

DNA 5354F

# ANALYSIS OF RADIATION EXPOSURE FOR TROOP OBSERVERS

## Exercise Desert Rock VI, Operation Teapot

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20. ABSTRACT (Continued)

observer dose--1.6 rem gamma and 4.5 rem neutron. The highest dose received by troop observers was 1.4 rem gamma and 1.4 rem neutron at Shot Tesla.

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NATD

SUBJECT: DNA Report, "Analysis of Radiation Exposure for Troop Observers, Exercise Desert Rock VI, Operation Teapot"

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1. The Defense Nuclear Agency, as the Department of Defense (DoD) executive agency for matters relating to low-level ionizing radiation, is conducting an extensive review of radiation exposures to military personnel who have participated in the United States nuclear weapons development programs. This program, termed the Nuclear Test Personnel Review (NTPR), began in 1977 in response to concern over possible health risks as a result of very low level radiation exposures. A major objective of the NTPR is the assessment of radiation exposure for participating troops.
2. Accurate radiation exposure data for individuals and units are essential to fulfill the objectives of the NTPR program. Because film badge data are not always available (some badges were lost or unreadable, some records are no longer available, not all personnel were badged for a given shot, etc.) DNA has developed procedures for reconstructing, with confidence, both external and internal exposures for DoD test participants.
3. The enclosed report by Science Applications Inc., written under contract to DNA, provides estimates of the radiation doses that would have been possible for troop observers on Operation Teapot (1955). These dose reconstructions are based upon: (1) Patterns of residual activity measured, documented and published shortly after the tests, (2) Extensive calculation and analysis of prompt radiation doses, (3) The documented movement histories, including arrival and departure times for each unit which operated in the vicinity of the tests, and (4) Current dose calculation methodologies.

NATD

Subject: DNA Report, "Analysis of Radiation Exposure for  
Troop Observers, Exercise Desert Rock VI, Operation  
Teapot"

4. DNA believes this report accurately represents a conserva-  
tive approach to dose estimation, and that the estimations are  
reasonable and appropriate.

FOR THE DIRECTOR:

1 Enclosure  
as



BOBBY R. ADCOCK  
Colonel, USA  
Director for Biomedical Effects

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Section 1  
INTRODUCTION AND SUMMARY

This is the third in a series of reports concerned with radiation dose reconstruction for military participants in the atmospheric nuclear weapons testing program. The first two reports were based on the exercises conducted in conjunction with Shot Smoky in Operation Plumbbob in 1957. This report is the first of several pertaining to military participation in Operation Teapot.

There were four types of military participation in Exercise Desert Rock VI, conducted at Nevada Test Site in conjunction with Operation Teapot in winter/spring 1955. The first type of participation consisted of troop observers, that is, military personnel who were sent to the test site for the specific purpose of witnessing one or more nuclear shots and who returned to their home stations immediately after this "indoctrination." This is the military participation addressed in this report.

The second type of military participation consisted of battalion-size maneuver units that moved to the site to engage in tactical exercises that tested doctrine and techniques being developed for the nuclear battlefield. The two such exercises conducted during Operation Teapot were the Marine Brigade Exercise at Shot Bee, and the Armored Task Force (TF RAZOR) maneuver at Shot Apple II. These two exercises, and the radiation exposure associated therewith, will be the subject of separate reports.

The third type of military participation centered around service equipment tests and operational training associated with nuclear warfare. There were several projects engaged in these activities, for which the radiation exposure will be treated separately.

Finally, there were the personnel who were assigned to Camp Desert Rock, usually for the duration of the exercise, who planned, supported, and administered the overall exercise in order that the other participants mentioned above

could concentrate their efforts on their particular missions. These activities and the associated radiation exposures will also be analyzed subsequently.

It should also be emphasized that a fifth type of major military participation, not a part of the four Exercise Desert Rock groups mentioned above, consisted of the Weapons Effects Test Group from Field Command, Armed Forces Special Weapons Project. This group measured, analyzed, and documented the effects of nuclear weapons for the Department of Defense. Their exposures are to be analyzed only if film badge dosimetry is incomplete or inconclusive.

The thrust of this report centers around the external radiation dose to observers during the course of their activities in contaminated areas of Nevada Test Site. Of the fourteen nuclear shots (Figure 1-1) of the Teapot series, Desert Rock observers participated in nine. The observer program is described in general, and the observer activities for each of the nine shots are traced from the pre-shot orientation through the shot activities to the post-shot equipment inspection, where appropriate. Time-dependent position information is presented in order that an exposure analysis can be performed to determine the integrated dose from all contributing sources, including the initial radiation dose from the shot being observed and the dose due to residual radiation from applicable preceding shots.

The analysis described herein utilizes, for the first time, an automated procedure for determining the dose due to residual radiation. This procedure utilizes raw radiological survey data in statistical regression analyses to fit space-time models of residual radiation intensity from which isointensity contours are then derived. The derived contours as well as the decay parameters are shown for the appropriate shots for which the procedure was used. Time and space factors associated with personnel movements (operations) through contaminated areas are combined with the refined and stored radiological data to determine the integrated radiation dose for a specific troop track through the defined area. A major feature of the automated procedure is that, once the

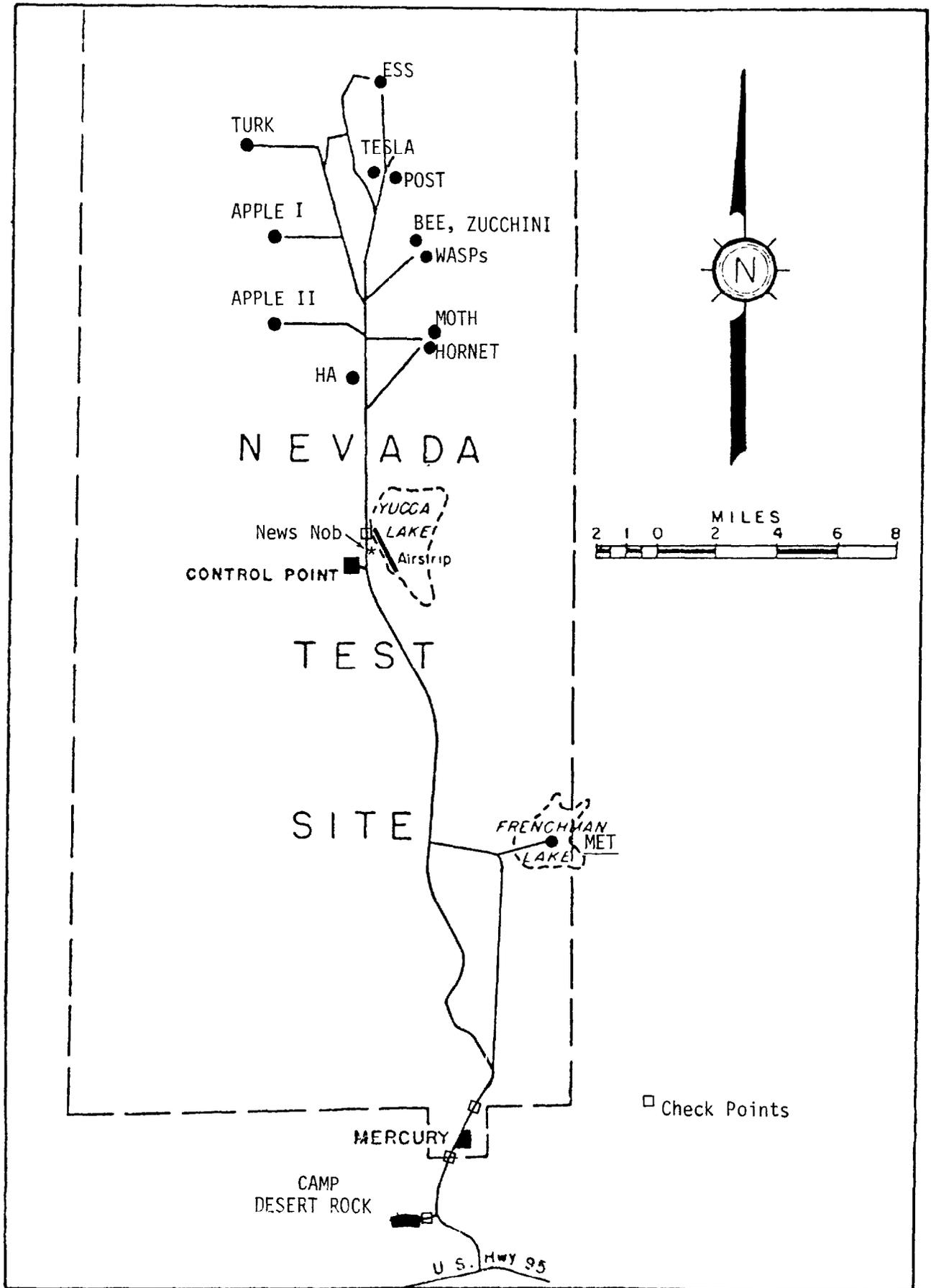


Figure 1-1 Operation Teapot Shot Locations

radiological environment is defined, variations in the time and space factors associated with troop operations are introduced to determine the sensitivity of the final integrated dose to the omissions and inconsistencies of the operational histories. The computer-based procedure facilitates such a sensitivity analysis and aids considerably in the overall uncertainty determination.

Due to inadequate film badge dosimetry data for Exercise Desert Rock VI, no significant comparison of calculated dose with film badge doses is possible. However, the methodology for determining dose is not significantly different than that used in previous analyses in which a comparison with dosimetric data established a high degree of confidence. Automation of the procedure has refined the confidence levels, and thus will facilitate subsequent exposure analyses of other troop operations in the same radiologically contaminated areas.

Major findings of this report are:

- The observers of nuclear shots in Operation Teapot were subjected to external radiation from prompt neutrons and gamma rays, and residual gamma radiation from fallout and neutron-activated soil.
- The reconstructed mean film badge dose for observers of Shot Tesla is  $1.4^{+0.4}_{-0.5}$  rem; for Shot Turk observers,  $1.3^{+0.9}_{-0.5}$  rem; for Shot Bee observers,  $0.85 \pm 0.35$  rem; for volunteer observers of Shot Apple II,  $1.6^{+1.0}_{-0.7}$  rem. Observers of other shots accrued much lesser doses.
- Free-field mean neutron doses of  $1.4^{+0.6}_{-0.3}$  rem and  $4.5^{+5.4}_{-3.0}$  rem are calculated for the in-trench positions of Shot Tesla observers and Shot Apple II volunteer observers, respectively. Neutron doses to other observers were much lower, on the order of 0.1 rem and less.
- The inhalation and ingestion of radioactive dust resulted in only a trivial addition to the dose of Operation Teapot observers.

## Section 2 OPERATIONS

### 2.1 SHOT DATA

Data for all nuclear shots of Operation Teapot are shown in Table 2-1. It should be noted that Desert Rock observers participated only in those shots marked with an asterisk. The other shots are shown for information and for investigation of residual radiation that could have contributed to the observers' radiation dose (Section 4).

### 2.2 PARTICIPATION

For Operation Teapot, there were four categories of the observer program conducted by Camp Desert Rock as a part of Exercise Desert Rock VI. These were as follows:

- A. Volunteer Observers (Project 40.22). This group, consisting of nine officers and one civilian (GS-12) from various Army service schools, participated in Shot Apple II. They each calculated the minimum safe in-trench observer distance for the upper limit of anticipated shot yield, and the consensus of the group determined the distance at which the shot would be observed from a trench.
- B. Troop Packets (Projects 41.3 and 41.7). This group, consisting of 523 personnel from the Army and 25 from the Air Force, participated in Shot Apple II. The Army personnel, part of Project 41.3, were from the six continental armies. The Air Force personnel were designated Project 41.7.
- C. Service Observers (Projects 40.11, 41.3, 41.4, 41.8). This group consisted of visitor observers from all services. The Army observers were also known as official observers, and were those personnel from Project 41.3 who were not in troop packets. They came to Camp

Table 2-1 Teapot Shot Data

Shot Name	Date Actual (Planned)	Local Time	Location NTS Area	Coord (UTM)	HOB (Ft) (Note 1)	Yield (KT)
*Wasp	18 FEB (18 FEB)	1200	T-7(4)	869047	762A	1
*Moth	22 FEB (21 FEB)	0545	T-3	871004	300T	2
*Tesla	1 MAR (25 FEB)	0530	T-9b	844090	300T	7
*Turk	7 MAR (15 FEB)	0520	T-2	784104	500T	43
Hornet	12 MAR (8 MAR)	0520	T-3a	867996	300T	4
*Bee	22 MAR (18 MAR)	0505	T-7(1a)	867056	500T	8
*Ess	23 MAR (15 MAR)	1230	T-10a	849138	-67U	1
*Apple I	29 MAR (18 MAR)	0455	T-4	797056	500T	14
Wasp Prime	29 MAR (20 MAR)	1000	T-7(4)	869047	737A	3
HA	6 APR (4 MAR)	1000	T-5	-	32,582A	3
Post	9 APR (1 MAR)	0430	T-9c	860086	300T	2
*MET	15 APR (1 MAR)	1115	FF	956728	400T	22
*Apple II	5 MAY (26 APR)	0510 (PDT)	T-1	798009	500T	29
Zucchini	15 MAY (1 APR)	0500 (PDT)	T-7(1a)	867056	500T	28

\* Exercise Desert Rock Observer participation

Note 1: A - Air T - Tower U - Underground

Desert Rock mostly as individuals rather than in groups, from various locations throughout the U.S. and overseas. The Navy and Marine Corps observers, Projects 41.4 and 40.11 respectively, followed essentially the same pattern. Their participation, however, was heavily slanted toward Shot Bee, at which the Marine Brigade exercise was conducted. The Air Force observers, Project 41.8, likely came from various bases in a manner similar to the other services.

The shot participation of the service observers is shown in Table 2-2. It should be noted that, due to possible multiple shot participation, the numbers in each project column are not necessarily additive. This is explained in Section 2.3.

- D. Camp Desert Rock (CDR) Observers. This group of observers was not associated with a particular project. It consisted of individuals assigned to the Camp Desert Rock permanent party, likely sent to the forward area in increments that varied in size somewhat inversely as the participation of other observer and troop maneuver projects. It can be assumed that everyone in the CDR organization was given the opportunity to observe one shot on a non-interference basis with other observers. With a station complement of approximately 2000, it would appear from Table 2-2 that virtually everyone took advantage of the opportunity to observe one of the shots. Because the priority for viewing a shot would have gone to those who had not yet seen one, the number of CDR personnel participating as observers on more than one shot would have been small.

## 2.3 CONCEPT

The purpose of the observer program was to indoctrinate service members at all grade levels by the observation of an actual detonation of a nuclear device, followed whenever possible by an examination of the effects of the device on an

Table 2-2 Observer Program Participation  
 Exercise Desert Rock VI  
 Operation Teapot

Shot Name	Project	USMC Observers	Volunteer Observers	Army Observers/Troop Packets	Navy Observers	USAF Troop Packets	USAF Observers	CDR Observers	TOTAL
		40.11	40.22	41.3	41.4	41.7	41.8		
1	Wasp	28		562	146		105	47	888
2	Moth	4		140	3		6	40	193
3	Tesla	24		20			1	478	523
4	Turk	1		14	2		2	445	464
5	Hornet								0
6	Bee	92		153	168		112		525
7	Ess	9		168			3	176	356
8	Apple I	28		13	2		15	550	608
9	Wasp Prime								0
10	HA								0
11	Post								0
12	MET			*				163	163
13	Apple II	11	10	131/523	36	25		57	793
14	Zucchini								0

\* Observers and troop packets originally scheduled for participation in Shot MET were postponed to Shot Apple II.

Source: References 1,13,14.

array of equipment. Volunteer observers and troop packets were scheduled to observe only one shot, Apple II. Service observers were scheduled for nine shots. They were programmed to arrive at Camp Desert Rock in groups, a day or two before the shot that the group was to observe. A new group was scheduled to arrive shortly after the previous group had departed. The observer population fluctuated considerably due to such factors as shot delays, which caused groups to overlap. Each group participated in an orientation program which included lectures and films on general nuclear weapon characteristics, a security briefing, a description of the exercise, and a pre-shot tour of the equipment display area. This pre-shot tour was probably conducted in conjunction with the AFSWP tour for its official observers and other VIPs. Observation of the nuclear shot was to be from trenches, if possible, as close to ground zero as safety criteria permitted. At approximately one hour before each shot, the observers were to be positioned in trenches (when appropriate), briefed on what to expect, and checked for proper safety procedures. After the shot, the group was to tour the equipment display area to see the effects of the detonation. The tour would be conducted by an instructor group, who would describe the effects at the various distances from the burst. The observer program was planned for each participation according to the following priority:

- I - One shot of 10KT or more.
- II - Two shots, one less than 10KT followed by one of 10KT or more, if feasible.
- III - One shot of less than 10 KT.

The plan for observer participation changed frequently due to shot postponements influenced by unfavorable weather conditions and other technical factors. Thus, the established priorities could not be met in many cases. Most observers were limited to one shot of any size and, in some cases because of the delays involved, many observers departed for their home station without witnessing any shot (Reference 13).

## 2.4 ACTIVITIES

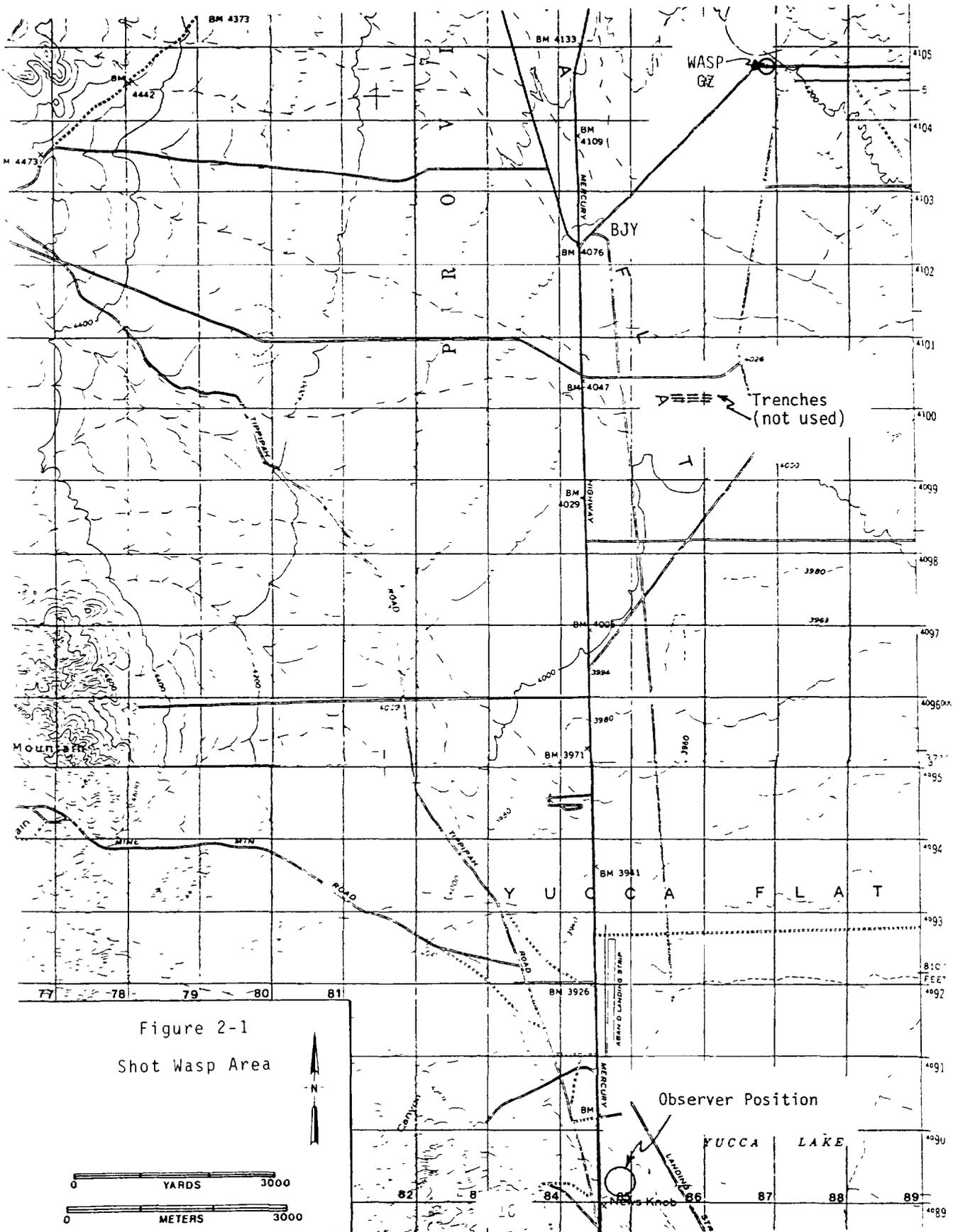
Within each category of observers--Volunteer Observers, Troop Packets, Service Observers, and CDR Observers--the activities were essentially the same for a particular shot. That is, each category remained as a group before, during, and after each shot in which it participated. Moreover, the last three categories all behaved as a single unit for each shot in which they participated. With the exception of the volunteer observers, all other participating categories for each shot were in the same trenches and viewed the same equipment display. In this section, observer activities are treated on a shot-by-shot basis. Time and space variances of the activities, due to the number of participants and the size of the areas, are considered in the uncertainty analysis (Section 5). Significant distances of interest, as used in the exposure analysis, are summarized in Table 2-3.

**2.4.1 Shot Wasp.** Two categories of observers were planned for this shot. Service Observers and CDR Observers, totaling 888 personnel (Table 2-2), intended to view the event from trenches 5000 yards from ground zero and to tour the equipment display thereafter. Based on overall observer schedules in References 13 and 14, it appears that they inspected the equipment display on 14 February, four days before the shot. Because the observer trenches and the display area were in the path of possible, if only slight, fallout, the observation point was shifted to News Nob and the post-shot tour of the display area was cancelled. Figure 2-1 shows the locations of the planned and actual observer activities relative to the shot. Due to the actual distance involved (10 miles), the observers were not exposed to significant nuclear radiation. This being the first shot of the series, there was no residual radiation from previous shots. No further analysis of the observer program for Shot Wasp is required.

**2.4.2 Shot Moth.** Service Observers and CDR Observers, totaling 193 personnel (Table 2-2), observed the shot, as planned, from trenches 2500 yards WSW ( $258^{\circ}$  azimuth) of ground zero. From the applicable operation order (Reference 3) it can be assumed that the observers arrived at the detrucking area on schedule between 0420 and 0430. The trench area was adjacent to the dismount area. Using other shot plans as a basis, the observers would have entered the trenches

Table 2-3. Observer to Ground Zero Distance Summary  
Exercise Desert Rock VI

<u>Shot</u>	<u>Observer Distance</u>	<u>Post-Shot Approach</u>
Wasp	10 miles (16 km)	None
Moth	2500 yards (2290 m)	None
Tesla	2400 yards (2190 m)	1000 yards (910 m)
Turk	5500 yards (5030 m)	1000 yards (910 m) (D+1)
Bee	3500 yards (3200 m)	600 yards (550 m)
Ess	9000 yards (8230 m)	None
Apple I	3500 yards (3200 m)	1000 yards (910 m)
MET	10,200 yards (9330 m)	None
Apple II	3500 yards (3200 m) 2600 yards (2380 m)	1000 yards (910 m) 1000 yards (910 m)



almost immediately in order to await the countdown. At H-1 hour, orientation and safety instructions were provided and attendance rosters were checked. The countdown was repeated over a loudspeaker system for all personnel to hear. At H-2 minutes, the observers were instructed to turn in one direction, crouch in the trenches, and shield their eyes. This position was to be maintained during the shot and until the blast wave had passed, after which they were allowed to rise to view the rising fireball. Within ten minutes the observers could have exited the trenches to prepare for the arrival of the vehicles (they had been parked about five miles to the south), which likely arrived by H+20 minutes. All personnel, other than the observer control group, would have departed for Camp Desert Rock by H+30 minutes. The locations of all observer activities are shown in Figure 2-2.

