINED ERROR FACTOR	1.78	1.62

The error factor providing 90 percent confidence limits for the geometric mean of the DIABLO exposure is computed as follows:

$$\text{error factor} = \text{antilog}\left[(\log 1.46)^2 + 2(\log 1.3)^2 + (\log 1.25)^2\right]^{1/2}$$
$$= 1.78.$$

For the smaller contributions to the total exposure, the error factors are not far from the above and need not be displayed.

In order to sum the estimated exposures from separate activities, the geometric (lognormal) error distributions are approximated by arithmetic (normal) distributions. For the magnitude of the error factors calculated, the arithmetic mean is slightly greater than the geometric mean. In addition, symmetric error bands are approximated to assist in the error determination of the total exposure. For DIABLO and SHASTA this yields approximately 280 ± 150 mrem and 130 ± 60 mrem, respectively. For the smaller contributions to the total dose, the correction to the mean is insignificant.

The arithmetic mean dose (to the nearest 10 mrem) from each activity and the totals are summarized in Table 2. For the troops,

$$\text{total dose} = (280\pm150) + (130\pm60) + (30\pm15) + (20\pm10) + (20\pm10) + (10\pm5)$$

$$= 490 \pm (150^2 + 60^2 + 15^2 + 10^2 + 10^2 + 5^2)^{1/2}$$

$$= 490 \pm 160 \text{ mrem.}$$

Those troops in the hottest areas of the DIABLO and SHASTA fields would have been subject to an estimated additional 30 percent from DIABLO and 20 percent from SHASTA, for a total of 600 ± 220 mrem.

5.2 INITIAL RADIATION EXPOSURE

The sources of error in the determination of the initial radiation exposure in the DOPPLER trenches include: (1) the calculation of the radiation field above the trenches, (2) the downward-directed fraction of that field, (3) the assumed angular independence of that down-directed component, (4) the statistical uncertainty of the Monte Carlo calculation, (5) the assumed torso depth within the trench, (6) the specified torso orientation, and (7) the truncation of the trench at a ten-foot length. The magnitude of the uncertainties in these quantities is stated or implied in Section 3.2.

Error factors, expressed in terms of 90% confidence limits, are displayed below for γ (film badge equivalent), γ (free-in-air), and n (free-in-air).

Source of Error	γ(badge)	γ(free)	n(free)
Field above trenches	1.5	1.5	1.25
Downward-directed fraction	1.1	1.1	1.1
Angular independence (upper	1.0	1.0	1.0
Angular independence (lower	undetermined	undetermined	undetermined
Monte Carlo calculation	1.20	1.15	1.17
Torso orientation (upper only)	1.1	1.0	1.0
Truncated trench (upper only)	1.1	1.1	1.1
COMBINED ERROR FACTOR (upper only)	1.69	1.65	1.46

TABLE 2. SUMMARY OF CALCULATED RESIDUAL RADIATION DOSE (mrem) FROM ACTIVITIES CONDUCTED IN CONNECTION WITH SHOT SMOKY

RESIDUAL DOSE (mrem)		ACTIVITY a Rehearsals (5-9 Aug)	b Phase I Preparation (12-14 Aug)	c Witness SMOKY (31 Aug)	d Phase II, III Exercises (31 Aug)	e Equip. Recovery (1 Sep)	f Phase I Inspect (1 Sep)	TOTALS
SHOT								
BOLTZMANN		—	20	—	—	—	—	20
FRANKLIN		—	—	—	—	—	—	—
WILSON		—	—	—	—	—	—	—
DIABLO		10	280	—	—	—	(30)*	290
KEPLER		20	—	30	—	—	—	50
PASCAL "A"		—	—	—	—	—	—	—
SHASTA		—	—	—	130	(60)*	(40)*	130
FRANKLIN PRIME		—	—	—	—	—	—	—
SMOKY		—	—	—	—	—	(50)*	—
GALILEO		—	—	—	—	—	—	—
TOTALS	TF Troops	30	300	30	130	(60)*	(120)*	490

*(doses in parentheses are ascribed to an unidentifiable subgroup).

The error factors on the lower side are at least as great as the above values of combined error factor. Therefore the lower error bands stated below are underestimated.

In order to combine the estimated initial radiation dose (455 mrem free-in-air, 133 mrem film badge equivalent) with other exposures accrued by Task Force WARRIOR, the geometric error distributions are converted to arithmetic distributions. The resultant adjusted mean values and associated symmetric 90 percent confidence limits for the initial radiation dose are 480 ± 220 mrem for total free-in-air dose and 140 ± 75 mrem for the film badge equivalent.

5.3 TOTAL EXPOSURE

The total free-in-air dose estimate for Task Force WARRIOR is 970 ± 270 mrem, determined from summing the above initial dose of 480 ± 220 mrem and the residual contribution of 490 ± 160 mrem calculated in Section 5.1. The film badge equivalent, determined in part by the conversion factor of .70 for residual gamma radiation (discussed in Section 6 and Appendix III), is 480 ± 135 mrem.

Section 6

FILM BADGE DOSIMETRY

6.1 EXPOSURE CORRECTIONS TO FILM BADGE EQUIVALENCE

Traditionally, film badge readings have been assumed to nearly approximate whole body radiation exposures. More specifically, a film badge worn on the front of the upper body had been assumed to indicate a 5 cm depth dose to the wearer; that is, the body shielding of radiation from the rear is offset by the lack of body shielding of radiation from in front of the wearer. Because of the potential importance of all traditional assumptions, the above approximations were analyzed specifically for the SMOKY study. The results of the analysis are provided in Appendix III.

The residual radiation intensities calculated in Sections 4.2 and 5.1 are given in terms of rem, a measure of free-field tissue dose. The exposures so obtained, therefore, cannot be compared directly to film badge readings where body shielding affects the exposure recorded by the wearer's film badge. A correction factor of 0.70, obtained from Appendix III, is applied to the calculated doses to permit direct comparison with film badge readings.

For the initial radiation intensities calculated in Section 3.2, there is no generally applicable correction factor. An independent calculation of film badge equivalent was required. The ratio of dose to its film badge equivalent is dependent on the neutron/gamma ratio, anisotropy of the radiation field, and geometry of the body-in-trench configuration. As mentioned in Section 3.2, the film badge is very insensitive to neutrons.

6.2 FILM BADGE DATA

The data set for Task Force WARRIOR was obtained by direct examination of the Lexington-Blue Grass Army Depot film badge records. Not only was a complete and accurate set obtained thereby, but a critical evaluation of the data was also afforded. Some difficulties were noted in categorization of the film badge records. For 22 badges which were lost, an "integrated reading" was assigned as a dose. It appears that these doses were assigned on some basis other than the task force average for the badge period, for they almost invariably exceed it substantially. Consequently, these doses were disregarded in the statistical analysis. Another incongruity among the film badges was the lack of a uniform badge period. Only equivalent badge periods warranted direct comparison of the readings. Some task force subgroups had differing periods generally, and several individuals had anomalous badge periods, sometimes including overlaps, for such reasons as late arrival at Camp Desert Rock or early departure therefrom, a lost previous badge, a suspected significant exposure, and absence during regular film badge exchanges.

Most of the 603 individuals in Task Force WARRIOR were issued two film badges. The predominant periods were from 25 or 26 July to 27 August 1957 and from 27 August to 2 September 1957. Subgroups with differing intervals were task force headquarters personnel (24 July to 14 August and 14 August to 2 September) and the Canadian platoon (25 July to 20 August and 20 August to 2 September). In all cases, the second period included SMOKY. More than 90 percent of the periods shown on the film badge records correspond to one of the above periods.

As discussed in Section 4.2, the dose estimates for Task Force WARRIOR were made assuming no distinction among the subelements (such as platoons). Other than as noted above, the film badge records do not contain subelement affiliation, and at this time there appears to be no means to identify such affiliation. The film badge data therefore are presented as a single group within a particular badge period. It is apparent from the distribution of readings, however, that distinct components may be present.

Shown in Figure 13 is a two-dimensional plot for those cases having records for at least one of the predominant periods (ending or starting on 27 August). The first row and column of the plot correspond to zero readings and disqualified film badges. The zeroes include those readings which are not above the film badge threshold (about 25 mrem). Disqualified records include those badges described as blank, lost, not turned in, light struck, damaged, or opened. Badges not closely corresponding to the other period fall into this group as well. Two clusters are evident in this plot. Their statistical characteristics are as follows:

Cluster	No. of Cases	Mean* and Standard Deviation of Readings 25 July - 27 Aug.	27 Aug. - 2 Sept.
1	387	390 ± 150	185 ± 60
2	20	405 ± 130	1140 ± 150

* In determining the mean, any case with a disqualified badge or a subthreshold reading was disregarded.

Figure 14 depicts the distribution of readings for each period separately. The figure clearly shows that, for the majority of cases, the first period readings were usually about double those for the second period covering the SMOKY maneuvers. There are exceptions to this, the most prominent of which is the cluster of 20 cases referred to above for which the second period reading was about three times the first period reading.

6.3 INTERPRETATION OF FILM BADGE DATA

Several conclusions can be drawn from the film badge data independently of a quantitative comparison with exposure estimates. The presence or absence of accrued doses in various film badge periods can help supplement the knowledge of what activities transpired in Yucca Flat. Furthermore, the distribution of readings permits inferences to be drawn concerning the uniformity of troop movements.

Reading (mrem) 25 Jul - 27 Aug \ Reading (mrem) 27 Aug - 2 Sep	Sub-threshold or Disqualified	0–100	100–200	200–300	300–400	400–500	500–600	600–700	700–800	800–900	900–1000	1000–1100	1100–1200	1200–1300	1300–1400	1400 +
1000 +			1(1040)													
900–1000																
800–900																
700–800	1		3		1											
600–700	6		9	12												1(2000)
500–600	6	4	46	43	3							1	2		1	
400–500	21	5	47	32	4					1		1	1	1		
300–400	16	2	42	23	1						1	1		1	2	
200–300	23	5	47	9	2								1	2		
100–200	19	1	10	3												
0–100	13		1													
Sub-threshold or Disqualified	20	3	16	10	2						1	1		1	1	1(2500)

TOTAL NO. = 524

Figure 13. Cross Plot of Film Badge Readings, By Period of Issue (for badges corresponding to at least one of the above periods)

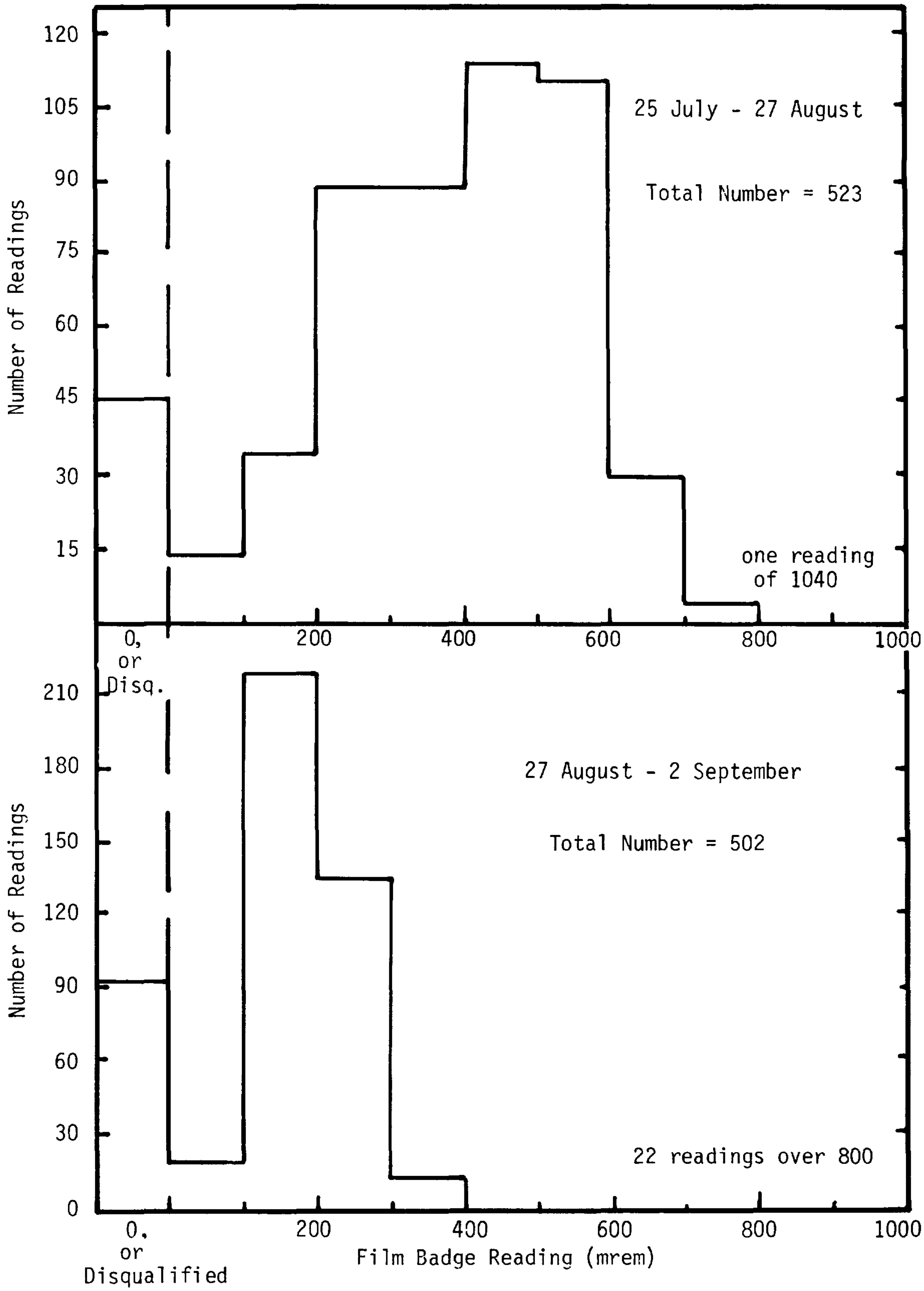

Figure 14. Distribution of Film Badge Readings for Each Period

The absence of gamma doses for an appreciable minority of Task Force WARRIOR troops is inconsistent with the record of events on the day of Shot SMOKY. For the main body of troops (who exchanged badges 27 August), only 3 had zero or subthreshold film badge readings for the first period, whereas 89 did for the second period. Apparently these 89 neither observed SMOKY from the location specified in Plan B (Reference 4) nor participated in the subsequent airlift exercise, for in either event gamma radiation would have been measured. The photographic evidence demonstrates that the remaining task force personnel may have witnessed SMOKY from News Nob, where no measurable radiation was present. In Figure 15, the rightmost of the nine troops shown "observing" Shot SMOKY from News Nob was identified by the Army as PFC McGinnis of Task Force WARRIOR. Unfortunately, his film badge is reported to have been lost, so verification from his film badge reading is impossible. The troops' evident lack of field gear suggests that they did not plan to later join the SMOKY exercise.