2.4.3 Shot Tesla. A total of 523 observers, most of whom were from Camp Desert Rock (Table 2-2), observed the shot from trenches 2400 yards\* southwest ( $235^{\circ}$  azimuth) of ground zero. They had inspected the display area on 28 February, the day before. In accordance with the usual planned procedure, the observers arrived at the detrucking area shortly after 0400 (H-1.5 hours) and moved to the trench area, about 100 yards from the road (see Figure 2-3). After the orientation and the safety, communications, and attendance checks were accomplished, the observers moved into the trenches at about H-15 minutes, where they remained through the countdown to the shot at 0530 and for an additional 5-10 minutes thereafter. By H+20 minutes, Desert Rock rad-safe monitors had cleared the way for the walk to the equipment display, located almost a mile toward ground zero. It is evident from the rad-safe situation map, however, that little of the planned tour could be accomplished, possibly due in part to the higher-than-expected shot yield. The limit of advance for all observer personnel was the 5r/hr line, which was established by rad-safe personnel at about 1000 yards from GZ. The equipment displays were located at 500 and 1000 yards from ground zero (Reference 1, Annex Q). Thus, only the 1000-yard line could have been viewed by the observers. They would have

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\*The planned distance was 2500 yards. Inspection of shot area photographs, however, places the trenches at this azimuth and distance.

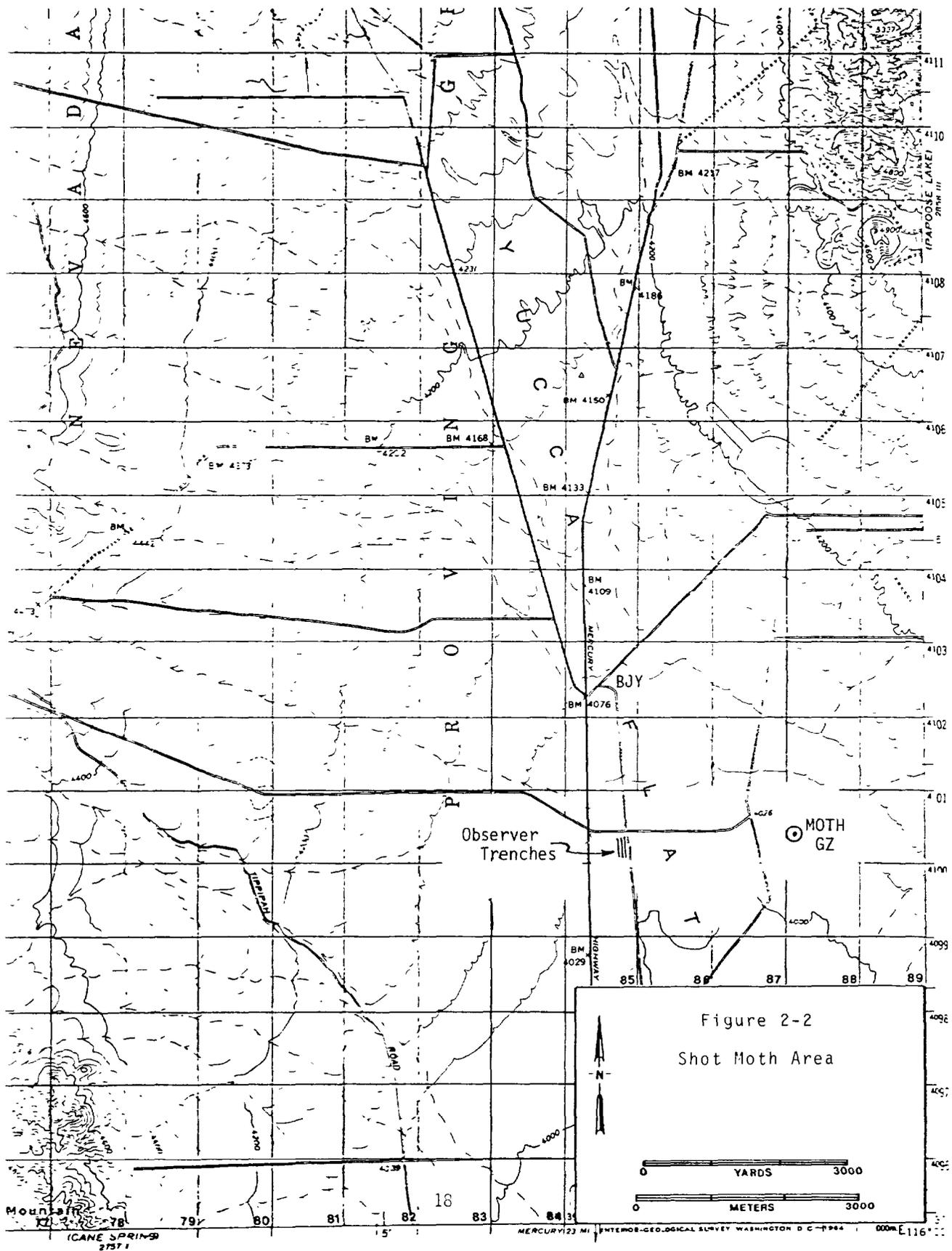


Figure 2-2  
Shot Moth Area

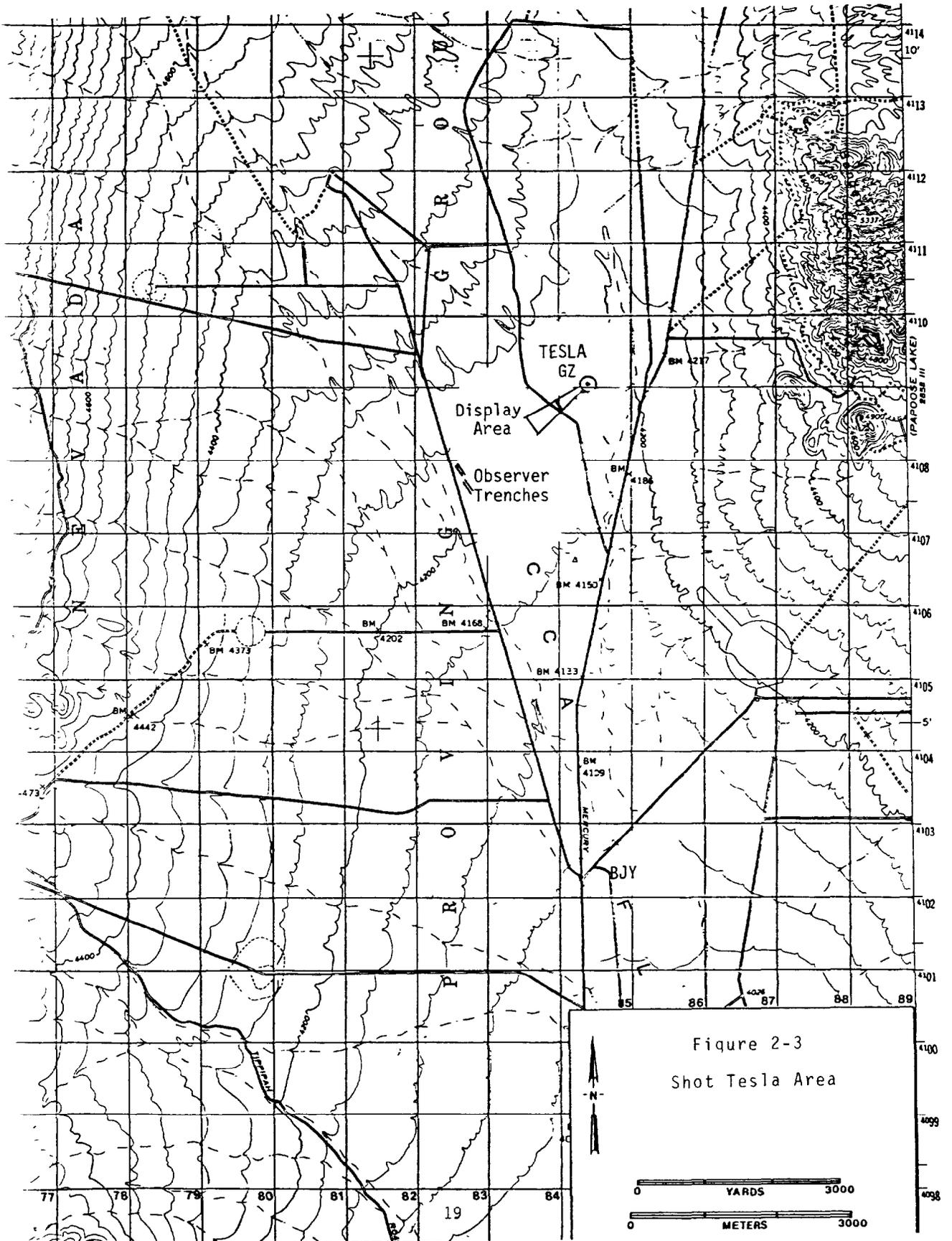
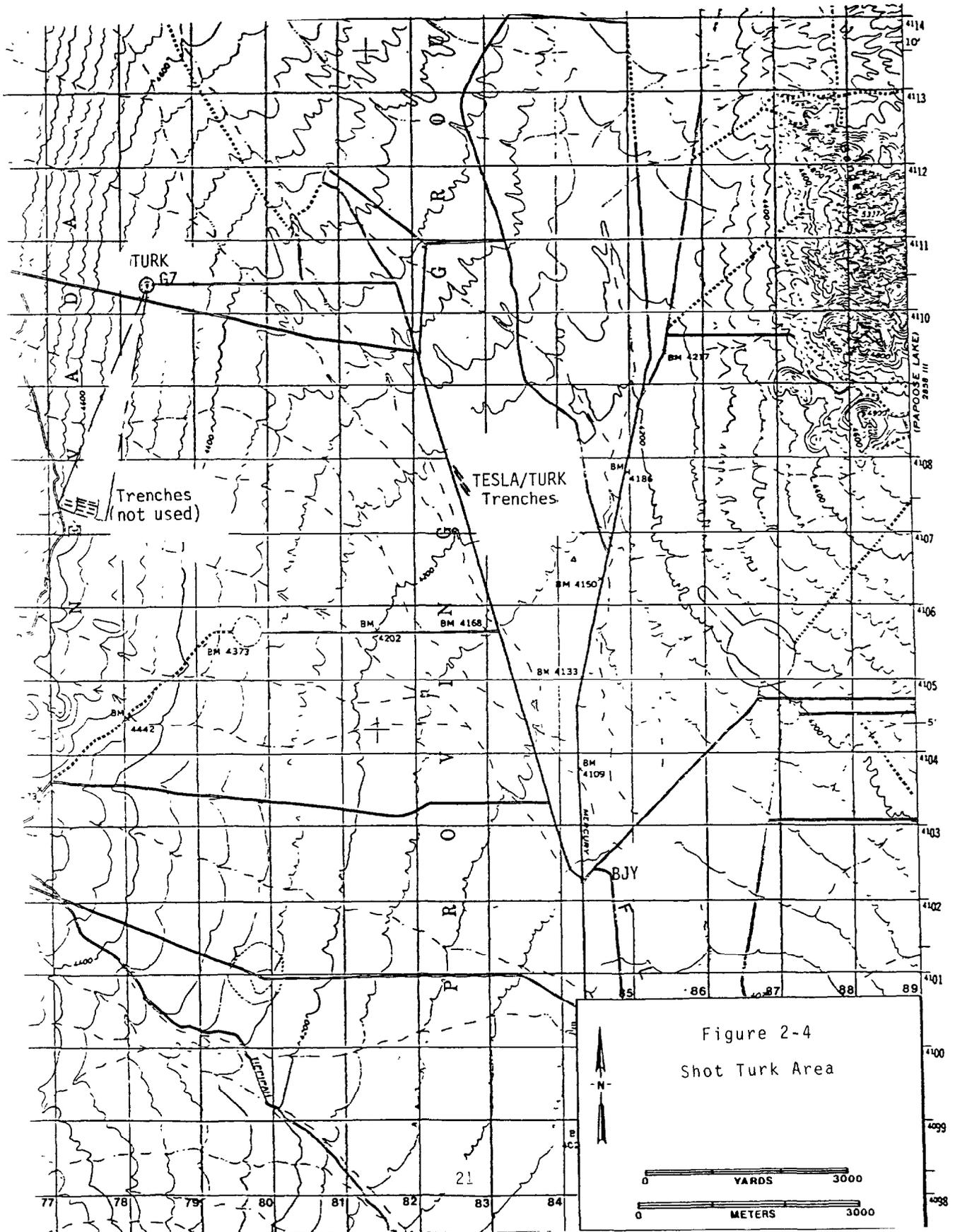


Figure 2-3  
Shot Tesla Area

arrived there approximately 30 minutes after leaving the trench area, or at about 0620. After a stay of 10-15 minutes, they had to return to the trench area (verified by Army photograph) to meet their vehicles rather than use the planned loading area near the 500-yard display line. Arrival at the trench area was about 0700, at which time the observers mounted and returned to Camp Desert Rock.

**2.4.4 Shot Turk.** A total of 464 observers witnessed the shot on 7 March from trenches located 5500 yards SE ( $120^{\circ}$  azimuth) of ground zero (Figure 2-4). Some observers had toured the display area on 14 February, the day before the original readiness date. Others toured the display on 2 March. As in the previous shot (Tesla), most of the observers consisted of the Camp Desert Rock permanent party (Table 2-2). This may have been due, in part, to the long delay of Shot Turk, the planned first shot of Operation Teapot, which could have caused some observers to depart before the shot. The trenches were the same ones used for Shot Tesla because the trenches prepared for Shot Turk, 3500 yards south of ground zero, were in the path of expected fallout. The observers, following the operation plan already used for Shot Tesla, arrived at the trenches between 0410 and 0420, in time for the usual pre-shot orientation and checks to begin at 0420 (H-1). It had been determined beforehand that, due to expected fallout, the forward area would be evacuated immediately after the shot. The vehicles, parked about 5 miles to the south, would have arrived at the trench area by 0535 (H+15 minutes), at which time they would have loaded and departed the area, possibly by 0545. They likely arrived back at Camp Desert Rock before 0700. As it turned out, because the cloud veered to the west, the trench area was not in the fallout path. However, the display area was contaminated to an extent that would have precluded an inspection on shot day, had the observers remained in the forward area.

On the following afternoon, observers returned to the shot area to view the equipment display, as evidenced by U.S. Army photographs. The photographs indicate levels of damage to equipment that are consistent with those to be expected as close as 1000 yards from a 43 KT burst. Because of the 20 mr/hr rad-safe limit for vehicular movement, the observers had to disembark just short



of the unused trench area. Their inspection, up to the 1000-yard displays, would have required about the two hours indicated in the operation order.

2.4.5 Shot Hornet. There was no Exercise Desert Rock observer participation in this event.

2.4.6 Shot Bee. A total of 525 service observers witnessed this shot from trenches located 3500 yards SW (220° azimuth) of ground zero. Because of the large number of planned participants, including some of the maneuver troops from the Marine Brigade Exercise (Project 41.6), there were no Camp Desert Rock permanent party observers. Of those from the Marine Brigade Exercise, 142 stayed with the observers for the post-shot tour and did not participate in the maneuver. As for previous shots, it is assumed that the exercise observers joined the other official observers to inspect the pre-shot condition of the equipment in the display area on 15 March, three days before the planned shot date of 18 March. On 22 March, the actual shot date, the observers arrived in the trench area (Figure 2-5) at about 0335, thirty minutes before the usual H-1 hour orientation and safety checks were begun. Shot Bee was detonated at 0505 hours. It was 0535 before the observers were given clearance to move toward the equipment display area, the first line of which was 700 yards forward of the trenches (2800 yards from GZ). Their itinerary through the display area (based on Reference 7) was as follows:

Depart trenches	0535	H+.5
Arr 2800-yard display	0545	H+.7
Arr 2300-yard display	0555	H+.8
Arr 1900-yard display	0605	H+1
Arr 1100-yard display	0625	H+1.3
Arr 700-yard display	0650	H+1.8
(includes displays to 500 yards)		
Dep 700-yard display	0705	H+2
Arr trench area, load vehicles	0740	H+2.6
Dep for Camp Desert Rock	0750	H+2.8

The observers would have arrived back at Camp Desert Rock at 0920, if it is assumed that they adhered to their itinerary in the same manner as they had for the entire operation.

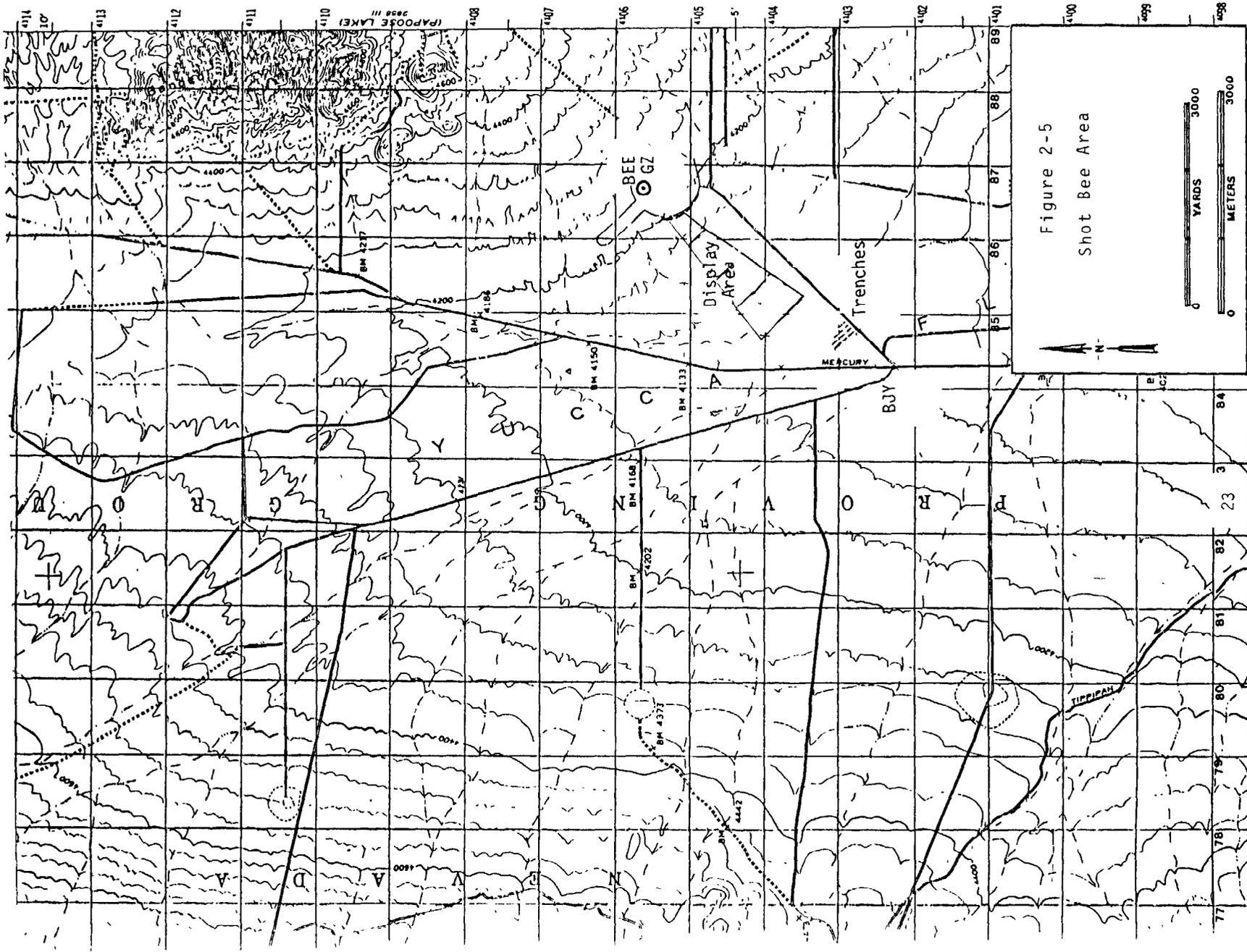
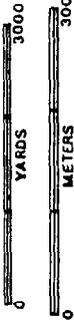
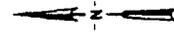


Figure 2-5  
Shot Bee Area

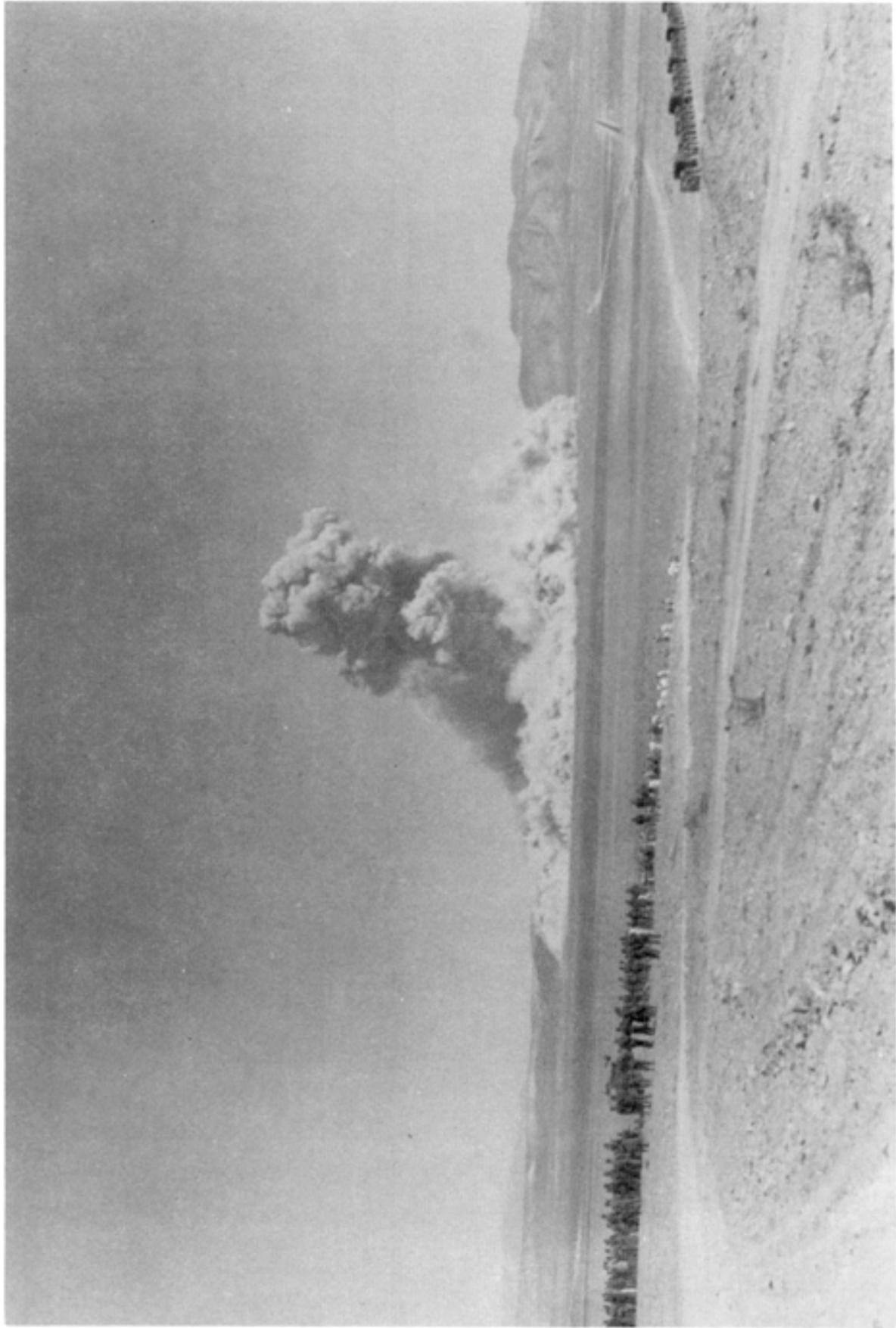


2.4.7 Shot Ess. There were 356 observers for this shot, a test of the Army's Atomic Demolition Munition (ADM). About half of the observers were from the Camp Desert Rock permanent party, as shown in Table 2-2. Because of the distance, and because the shot was detonated at a depth of 67 feet, no trenches were necessary for the observers. There was no Desert Rock display area, hence, no pre-shot inspection. They witnessed the shot from 9000 yards southwest ( $248^{\circ}$  azimuth) of ground zero, coordinates 773104. It is assumed that they arrived at the observer area at 1100 hours (H-1.5), having approached the area from the south, through Area 4. After the usual pre-shot checks and orientation, they waited through the countdown to the shot at 1230. After the shot (Figure 2-6), they would have boarded the vehicles within 20 minutes for the return trip to Camp Desert Rock. The return route was the reverse of the route used before the shot. Figure 2-7 shows the significant roads and areas of interest.