A comparison of film badge readings from different overlapping periods is useful in temporal resolution of the doses that were accrued. Three groups that permit such resolution are the Canadian platoon, the task force headquarters personnel, and the main body of troops. All received their first film badges in late July (the exact date is not important), and all turned in badges on 2 September. Assuming that the personnel in each group performed the same activities (which appears to be true owing to similar total dose levels), the various badge exchange dates permit sub-period information to be extracted. In the chart below, the statistical information for each group is presented, disregarding outliers which will be discussed later.

Figure 15. Observation of Shot SMOKY from News Nob 31 August 1957 (U.S. Army Photograph)

Group	Period	Number of Cases	Mean (mrem)	Standard Deviation	Standard Error
Main	before 27 Aug	478	392	153	7
Canadian	before 20 Aug	38	271	106	17
Hq	before 14 Aug	28	250	150	29
Main	after 27 Aug	387	186	59	3
Canadian	after 20 Aug	38	338	53	9
Hq	after 14 Aug	15	365	88	22

Any two groups may be compared by differencing both their badge periods and readings. Two values of net dose result for a sub-period so determined (unless the total doses are identical). For example, a comparison of the main and Canadian groups indicates that for the period 20 to 27 August, the dose differences are 121 ± 18 (standard error, or standard deviation of the mean) mrem and 152 ± 9 mrem. Similar analysis for all pairs of groups provides the following information:

Period	Mean Dose and Standard Error (mrem) for Each Possibility)	Approx. Net Mean Dose (mrem)
20-27 Aug	121 ± 18, 152 ± 9	140 ± 20
14-20 Aug	21 ± 34, 27 ± 24	25 ± 30
14-27 Aug	142 ± 30, 179 ± 22	165 ± 35

Between 14 and 20 August, as seen above, it is not certain that Task Force WARRIOR received any dose. Any possible dose would have been small. Documentation of Task Force WARRIOR activities does not indicate any training in areas contaminated with residual gamma radiation. For the week of 20 to 27 August, the inferred 140 ± 20 mrem film badge dose is clear indication of a task force activity in the forward area. On the 23rd, it is known that Task Force WARRIOR observed Shot DOPPLER from trenches. No other dose-yielding activity for the task force is reported for that week. Two visiting general officers with film badge periods of 22 to 23 August and 19 to 23 August had readings of 119 and 156 mrem, respectively. Observation of DOPPLER from the trenches would have been their most logical activity in the forward area. Seven soldiers had a film badge period of 14 to 30 August. Given that no dose was accrued between 27 and 30 August, their mean dose of 164 ± 34 compares well with the value for 14 to 27 August obtained above from larger sample spaces.

By yielding film badge values that can be associated with smaller time intervals and thus more likely with single exercises, a more detailed comparison will be possible between exposure estimates and film badge readings.

6.3.1 Outliers

The principal departure from the main film badge distributions of Task Force WARRIOR is the group of 20 troops who received between 800 and 1400 mrem during the period 27 August to 2 September. Not only are their doses far above all readings in the main distribution, but reasonably similar as well. The spectrum of the radiation is similar for all 20 film badges, as judged by similar attenuation ratios between pairs of filtered elements of the film badge described in Appendix III. That all beta radiation doses in this group are similar (under 100 mrem) is evidence of the spectral similarity.

From the above, it may be presumed that the group of 20 was indeed together. If the high dose was, as presumed, accumulated on the day of SMOKY, it follows that the group would have been closer to SMOKY GZ than the task force as a whole. Nowhere else on 31 August could the 800 to 1400 mrem dose level have been achieved unless the group was subjected to the radiation field of SMOKY itself. It could be postulated from the film badge evidence, together with the structure of the group (one LT, one M/Sgt, one SFC, one Sgt, one Cpl, and 15 other EM) that a platoon section, or like patrol or task group, could have proceeded due east from the objective area toward Smoky Hill and the Phase I positions instead of assaulting Quartzite Ridge to the northeast. Whether such an excursion was by oversight or design is immaterial. In either case, it is undocumented. The excursion would explain, however, why the assault was halted due to rad-safe considerations, presumably at the 500 mr/hr level. An examination of the SMOKY residual contamination contours would support this hypothesis--the group would have halted short of Smoky Hill near the Phase I defensive positions, having proceeded less than two miles in about 45 minutes. Although halted, they could have remained in the vicinity of the 500 mr/hr line until exercise termination at 0945, inspecting the post-shot damage to the defensive positions they had prepared more than two weeks previously. If they had adhered to the 500 mr/hr limit, had not encountered any hot spots, and had departed promptly at exercise termination, their total dose from this excursion would have been about 300 mrem. They may have encountered hot spots, however. It is also possible that they ventured toward the close-in positions where intensities were greater, or stayed long enough to view all the positions. Given the uncertainties of this excursion, doses on the order of 1000 mrem cannot be ruled out.

There are also individual outliers that deserve mention. One dose of 2500 mrem, accrued between 27 August and 2 September, was accompanied by a beta reading of 2600 mrem. Another gamma dose of 2000 mrem during the same period was accompanied by 920 mrem beta. Very few film badges for Task Force WARRIOR had these large beta/gamma ratios. As distinguished from the group of 20, the high beta readings would indicate that the film badges were on the ground for considerable periods, possibly having been lost during the SMOKY exercise and found during the subsequent equipment recovery on 1 September.

The highest single reading of 2740 mrem was obtained between 27 and 30 August by a master sergeant, yet no known troop activity transpired in that interval. The badge record was initially labeled "lost," then altered to record the dose. It is likely that this badge had indeed been left for a substantial time in a gamma field of some intensity.

Of the task force headquarters group, the task force commander and a lieutenant accrued 920 and 695 mrem gamma, respectively, between 14 August and 2 September. It is reasonable to assume that these individuals would have spent considerable extra time in the forward area, accounting for considerably higher doses. A few other troops had readings in this range on single film badges from early August to 2 September. Since this period probably encompassed almost all radiological activities of the task force, these troops' doses may be regarded as high-average.

Some qualitative account may be given to the spread of the film badge readings. In addition to the approximate 10 percent inaccuracy of individual film badges (see Appendix III), the data spread is influenced by the distribution of troops throughout the exercise area (as discussed in Sections 2.6 and 4.2), possible incomplete attendance by troops at all rehearsals, extra activities requiring few personnel (such as equipment recovery and Phase I inspection), differing arrival times (as documented for the SMOKY exercise), and local variations in the residual radiation intensity.

Section 7

CONCLUSIONS

There were nine shots during Operation Plumbbob which could have contributed to the residual radiation exposure of Task Force WARRIOR and related units which participated in the Infantry Troop Test conducted in conjunction with Shot SMOKY. Additionally, Shot DOPPLER contributed an initial radiation component to the total. Of the nine shots with possible contribution to exposure from residual radiation, four were of little or no significance. The other five contributed in varying degrees to the total exposure, as shown in Table 2. It should be noted that Shot SMOKY contributed little if any dose to the troop units discussed. It is apparent from the GALILEO report (Reference 23), however, that the SMOKY fallout was a major contributor to the radiation exposure of Task Force BIG BANG in conjunction with the HumRRO troop test. The discussion of this activity and the exposure associated therewith is contained in the GALILEO report (to be published).

A comparison of the film badge readings with the calculated dose for Task Force WARRIOR is made by applying the correction factor of 0.70, obtained in Section 6.1, to the doses calculated in Sections 4.2 and 5.1. This adjustment yields a total film badge equivalent value of 340 mrem from residual radiation. To this value, the calculated and adjusted initial contribution from DOPPLER (about 140 mrem) is added, yielding a total of 480 mrem. This is comparable to the combined mean reading of 575 mrem obtained from the film badges.

Except for the group of 20 (discussed in Section 6.3), the calculated (and adjusted) doses correlate reasonably well with the two primary film badge issue periods. For the first period, up to 27 August, the calculated dose of 330 mrem is adjusted to 230 mrem, to which the DOPPLER contribution is again added for a total of 370 mrem. This compares to the first period mean film badge reading of 390 mrem. For the second period, the calculated dose, after adjustment to film badge equivalence, is 110 mrem, which compares to the mean film badge reading of 185 mrem.

Table 3 summarizes free-in-air doses and inferred film badge exposure-equivalent values, and lists film badge readings for comparison. The data result from all efforts to reconcile the available information on the history and magnitude of test personnel radiation exposure. It is evident the data indicate that film badge records compare well with equivalent values inferred from radiation field measurements and troop movement records. The mean total film badge reading is within the 90 percent confidence limits of the adjusted total dose estimate.

In the same manner that film badge readings were compared to the adjusted dose estimates, a reasonable upper limit of troop exposure is deduced and compared to the highest film badge readings. For this purpose, mean dose values ascribed to various events are considered correct, but the distribution of position and stay time among the troops causes calculable exposure variation. The former, as discussed in Section 5.1, permits the estimated residual dose to be as much as 600 mrem. Stay times might have been as much as 25 percent higher than the mean for some troops because of extended arrival and departure intervals, especially when helicopters were used. Those few troops participating in the equipment recovery and post-shot inspection of Phase I defensive positions would have accrued 180 mrem more than the task force as a whole (see Table 2). Thus, some individuals could have been exposed to 930 mrem (650 mrem film badge equivalent) of residual radiation.

The initial radiation dose from Shot DOPPLER may have been considerably greater than the mean in some cases. The following might represent an extreme: a soldier misestimates his depth in the trench so that his head, which is bent over a nearly erect torso, is only 1 foot below surface level. His film badge, worn on his collar (as some personnel did) and essentially unshielded, is at about the same 1 foot depth. This individual would have accrued about 400 mrem on his film badge. The free-in-air dose at mid-torso depth would have been

TABLE 3

COMPARISON OF DOSES AND FILM BADGE
EQUIVALENCE WITH FILM BADGE DATA
TASK FORCE WARRIOR TROOPS

Period	Free-In-Air Exposure {a} (mrem)	Film Badge Exposure Equivalence {a} (mrem)	Film Badge Readings {b} (mrem)	Inferred Mean Film Badge Doses {a} (mrem)
25 July - 14 August	330 ± 150	230 ± 105		250 ± 50
14 August - 20 August	0	0	390 ± 240	25 ± 50
20 August - 27 August	480 ± 220 {d}	140 ± 75		140 ± 35
27 August - 2 September	160 ± 60	110 ± 40	185 ± 95	
TOTALS	970 ± 270 {d}	480 ± 135	575 ± 250 {c}	

a With 90 percent confidence limits.

b With 90 percent data range.

c Includes all troops with full participation in TF WARRIOR.

d The lower error bands are underestimated.
The unit of exposure is independent of specific biological effects.

about 500 mrem (including neutrons), which, like this individual's mid-torso position, would have been near the mean. If this individual were in the front trench rather than the middle trench, his dose would have been 13 percent greater for gamma and 26 percent greater for neutrons.

Combining residual and initial doses, the upper limit of dose is estimated to have been 930 + 600 = 1530 mrem, with a film badge equivalent of 650 + 450 = 1100 mrem. If the group of 20 and the three outliers exceeding 2000 mrem (discussed in Section 6.3) are excluded due to evident incompatibility with the troop movements as known, the film badge equivalent of the upper exposure limit compares favorably with the highest combined film badge readings for any individual (1235 mrem; 1090 mrem is next highest).