2.4.8 Shot Apple I. Table 2-2 shows the breakdown of the 608 exercise observers, most of whom were from the Camp Desert Rock permanent party. They had visited the shot area on 28 March, the day before the shot, to conduct the usual pre-shot equipment display inspection. On shot day, they arrived at the detrucking area at 0325 hours (H-1.5 hours). The pre-shot activities were essentially the same as for previous shots. They entered the observer trenches, located 3500 yards SSW ( $205^{\circ}$  azimuth) of ground zero, at 0355 hours (H-1 hour). Within twenty minutes after the shot, they began the tour of the equipment display area, walking forward to the displays between 2500 and 1000 yards from ground zero. They then returned to the bus loading area at approximately 2000 yards from ground zero. They loaded the buses at 0615 for the return trip to Camp Desert Rock. Figure 2-8 shows the significant points and roads involved.

2.4.9 Shot Wasp, HA, and Post. There was no Exercise Desert Rock observer participation in these events.

2.4.10 Shot MET. The pre-shot tour of the equipment display area was conducted on 10 April, almost a week before the shot. A sizeable observer



(US Army Photograph)

Figure 2-6 Observers at Shot Ess

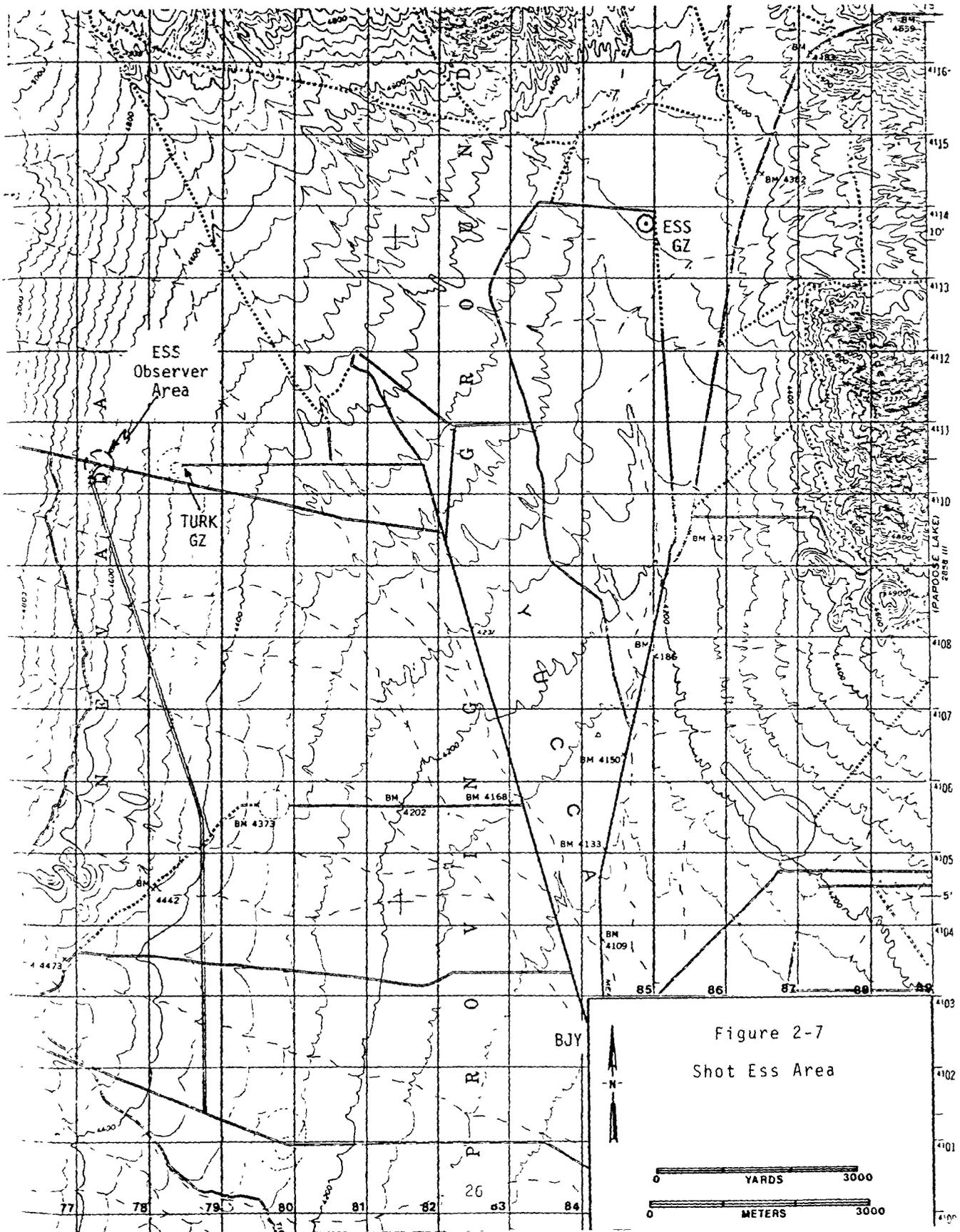


Figure 2-7  
Shot Ess Area

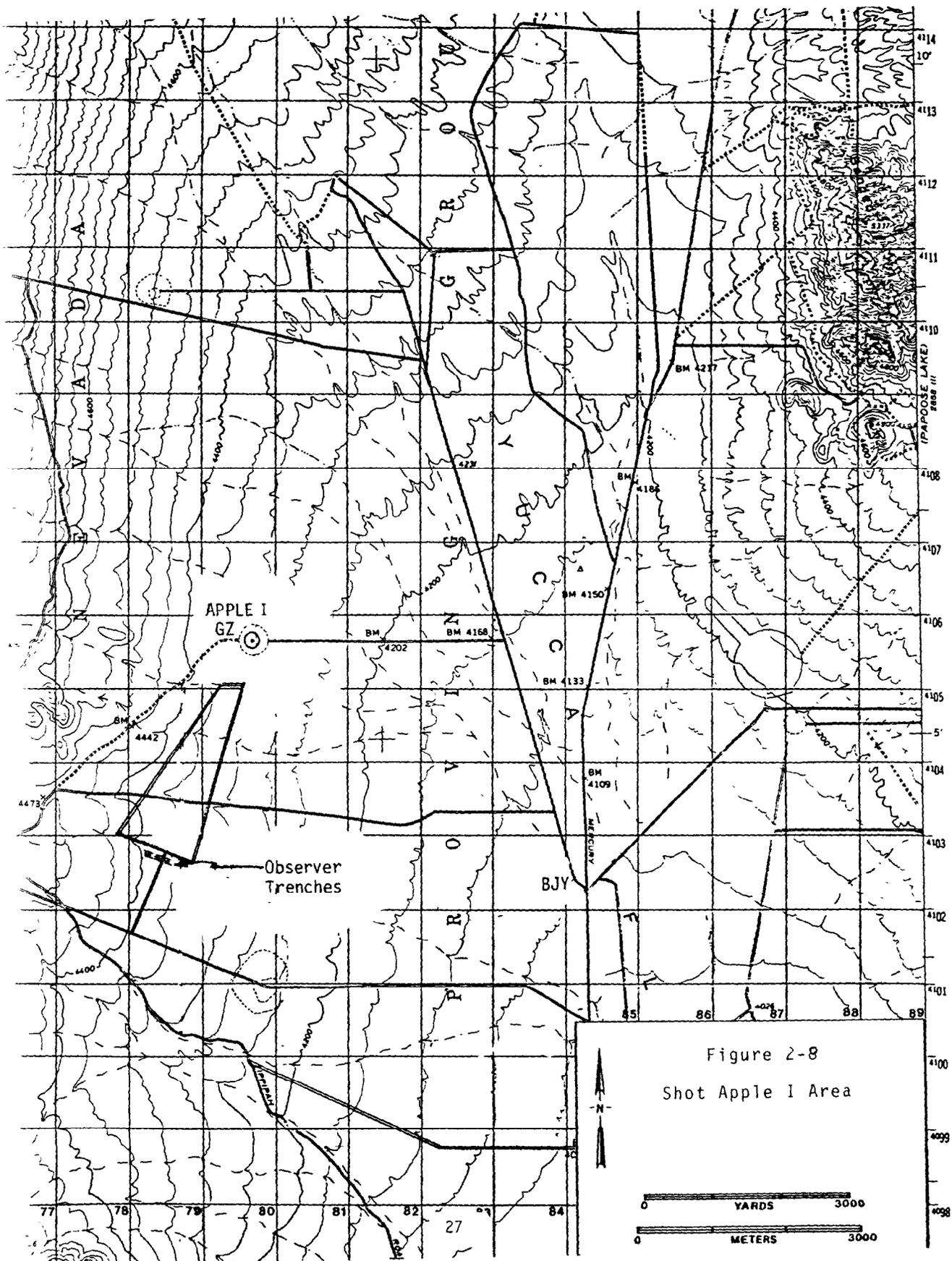
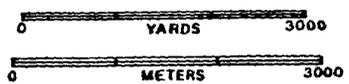
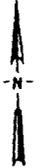


Figure 2-8  
Shot Apple I Area



program was planned for this Military Effects Test (MET) shot, the only one of the series conducted on Frenchman Flat. Due to the danger from pilotless drone aircraft, observer participation, probably programmed for the old (Desert Rock V) trenches 5000 yards WSW (225° azimuth) of ground zero, was cancelled, as well as planned tours of the equipment display area. The only observers to participate were 163 members of the Camp Desert Rock permanent party, who witnessed the shot from 10,200 yards to the southwest, as shown in Figure 2-9. A few minutes after the shot, they boarded the buses and returned to Camp Desert Rock, just seven miles south of the observer point.

2.4.11 Shot Apple II. For this shot, all four categories of observers participated, together with Task Force RAZOR, Project 41.2. All observers had inspected the pre-shot equipment display on 25 April. On shot day, 5 May, ten volunteer observers (Project 40.22) witnessed the shot from a trench located 2600 yards south (175° azimuth) of ground zero. The main group of observers were in trenches 900 yards farther south, 3500 yards from ground zero. A last group of observers, to include VIPs, was in trenches almost 4900 yards southwest (210° azimuth) of ground zero. All observers had left Camp Desert Rock shortly after 0100 and had arrived at their respective observer areas at approximately 0300, almost two hours before the shot. At H-1 hour, all observers were in position, and the pre-shot checks and orientation had begun. The observers remained in their positions through the countdown to the shot at 0510. After the shot, the volunteer observers likely remained in their trench for about five minutes, after which they walked back to the command trench at the 3500-yard line. They would have arrived by H+15 minutes. At about this time, rad-safe monitors were completing their initial survey of the display area. At H+20 minutes, the observers from the trench area began their walk-through of the equipment display. Due to rad-safe considerations, the observers would have been allowed to view the equipment only up to 1000 yards from ground zero. The observers also could have watched the tank exercise which was underway to their left (west). At H+1 hour, the inspection was complete and the observers were assembled at the bus loading area for the return trip to Camp Desert Rock. The bus pick-up point was at the 20 mr/hr line (Reference 10), probably in the



vicinity of the volunteer observer trench. By 0640 (H+90 minutes), the observers had mustered, brushed off, loaded into buses, and departed for Camp Desert Rock. Figure 2-10 shows the significant areas of interest for the observer participation in Shot Apple II.

Although it could be assumed that the volunteer observers would not have joined the other observers in the equipment inspection, the possibility cannot be ruled out. Because of the necessity for timely follow-up tests on their post-shot condition, the volunteer observers probably would have been evacuated immediately after their return to the command trench. If they had stayed to inspect the equipment, they would have accrued an additional dose from this activity. For the purpose of this report, this is assumed for an upper limit of dose.

There is no evidence to suggest that the observers back at the 4900-yard area were brought up to inspect the equipment display after the shot. They presumably stayed near the VIP observer area until about 0610 (H+1 hour), at which time the buses from the vehicle park arrived to load up and return to camp.

2.4.12 Shot Zucchini. There was no observer participation in this event, the last shot of Operation Teapot.

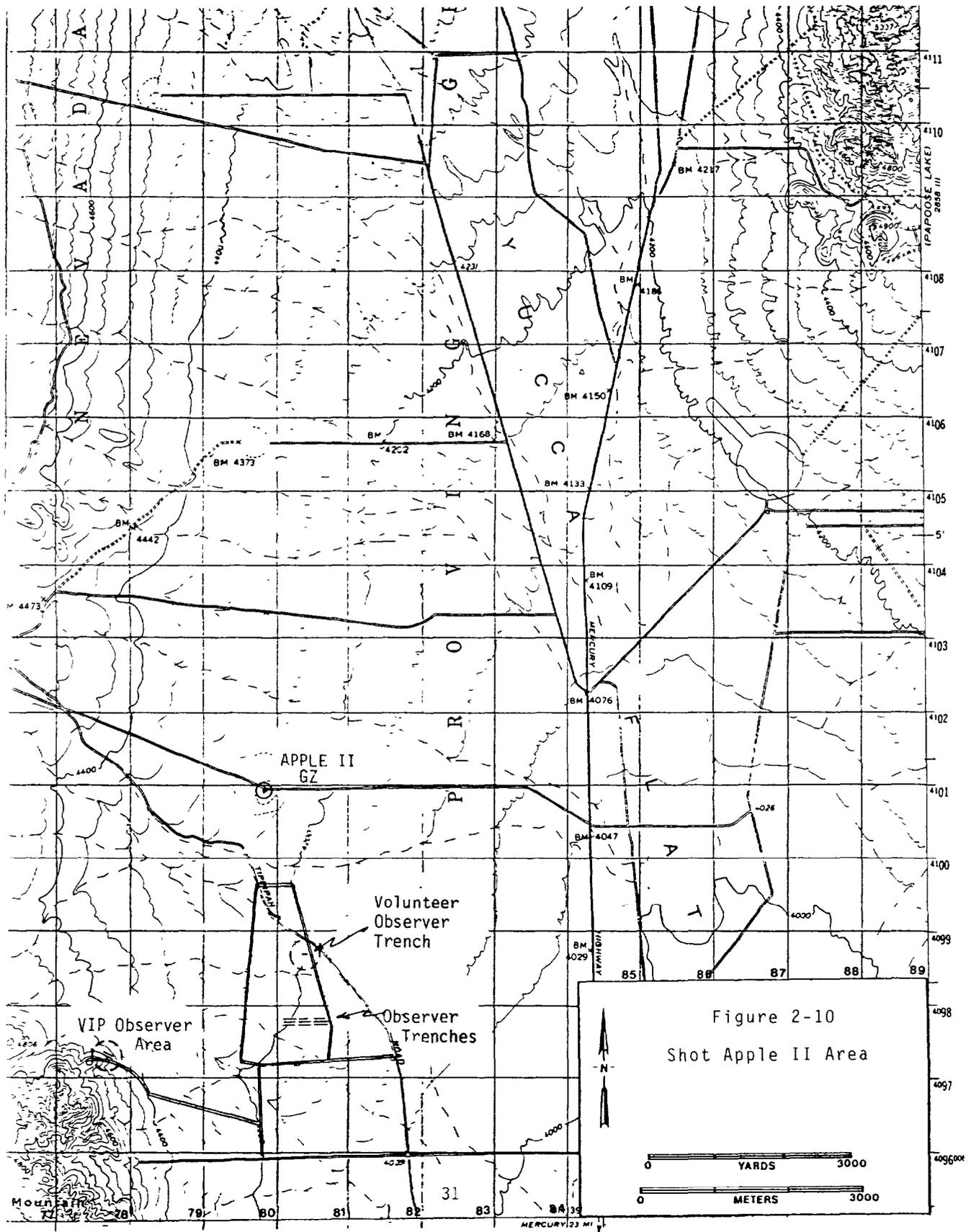


Figure 2-10  
Shot Apple II Area



## Section 3 INITIAL RADIATION

Of the nine shots at which observers participated in Exercise Desert Rock VI, six are investigated to determine the possible exposure to initial gamma and neutron radiation. These are Shots Moth, Tesla, Turk, Bee, Apple I, and Apple II, the details of which are listed in Table 2-1. The other three shots (Wasp, Ess, MET) require no further investigation of initial exposure, because the distances at which observers were actually positioned for these shots were well beyond the range of significant initial radiation. This section discusses the general method used to compute the initial radiation dose to personnel, and the specific treatment of each of the six shots of interest.

### 3.1 COMPUTATIONAL METHOD

Because the observers were located in trenches at the times of detonation, the calculation of the radiation dose for observer personnel is accomplished in two steps. First, the free-field radiation environment above the trenches is determined. This environment is then used to calculate the radiation doses to personnel in the trenches.

In the first step, the neutron and gamma radiation environment is determined with radiation transport codes ATR4 (Reference 22) and ATR4.1 (Reference 23). The first code contains provisions to correct for the presence of Nevada soil at the air-ground interface; the second, although using a West German soil type, contains improved source-energy dependent ground correction factors. Hence, ATR4 is used to calculate neutron and neutron-induced gamma radiation, which are sensitive to the hydrogen (water) content of the soil (Reference 24), while ATR4.1 is used to calculate fission product gamma and prompt\* gamma radiation, neither of which is sensitive to the presence of hydrogen in the soil. Neutron doses are calculated from tissue (Ritts) kerma factors, while Henderson tissue doses are used for gamma radiation.

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\*Defined as from the fission reaction.

A required input to the ATR codes is the weapon neutron output spectrum. This is not available, however, for any of the six shots considered. Therefore, the neutron spectrum is estimated for each shot by first choosing a trial neutron spectrum based on specific weapon design characteristics (e.g., boosting, high explosive thickness) and known spectra for similar weapons. This spectrum is used in ATR4 to calculate the neutron dose as a function of range, which is then expressed in the form

$$DR^2 = e^{-AR+B},$$

where D is the dose, R is slant range, and A and B are constants. The parameters A and B are determined by a least squares fit to the calculated doses in the range 400-1300 yards. The trial spectrum is then systematically modified to obtain agreement with initial radiation measurements taken at the time of the shot. Neutron fluence measurements were made for several shots, using fission (plutonium, neptunium, uranium) and activation (gold, sulfur) foils. These foil measurements are converted to neutron dose using an equation which was derived by collapsing tissue (Ritts) kerma factors to conform to the foil energy boundaries. This was done using published kerma (Reference 22) and neutron fluence (Reference 30) values, the latter calculated at one meter above the ground, 1500 meters from a bare fission source located at a height of 50 feet. The resulting expression for free-field tissue dose is:

$$\begin{aligned} \text{rad (tis)} = & \phi_{\text{Au}} (9.36 \times 10^{-12}) + (\phi_{\text{Au}} + \phi_{\text{Pu}}) (1.73 \times 10^{-11}) \\ & + (\phi_{\text{Pu}} - \phi_{\text{Np}}) (7.69 \times 10^{-10}) + (\phi_{\text{Np}} - \phi_{\text{U}}) (2.17 \times 10^{-9}) \\ & + (\phi_{\text{U}} - \phi_{\text{S}}) (3.00 \times 10^{-9}) + \phi_{\text{S}} (4.464 \times 10^{-9}) \end{aligned}$$

where  $\phi$  is a fluence value measured with the appropriate foil. The epithermal contribution to the dose (second term) is estimated by assuming that 52 percent of the total neutron fluence is in the range .3 eV to 10 KeV, as suggested in Reference 19. Dose range points derived in this manner from foil data are fit with an analogous exponential expression,  $DR^2 = e^{-A'R+B'}$ , and the parameters A'

and B' are compared with those developed from the trial spectrum. If necessary, the neutron distribution in the trial spectrum is adjusted so that the slope parameter A agrees with the observed value A' (the reciprocal of which is the neutron dose relaxation length) over the range of 400-1300 yards, where most foil data are available. After this adjustment, the total neutron output (or, equivalently, the neutron normalization in neutrons per KT yield) is adjusted as necessary to obtain agreement in the "B" parameter. The spectrum so derived, when used in ATR4, predicts a neutron dose which agrees with the dose calculated from foil data over the range 400-1300 yards.

A final neutron spectrum adjustment is then made, if necessary, to obtain agreement between the measured and the ATR-calculated gamma dose-range curves. Gamma doses are calculated as described previously, using ATR4 for neutron-induced (secondary) gamma and ATR4.1 for prompt and fission product (debris) gamma. The total calculated gamma doses are then compared with dose measurements. Because a significant gamma component is due to secondary gamma from radiative capture of thermal neutrons, the low energy portion of the trial neutron spectrum may be adjusted, within reasonable limits, to obtain better agreement between the two gamma dose curves. This adjustment does not significantly alter the neutron dose curve in the range 400-1300 yards; thus, the neutron dose need not be readjusted. The final adjusted spectrum is used in ATR4 to determine both neutron and neutron-induced gamma doses at the distances of the observer trenches (generally 2500-3500 yards).

The gamma dose-range curves calculated in this manner generally agree well with the measured dose-range curves in the range 1000-2000 yards. However, for many Teapot shots, the measured gamma data display a rather abrupt change in slope at approximately 2000 yards, as shown for Moth in Figure 3-2 (at 1500 yards), Bee in Figure 3-7 (2000 yards), Apple I in Figure 3-8 (2050 yards), and Apple II in Figure 3-9 (2400 yards). The ATR calculations are unable to duplicate this behavior, which is unclear. The locations of the discontinuities in slope correspond to ranges at which film types were changed--film types 1290 and 606 were used at closer distances, while types 510 and 502 were used farther out. Film types 510 and 502 were used sparingly in the Tesla and Turk shots, where no slope change is evident. Therefore, it appears that the

slope change and consequent discrepancy between measured and predicted gamma doses may be related to the sensitivity and/or processing of film types 510 and 502. On the other hand, examination of gamma dose data from Operations Tumbler-Snapper, Upshot-Knothole, and Plumbbob reveals examples of similar changes in slope that occur either in the range of a single film type or as measured with chemical dosimeters. Because the ATR gamma doses are consistently lower than the measured doses at ranges beyond this change in slope, a high-sided estimate of dose at the trench location is obtained by extrapolation from measured data. This method is applied to obtain the gamma dose for those shots displaying this effect. Individual gamma dose components (prompt, secondary, and debris gamma) are then estimated by increasing the ATR-predicted component doses proportionally to agree with the extrapolated total dose.

The second step of the calculation uses the free-field radiation environment to determine the dose within the trench. It is convenient to define a trench factor as the ratio of dose (neutron or gamma) in the trench to dose (neutron or gamma) above the trench. These factors must be calculated for each of the major components of radiation--neutron, secondary gamma (created by neutron capture or inelastic scattering in the atmosphere and ground), local gamma (created locally by neutron capture in the trench walls), and fission product (debris) gamma. It is found that the trench factors depend also on ground range, height of burst, weapon yield, trench dimensions, and depth in the trench. For the shots of interest, two trench sizes were utilized. The volunteer observers at Shot Apple II were in trenches three feet wide with an estimated depth of five feet. All other observers were in trenches approximately two feet wide and five feet deep. The in-trench free-field neutron and gamma doses for personnel in the crouched position are calculated at a depth of 2.33 feet below the lip of the trench, which corresponds approximately to the mid-torso depth for personnel in this position. For personnel standing upright in the trench, as probably occurred soon after passage of the shock wave, free-field doses are calculated at a point .5 feet below the lip at the mid-trench position; this corresponds approximately to the location of a properly-worn film badge for a

standing observer. Brief discussions of the derivations of the various trench factors are presented in Appendix I of Reference 31.

The in-trench dose (in rads) is converted to an equivalent tissue dose (in rem) using the quality factors and methods prescribed in Reference 32. It is found that the "effective" quality factor for this rad-to-rem conversion for neutrons is an almost constant value of 13 for the weapon types and ranges of interest. The quality factor for gamma radiation is taken to be unity. Finally, representative film badge readings for personnel in the trenches are estimated. The factors that are used to convert the in-trench free-field doses to film badge (chestworn) readings were developed from calculations utilizing the adjoint mode of the computer code MORSE (Reference 26). These film badge conversion factors are strongly dependent on the posture and orientation of the personnel in the trench; mean values of these parameters were determined from MORSE calculations involving extreme variations in individual posture and orientation. The "dose equivalent in trench" values reported for each shot in Section 3.2 are the equivalent tissue dose for neutron radiation and the film badge dose for gamma radiation.

The neutron, secondary gamma, and local gamma doses are accrued rapidly (essentially within the first second) after detonation. Thus, the posture in a trench could not be altered significantly during this exposure. The debris gamma dose, however, is delivered over a period of many seconds. Therefore, the possibility of individual reorientation (e.g., standing up) in the trench must be considered. It is unlikely that a person crouched in the trench at the time of detonation would have attempted any significant movement until after the shock wave had passed and the blast winds had subsided. Therefore it is assumed that, within a few seconds after passage of the shock wave, most of the observers were standing upright in the trench, watching the rising cloud. This reorientation changed both the trench factors and film badge conversion factors for such an individual. For an observer crouched in the trench from  $t_o$  until  $t_u$ , and standing upright in the center of the trench facing the rising cloud at times  $t > t_u$ , his film badge dose,  $D_d$ , due to debris gamma is calculated by:

$$D_d(t_u) = F_c \int_{t_o}^{t_u} T_c(t) I_d(t) dt + F_u \int_{t_u}^{\infty} T_u(t) I_d(t) dt,$$

where  $F_c$  = film badge conversion factor, debris gamma, crouched position,  
 $F_u$  = film badge conversion factor, debris gamma, upright position,  
 $T_c(t)$  = debris gamma trench factor, crouched position,  
 $T_u(t)$  = debris gamma trench factor, upright position,  
 $I_d(t)$  = debris gamma free-field intensity.

The trench factors  $T_c(t)$  and  $T_u(t)$ , which are time-dependent due to the rising source, are discussed in Appendix I of Reference 31. Intensities  $I_d(t)$  are calculated with computer codes NUIDEA (Reference 33) and ATR4 for the shots and ranges of interest. The film badge conversion factors  $F_c$  and  $F_u$  were discussed previously; their values for debris gamma calculations are taken as  $F_c = .46$ ,  $F_u = .95$ . In calculating the debris gamma dose, it is assumed that the observers stood upright in the trenches at three seconds after the shock wave passed their position. The values of debris gamma trench factor given in the following section are the results of this calculation. These parameters are used to convert from above-trench debris gamma dose to film badge reading for a person standing up at the reference time, and thus include the effects of both trench shielding and film badge conversion.

## 3.2 RESULTS

The results of the computations are discussed in the following subsections for each of the six shots of interest. Due to lack of required input data for some shots, some deviation from the general computational method discussed above was required. When such deviations were necessary to perform the analysis for a given shot, the details are presented.

**3.2.1 Shot Moth.** The general computational method was used, as described in Section 3.1. Neutron fluences derived from foil measurements were taken from References 20 and 21, corrected by factors given in Reference 27 to reflect improved knowledge of reaction cross section, and converted to free-field tissue doses using spectral-averaged kerma factors. The ATR fit to these "measured"

doses is displayed in Figure 3-1. Only one complete set of foil data exists for the ranges of interest. However, many individual foil measurements were taken at various distances, so that accurate fluence versus distance curves can be constructed for individual foils. These can be used to analytically determine neutron dose at any desired distance within the range spanned by the foil measurements. This method was used to determine the parameters A and B to which the ATR neutron dose was fit.

The gamma dose measurements from Reference 19 are shown in Figure 3-2, together with the ATR-derived gamma dose curve and an extrapolation from measured data. At the trench location (2500 yards from ground zero), the gamma dose obtained by extrapolation is 36 percent higher than the dose calculated with ATR. This higher dose value is used as the dose estimate.

The results of the dose calculations at the trench location are as follows:

	<u>Prompt Gamma</u>	<u>Secondary Gamma</u>	<u>Debris Gamma</u>	<u>Local Gamma</u>	<u>TOTAL GAMMA</u>	<u>NEUTRON</u>
Tissue Dose above Trench (mrad)	40	480	240	-	760	49
Trench Factor	.06	.020	.22	.08	-	.25
Film Badge Con- version Factor	.46	.53	-	.7	-	-
Dose Equivalent in Trench (mrem)	1*	5*	53*	3*	62*	160
*Film Badge Dose						

3.2.2 Shot Tesla. In addition to the gold and sulfur neutron foil measurements reported in Reference 20, two nearly-complete sets of foil data are given in Reference 34. Doses derived from the latter data (and shown in Figure 3-3) were fit with an ATR calculation; the source spectrum so derived was used to determine the free-field neutron environment at the trench location (2400 yards from ground zero). Gamma dose data are presented in Reference 19, and

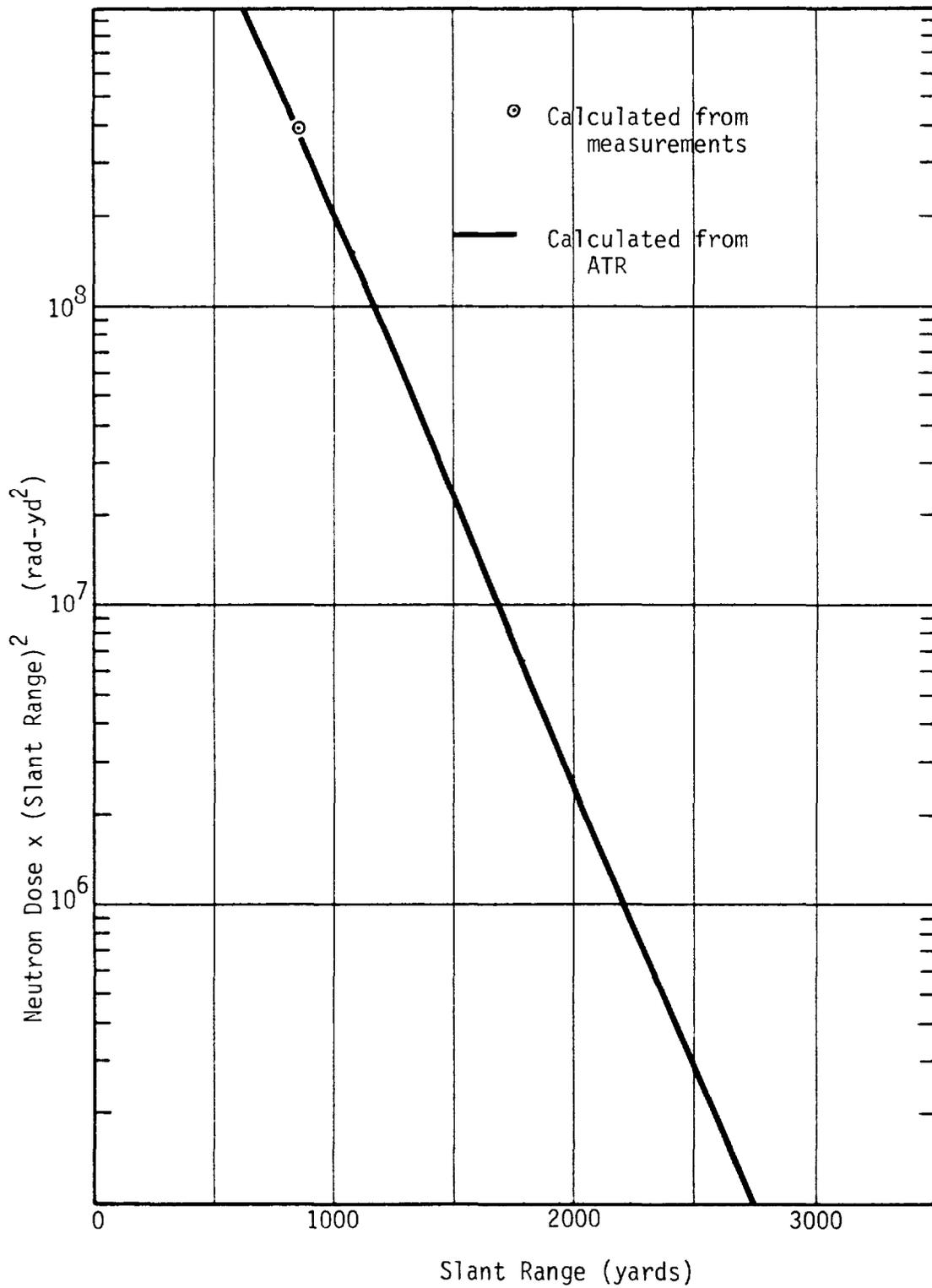


Figure 3-1 Shot Moth Neutron Dose

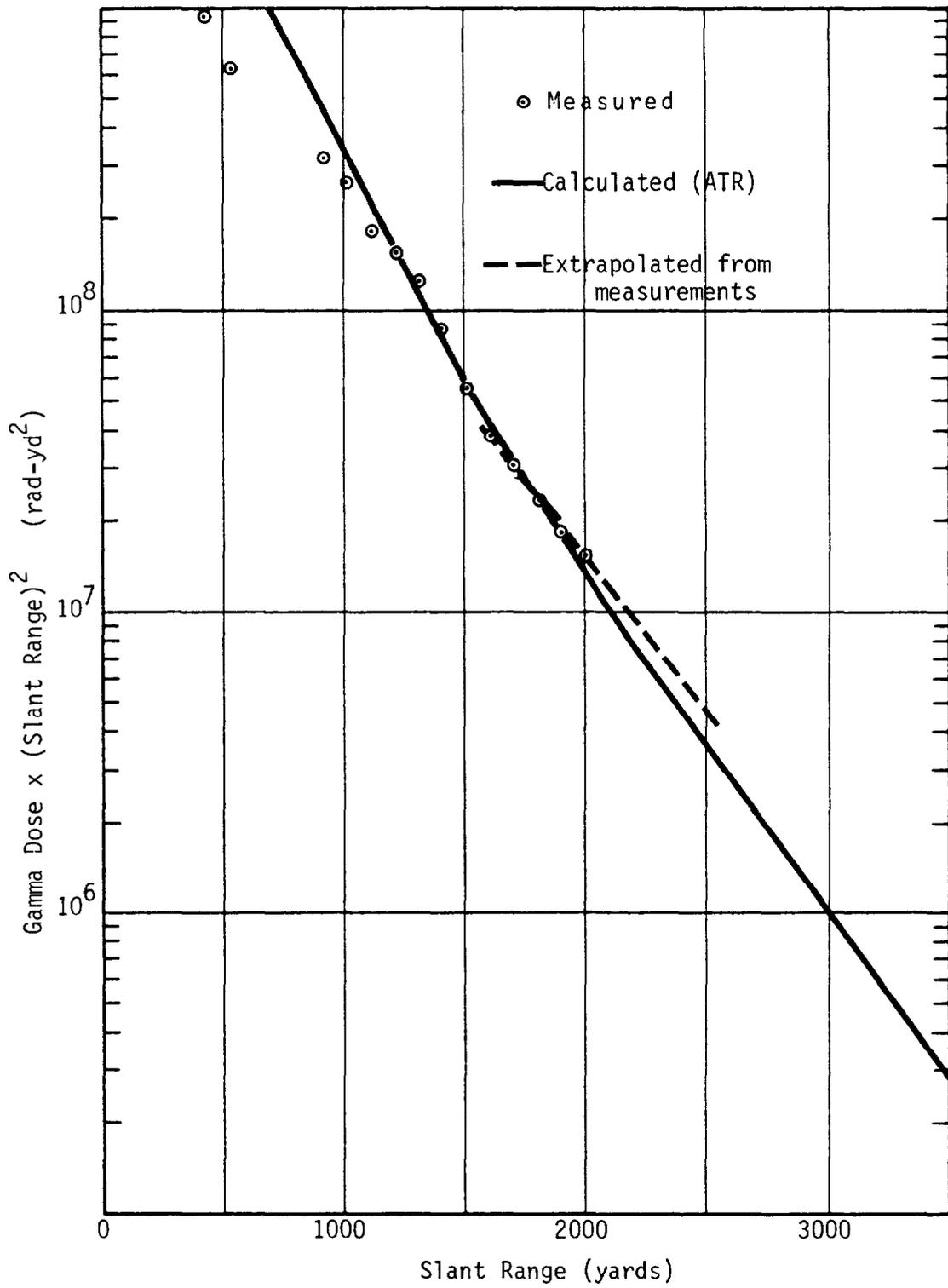


Figure 3-2 Shot Moth Gamma Dose

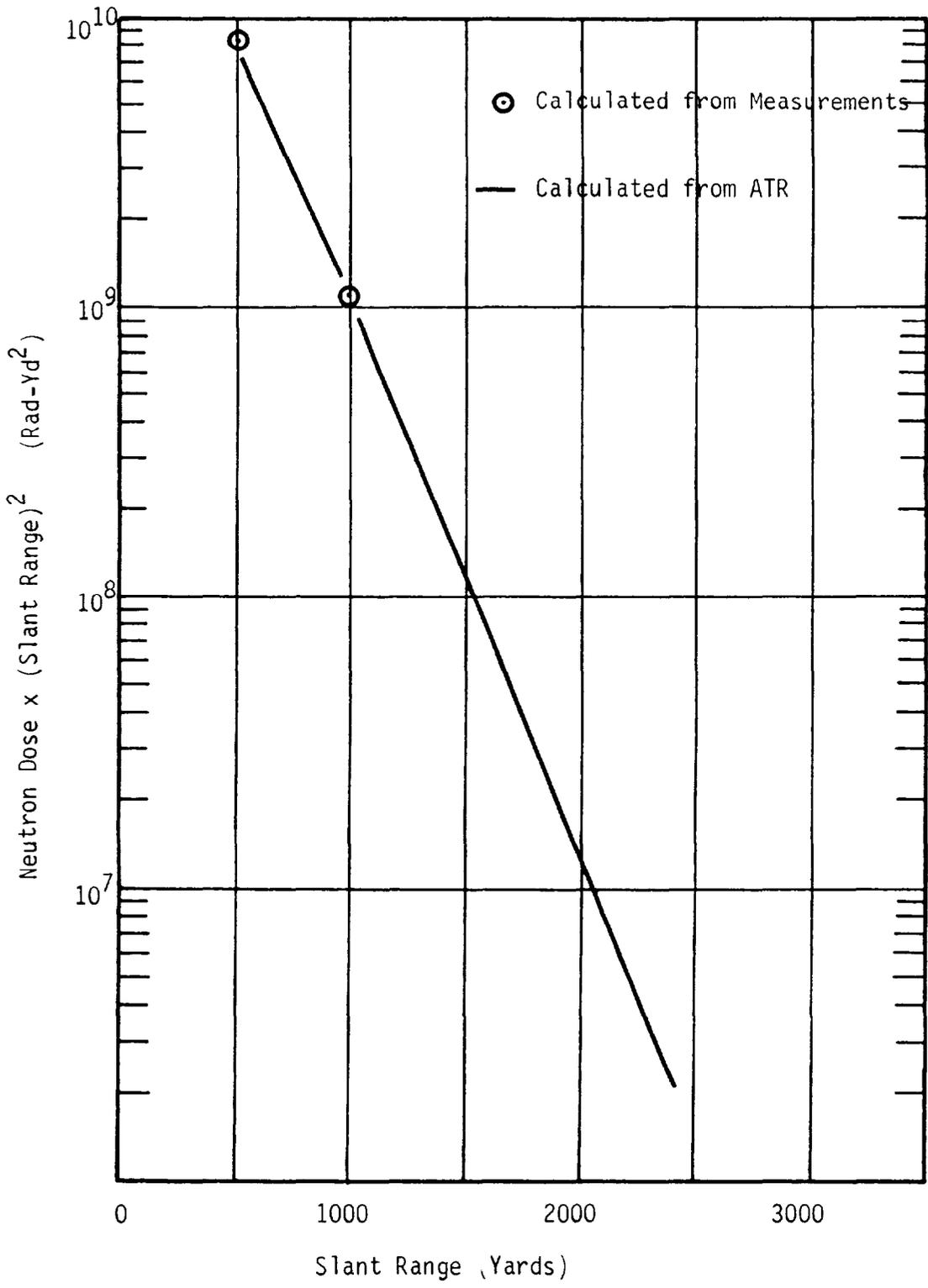


Figure 3-3 Shot Tesla Neutron Dose

displayed in Figure 3-4, together with the ATR-calculated gamma dose. The agreement is generally good.

Tesla was an asymmetric device with its axis generally in the north-south direction (8° azimuth). The neutron data from Reference 20, taken along lines 0°, 45°, and 90° to the weapon axis, show only minor variations with azimuth. The neutron data from Reference 34 were taken along an azimuth of 65°; the gamma data in Reference 19 were taken along the device axis; the trenches were located approximately between the azimuths 230°-240°. Since asymmetries in the radiation output of this device do not appear to be significant, it is assumed in performing these calculations that the output was approximately symmetrical. The estimated radiation environment at the trench location for Shot Tesla is as follows:

	<u>Prompt Gamma</u>	<u>Secondary Gamma</u>	<u>Debris Gamma</u>	<u>Local Gamma</u>	<u>TOTAL GAMMA</u>	<u>NEUTRON</u>
Tissue Dose above Trench (mrad)	80	760	1220	-	2060	400
Trench Factor	.06	.021	.20	.08	-	.25
Film Badge Con- version Factor	.46	.53	-	.7	-	-
Dose Equivalent in Trench (mrem)	2*	8*	240*	20*	270*	1310
*Film Badge Dose						

3.2.3 Shot Turk. No neutron foil data were taken for Shot Turk; gamma dose data (uncorrected due to lack of foil data) are provided in Reference 19. A neutron source spectrum was chosen based on weapon design characteristics. Because of the distance of the trench from ground zero (5500 yards), the neutron dose above the trench is found to be negligible (less than  $1 \times 10^{-6}$  rads). The ATR-calculated gamma dose is approximately 60 percent higher than the measured gamma dose as shown in Figure 3-5. Due to the very small doses involved and the apparent conservativeness inherent in these ATR calculations, further refinements were not attempted.