Section 8

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APPENDIX I

FALLOUT PLOTS

Because the radiation dose accrued by individuals at the Nevada Test Site in 1957 was caused, to a significant extent, by the exposure to fallout from several shots, it is imperative that all Plumbbob shots be examined and, where appropriate, the fallout plotted. Table I-1 lists the shots that were examined and identifies those for which fallout plots are produced in the figures following. For those not plotted, the reason is primarily that the height of burst was sufficient for that yield to reduce local fallout, beyond the immediate area around ground zero, to insignificant levels. This is verified through inspection of post-shot rad-safe surveys by Reynolds Electrical Engineering Company (REECO) and the Civil Effects Test Group (CETG), Program 37 (References 1 and 11).

The fallout plots shown in Figures I-1 through I-9 were derived from the information contained in the above references. Plots of actual radiation levels, measured at specific times after each shot, were normalized to H+12 hours by using the decay schemes described in Appendix II. A single composite fallout plot was obtained from the survey data through averaging the normalized values. The REECO dose rate plots were not used in their entirety; only actual data points were considered (where the REECO iso-intensity contours intersect roads). Because the roads depicted in the REECO plots were sufficiently straight, sets of collinear data values were obtained which could be processed mathematically.

Because dose rates tended to vary exponentially with distance, the data were fit to an exponential form. The simplest, after taking logarithms, is

$$\log \dot{D} = ax + b$$

TABLE I-1

OPERATION PLUMBBOB FALLOUT DETERMINATION
28 MAY TO 2 SEPTEMBER 1957

SHOT	YIELD	DATE & TIME	BURST HEIGHT	AREA	COORD	FALLOUT
BOLTZMANN	12KT	28 May, 0455	500' Tower	7	867056	Fig. I-1
FRANKLIN	140T	2 Jun, 0455	300' Tower	3	870004	Fig. I-2
LASSEN	.5T	5 Jun, 0455	500' Balloon	9b	852100	Insig.
WILSON	10KT	18 Jun, 0455	500' Balloon	9b	852100	Fig. I-3
PRISCILLA	37KT	24 Jun, 0630	700' Balloon	FF	956729	Offsite East
HOOD	74KT	5 Jul, 0440	1500' Balloon	9b	852100	Insig.
DIABLO	17KT	15 Jul, 0430	500' Tower	2b	792118	Fig. I-4
KEPLER	10KT	24 Jul, 0450	500' Tower	4	797057	Fig. I-5
OWENS	9.7KT	25 Jul, 0630	500' Balloon	9b	852100	Insig.
PASCAL "A"	S(N)	26 Jul, 0100	Underground	3j	858009	Fig. I-6
STOKES	19KT	7 Aug, 0525	1500' Balloon	7b	867047	Insig.
SHASTA	17KT	18 Aug, 0500	500' Tower	2a	794093	Fig. I-7
DOPPLER	11KT	23 Aug, 0530	1500' Balloon	7b	867047	Insig.
FRANKLIN PRIME	4.7KT	30 Aug, 0540	750' Balloon	7b	867047	Fig. I-8
SMOKY	44KT	31 Aug, 0530	700' Tower	8(2c)	828159	Fig. I-9

S(N) - Safety shot with some nuclear yield

A least squares linear regression was performed on log $\dot{D}$. The locations of $\dot{D}$=10, 100, and 1000 mr/hr were obtained according to the fit. Usually, the data, when normalized to H+12, spanned these values. If not, no extrapolation was performed.

The log-linear fit is clearly inappropriate across GZ or the hot line. A higher order fit, akin to a Gaussian, was tried in order to permit a functional maximum:

$$\log \dot{D} = ax^2 + bx + c$$

While this form was useful in obtaining gamma intensity on hot lines, it underestimated GZ values. When used on data not crossing GZ, there was a tendency toward unrestrained exponential growth (i.e., positive a), just as for the log-linear fit. So long as the data lines did not cross GZ or the hot line, the difference in 10, 100, and 1000 mr/hr locations from the first order to second order fit was well within the standard deviation of the data. For these reasons, the log-linear fit was used to construct composite plots.

The consistency of the data was assessed from log $\dot{D}(x)$. The standard deviation, σ, of log $\dot{D}$ from the best linear fit was computed along all lines used. A markedly similar scatter in the data was observed not only from line to line, but also from shot to shot. For all lines used on all plots, the error factor, defined as $10^{1.65\sigma/\sqrt{n-1}}$, where n is the number of data points along a line, averages 1.46. Its own standard deviation is 0.05. The consistency of the error factor supports the disregarding of isolated data far outside reasonable confidence limits.

Thus, all the composite plots may be regarded as depicting exposure along the roads within a factor of 1.46, with 90 percent reliability. Where the contours have been interpolated between roads, the error factor would be slightly greater. The on-site composite plots were reasonably consistent with the off-site surveys from Program 37 (Reference 11). For most shots, interpolation was necessary in the gap between the composite contours obtained from on-site surveys and off-site surveys. In those cases, azimuthal consistency as well as magnitude determined the overall correlation. Where the contours have been interpolated (dashed lines), the error factor grows considerably, particularly where contours are closely spaced.

In general, available data was used or interpolated for all areas of interest. One obvious exception is evident for SMOKY, where the upwind radiation intensity is crucial to determine the dose received by Task Force WARRIOR and supporting elements operating in the upwind area. The steep terrain obviously prevented post-shot ground or aerial rad-safe surveys immediately upwind. The upwind contours were therefore estimated as being virtually circular, under the conservative assumption that upwind fallout would have carried no farther from ground zero than crosswind fallout, particularly in the face of rising terrain. In this case, as well as others, both estimated and interpolated contours are dotted.

It should be noted that the fallout plots shown in the figures differ from earlier estimates of fallout, such as that provided by the DASA 1251 report (Reference 10). Because the plots are all derived from the same data (References 1 and 11), some explanation for the difference is in order. First, presumed actual survey points along roads were used as data points rather than the entire sketched contours. Second, DASA 1251 ascribed more reliability to the contours than could have possibly existed. For instance, the northwest quadrant of SMOKY fallout should be considered highly suspect simply on the basis that the steep terrain would have precluded surveys in that area. Third, the influence of previous shots on subsequent surveys was apparently not considered in DASA 1251. This is particularly evident for SMOKY, where the REECO surveys were biased by the northerly SHASTA fallout of two weeks previous and DIABLO fallout of seven weeks previous. Thus, any composite SMOKY fallout plot, using REECO data, would reflect higher intensities on the western side than actually resulted from shot SMOKY itself. Finally, the DASA 1251 fallout contours were normalized (to H+1) using a decay rate of $t^{-1.2}$. The plots contained herein are normalized to H+12 through the use of actual shot decay rates where available from Program 37. Where the actual data are not available, the composite Plumbbob decay is used. In either case, significant variations from the traditional $t^{-1.2}$ "rule" are evident. This is discussed in Appendix II where actual decay rates and schemes used to derive the composite plots are described in greater detail.

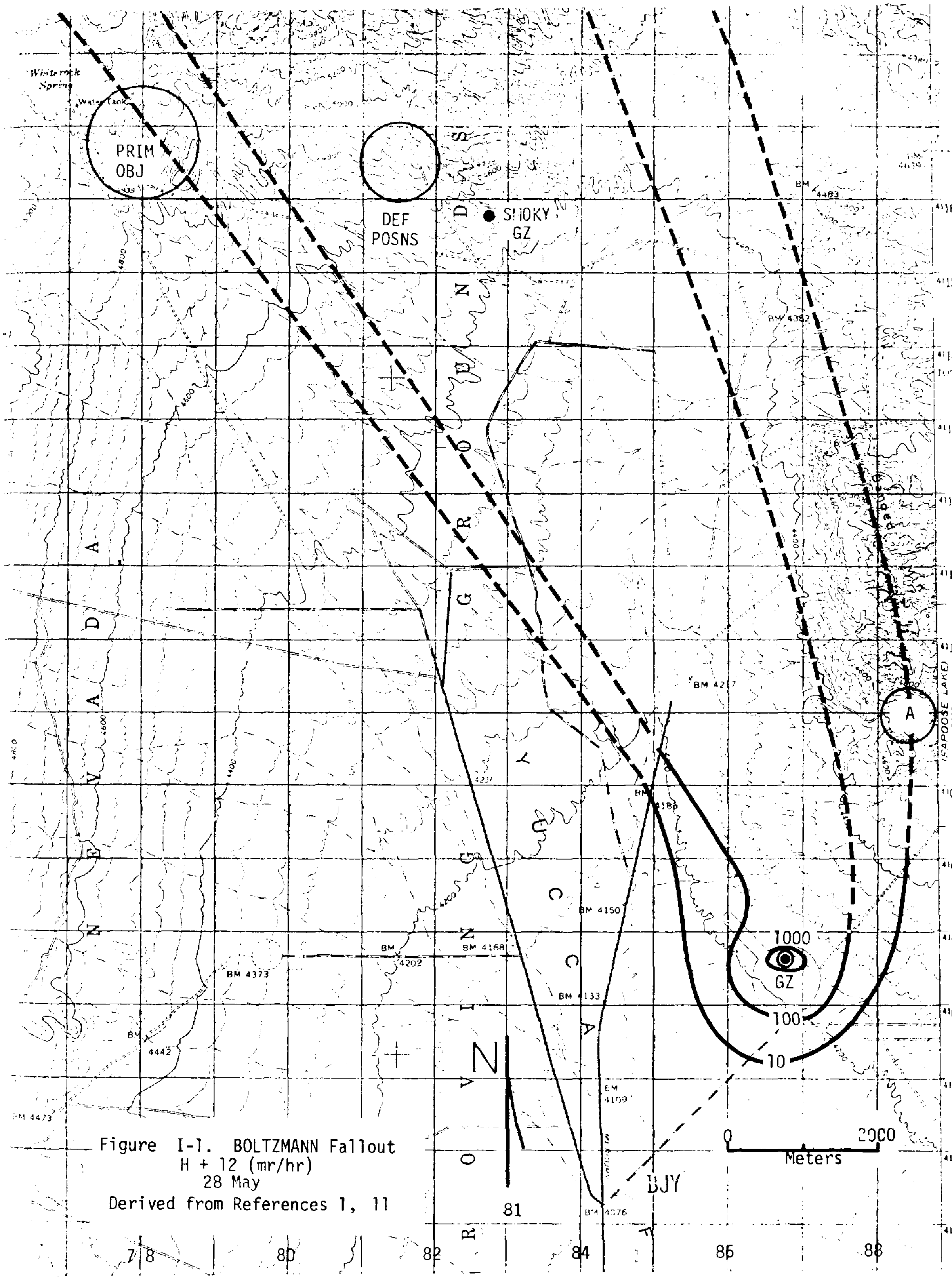

Figure I-1. BOLTZMANN Fallout
H + 12 (mr/hr)
28 May
Derived from References 1, 11