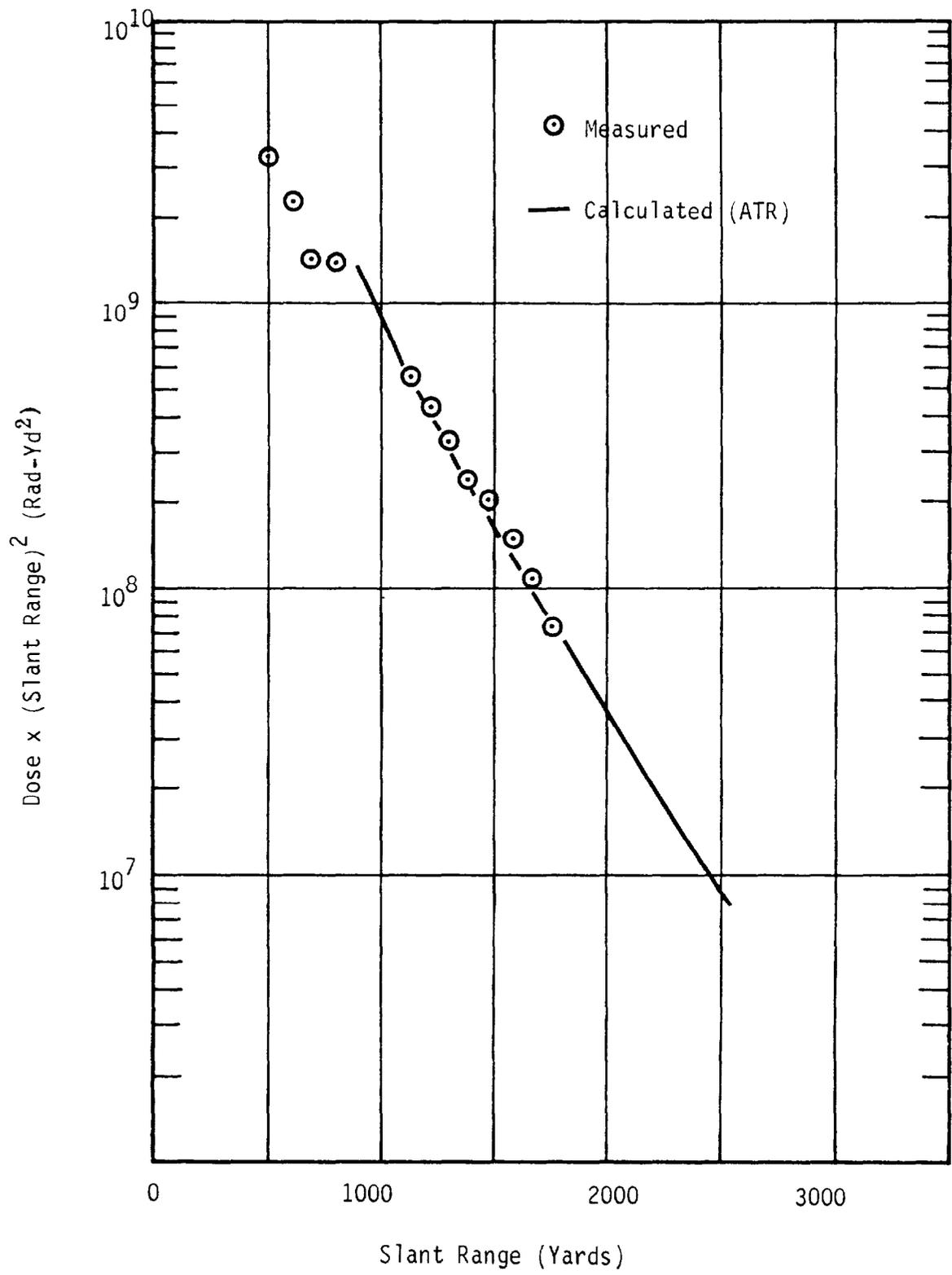


Figure 3-4 Shot Tesla Gamma Dose

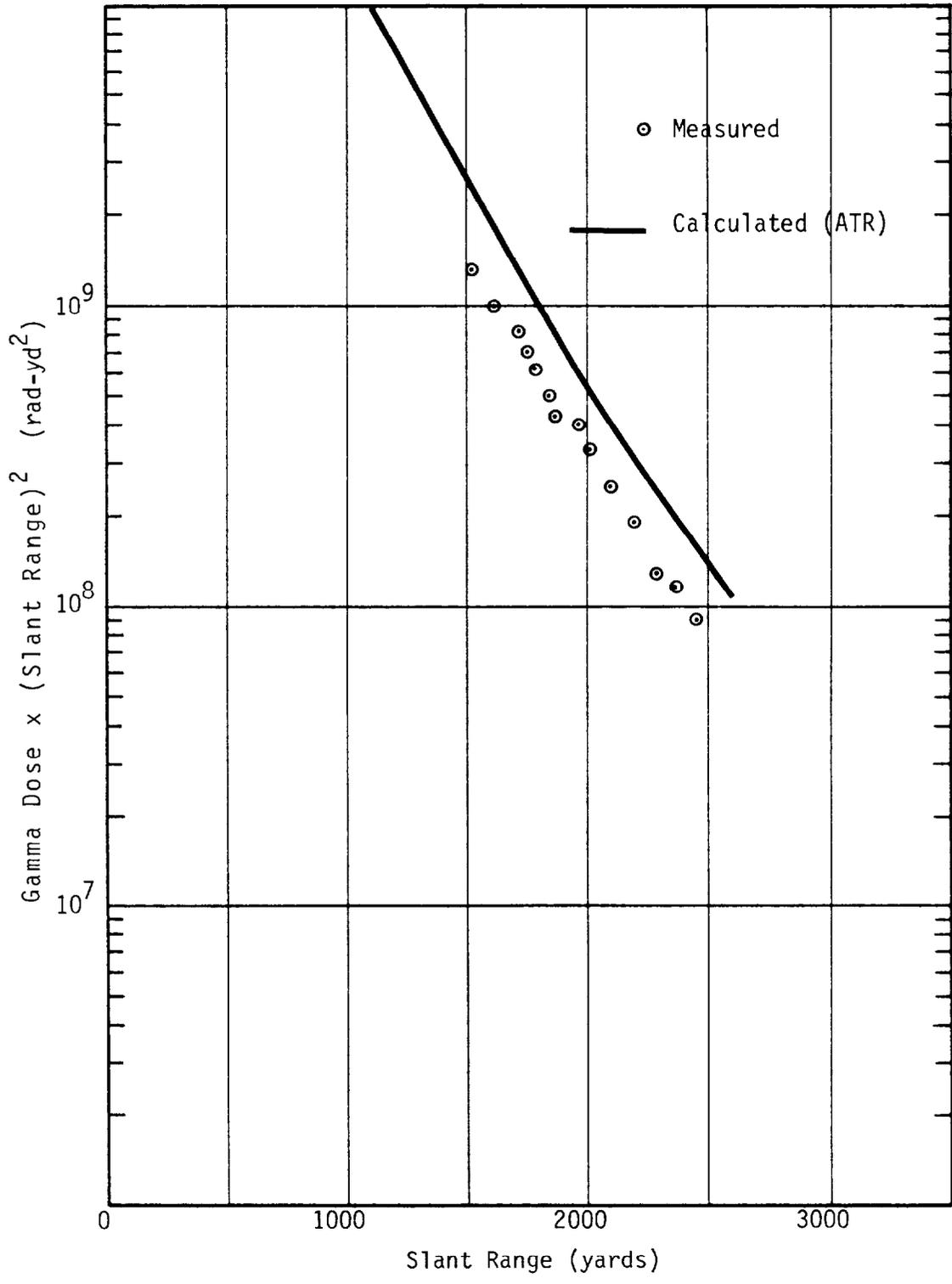


Figure 3-5 Shot Turk Gamma Dose

The estimated radiation dose at the trench location is as follows:

	<u>Prompt Gamma</u>	<u>Secondary Gamma</u>	<u>Debris Gamma</u>	<u>Local Gamma</u>	<u>TOTAL GAMMA</u>	<u>NEUTRON</u>
Tissue Dose above Trench (mrad)	<1	3	1	-	4	<1
Trench Factor	.03	.015	.13	.08	-	.25
Film Badge Con- version Factor	.46	.53	-	.7	-	-
Dose Equivalent in Trench (mrem)	<1	<1	<1	<1	<1	<1

3.2.4 Shot Bee. Neutron fluence measurements were taken from References 20 and 21, corrected by the factors in Reference 27, and converted to dose. The ATR fit to these doses is displayed in Figure 3-6. The measured gamma doses, from Reference 19, the ATR gamma dose curve, and the extrapolation from measured data are shown in Figure 3-7. The gamma dose obtained by extrapolation is 95 percent higher than the ATR-calculated dose at the trench location (3500 yards from ground zero). This higher gamma dose value is used as the dose estimate.

The results of the dose calculations at the trench location are as follows:

	<u>Prompt Gamma</u>	<u>Secondary Gamma</u>	<u>Debris Gamma</u>	<u>Local Gamma</u>	<u>TOTAL GAMMA</u>	<u>NEUTRON</u>
Tissue Dose above Trench (mrad)	10	235	85	-	330	3
Trench Factor	.03	.015	.19	.08	-	.25
Film Badge Con- version Factor	.46	.53	-	.7	-	-
Dose Equivalent in Trench (mrem)	<1	2*	16*	<1	18*	10
*Film Badge Dose						

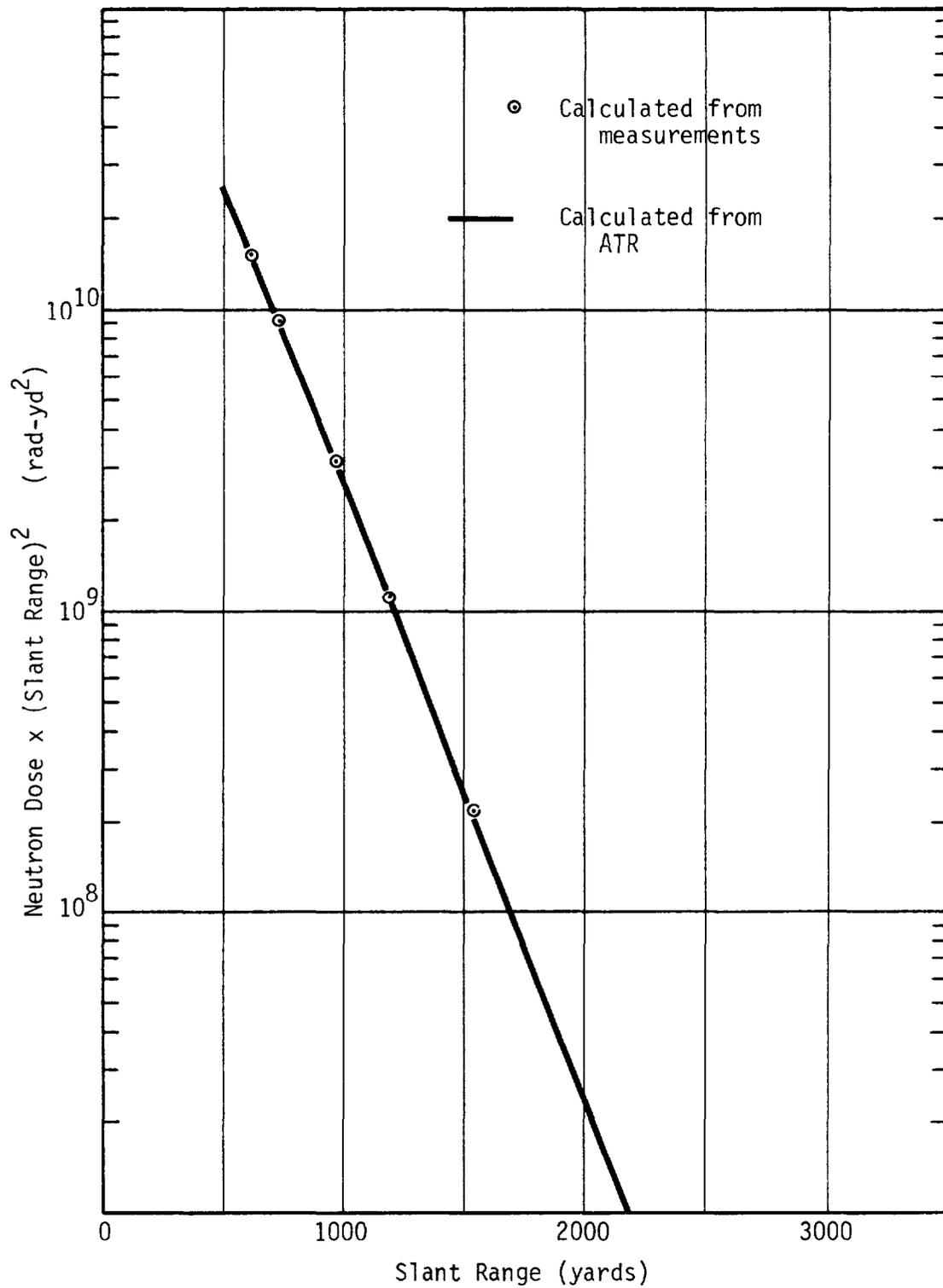


Figure 3-6 Shot Bee Neutron Dose

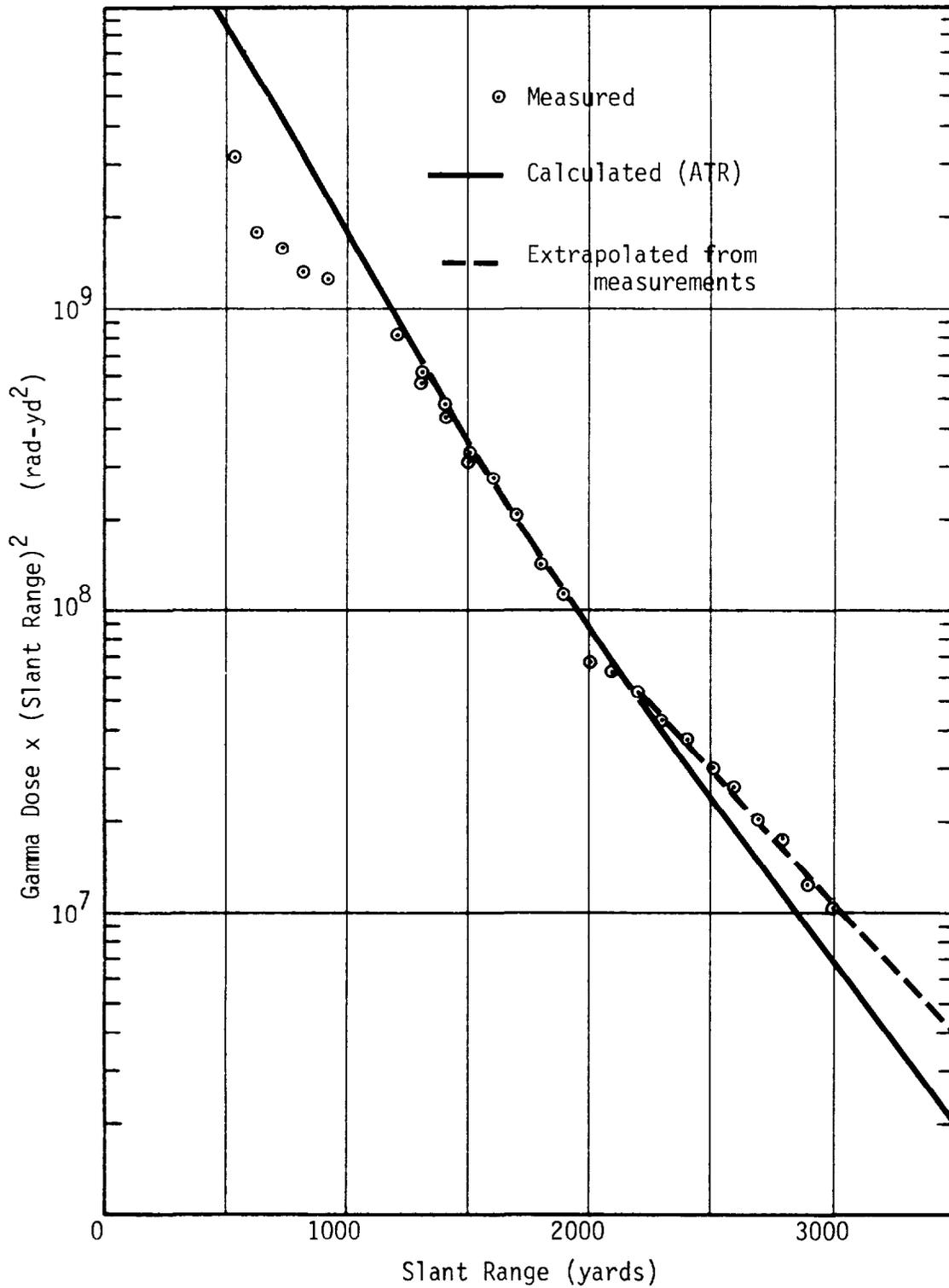


Figure 3-7 Shot Bee Gamma Dose

3.2.5 Shot Apple I. Only gold and sulfur foils were used to measure neutron fluences for Apple I (Reference 20), and therefore doses from measured data cannot be calculated. A representative neutron source spectrum, based on weapon parameters, was chosen from Reference 28 for use in ATR to perform dose calculations. The gamma dose data from Reference 19 and the ATR fit are displayed in Figure 3-8. The ATR slope appears to be correct and the values somewhat on the high side over the range 1400-2200 yards. Beyond 2200 yards, where film types 510 and 502 were used, the change in slope of the measured gamma data causes an apparent anomaly, as noted previously. An extrapolation from the data was used to estimate the gamma dose at the trench location, 3500 yards from ground zero.

The results are as follows:

	<u>Prompt Gamma</u>	<u>Secondary Gamma</u>	<u>Debris Gamma</u>	<u>Local Gamma</u>	<u>TOTAL GAMMA</u>	<u>NEUTRON</u>
Tissue Dose above Trench (mrad)	10	360	150	-	520	7
Trench Factor	.03	.015	.17	.08	-	.25
Film Badge Con- version Factor	.46	.53	-	.7	-	-
Dose Equivalent in Trench (mrem)	<1	3*	25*	<1	28	23
*Film Badge Dose						

3.2.6 Shot Apple II. No neutron foil data are available for Apple II (Reference 20); gamma dose data are given in Reference 19. Because the Apple I and Apple II devices were similar, the same neutron source spectrum was used for both. Figure 3-9 depicts the generally good agreement between the measured gamma dose and the ATR-calculated gamma dose. For the Apple II shot, trenches were located at distances of 2600, 3500, and 4900 yards from ground zero. The gamma doses were estimated by extrapolation from the data for the latter two distances. The results of the analysis are presented in Table 3-1.

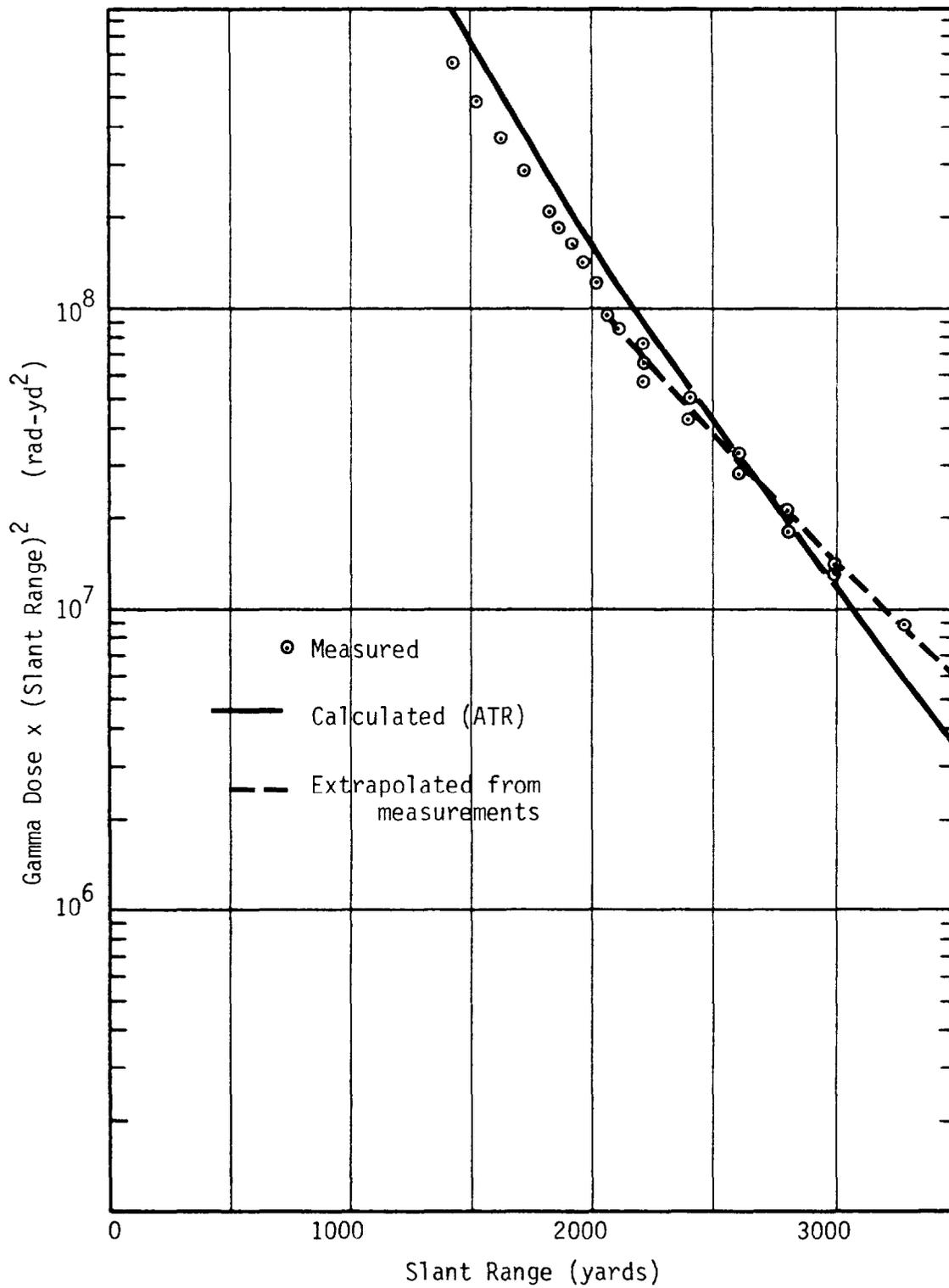


Figure 3-8 Shot Apple I Gamma Dose

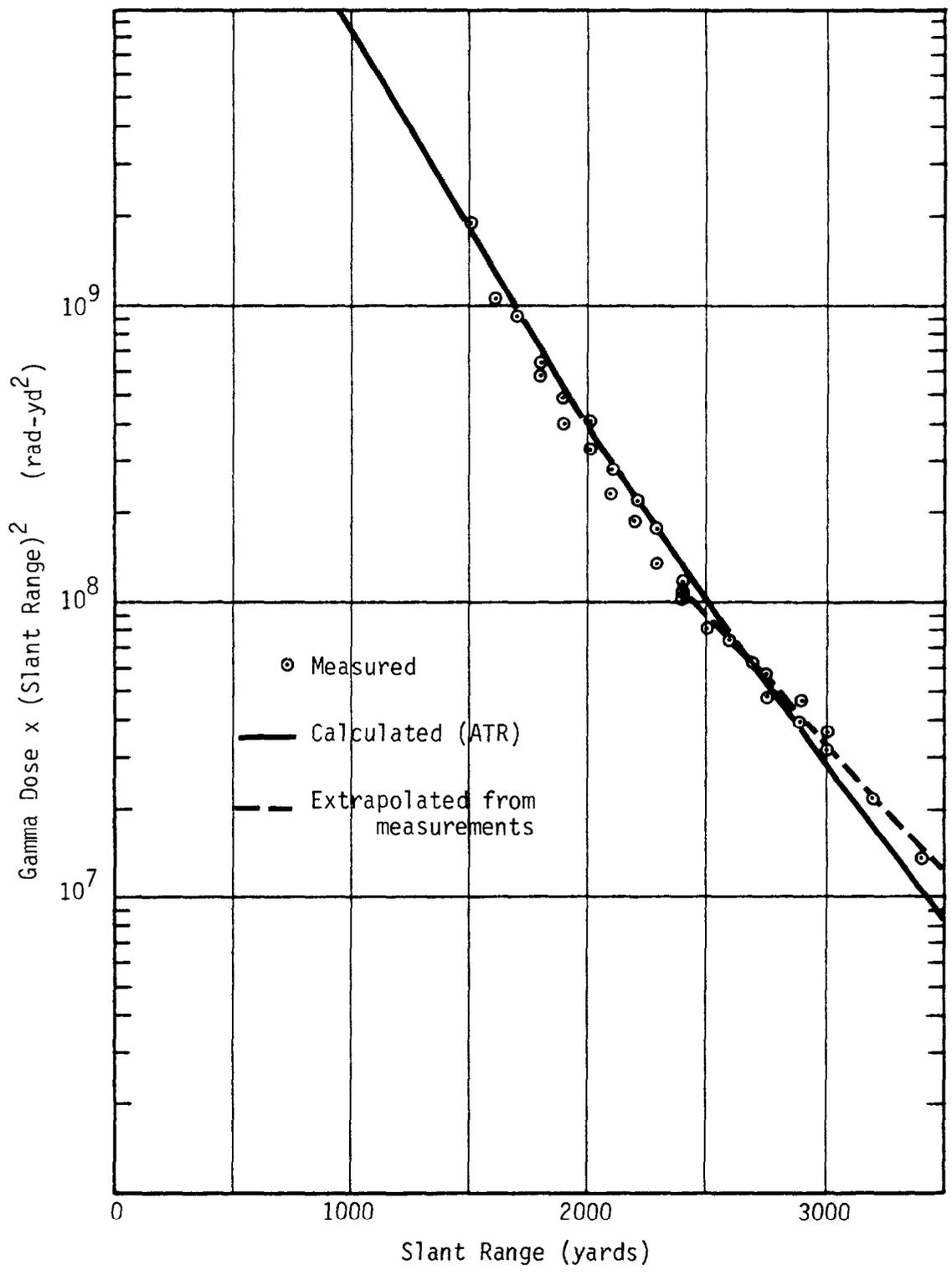


Figure 3-9 Shot Apple II Gamma Dose

Table 3-1. Initial Radiation Dose, Shot Apple II

	<u>Prompt Gamma</u>	<u>Secondary Gamma</u>	<u>Debris Gamma</u>	<u>Local Gamma</u>	<u>TOTAL GAMMA</u>	<u>NEUTRON</u>
TRENCHES AT 2600 YARDS (VOLUNTEER OBSERVERS):						
Tissue Dose above Trench (mrad)	310	5700	5800	-	11800	1080
Trench Factor	.07	.030	.18	.08	-	.27
Film Badge Con- version Factor	.46	.53	-	.7	-	-
Dose Equivalent in Trench (mrem)	10*	90*	1040*	60*	1200*	3800
TRENCHES AT 3500 YARDS:						
Tissue Dose above Trench (mrad)	20	630	350	-	1000	16
Trench Factor	.03	.015	.14	.08	-	.25
Film Badge Con- version Factor	.46	.53	-	.7	-	-
Dose Equivalent in Trench (mrem)	<1	5*	48*	1*	54*	50
TRENCHES AT 4900 YARDS:						
Tissue Dose above Trench (mrad)	<1	20	5	-	25	<1
Trench Factor	.03	.015	.13	.08	-	.25
Film Badge Con- version Factor	.46	.53	-	.7	-	-
Dose Equivalent in Trench (mrem)	<1	<1	<1	<1	<1	<1
*Film Badge Dose						

## Section 4 RESIDUAL RADIATION

### 4.1 RESIDUAL GAMMA RADIATION EXPOSURE

Gamma doses are reconstructed for military observers, based on their activities in the fallout and neutron-induced activity fields of various shots of Operation Teapot. A computerized methodology, described in the appendix, determines the radiological environment encountered by the observers. From this, doses are calculated based on the scenario of troop activities. Iso-intensity countours with superimposed troop tracks are displayed in Figures 4-2, 4-3, 4-4, 4-6, and 4-8 for Shots Tesla, Turk, Bee, Apple I, and Apple II, respectively. Other shots, which did not contaminate the observers, have gamma fields outlined in Figures 4-1, 4-5, and 4-7 to show their relationship to the observer positions. A composite plot of residual radiation from applicable Teapot shots in Yucca Flat is shown in Figure 4-9.

The computer-calculated doses do not reflect the presence of the human body in the radiological environment. Despite the penetrating ability of gamma rays from fission and activation products, the body affords some shielding; hence, the gamma dose to any organ depends on the geometry of the radiation source and the body position. In order to represent reconstructed film badge readings, gamma doses are calculated for the surface of the chest, where a film badge is normally worn. The free-field gamma intensity is converted to a film badge dose rate through the factor developed in Reference 17: 1 r/hr = 0.7 rem/hr. This conversion is applicable to an erect individual wearing a film badge on his chest, and standing in a uniform, plane fallout field. These conditions are met in the observers' scenarios except that there are intensity gradients in the gamma fields (the calculated film badge dose is identical to the "film badge equivalent dose" of Reference 17).

Observer dose calculations are categorized by the shot in conjunction with which each observer group participated. Contributions from previous shots to the dose are noted as they arise.

4.1.1 Shot Wasp. As indicated in Section 2.4.1, observers proceeded no closer to the shot area than News Nob, and received no dose at this ten-mile distance.

4.1.2 Shot Moth. Observers of Shot Moth may have encountered very light fallout before departing the trench area within a half hour after the shot. No radiological survey data were reported as far from GZ as the trenches; however, a reading of 10 mr/hr was obtained at H+42 minutes at a position about 600 meters nearer GZ. Any fallout in the trench area, even if as early as H+10 minutes, would not have had an intensity greater than several mr/hr. The dose to the observers, then, was probably on the order of 1 mrem. A dose this small would have been below the threshold of a film badge. Figure 4-1 shown the residual radiation area and the observer trenches.

4.1.3 Shot Tesla. The observers encountered fresh fallout, beginning a few hundred yards in front of their trenches. Most of their dose, however, resulted from their inspection of the equipment display line at 1000 yards from GZ. The gamma intensity during their 10-15 minute inspection of this display is calculated to have decreased from about 5 to 4 r/hr. Thus, the observers were still near the rad-safe limit, and would not have attempted to approach the 500-yard display line, which is calculated to have been at about 50 r/hr at H+1 hour (see Figure 4-2). The decay exponent associated with the isopleths is calculated to be  $-1.16$ . The total film badge dose calculated for the Tesla observers is 1100 mrem.

4.1.4 Shot Turk. Observers for this shot received no residual dose on shot day. Both their pre-shot tour of the equipment display and the Tesla trenches from which they witnessed the shot were in uncontaminated areas. The anticipated fallout from Turk at their trench position did not materialize (although it came close--see Figure 4-3), so that no dose would have resulted even if the observers had not been evacuated. The calculated decay exponent associated with the isopleths in the figure is  $-1.04$ .

On the day after the shot, the observers could view the equipment display as close as the 1000-yard line within the 5 r/hr rad-safe limit. Available photography shows that the observers walked toward GZ along the eastern boundary road of the display area. They would have accrued most of their dose

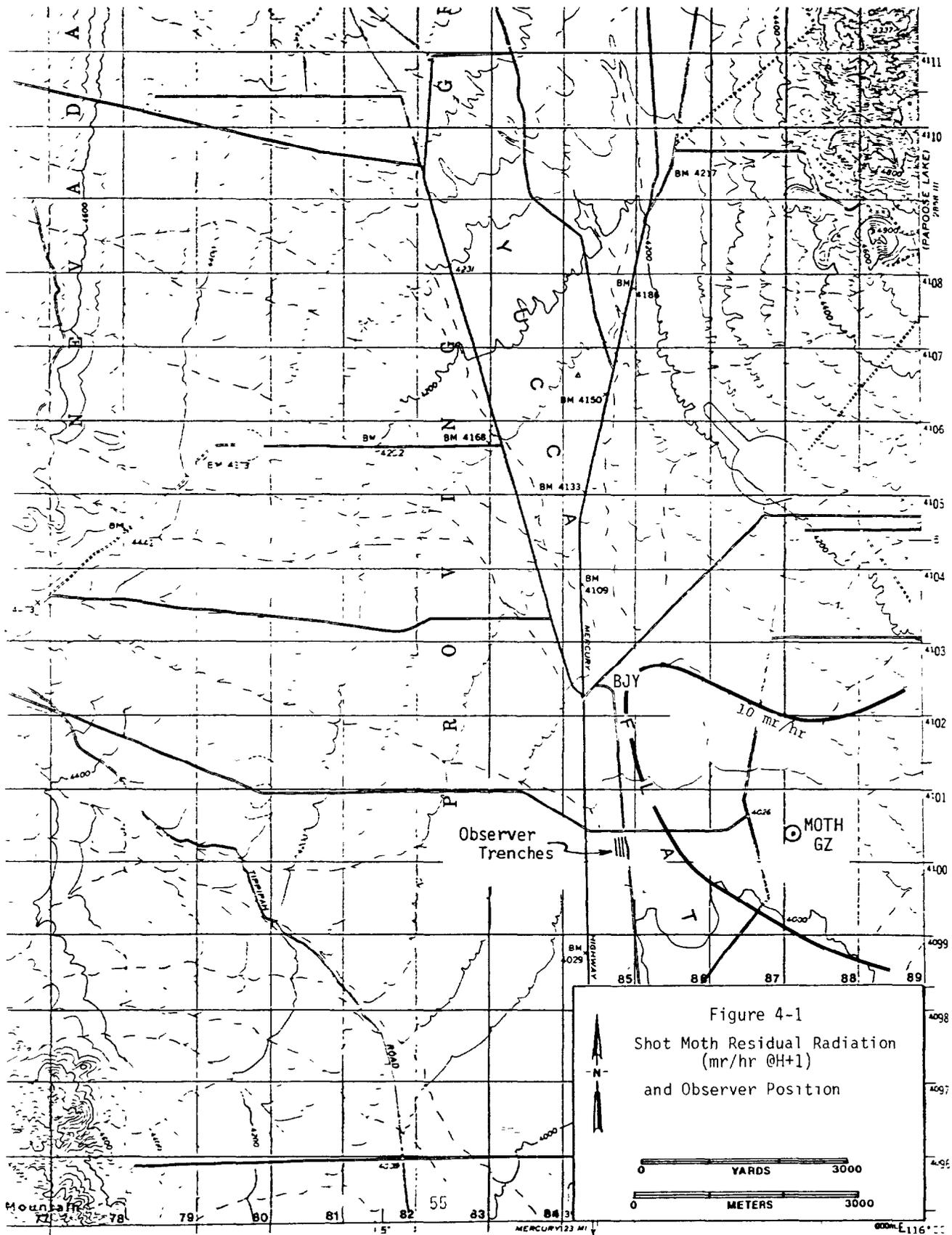
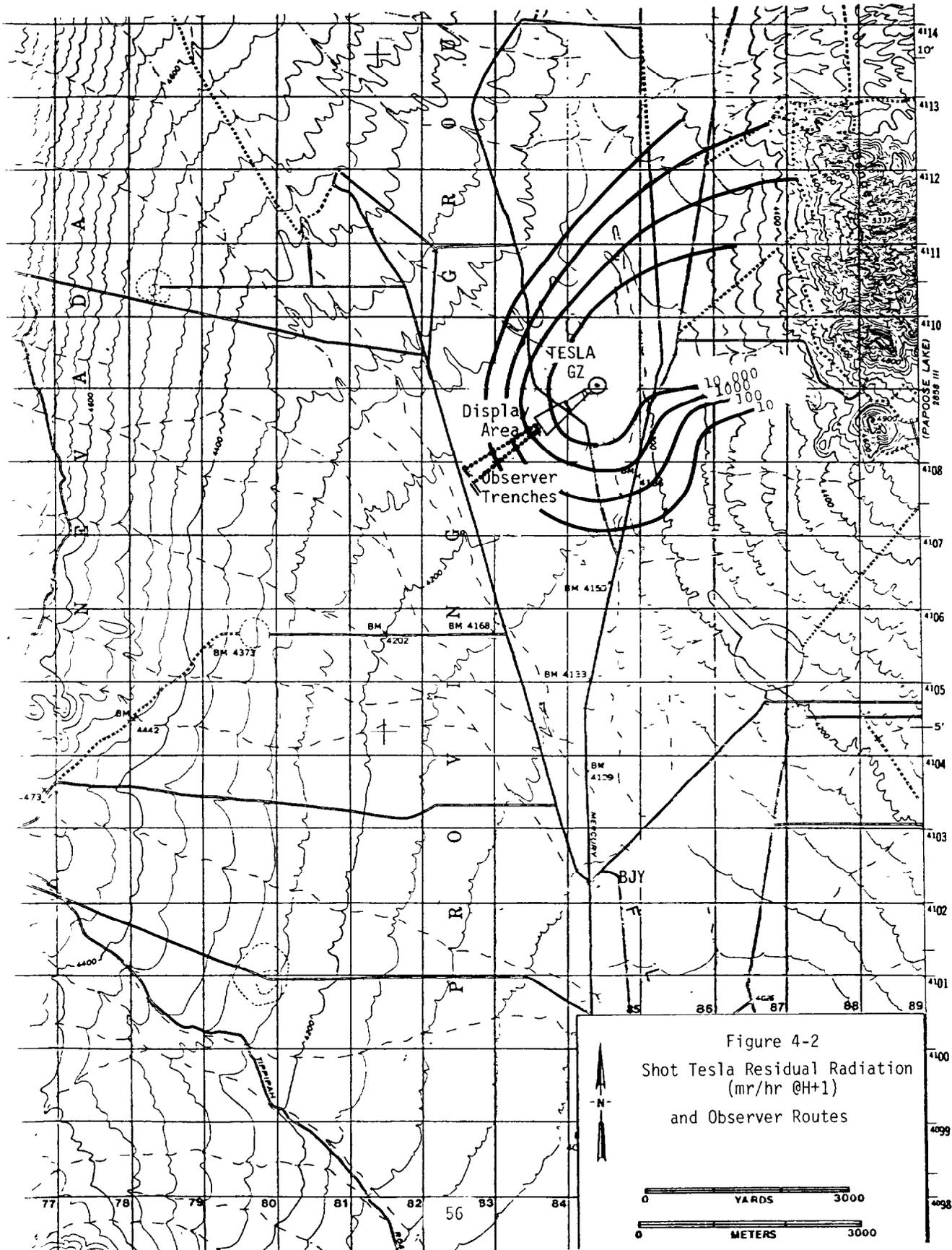
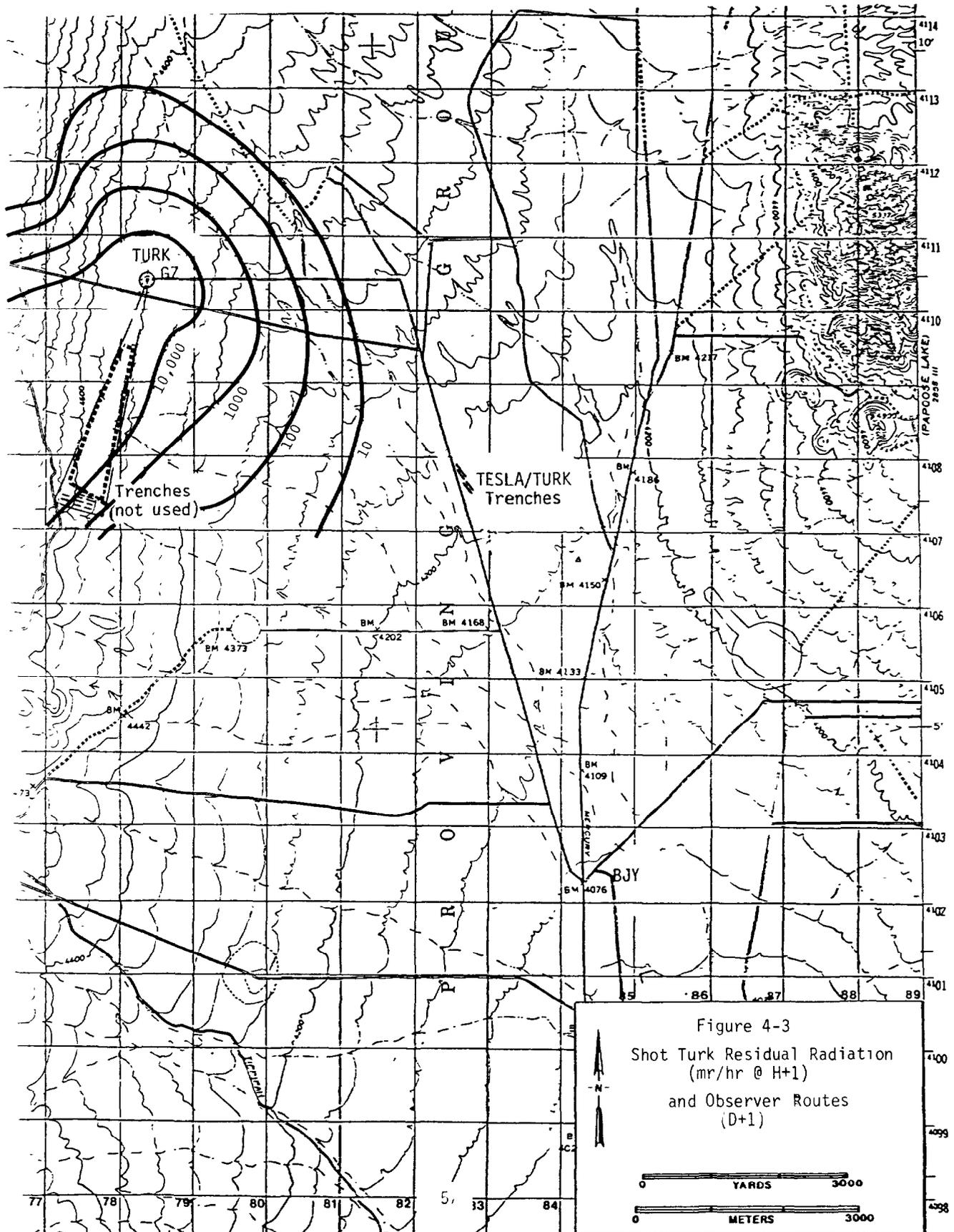


Figure 4-1  
 Shot Moth Residual Radiation  
 (mr/hr @H+1)  
 and Observer Position

0 3000  
 YARDS

0 3000  
 METERS





while returning along the (assumed) western road, which, paralleling the direction of fallout, had little decrease in intensity with distance. The calculated film badge dose for this circuit is 1240 mrem.

4.1.5 Shot Bee. The radiation field encountered by Shot Bee observers resulted from neutron activation of the soil. Entering from the southwest, the observers were well removed from the light fallout that drifted to the east (see Figure 4-4). It is assumed that the observers reached their rad-safe rate limit because the display line that ranged 700 to 500 yards from GZ crossed the 5 r/hr line at about 600 yards. The calculated film badge dose for Bee observers is 830 mrem.

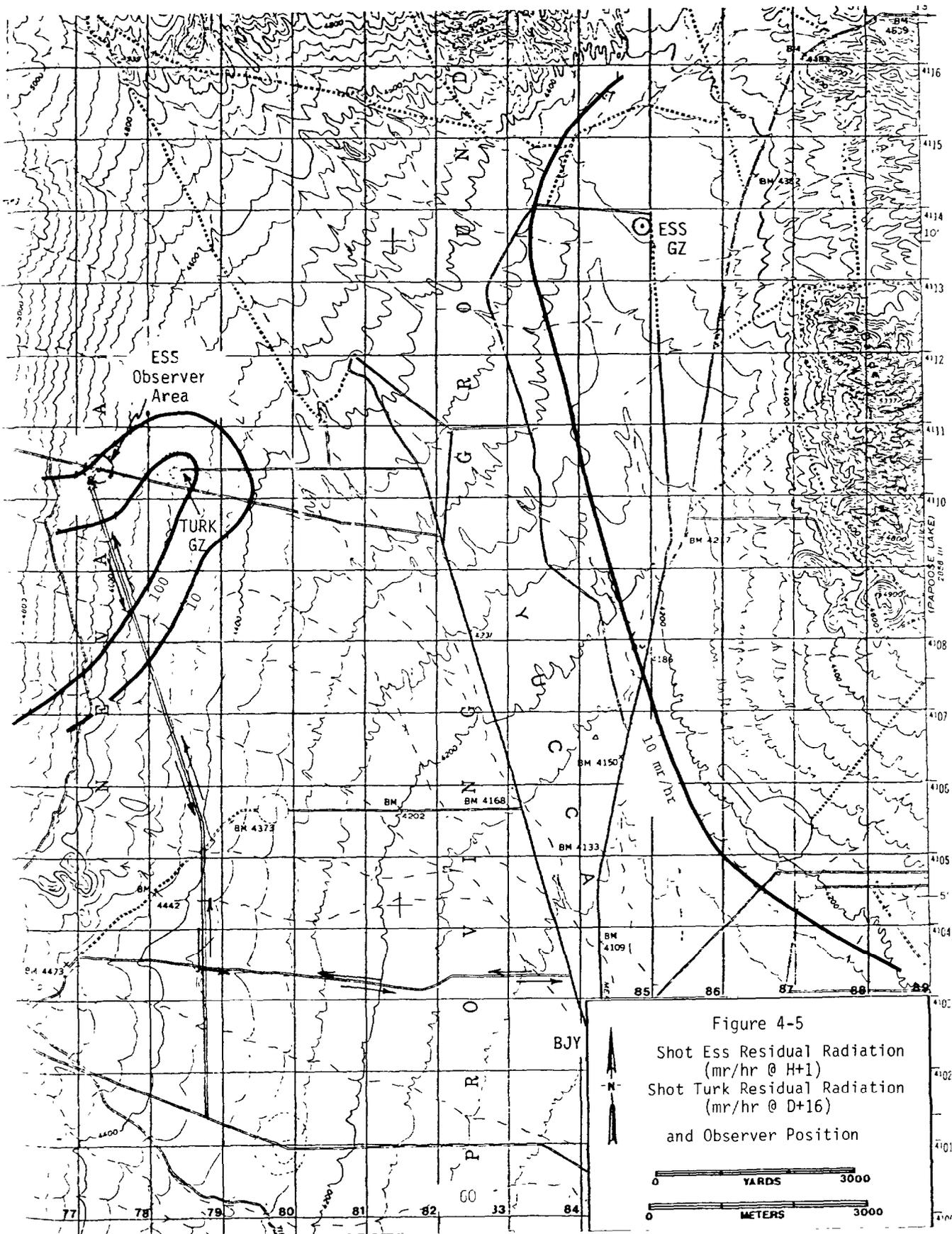
4.1.6 Shot Ess. Observers of Shot Ess were well removed from its fallout (see Figure 4-5), and thus accrued no dose from this source. However, they observed Ess from positions in the 16-day old Turk fallout field (Figure 4-3). While being trucked to and from their position, they crossed the Turk hotline, calculated to have had an intensity of nearly 200 mr/hr at that time. Much of their calculated film badge dose, 43 mrem, resulted from the longer time spent at the observer positions, although the intensity there was less than 20 mr/hr. No correction is made for truck shielding or for the close spacing of the personnel within.

4.1.7 Shot Apple I. This shot resulted in a mixed gamma field. Although there was moderate fallout to the northeast (Figure 4-6), induced activity predominated elsewhere (as determined from fitting the data). Consequently, the observers, who entered the contaminated area from the southwest, are assumed to have encountered no fallout. Because the shot yield was far less than anticipated, the observers were able to view the innermost display line without being close to the rad-safe limit. Their calculated film badge dose is 84 mrem.

4.1.8 Shot MET. Observers were well distant from the Shot MET contamination (Figure 4-7), and thus accrued no dose. Moreover, the Frenchman Flat area was uncontaminated during the pre-shot equipment inspections.