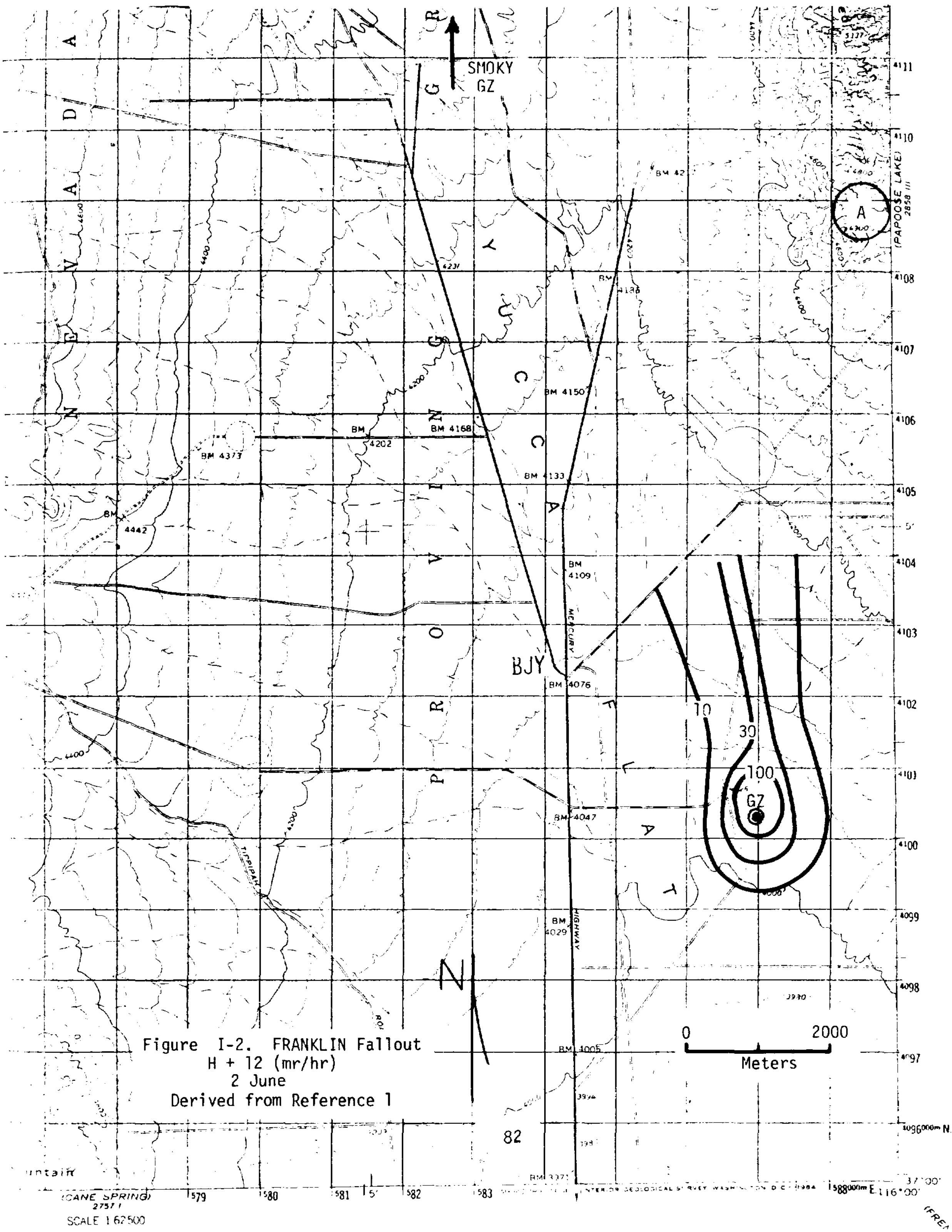

Figure I-2. FRANKLIN Fallout
H + 12 (mr/hr)
2 June
Derived from Reference 1

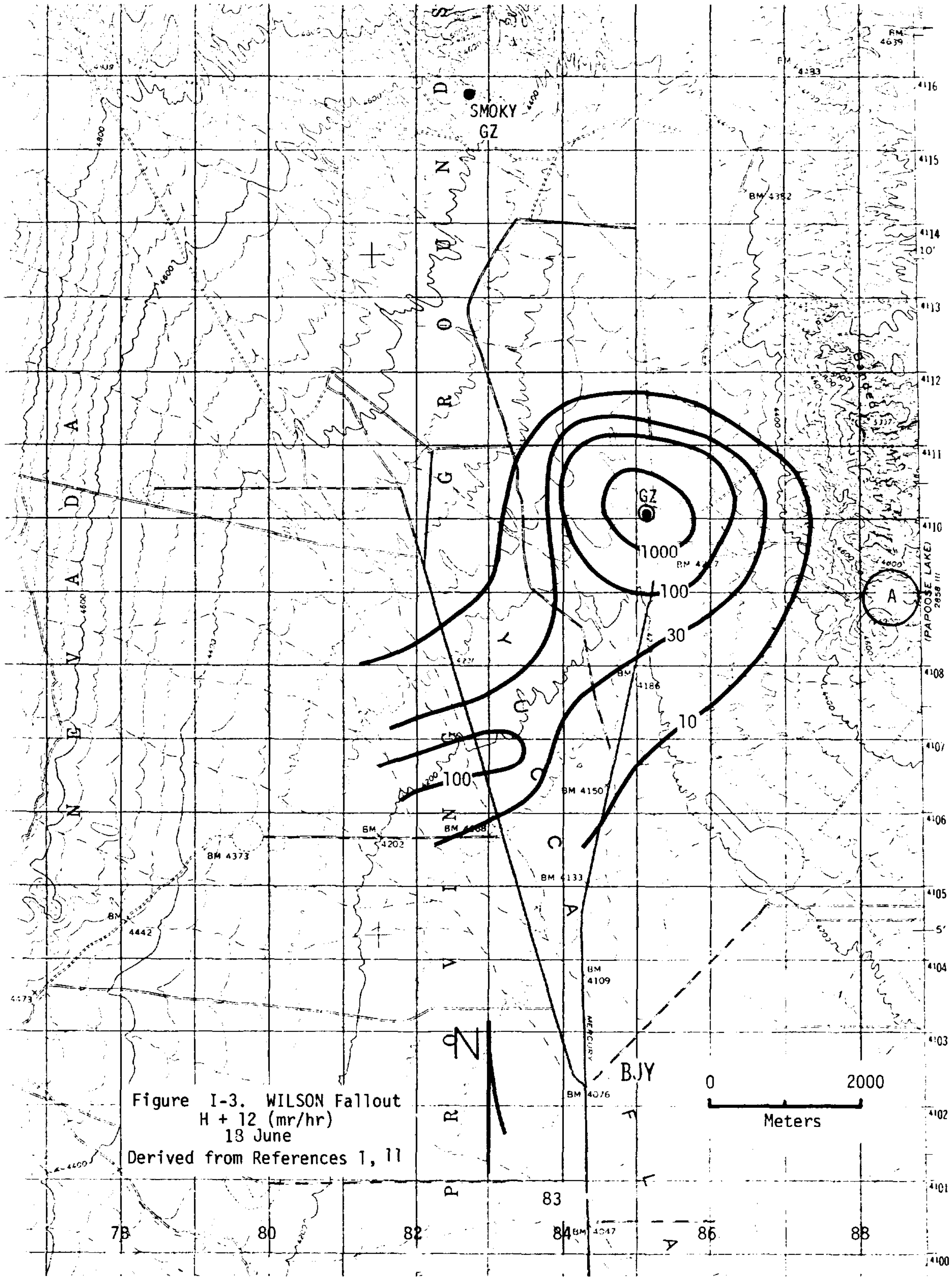

Figure I-3. WILSON Fallout
H + 12 (mr/hr)
18 June
Derived from References 1, 11

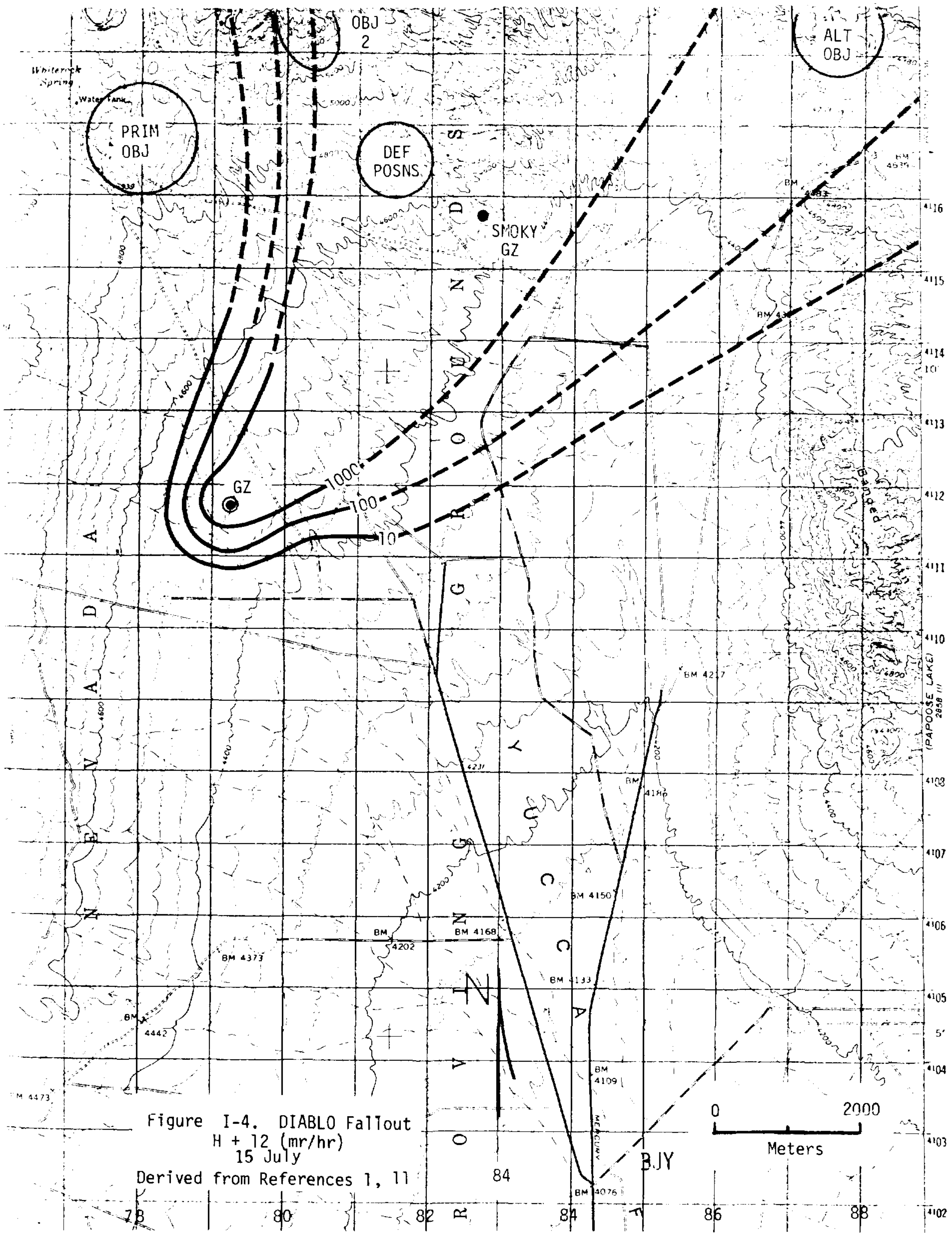

Figure I-4. DIABLO Fallout
H + 12 (mr/hr)
15 July
Derived from References 1, 11

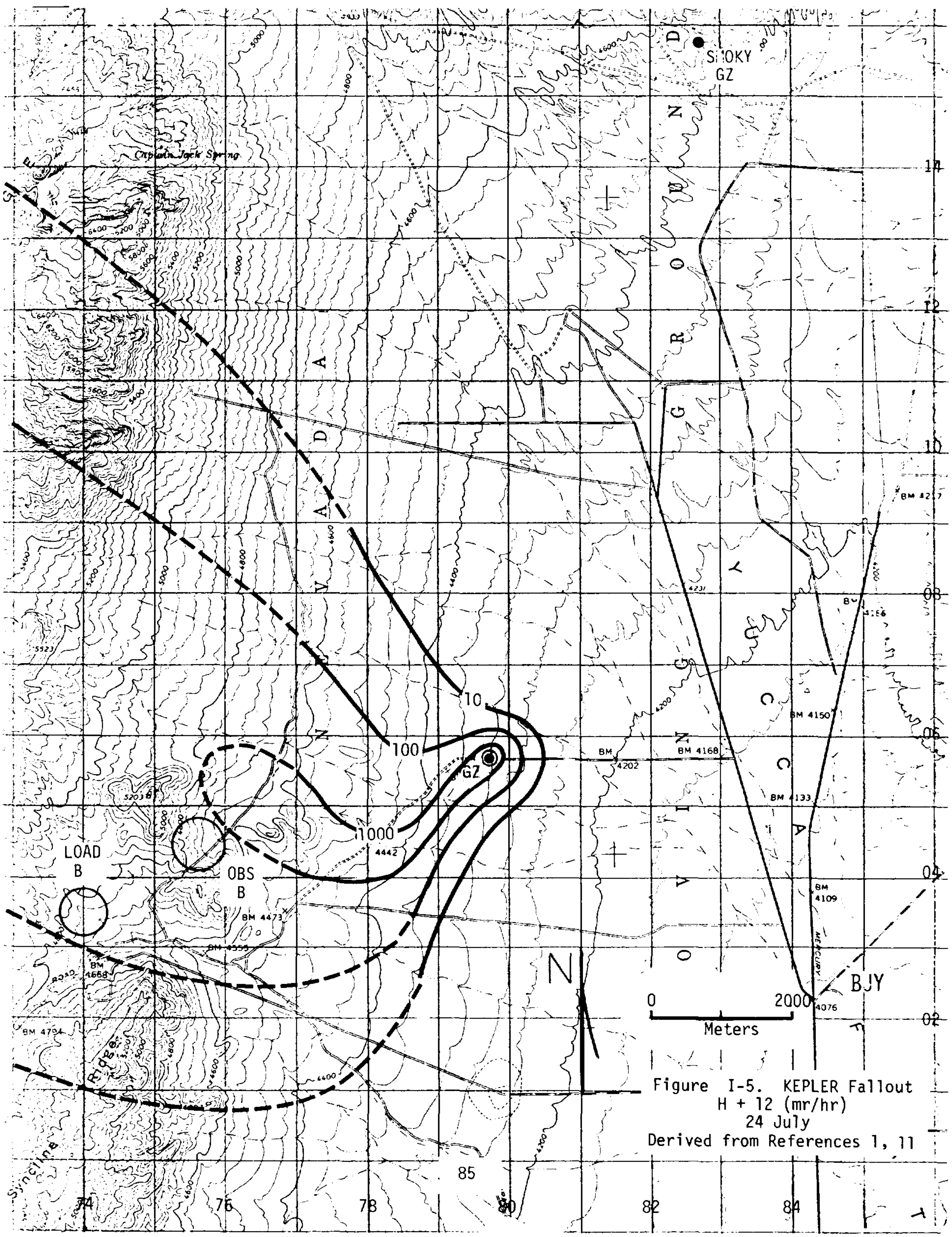

Figure I-5. KEPLER Fallout