4.1.9 Shot Apple II. Measurable fallout from Apple II reached about 3000 yards in the direction of the trenches (Figure 4-8). The volunteer observers would have withdrawn beyond this distance within ten minutes, at which time fallout had probably not arrived. Therefore, the volunteers accrued a residual radiation dose





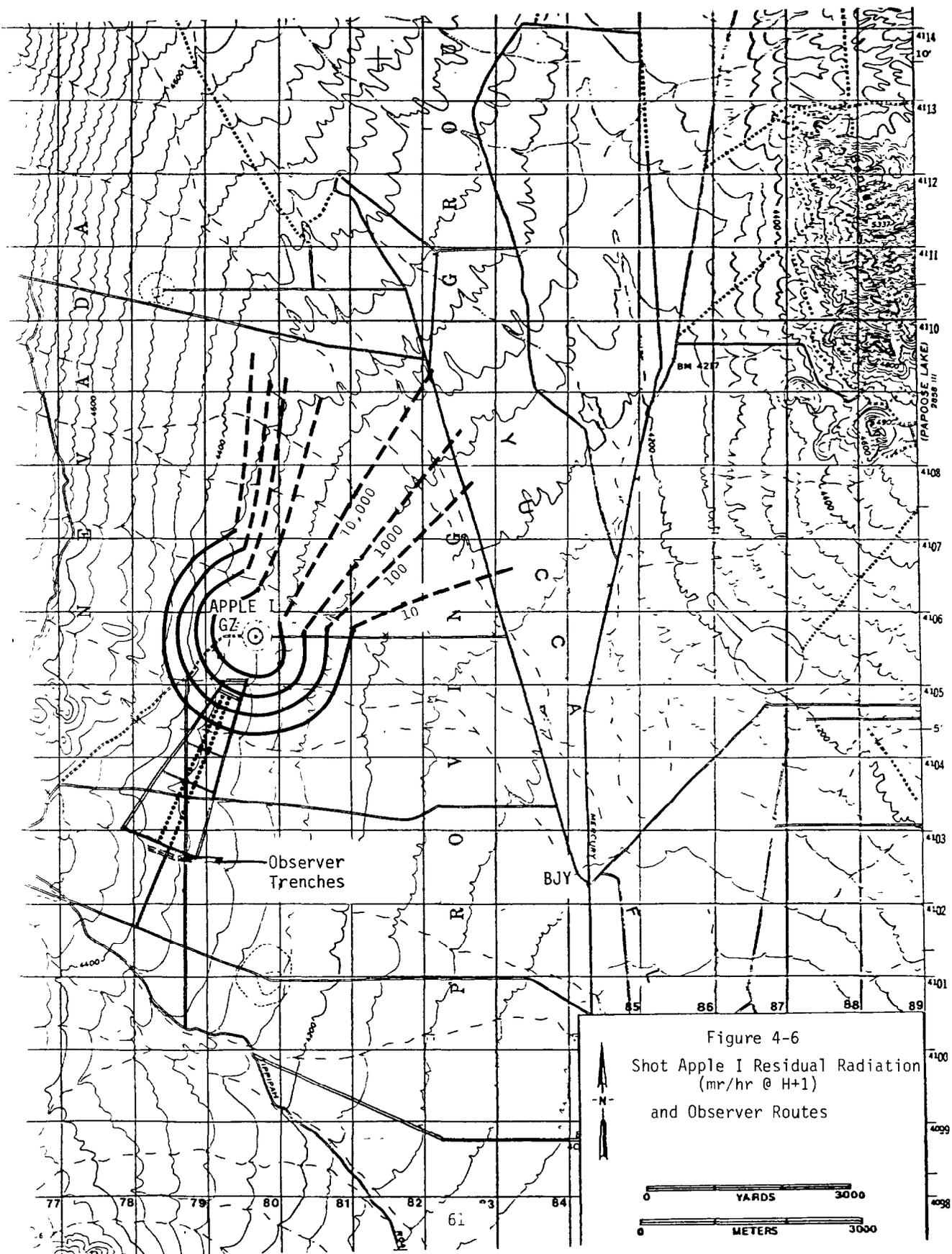


Figure 4-6  
 Shot Apple I Residual Radiation  
 (mr/hr @ H+1)  
 and Observer Routes



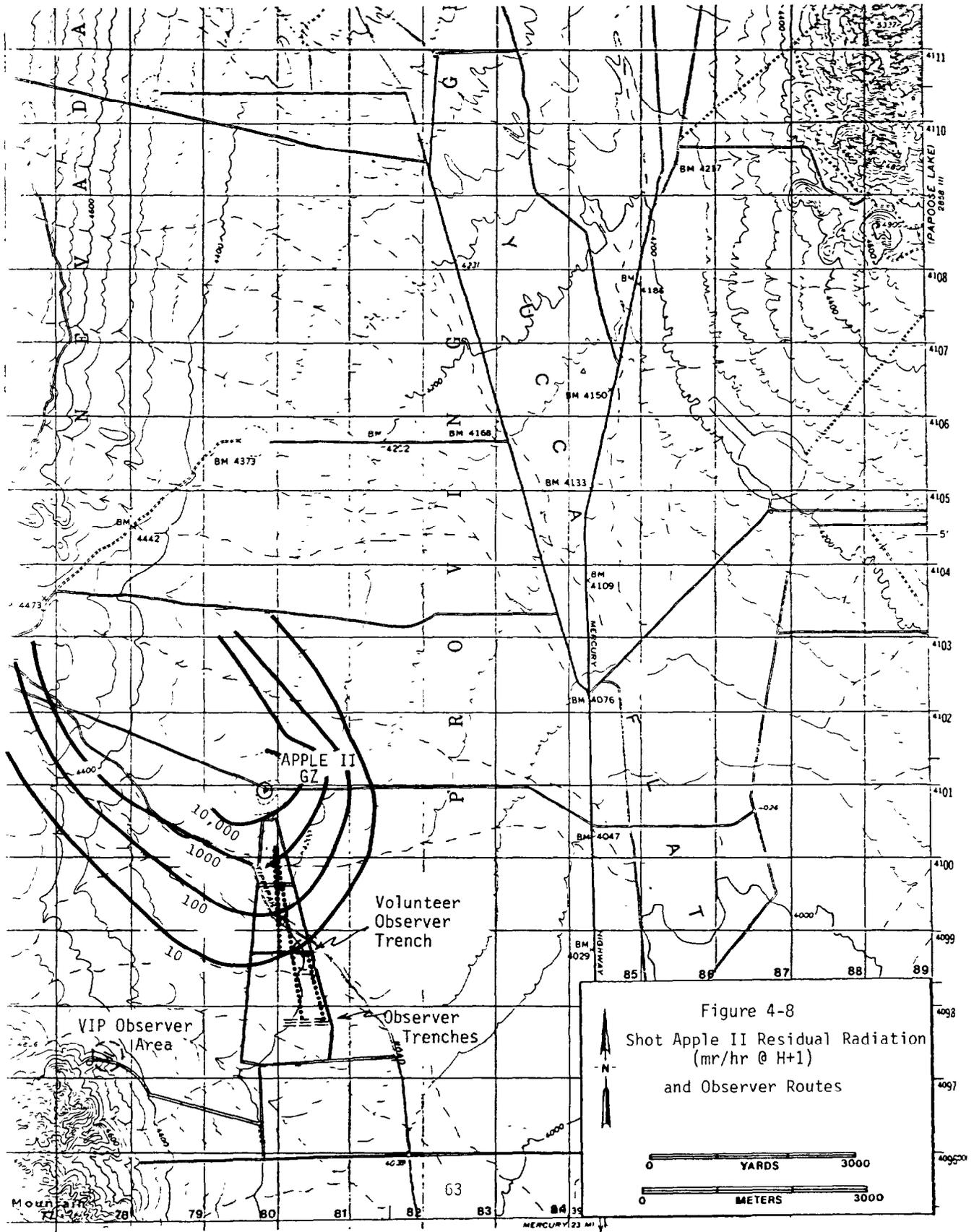
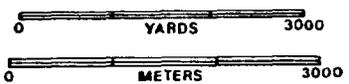


Figure 4-8  
 Shot Apple II Residual Radiation  
 (mr/hr @ H+1)  
 and Observer Routes



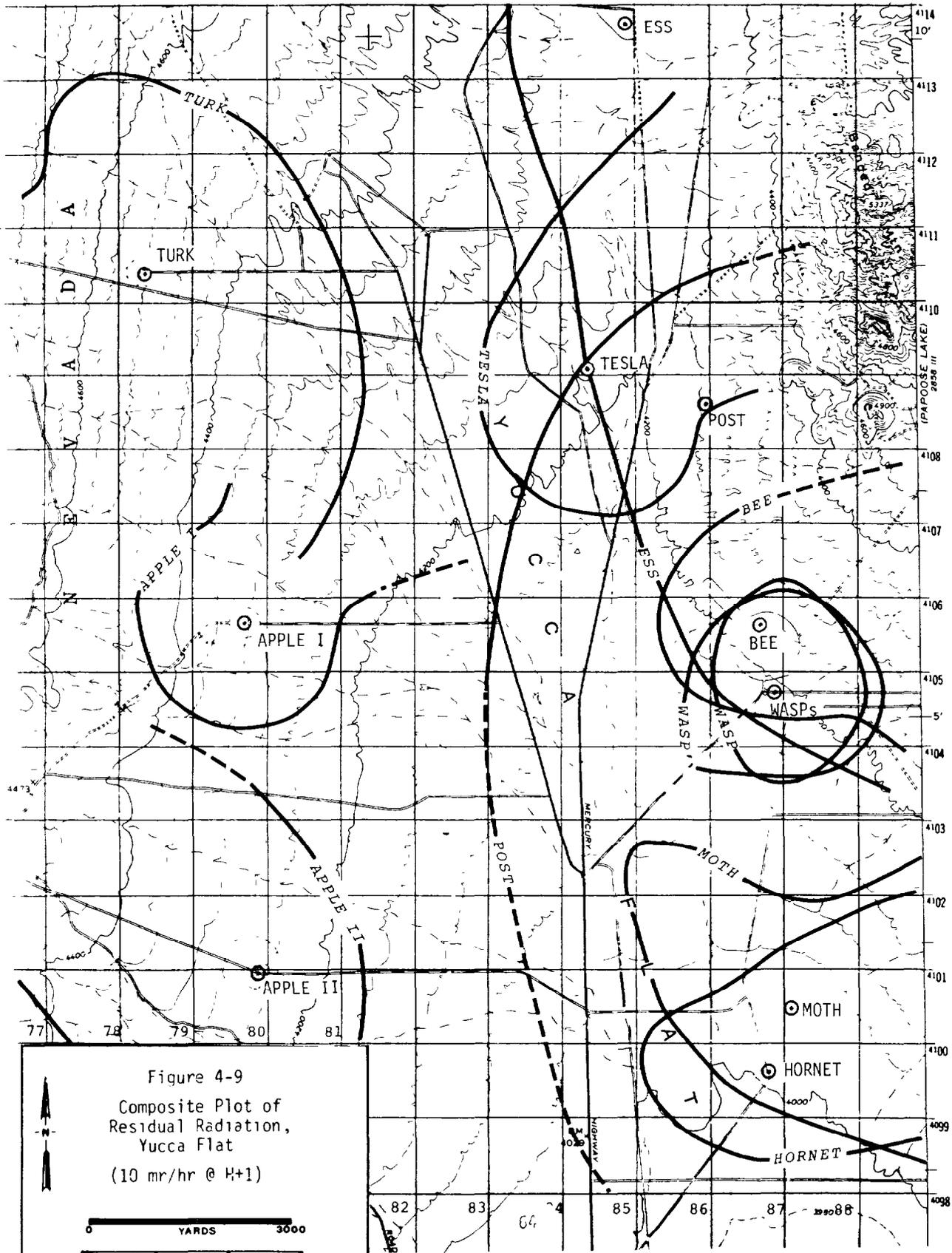


Figure 4-9  
 Composite Plot of  
 Residual Radiation,  
 Yucca Flat  
 (10 mr/hr @ H+1)

0 3000  
 YARDS

0 3000  
 METERS

only if they went forward to view equipment with the main body of observers. Observers would have encountered contamination at about H+25 minutes. Fallout deposition most likely had occurred by then; if not, the calculated dose is slightly high-sided. If it is assumed that the observers did not pass the 1000-yard display line in an attempt to reach the 500-yard line (which was too contaminated, with an intensity approaching 10 r/hr), the calculated film badge dose is 180 mrem. The calculated decay exponent associated with the isopleths in Figure 4-8 is -0.94.

#### 4.2 INTERNAL RADIATION EXPOSURE

The only situation for Operation Teapot observers in which a potential internal radiation hazard need be considered is the trucking of the Shot Ess observers across the Shot Turk fallout field (the breathing of dust therefrom). An estimate of their dose is obtained by comparison with the internal dose calculation for Task Force BIG BANG in Operation Plumbbob (Reference 18). This task force had one source of exposure on their exercise day similar to Shot Turk at D+16 days: Shot Shasta at D+15 days. The time-integrated gamma intensity for the Shot Ess observers while being trucked is calculated as 24 mr; for TF BIG BANG from Shot Shasta, it was 0.83 mr (Reference 18, p. 28). The Shot Shasta contribution to the BIG BANG internal dose on D+15, excluding the infiltration course, was 0.08 mrem, based on a resuspension factor of  $10^{-5} \text{ m}^{-1}$  (Reference 18, p. 40). Resuspension factors for dust raised by vehicles has also been reported as being on the order of  $10^{-5} \text{ m}^{-1}$  (Reference 29). By proportionality, the 50-year internal bone dose commitment for the Shot Ess observers is estimated to have been about 2 mrem.

#### 4.3 RESIDUAL RADIATION DOSE SUMMARY

The calculated film badge doses to Operation Teapot observers from residual radiation are summarized as follows:

Shot	Wasp	Moth	Tesla	Turk	Bee	Ess*	Apple I	MET	Apple II
Dose (rem)	0	0.001	1.1	1.2	0.83	0.043	0.084	0	0.18

\*Also, a 0.002 rem 50-year bone dose commitment.



## Section 5

### UNCERTAINTY ANALYSIS AND TOTAL DOSE DETERMINATION

The sources of error in the calculation of initial and residual doses are examined in order to quantitatively estimate the uncertainty in the total dose for each group of observers.

#### 5.1 UNCERTAINTIES IN INITIAL RADIATION DOSE

5.1.1 Neutron Dose. For those shots (Moth, Tesla, Bee) for which neutron data exist, the sources of error in the calculation of neutron dose include: (1) uncertainties in doses derived from foil measurements, (2) uncertainties in neutron output spectra of the devices, (3) errors associated with the use of the ATR4 to extrapolate beyond the range of measured data, and (4) errors in relating above-trench dose to in-trench dose equivalent. A detailed analysis of the neutron dosimetry techniques employed in Operation Teapot indicates that the major sources of uncertainty in foil measurements are due to error in the reactor thermal neutron fluence used to calibrate the fission and gold detectors, and to foil activity counting precision and technique. The error factor, expressed in terms of 90-percent confidence limits, is determined to be approximately 1.25. The error due to neutron output spectral uncertainty is estimated by calculating neutron doses at a typical trench range resulting from various output spectra, all of which match the measured doses over the range of neutron measurements. It is found that the error factor associated with spectral uncertainty is about 1.15 for those ranges at which significant doses are possible. The error in using ATR4 to extrapolate from the range of measured data to trench locations is estimated by comparing ATR results with those of recent two-dimensional discrete ordinates calculations; this error factor is determined to be approximately 1.15. Finally, the error factor associated with relating the above-trench environment to the in-trench dose equivalent is estimated to be 1.25. The combined error factor for the neutron dose from Shots Moth and Bee is therefore 1.45. For Shot Tesla, an additional uncertainty due to device asymmetry must be considered. It is estimated that the error factor associated with this uncertainty is approximately 1.20, resulting in a combined error factor of 1.51 for Shot Tesla.

For those shots (Turk, Apple I, Apple II) lacking sufficient neutron data to determine experimental dose versus range, the uncertainty increases significantly. Without the capability to normalize to measured data, the uncertainties in neutron output spectra and environmental factors dominate. These uncertainties are estimated by examining the distribution of dose versus range curves for six Teapot shots for which full neutron foil data were taken, after normalization to common yield and air density. It is felt that this distribution is representative of Teapot-era devices, and that the prediction of dose versus range from a best-estimate output spectrum without normalization to measured data will probably conform to such a distribution. The error factors determined in this manner are estimated to increase from 2.2 at 2000 yards to 3.2 at 4000 yards. Including the ATR<sup>4</sup> extrapolation error factor (1.15) and the trench calculation error factor (1.25) results in combined error factors of 2.3-3.3 for ground ranges of 2000-4000 yards.

5.1.2 Initial Gamma Dose. Sources of error in the calculation of initial gamma dose include: (1) uncertainty in experimental film badge readings, (2) extrapolation/interpolation techniques to determine dose at trench locations, (3) errors in relating above-trench dose to in-trench dose, (4) uncertainty in converting in-trench dose to film badge reading for personnel in a fixed position, and (5) uncertainty in personnel reorientation (i.e., standing up) in the trench. While the other sources of error are systematic, the latter two uncertainties provide an indication of the spread in film badge readings expected due to the various orientational factors.

The error factor associated with experimental film badge readings is determined to be approximately 1.4, based on estimates made in Reference 19; a somewhat larger factor is estimated for Shot Turk, since neutron data were not available to allow correction of the gamma data. The error in interpolation/extrapolation techniques used to determine the gamma doses at trench locations is range-dependent, with estimated values from 1.1 (when interpolation is required) to 2.0 (for the long-range extrapolation required for Shot Turk). The factors used for Shots Moth, Bee, Apple I, and Apple II (3500- and 4900-yard trenches) reflect the uncertainty in extrapolating from the 502- and 510-type film data, as discussed previously. It is estimated that the uncertainty in the gamma trench factors, which relate the above-trench dose to

in-trench dose, introduce error factors of 1.2 for 2-foot wide trenches and 1.3 for the 3-foot wide volunteer observer trench in Shot Apple II. The uncertainty in relating the in-trench gamma dose to film badge reading (for stationary personnel) is due primarily to variations in body orientation among individuals in the trench and the placement of the film badge on the body. This error factor for all observers is estimated to be 1.5.

The final uncertainty in initial gamma dose results from the probability that the observers stood up in the trenches to observe the rising cloud soon after the blast effects of the weapon had subsided. It is considered unlikely that anyone stood up before one second after the blast wave passed the trench location, because the blast effects and fireball luminosity still would have been significant. It is also considered probable that most observers were standing by six seconds after passage of the blast wave. The values of one and six seconds after passage of the blast wave are therefore considered the 90-percent confidence limits on standup time. Using a reference standup time of three seconds after passage of the blast wave, these limits introduce error factors of 1.1-1.3 in the total initial gamma doses.

These gamma dose error factors for shots of interest are as follows:

Source of Uncertainty						
Shot	Experimental Data	Extrapolation/ Interpolation	Trench Factor	Trench Posture	Standup Time	Combined Error Factor
Moth	1.4	1.3	1.2	1.5	1.1	1.9
Tesla	1.4	1.1	1.2	1.5	1.2	1.8
Turk	1.5	2.0	1.2	1.5	1.2	2.5
Bee	1.4	1.5	1.2	1.5	1.2	2.1
Apple I	1.4	1.3	1.2	1.5	1.2	2.0
Apple II	1.4					
2600 yd		1.1	1.3	1.5	1.3	1.9
3500 yd		1.3	1.2	1.5	1.2	1.9
4900 yd		1.7	1.2	1.5	1.2	2.2

5.1.3 Accuracy of ATR. The ATR4 code used for initial neutron and gamma radiation environment determination possesses great flexibility in accepting wide ranges of burst heights, atmospheric densities, source spectra and other parameters affecting such determination. It also is very fast-running, a necessary quality for any code used as part of the iterative process described in Section 3. The ability of the ATR code to replicate measured neutron and gamma ray dose data at slant ranges of up to 2000 meters is demonstrated in this and a previous report (Reference 17). However, the ability of the ATR code to predict dose values beyond the measurements has not been proven. Further, even in the range where measurements are available, some normalization has been required to obtain a match between ATR results and such data. Therefore, in order to gain confidence in the ATR predictive capability at extended ranges, and to improve the understanding of its application in the ranges where experimental data exist, a program of comparison between experimental data, ATR results, and results of computations using state-of-the-art radiation transport methods has been initiated. This program was not finished as of the date of publication of this report. Its results will be published in a future report. Initial results indicate good agreement (difference ,10 percent) between secondary gamma radiation free-field doses predicted by ATR4 and state-of-the-art methods at ranges to 3000 meters. On the other hand, initial results for neutron free-field dose indicate that, in comparison to state-of-the-art methods, ATR4 overpredicts the neutron dose by 30 and 40 percent at ranges up to 2000 meters for the Teapot (low humidity) and Plumbbob (high humidity) shots, respectively. At ranges of 3000 meters the overprediction of ATR for these series is as much as 45 and 85 percent, respectively. Therefore, while ATR gamma free-field dose is a good representation of that obtained from state-of-the-art methods, the ATR neutron free-field dose must be regarded as conservative. However, the present calculational method of normalizing ATR4 results to measured neutron doses by adjustment of neutron output spectra eliminates much of this discrepancy.

## 5.2 UNCERTAINTIES IN RESIDUAL RADIATION DOSE

The uncertainty in calculated residual radiation doses arises from two basic sources: (1) the gamma radiation environment, and (2) the space-time scenario of troop movements. The 90-percent confidence limits in the gamma intensity, including the uncertainty in the decay parameter, are provided by the automated

procedure described in the appendix. Parametric studies are made using the automated procedure to determine the influence of scenario variations on personnel dose.

Errors in position, time, and gamma intensity are not independent because of the rad-safe constraint limiting troops to intensities of less than 5 r/hr. Troop positions are well known except with regard to the limit of advance in the display areas. Because the references do not report which equipment display lines were inspected by the observers, the assumption is made that all of the displays within rad-safe limits were inspected. Consequently, the upper limit on dose is not necessarily obtained by considering the upper confidence limits in field intensity or by maximizing the number of display lines visited; it is instead found by considering the scenario variation which maximizes the time spent at or near the 5 r/hr line.

Other than with regard to the limit of troop advance, there is essentially no error in dose resulting from uncertainty in troop position. The bounding azimuths of the equipment display sector have been well identified for each shot from operation plans, shot area maps, and shot area photographs. For the shots considered, the uncertainty in angle of troop position within the display sectors has a negligible influence on dose. That the distances from GZ of the display lines are known identifies where observers would linger and limits the position of farthest advance to a few discrete possibilities.

The timing of the observers' march is generally based on the planned time of moving out from the trenches and arriving at the pickup point. Reasonable march speeds and display area stay times are assumed to construct a scenario consistent with the known times. The most important influence of timing on the uncertainty in dose is the time spent at the position of greatest gamma intensity. Consequently, this duration is emphasized in the uncertainty analysis.

Each shot for which the observers encountered residual radiation is considered separately. The various sources of error cannot be combined rigorously due to the disparity of their associated distributions. These distributions may be normal (e.g.,  $\pm 5$  minutes), lognormal (as for the gamma

intensity), or truncated (due to the 5 r/hr limit). Ninety-percent confidence limits for each area are approximated to be roughly correct for both normal and lognormal distributions, and the upper and lower limits are treated separately, so that asymmetrical error bands are permitted.