H + 12 (mr/hr)
24 July
Derived from References 1, 11

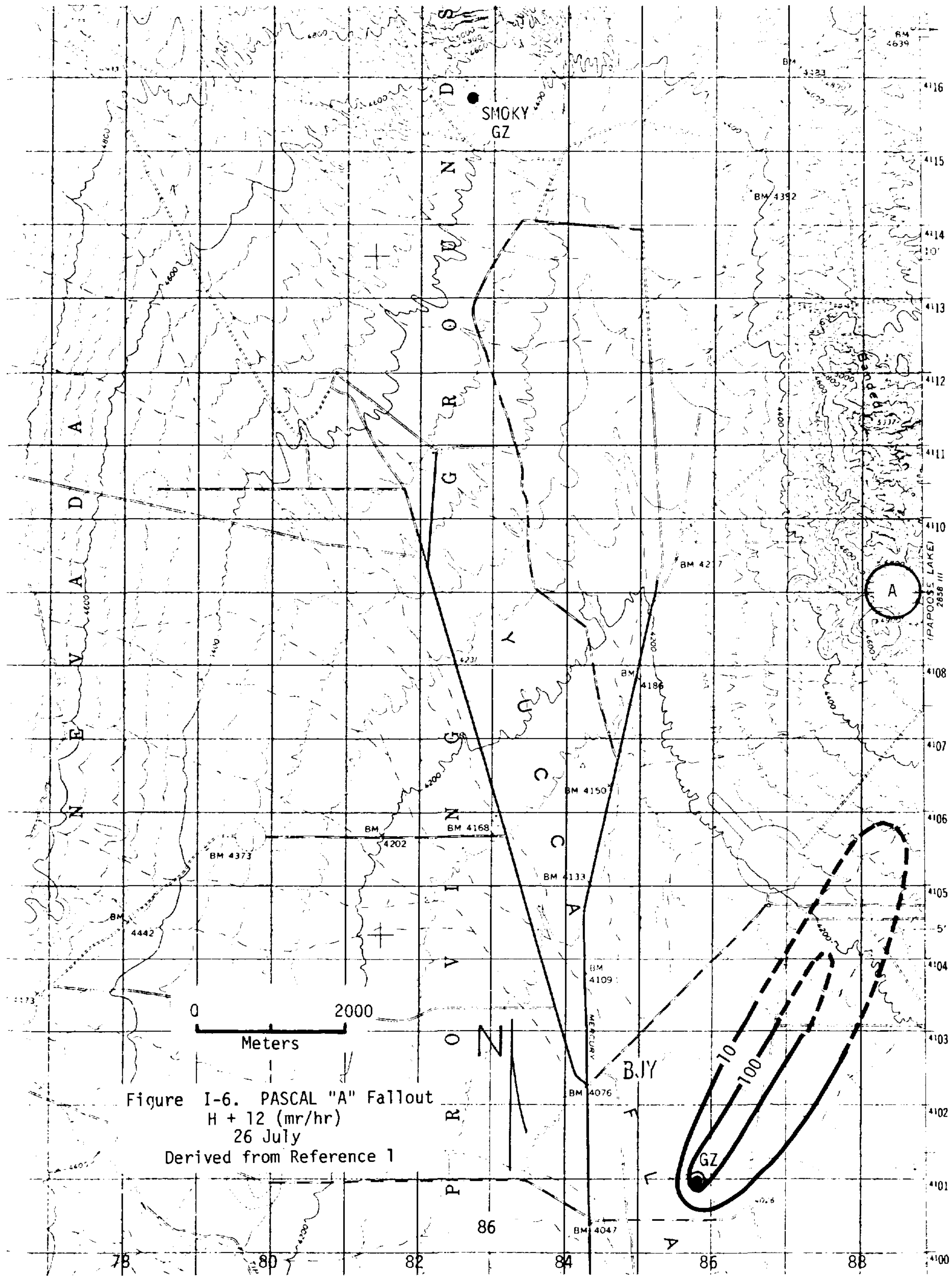

Figure I-6. PASCAL "A" Fallout
H + 12 (mr/hr)
26 July
Derived from Reference 1

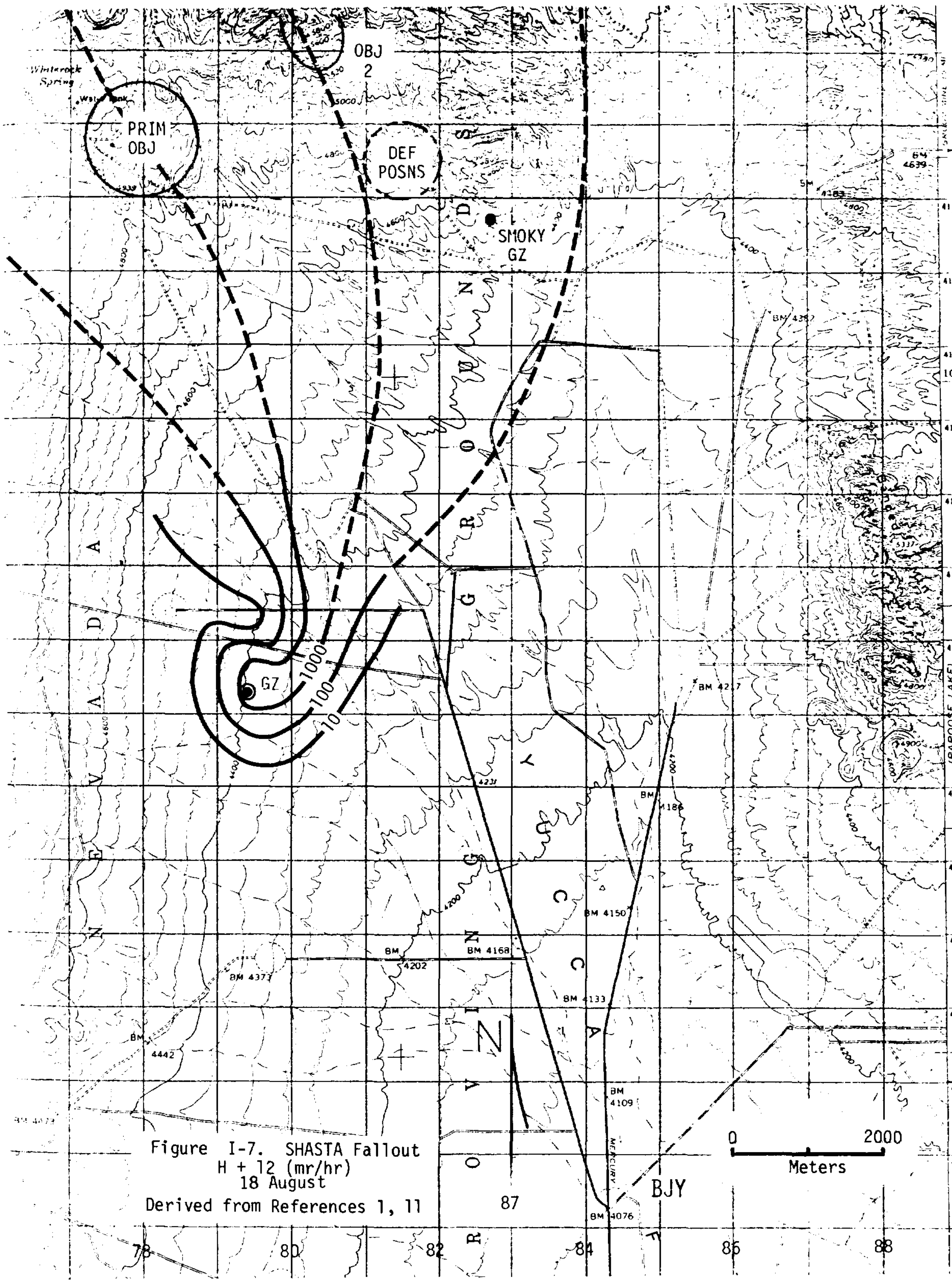

Figure I-7. SHASTA Fallout
H + 12 (mr/hr)
18 August
Derived from References 1, 11

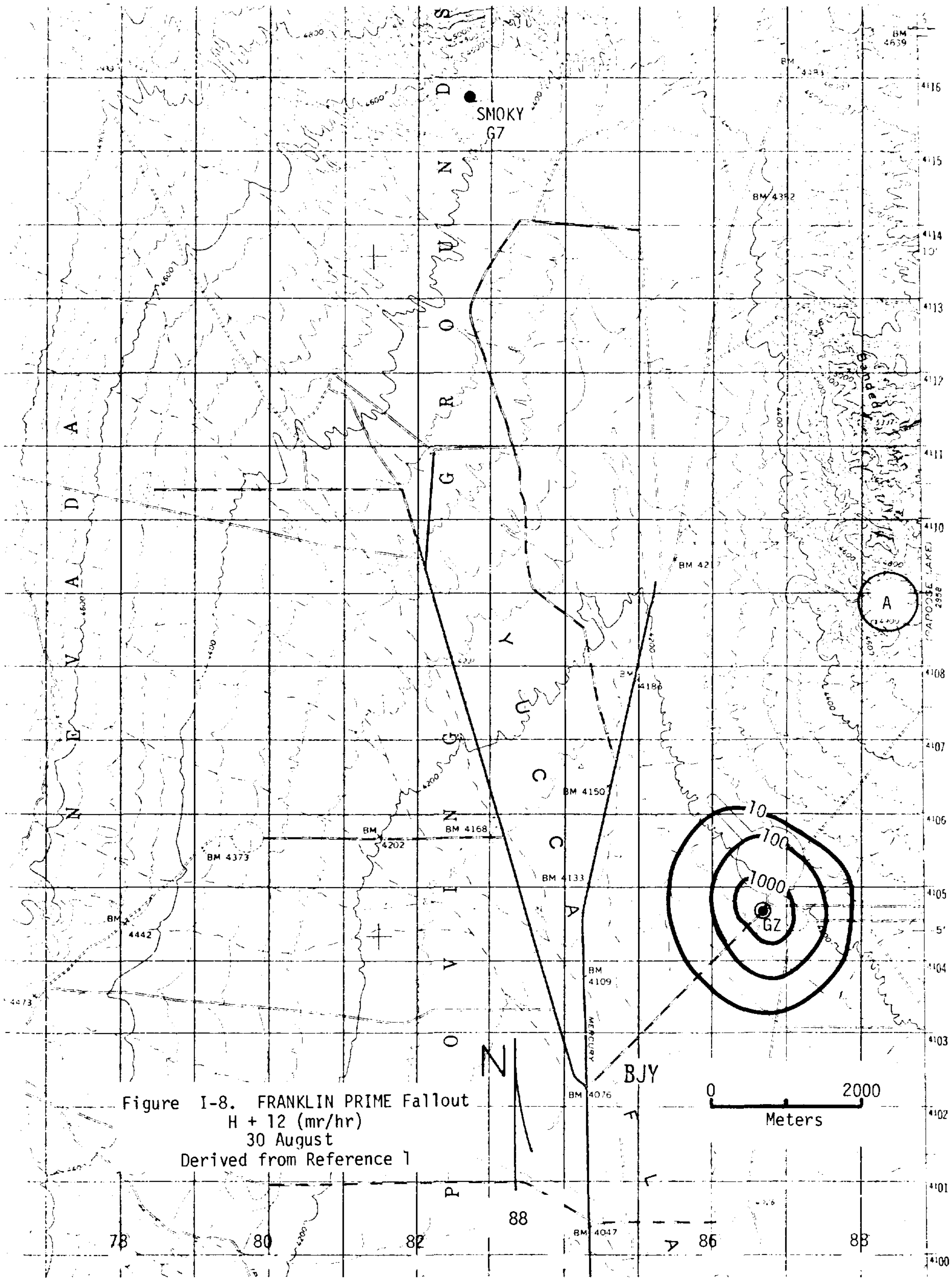

Figure I-8. FRANKLIN PRIME Fallout
H + 12 (mr/hr)
30 August
Derived from Reference 1

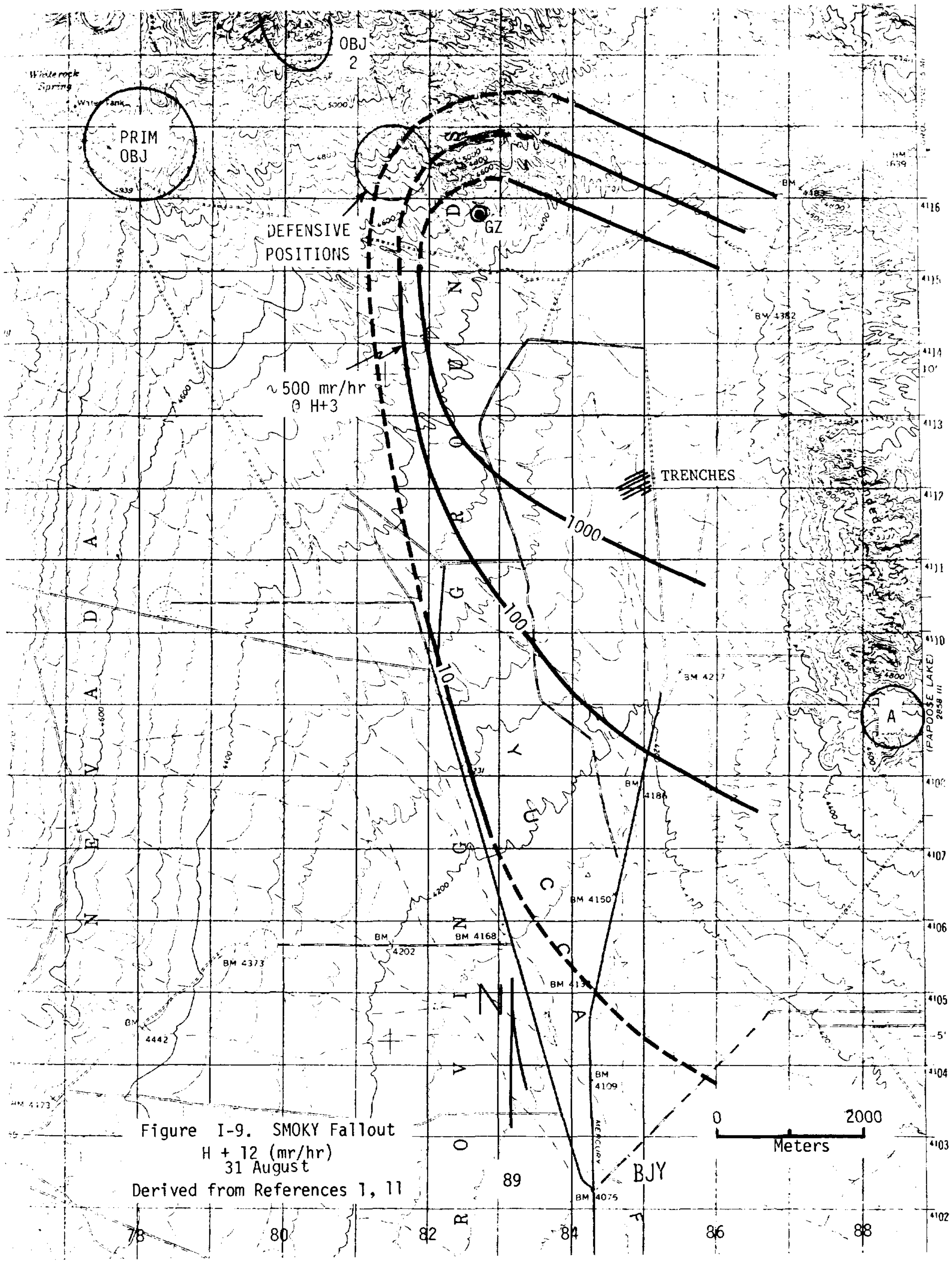

Figure I-9. SMOKY Fallout
H + 12 (mr/hr)
31 August
Derived from References 1, 11

APPENDIX II

FALLOUT DECAY

The decay of fallout contamination was examined in detail for two specific reasons. First, the rate was used to normalize all survey data to H+12. From these reduced data, the fallout plots shown in Appendix I were constructed. Second, precise decay rates were needed to facilitate evaluation of the actual intensity of each fallout field at various times after the shot when troop units were operating therein.

Several decay curves were examined, particularly the actual decay rates for specific shots as measured by Program 37 (Reference 11) whenever they were available. For the other shots where no decay data was available, the Plumbbob composite decay, as compiled by Program 37, was examined. It was noted that these decay rates vary considerably from the traditional $t^{-1.2}$ "rule". They also vary from the decay rate used in the DELFIC code (DoD Standard fallout model), which determines a composite decay from the decay of each fission product. While DELFIC agrees quite well with the $t^{-1.2}$ "rule", it does not consider the case of tower shots where substantial amounts of extraneous material, such as iron, may be in the fireball.

The actual decay rates were used for Shots BOLTZMANN, DIABLO, SHASTA, and SMOKY. These are shown in Tables II-1 through II-4. For all other shots, the overall Plumbbob composite decay was used, as shown in Table II-5.

Although the differences in decay rates are not significant for some time intervals, it should be noted that the actual decay rates are generally more consistent with each other than with $t^{-1.2}$.

TABLE II-1

BOLTZMANN FALLOUT DECAY

H+ (hours)	Decay Rate, x*
<2	Plumbbob Composite
2-3	-0.65
3-5	-0.89
5-8	-1.00
8-13	-1.33
13-900	Plumbbob Composite
900-1400	-1.17
1400-4000	-1.20

*as used in the expression, t^x

Source: Reference 11

Conversion of REECO Survey Data* to H+12

Survey	H+	Factor
Initial (0551)	0.927	.030
H+8 (1319)	8.4	.622
D+1 (0648)	25.9	1.90
D+3 (0550)	72.9	4.46
D+7 (1352)	177	11.8

* Reference 1

TABLE II-2

DIABLO FALLOUT DECAY

H+ (hours)	Decay Rate, x*
1-2	Plumbbob Composite
2-5	-1.30
5-6	-1.71
6-15	-1.13
15-25	-0.50
25-30	-2.38
30-80	Plumbbob Composite
80-180	-1.06
180-300	-1.84
300-400	-1.64
400-600	-1.33
600-2300	-1.21

*as used in the expression, t^x

Source: Reference 11

Conversion of REECO Survey Data* to H+12

Survey	H+	Factor
Initial (0551)	1.35	.043
H+7 (1118)	6.8	.526
D+1 (0645)	26.25	1.87
D+2 (0652)	50.4	3.74
D+3 (0642)	74.2	5.45
D+4 (0755)	99.4	7.33

* Reference 1

TABLE II-3

SHASTA FALLOUT DECAY

H+ (hours)	Decay Rate, x*
<3	Plumbbob Composite
3-5	-1.21
5-8	-0.92
8-10	-0.65
10-70	-0.76
70-180	-1.21
180-400	-1.67
400-1500	-1.28
1500-3000	-1.19

*as used in the expression, t^x

Source: Reference 11

Conversion of REECO Survey Data* to H+12

Survey	H+	Factor
Initial (0740)	2.7	0.21
H+6 (1124)	6.4	0.61
D+1 (0729)	26.5	1.83
D+2 (0650)	49.8	2.95
D+3 (0625)	73.4	4.05

* Reference 1

TABLE II-4

SMOKY FALLOUT DECAY

H+ (hours)	Decay Rate, x*
3-6	Plumbbob Composite
6-8	-1.34
8-19	-0.74
19-42	-0.83
42-85	-0.95
85-650	Plumbbob Composite**
650-800	-2.39
800-900	-1.23
900-1400	-1.00
1400-3000	-1.17

*as used in the expression, t^x

**The reference does not portray Plumbbob Composite decay in this interval.

Source: Reference 11

Conversion of REECO Survey Data* to H+12

Survey	H+	Factor
H+8 (1309)	7.65	.698
D+1 (0628)	24.97	1.76
D+3 (1415)	80.75	5.02
D+5 (1318)	127.8	8.95

* Reference 1

TABLE II-5

PLUMBBOB COMPOSITE FALLOUT DECAY

H+ (hours)	Decay Rate, x*
<2	-2.18
2-3	-0.70
3-6	-1.30
6-14	-1.03
14-50	-0.78
50-100	-0.90
100-180	-1.20
180-400	-1.58
400-600	-1.29
600-1600	-1.34
1600-3000	-1.45
3000-4000	-1.68
4000-5000	-1.76

*as used in the expression t^x

Source: Reference 11

Figure II-1 is a plot of each specific decay for the shots named, together with the Plumbbob composite, compared with the traditional decay, all normalized to H+12 hours.

Thus, to find the dose rate at a time H+t, given the dose rate at time H+t_o, the following expression is used:

$$\frac{\dot{D}_t}{\dot{D}_o} = \left(\frac{t}{t_o}\right)^x$$

where x is the slope of the decay curve, obtained from Tables II-1 through II-5, for successive time intervals. In this manner, all radiological survey data were normalized to H+12 hours to aid in deriving the fallout plots shown in Appendix I. The iso-intensity contours so reconstructed were then used for all subsequent analyses of personnel exposures. The analyses required that the actual fallout intensities be determined at various times after each shot for specific troop locations. Table II-6 shows the factors used in the analyses. These factors were derived from the above expression to aid in converting H+12 intensities to any subsequent time. For precise conversions, particularly within one to two days after a given event, the above expression should be used.

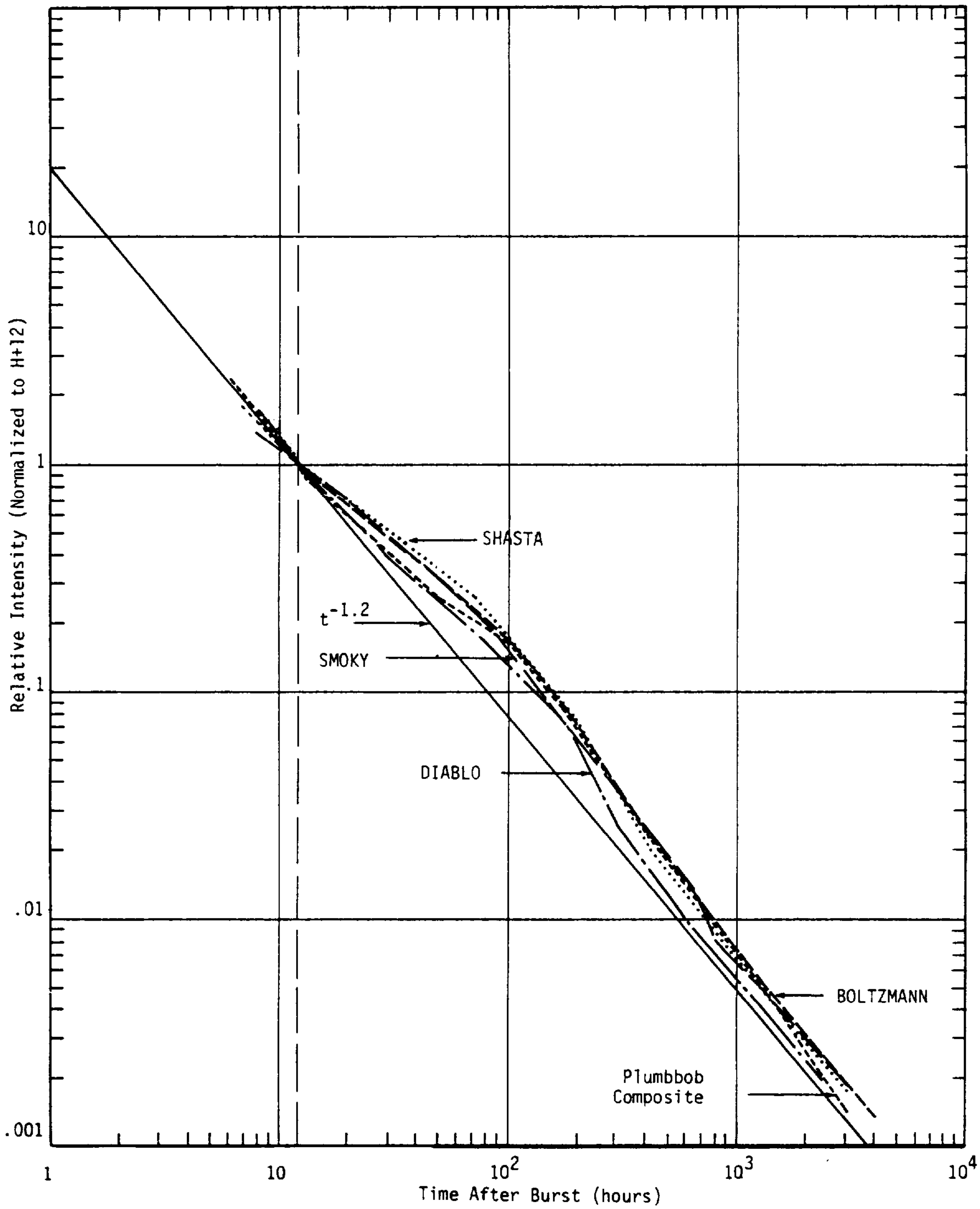

Figure II-1. Fallout Decay Comparison

TABLE II-6

FACTORS TO CONVERT H+12 INTENSITIES TO INTENSITIES ON SPECIFIC DATES

Date →	JULY									AUGUST															SEPTEMBER	
Shot ↓	15	17	19	21	23	25	27	29	31	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	1	3
BOLTZMANN	.006	.006	.005	.005	.005	.005	.005	.004	.004	.004	.004	.004	.004	.004	.004	.003	.003	.003	.003	.003	.003	.003	.003	.003	.003	.003
FRANKLIN	.007	.006	.006	.006	.005	.005	.005	.005	.004	.004	.004	.004	.004	.004	.003	.003	.003	.003	.003	.003	.003	.003	.003	.002	.002	.002
WILSON	.012	.011	.010	.009	.009	.008	.008	.007	.007	.006	.006	.006	.005	.005	.005	.005	.004	.004	.004	.004	.004	.004	.003	.003	.003	.003
DIABLO	1	.22	.12	.084	.058	.039	.028	.022	.018	.015	.013	.012	.011	.010	.009	.008	.008	.007	.007	.006	.006	.005	.005	.005	.005	.004
KEPLER						.41	.20	.12	.084	.058	.043	.033	.027	.022	019	.017	.015	.014	.012	.011	.010	.009	.009	.008	.008	.007
PASCAL "A"							.41	.20	.12	.084	.058	.043	.033	.027	.022	.019	.017	.015	.014	.012	.011	.010	.009	.009	.008	.008
SHASTA																		1	.29	.15	.10	.068	.048	.036	.028	.022
FRANKLIN PRIME																								1	.27	.15
SMOKY																									.42	.19
GALILEO																										.41

NOTE: Dates shown are based on 24-hour increments after H+12. For more precise conversions, use the method described in the text.

APPENDIX III

FILM BADGE DOSIMETRY

X-ray or photographic film, after exposure to ionizing radiation, shows an increased optical density upon development. The sensitivity of the film to such radiation is a function of the exposure intensity up to the saturation level of the film. Greater intensities serve only to reduce the developed optical density, a process called solarization. The degree of sensitivity depends on radiation type, radiation energy, and film type.

Film is quite sensitive to incident electrons and photons but essentially insensitive to incident neutrons. Figure III-1 shows the response to saturation of DuPont Type 502 film for three different incident photon energies. It is possible to develop a series of such curves for various energies and, normalizing to the response of a particular energy radiation (usually that of Co 60 at 1.25 MeV), obtain the relationship of film response to an exposure in roentgens for the entire useful photon spectrum. This relationship is not unique but is instead an envelope of values, since the shape of the film sensitivity curve is not quite the same for all energies. The film response to roentgen exposure as a function of energy is given in Figure III-2. Note that the film is much more sensitive than the roentgen measure to photons below a few hundred keV. This is because the film contains higher Z materials than air and, thus, possesses a much higher photoelectric cross section. On the other hand, in the region of dominance of the Compton cross section, the ratio of film response to roentgen response is at or near unity.

Because of non-uniform sensitivity among film types, film badges usually contain two or more film types, one for low exposures, one for high exposures, and, sometimes, one for mid-range exposures. The exact sensitivity range of each film type determines the quality of the

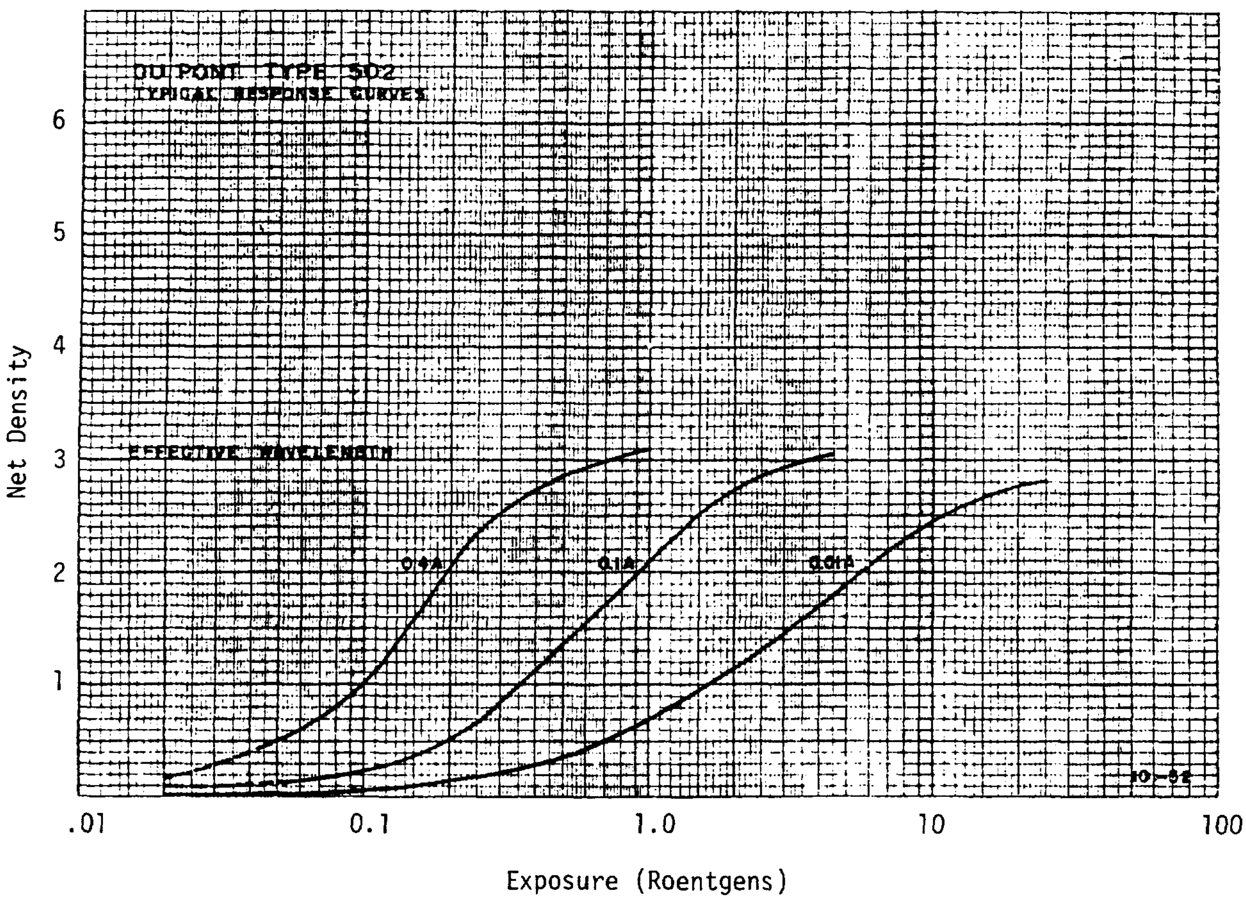

Figure III-1. DuPont Type 502 Film, Typical Response Curves.
(Reference 12)

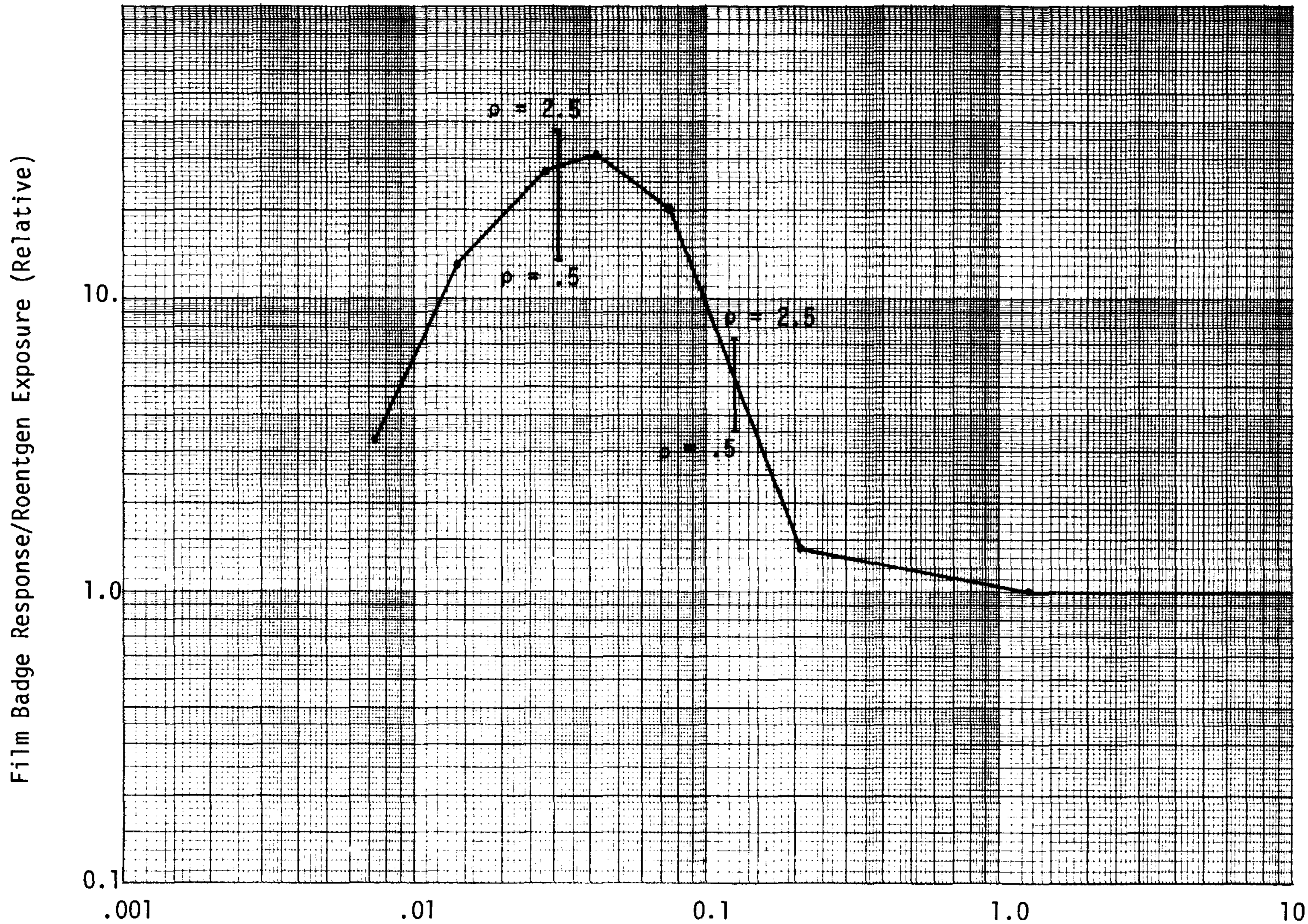

Figure III-2. Typical Photon Response for Bare DuPont Type 502 Film Packet Showing Limits for Two Net Film Densities. (Reference 13) reading in the region of overlap between film types. The films are enclosed in a paper container similar to that used for dental x-rays. This is further contained in a thin plastic case, usually with an opening on one side. The badge is usually worn on the chest with the opening facing away from the body.

Because of the film's proclivity to over-respond to low-energy photons, a metallic shield is usually placed on the outside of the paper container before it is placed in the plastic case. This shield is so thin that it has little effect on high energy photons but is capable of making a substantial reduction of the low-energy photon response of the film badge.

Two types of badges were employed during Operation Plumbbob and Exercise Desert Rock VII and VIII (Reference 14); one by Reynolds Electrical Engineering Co. (REECO) and the other by Lexington-Blue Grass Army Depot. REECO badges were issued to military and civilian scientific teams, and to AEC and AEC-contractor personnel. Lexington badges were issued to Desert Rock units participating in the tests. Both badges were based on the DuPont Type 559 film pack, the low and high dose film components of which were Types 502 and 606, respectively. The REECO film pack was shielded with a lead clip of dimensions 1/2 x 1 x 0.0283 in. thick, covering opposing sides (Reference 14). Photon exposure was determined from film density recorded under the lead clip.

The Lexington-Blue Grass Army Depot film packet was produced with four regions of dosimetric interest (Reference 15). The first was unshielded; the second and third were shielded front and back with aluminum and copper disks respectively, each 9/16 in. diameter and 0.040 in. thick; and the fourth region was shielded front and back with a lead-tin laminate disk 9/16 in. diameter with 0.042 in. Sn and 0.012 in. Pb, the lead being closest to the film. In the complex reading scheme used by Lexington, opacity readings from the four regions were recast as ratios to one of the four. By simultaneous analysis of these ratios, exposures from photons of descending energy were effectively "peeled off" until the lowest energy x-rays and beta particles were accounted for. In general, the highest density filter (Pb/Sn) dominated the measurement of photons in the region above ∿30 keV. The response relative to Roentgen exposure of the lead shielded low range (Type 502) film under the Pb/Sn shield is shown in Figure III-3.

Each batch of film was calibrated separately to establish density versus exposure in a fully assembled badge configuration. Badges were exposed to known intensities of normally incident photons from Co 60 (1.25 MeV) and, in the case of Lexington Depot, other photon energy sources. Development chemistry, duration and temperature used to process film exposed in the field duplicated that used in the calibration.

According to Lexington Depot (Reference 15), the probable accuracy to which the film density could be read in 1957 was about 50 percent for exposures near the density crossover of the low and high range film components, while accuracy as good as ten percent in the low density range of each film could be expected. For exposure to gamma radiation, this crossover occurred between 8 and 10 roentgens.

According to REECO (Reference 14), during the period from 17 January 1957 to 17 October 1957, the process used for the analysis of the film components gave an exposure range of 20 mr to 10 r for the Type 502 film and 5 r and up for the Type 606. REECO agrees with the 10 percent reading accuracy given by Lexington for the nonoverlap region, but asserts that any reading error in the overlap region could not be greater than about 2 r, or between 20 and 40 percent.

Film badges were calibrated by exposure to normally incident radiation from known sources in the absence of the body mass in close proximity to which they are normally employed. This neglects the shielding provided by the body to radiation incident over approximately half the available angles of approach to the badge (assuming that the film badge is worn on the chest) and the contribution from backscattered radiation from the body. Because badge shielding brings the low energy (30 - 300 KeV) into line with the roentgen response, one can surmise that the dominant effect from the presence of the body would be that of

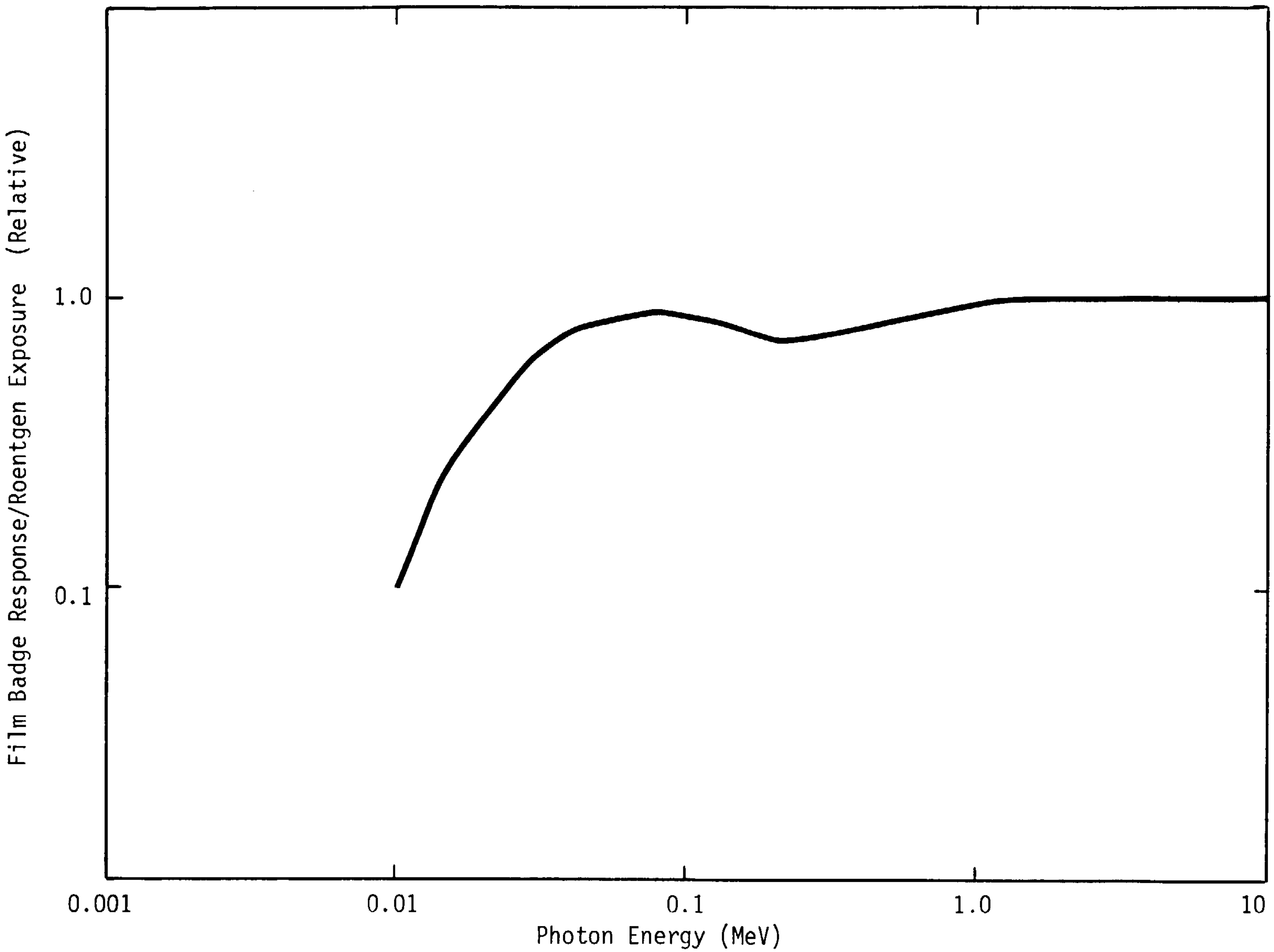

Figure III-3. Lexington Blue Grass Army Depot Pb-Sn Shielded Type 502 Film Response Relative to Roentgen Response (Reference 13) shielding; hence, the badge reading would indicate a lower exposure than the free-in-air tissue dose under the same exposure conditions.

To assess the in-situ response of the film badges of interest, radiation transport calculations were performed using an adjoint Monte Carlo technique (Reference 22) and a man phantom model previously developed for Defense Nuclear Agency (Reference 16). The man phantom model represents an average Western male, 5 ft 8-1/2 in. in height and weighing 154 lbs. In this technique photons are started in a region of interest (in this case the film badge), sampled from a given energy distribution (the bare film badge response), and followed as they move backward in time and space and upward in energy until they escape the film badge-phantom region entirely. As they escape they are tallied by energy and angle. The result is a weighting of the sample response of the film badge due to the presence of the transport medium, the man phantom. That man phantom model is shown in Figure III-4. The film badge was not modeled explicitly but was taken to be a point 0.09 cm from the surface of the chest, 20 cm down from the top of the torso, and 10 cm to the right of midline.

The results of the radiation transport calculations are shown below for the Lexington Blue Grass Army Depot film badges. Response factors are given for the photon energy bands used in the calculation.

Film Badge In-Situ Response/Roentgen Exposure
Normalized to Co 60 (1.25 MeV) at Normal Incidence

Photon Energy (MeV)	Response
.1 – .15	.70
.15 – .3	.64
.3 – .45	.67
.45 – .7	.71
.7 – 1.0	.66
1.0 – 1.5	.77
1.5 – 2.0	.78
2.0 – 3.0	.82

These results apply specifically to readings from the low range film at low opacity readings (∿0.5). Such readings are typical of those recorded for members of military units participating in the Desert Rock VII-VIII exercise. No calculations have been performed on the REECO configuration.

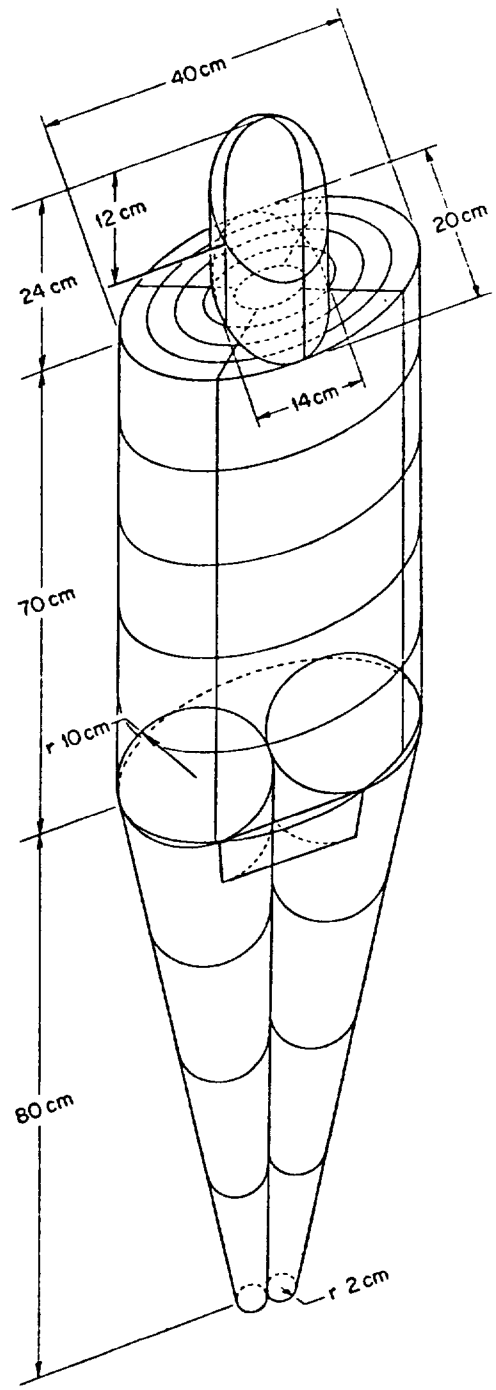

Figure III-4. The Adult Man Phantom

There are some uncertainties associated with the response factors. Each is accurate to an estimated 5 percent based on the statistical nature of the transport calculations. Some angular dependence of response results from the variation of effective filter thickness with angle of photon incidence. For typical gamma ray energies, this effect is minimal. There is no angular dependence for the film itself because the increased photon path length in the film at grazing incidence is exactly offset by the loss of projected badge area.

Precise use of the in-situ response factors required knowledge of the energy distribution of the incident gamma rays. The fallout gamma spectrum is weapon- and time-dependent. A sample fission product spectrum is shown in Figure III-5. Scattering of the gamma radiation occurs in air and as dependent on ground roughness. The scattered photon flux may be of the same order as the uncollided photon flux. Therefore the spectrum as detected by the film badge will have a significant component down into the low 100 keV range (References 18 and 19).

In order to utilize the in-situ response factors in the absence of spectral information, an average value must be determined. For any realistic gamma spectrum, a response factor of .70 is accurate to within 10 percent. Therefore .70 will be used to transpose between free field and film badge exposure. This conversion factor is applicable to the gamma radiation incident on a film badge worn on the chest of a person standing upright in a uniform fallout field.

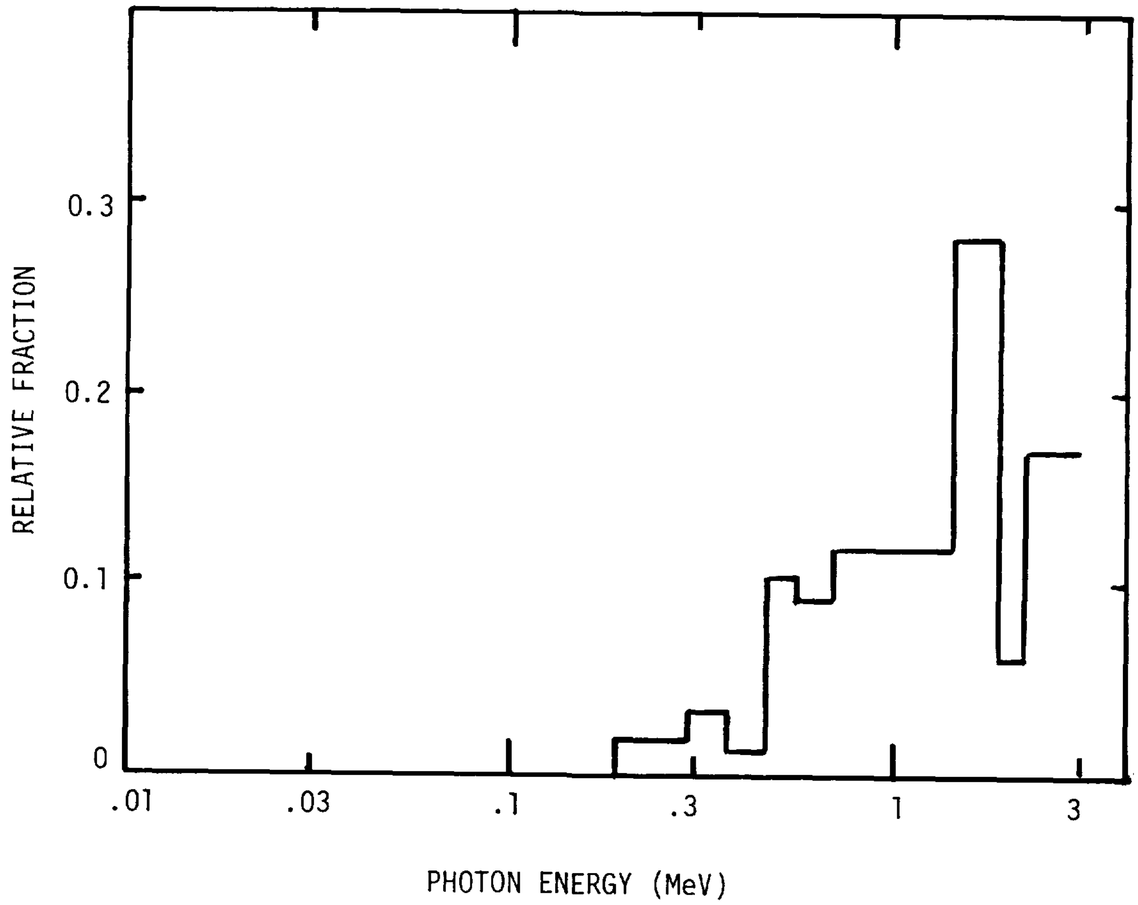

FIGURE III-5. Relative Spectral Structure of Fission Product Photons (Reference 17)

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U.S. House of Representatives
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