5.2.1 Shot Tesla. Because the observers are calculated to have reached 5 r/hr at the 1000-yard display, the uncertainty in the gamma field could contribute only to a lower dose. With regard to time, the confidence limits are taken as a five-minute earlier departure from the trenches to allow five additional minutes at the 1000-yard display, and a five-minute later trench departure, with five fewer minutes at 1000 yards. With regard to intensity, the dose is  $1100^{+0}_{-440}$  mrem; with regard to time, it is  $1100^{+400}_{-300}$  mrem. The overall 90-percent confidence limits are approximately  $1100^{+400}_{-500}$  mrem.

5.2.2 Shot Turk. The uncertainty in the intensity field allows the possibility that the observers viewed the 500-yard display, despite the absence of photographs at that range. If the entire breadth of the 500-yard display was viewed, the additional dose could have been as much as 980 mrem. Because of uncertainty in the intensity field, the dose resulting from the walk forward to the 1000-yard display could be as much as 600 mrem less than that calculated. Uncertainty in timing results in little increase in the confidence limits, which are approximately  $1240^{+1000}_{-600}$  mrem.

5.2.3 Shot Bee. Because the innermost Bee display stretched from 500 to 700 yards from GZ, the observers would have been able to view some equipment at the 5 r/hr line for all intensity fields within the confidence limits. The only influence of the uncertainty in intensity is with regard to the walking time required to reach the 5 r/hr line. This could have varied  $\pm 3$  minutes, and probably would have been reflected in the time spent at the 5 r/hr line. With regard to time alone, the same  $\pm 5$  minutes perturbation to the scenario is assumed as for Shot Tesla. Thus, the confidence limits on intensity imply a dose of  $830 \pm 180$  mrem; those on time imply  $830 \pm 300$  mrem. The overall 90-percent confidence limits are approximately  $830 \pm 350$  mrem.

5.2.4 Shot Ess. The uncertainty in dose to the Ess observers is almost entirely due to the uncertainty in the Turk fallout field intensity. For this, the 90-

percent confidence limits yield a dose calculation of  $43^{+19}_{-13}$  mrem. The truck speed while crossing the Turk hotline is probably estimated to within 20 percent, and the uncertainty in time spent at the observation position is about 10 percent (because the observers were in position a full 1½ hours before detonation). These, each of which applies only to part of the dose, add negligibly to the overall uncertainty in dose.

5.2.5 Shot Apple I. For Apple I, the innermost equipment display was at an intensity of less than 5 r/hr, for all gamma fields within the 90-percent confidence limits of intensity. Consequently, the observers are certain to have walked to this display, but no farther. For the assumed scenario, the gamma intensity uncertainty implies a dose of  $84^{+74}_{-40}$  mrem. For the calculated intensity field,  $\pm 5$  minutes at the innermost display implies  $84 \pm 30$  mrem. The overall 90-percent confidence limits are approximately  $84^{+80}_{-50}$  mrem.

5.2.6 Shot Apple II. There is considerable uncertainty in the Apple II intensity field. Near the upper intensity limit, the 1000-yard display which the observers are presumed to have reached would have had an intensity of about 5 r/hr. Near the lower intensity limit, the observers would have been able to reach the 500-yard display. In order to obtain a lower limit on dose, it must be assumed that the intensity field was such that the 500-yard display was just over 5 r/hr (as could have been determined by rad-safe monitors preceding the observers), and that the observers did not advance beyond the 1000-yard line. These imply  $180^{+430}_{-70}$  mrem. The planned duration of the walk-through did not allow time for stopping at any of the displays. Therefore, only an upper limit on time, allowing five minutes at each display, is calculated. For the computed intensity field, these stops would increase the dose by 150 mrem. The approximate overall 90-percent confidence limits are  $180^{+450}_{-70}$  mrem. See also below.

### 5.3 TOTAL MEAN DOSE SUMMARY

The reconstructed neutron and gamma doses for Operation Teapot observers are presented in Table 5-1. From the best-estimate doses of Sections 3 and 4, and the error distribution of this section, the mean neutron and gamma doses for each observer group are calculated. These are presented in the table with estimated 90-percent confidence limits. The doses are not added because

Table 5-1 Observer Dose Summary\*

<u>Shot</u>	<u>Neutron Dose (rem)</u>	<u>Initial Gamma Dose (rem)</u>	<u>Residual Gamma Dose (rem)</u>	<u>Total Gamma Dose (rem)</u>
Moth	0.16 <sup>+0.07</sup> -0.05	0.067 <sup>+0.051</sup> -0.034	~ 0.001	0.07 <sup>+0.05</sup> -0.04
Tesla	1.4 <sup>+0.6</sup> -0.5	0.29 <sup>+0.20</sup> -0.14	1.1 <sup>+0.4</sup> -0.5	1.4 <sup>+0.4</sup> -0.5
Turk	0	< 0.001	1.3 <sup>+0.9</sup> -0.7	1.3 <sup>+0.9</sup> -0.7
Bee	0.010 <sup>+0.005</sup> -0.003	0.020 <sup>+0.018</sup> -0.011	0.83 ± 0.35	0.85 ± 0.35
Ess	0	0	0.04 <sup>+0.02</sup> -0.01	0.04 <sup>+0.02</sup> -0.01
Apple I	0.029 <sup>+0.041</sup> -0.021	0.031 <sup>+0.025</sup> -0.017	0.092 <sup>+0.072</sup> -0.058	0.12 <sup>+0.08</sup> -0.06
Apple II Vol. Obs.	4.5 <sup>+5.4</sup> -3.0	1.30 <sup>+0.98</sup> -0.67	0.34 <sup>+0.29</sup> -0.23	1.6 <sup>+1.0</sup> -0.7
Trp. Obs.	0.063 <sup>+0.090</sup> -0.047	0.058 <sup>+0.045</sup> -0.030	0.34 <sup>+0.29</sup> -0.23	0.40 <sup>+0.30</sup> -0.23
VIP Obs.	< 0.001	~ 0.001	0	0.001

\*Reconstructed mean film badge dose, except for mean neutron dose.

the neutron dose would not have been recorded by film badges. It should be noted that the mean dose and the best estimate dose may differ according to the error distribution. For most shots, the difference is on the order of 10 percent. For Shot Apple II, however, the highly asymmetric error distribution results in a calculated mean that is nearly twice the best estimate.



## Section 6 CONCLUSIONS

Of the nine shots of Operation Teapot in which Desert Rock observers participated, only four were significant in terms of radiation dose accrued. These were Shots Tesla, Turk, and Bee for troop observers, and Shot Apple II for the volunteer observers, for which the calculated mean gamma film badge doses are 1.4, 1.3, 0.85, and 1.6 rem, respectively. For these shots, the calculated mean neutron doses are 1.4, 0, 0.01, and 4.5 rem, respectively. From the neutron doses, it is seen that Shot Tesla offered the highest initial radiation dose to troop observers, probably due in part to the higher-than-anticipated shot yield of 7 KT (vs. 2 KT expected). Shots Tesla and Turk contributed the highest residual dose to observers as they inspected the post-shot equipment displays. When confidence limits are applied to the above calculations, the upper limits of gamma dose for Shots Tesla, Turk, Bee, and Apple II are calculated to be 1.8, 2.2, 1.2, and 2.6 rem, respectively. Upper confidence limits for neutron dose are 2.0 and 9.9 rem for Shots Tesla and Apple II (volunteers), respectively.

As might be expected, the volunteer observers at Shot Apple II received the highest gamma and neutron radiation doses. Although their exposure criteria were higher (10 rem, 5 rem of which could be initial) than for the other observers, it would appear that their calculated mean doses of 1.6 rem gamma and 4.5 rem neutron did not significantly exceed the regular troop exposure limit of 6 rem. If upper limits are considered, the doses of 2.6 rem gamma and 9.9 rem neutron result in a 25-percent overdose, however improbable.

Only limited dosimetric information is available for comparison with calculated doses. Although no specific details are provided, Reference 13 states that the average film badge reading for the volunteer observers at Shot Apple II was 1.3 rem. It is noted that the calculated film badge gamma dose of 1.6 (0.9-2.6) rem compares very favorably with the average reading. Data on Marine participants at Shot Bee include 10 officer observers with film badge readings (within 10 percent) of 0.54 rem, in reasonable agreement with the calculated

film badge dose of 0.85 (0.5-1.2) rem. Because of the few personnel involved, these comparisons are considered insufficient to establish overall correlation with all calculated doses for all shots.

Section 7  
REFERENCES

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3. Operation Order No. 2 (Shot Wasp), Desert Rock VI, 15 February 1955.
4. Operation Order No. 3 (Shot Moth), Desert Rock VI, 21 February 1955.
5. Operation Order No. 4 (Shot Tesla), Desert Rock VI, 5 February 1955.
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8. Operation Order No. 7 (Shot Ess), Desert Rock VI, 21 March 1955.
9. Operation Order No. 8 (Shot MET), Desert Rock VI, 6 April 1955.
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11. Operation Plan 1-55 (Shot Bee), Headquarters, 3d Marine Corps Provisional Atomic Exercise Brigade, Camp Pendleton, California, 23 February 1955.
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APPENDIX  
 AUTOMATED PROCEDURE FOR EXTERNAL RESIDUAL  
 GAMMA DOSE RECONSTRUCTION

A computer-aided methodology for the estimation of the residual gamma radiation from nuclear bursts at Nevada Test Site is described. This procedure, a generalization of that used in Reference 17, combines the gamma intensity data from the several radiation surveys of each shot to construct the gamma environment within quantified confidence limits. Dose estimates can then be made for personnel at the test site for any specified position/time scenario.

The methodology was constructed to utilize survey data in whatever form available to best model the gamma field so that personnel dose could be computed with a minimum of uncertainty. A computer was employed not only to rapidly provide dose estimates, but also to evaluate the sensitivity of estimates to radiation field modeling, variants of troop scenarios, and outliers among the survey readings. In contrast to that of Reference 17, the present methodology computes (and graphically displays) analytically determined isointensity contours, interpolates anywhere within the range of survey data, models both fallout and neutron-induced gamma fields, and models radiological decay in addition to spatial variation of intensity.

As in Operation Plumbbob, most of the radiological survey data for Operation Teapot were collected along straight roads, usually radial tracks from ground zero (GZ). Consequently, the data are fit to one-dimensional spatial models. Intensities at positions between roads are found through a polynomial fitting of isointensities from all roads. Gamma decay is assumed to be identical throughout the field. The one-dimensional space-time intensity models employed for Operation Teapot residual gamma fields are:

$$I = t^{-n} e^{-ax+b} \quad \text{for fallout, and}$$

$$I = (2^{-t/15} + c \cdot 2^{-t/2.58}) e^{-ar+b} \quad \text{for induced activity,}$$

where  $I$  = gamma intensity (r/hr)  
 $t$  = time in hours after burst  
 $r$  = slant range from burst  
 $x$  = distance from an arbitrary origin  
 $a, b, c, n$  are parameters determined from data fitting.

The automated procedure permitted fallout data to be combined in the absence of independent decay information (that was available from Operation Plumbbob for use in Reference 17). The quality and quantity of the survey readings determined the level of detail to which power law modeling ( $t^{-n}$ ) could be used for gamma decay. It was not possible to obtain a statistically significant value of  $n$  for each interval between surveys, nor was it possible (for the entire period of surveys) for data along individual roads. Consequently, the one best fitting  $n$  for all of the given shot's data was determined; this was done by averaging the values found for each road, weighted according to the quantity of data available along each road. The data for each road, which had been fit according to multiple linear regression of the logarithmic form of the model, were then refit with the imposed time decay by linear regression in the spatial variable only.

The model for induced activity incorporates the decay of the only radioisotopes of consequence to military maneuvering in neutron-activated areas of Nevada Test Site:  $\text{Na}^{24}$  ( $t_{1/2} = 15.0$  hr) and  $\text{Mn}^{56}$  ( $t_{1/2} = 2.58$  hr). As stated, the model cannot be linearized; however, linear regression can be performed after decoupling the Na and Mn contributions. Because surveys performed from one to about five days after the shot reflect almost entirely  $\text{Na}^{24}$  activity, a fit is obtained for this isotope alone in this timeframe. With parameters  $a$  and  $b$  already determined,  $c$  is found from the best fit to shot-day data. Only a single value of  $c$  for the entire field is statistically significant.

The spatial factor in both models is a simple exponential form. For induced fields, the actual distance from the point of burst is the appropriate scale. Simple physical reasoning based on a uniform, isotropic, neutron-

attenuating medium would indicate inclusion of an additional factor of  $1/r^2$ . However, the presence of the ground, its orientation relative to the burst point, and the depth distribution of the activated nuclei makes analysis of the intensity-distance relationship far more complex. The form chosen fits the data at least as well as a more complicated model. For fallout fields, the exponential form is purely empirical. It best applies where intensity gradients are large. The addition of a quadratic term to the exponent does not significantly improve the fit (as reported in Reference 17), but its inclusion is vital to analysis of data sets which approach or span the hotline (axis of fallout). For these, the Gaussian form so obtained generally provides the best fit of linearizable functions.

Intensities at positions not on survey roads are found from interpolation of the fitted data along neighboring roads. The interpolation is accomplished through a three-step procedure: (1) the position of the 10, 100, 1000, and 10000 mr/hr intensities is determined on each survey road at a standardized time; (2) isointensity contours are constructed from analytical functions in which range (slant range for induced fields) from GZ is expressed as a cubic polynomial in azimuth around GZ; a six-pointed scheme that produces smooth contours is used; and (3) the ranges of these contours for the azimuth of any specified position define intercepts which determine parameters of the applicable model along that azimuth; the intensity at the desired position and time is then obtained directly from the model. Contours are displayed graphically so that they can be compared with hand-drawn contours accompanying the raw survey data, be checked for consistency with personnel dose calculations, and indicate contaminated areas of Nevada Test Site that could be relevant to subsequent military operations. Contours can be displayed with standardized intensity levels for any time of interest.

Personnel dose is computed by time-integration of the intensity encountered by troops present in a gamma field. The troops are traced in space and time through the field in small, discrete steps. The intensity and time interval associated with each step determine the incremental dose accrued for that step. Wide latitude is allowed in the type of position-time data required to

specify the troop scenario. A sample output of the dose calculation concludes this appendix (Figure A-1).

The automated procedure quantifies uncertainties associated with the computed gamma environment. (These are combined with the uncertainties in the troop activity scenario to determine overall confidence limits in the reconstructed personnel dose). In contrast to Reference 17, in which one approximate parameter characterizes an entire gamma field, the computer permits a point-by-point determination of uncertainty. The standard error of the model, as a function of position and time, is calculated in conjunction with the regression along survey roads. Off these roads, standard error is found by a linear interpolation along contours followed by a linear interpolation between contours on the azimuth of interest. Between roads, an additional source of error in the gamma intensity results from the manner in which contours are computed. An approximate measure of this error is found by comparison with an alternate means of curve fitting, for example the cubic polynomial determined by four neighboring isointensity points. The implied deviation in intensity by the displaced contour is used to estimate the curve fitting error. The overall uncertainty in intensity is used at each step in incrementing the dose. These errors are simply added from step to step; this approach is preferred because the intensity error along a troop path is much more likely to be systematic than random with each integration step.

It is cautioned that the error analysis is no better than the models to which the radiological survey data are fit. Diagnostic printouts of statistical parameters ensured that the choice of models was sound and that outliers which significantly influenced the regressions and uncertainty analysis could be identified and disregarded. Nevertheless, the confidence in the models and the statistics associated therewith is minimal beyond the range of times and distances at which the surveys were taken. In practice, this is of little importance--far from GZ the intensities make an insignificant contribution to personnel dose, and rarely did troops penetrate closer to GZ than where surveys were made.

Figure A-1 is a printout of a dose reconstruction (for Shot Tesla) that displays the variations in uncertainty with position and time. For intensities less than 0.1 mr/hr, dose calculations are suppressed. The totals are to be multiplied by the conversion factor of 0.7 to obtain film badge dose.

WHICH DATA FILE DO YOU WISH TO ACCESS?

3

INPUT 1 TO GET INPUT DATA PRINTS

0

ENTER 1 TO GET DOSCAL DEBUGGING PRINTS

0

ENTER 1 TO GET DEBUGGING PRINTS

0

NTPR INTEGRATION PROGRAM

VERSION 2 -- CUBIC MODEL

SELECT OPTION--1. .DEFINE MODEL

2...DEFINE HOT-LINE SECTOR

3. .GRAPHICAL DISPLAY AT REFERENCE TIME

4. .SET PRINT DETAIL

5...PERFORM DOSE INTEGRATION

6. .STOP

1

THE FOLLOWING VALUES HAVE BEEN INPUT FROM TAPE:

SLANT RANGE FLAG= 0 HOB= 100

MILITARY COORDINATE OF GZ= 844090

MODEL # = 1

REFERENCE TIME= 12

C-VALUE(for Model#2),FINAL C-VALUE(for Model#5),or

DECAY RATE(for Model#1 or 3)= -1.1633

ENTER 1 TO CHANGE VALUES, OTHERWISE ENTER 0

0

ENTER CONTOURS TO BE OPEN ENDED BY ENTERING ALL CONTOUR  
INTENSITIES IN ASCENDING ORDER ENTERING A 0 FOR CONTOURS  
THAT ARE OPEN ENDED, EG 0,2,3,4

0,0,0,0

Figure A-1. Sample Computer Printout of Dose Determination Procedure

```
ENTER LOWER,UPPER ANGLES OF OPEN END, IF OPEN END DOES  
NOT EXIST ENTER 0,0  
46.48  
SELECT OPTION (1-6):  
4  
ENTER INTERVAL AT WHICH TO PRINT DETAILS( 0 FOR SUMMARY),  
10  
SELECT OPTION (1-6):  
5
```

Figure A-1. Sample Computer Printout of Dose Determination Procedure (Continued)

\*\*\*START OF TRACK\*\*\*  
DEFINE THE FIRST LINE SEGMENT OF THE TRACK  
ENTER START TIME, IN HOURS AFTER H-HOUR:  
.333  
SELECT METHOD OF SPECIFYING START POINT  
1. .MILITARY COORDINATE  
2. .DEGREES FROM N, AND YARDS FROM GZ  
2  
ENTER START POINT, IN DEGREES FROM N AND YARDS FROM GZ  
235,2400  
SELECT METHOD OF SPECIFYING DIRECTION OF MOVEMENT  
1...END POINT IN MILITARY COORDINATES  
2...END POINT IN DEGREES FROM N AND YARDS FROM GZ  
3. .DEGREES FROM N RELATIVE TO START POINT  
2  
ENTER END POINT IN DEGREES FROM N AND YARDS FROM GZ:  
235,1000  
SELECT METHOD OF SPECIFYING TIME ON SEGMENT--  
1...VELOCITY (in MPH)  
2...ELAPSED TIME  
3. .VELOCITY (in YARDS PER MINUTE)  
2  
ENTER ELAPSED TIME IN HOURS:  
5  
SELECT STOPPING RULE--  
1...WHEN REACH END POINT  
2...WHEN EXCEED SPECIFIED DOSE RATE  
3...WHEN FALL BELOW SPECIFIED DOSE RATE  
4...WHEN HAVE GONE SPECIFIED DISTANCE FROM START POINT  
1  
ENTER INTEGRATION INCREMENT IN YARDS:  
10

Figure A-1. Sample Computer Printout of Dose Determination Procedure (Continued)

INC #	TIME AT INC END (HRS)	YARDS		ANGLE	INC DOSE RATES (MR/HR)		CUM DOSE (MR)	ERROR FACTOR	CONFIDENCE LIMITS	
		FROM START	GZ		START	END			LOWER	UPPER
1	0.34	10	2390	235.0	0	0	0	0.000	0	0
10	0.37	100	2300	235.0	0	0	0	0.000	0	0
20	0.40	200	2200	235.0	0	0	0	0.000	0	0
30	0.44	300	2100	235.0	7	7	0	2.093	0	0
40	0.48	400	2000	235.0	12	13	0	1.989	0	1
50	0.51	500	1900	235.0	21	23	1	1.897	1	2
60	0.55	600	1800	235.0	39	41	2	1.818	1	4
70	0.58	700	1700	235.0	70	74	4	1.754	2	8
80	0.62	800	1600	235.0	128	136	8	1.705	4	14
90	0.65	900	1500	235.0	233	248	14	1.672	8	24
100	0.69	1000	1400	235.0	427	454	26	1.657	15	44
110	0.73	1100	1300	235.0	785	835	47	1.660	28	80
120	0.76	1200	1200	235.0	1448	1540	87	1.681	52	147
130	0.80	1300	1100	235.0	2677	2847	161	1.720	95	272
140	0.83	1400	1000	235.0	4963	5280	297	1.775	173	511

68

INTEGRATION ALONG THIS SEGMENT STOPPED WITH

DISTANCE FROM START IS 1400.0 YARDS

CURRENT POSITION IS 235.0 DEGREES  
1000.0 YARDS FROM GZ

MILITARY COORDINATE IS 837085

ENTER 1....TO SPECIFY STAY TIME AT THIS POINT  
2....TO SPECIFY THE NEXT SEGMENT OF THE TRACK  
3....TO END THIS TRACK

Figure A-1. Sample Computer Printout of Dose Determination Procedure (Continued)

ENTER STAY TIME AND INTEGRATION INCREMENT  
 BOTH IN HOURS.  
 25.01

INC #	TIME AT		YARDS FROM START	ANGLE	YARDS FROM GZ	INC DOSE RATES (MR/HR)		CUM DOSE (MR)	ERROR FACTOR	CONFIDENCE LIMITS	
	INC	END (HRS)				START	END			LOWER	UPPER
1	0.84	1400	1400	235.0	1000	5280	5207	350	1.782	203	605
10	0.93	1400	1400	235.0	1000	4686	4628	795	1.757	454	1391
20	1.03	1400	1400	235.0	1000	4158	4111	1233	1.732	706	2156
26	1.08	1400	1400	235.0	1000	3891	3891	1434	1.719	822	2503

CURRENT POSITION IS 235.0 DEGREES  
 1000.0 YARDS FROM GZ

MILITARY COORDINATE IS 837085

ENTER 1....TO SPECIFY STAY TIME AT THIS POINT  
 2....TO SPECIFY THE NEXT SEGMENT OF THE TRACK  
 3....TO END THIS TRACK

2  
 SELECT METHOD OF SPECIFYING DIRECTION OF MOVEMENT  
 1. .END POINT IN MILITARY COORDINATES  
 2. .END POINT IN DEGREES FROM N AND YARDS FROM GZ  
 3. .DEGREES FROM N RELATIVE TO START POINT

2  
 ENTER END POINT IN DEGREES FROM N AND YARDS FROM GZ:  
 235,2400

SELECT METHOD OF SPECIFYING TIME ON SEGMENT--  
 1. .VELOCITY (in MPH)  
 2. ELAPSED TIME  
 3. VELOCITY (in YARDS PER MINUTE)  
 2

Figure A-1. Sample Computer Printout of Dose Determination Procedure (Continued)

```
ENTER ELAPSED TIME IN HOURS:
.5
SELECT STOPPING RULE--
1. . WHEN REACH END POINT
2. . WHEN EXCEED SPECIFIED DOSE RATE
3. . . WHEN FALL BELOW SPECIFIED DOSE RATE
4. . . . WHEN HAVE GONE SPECIFIED DISTANCE FROM START POINT
1
ENTER INTEGRATION INCREMENT IN YARDS:
10
```

Figure A-1. Sample Computer Printout of Dose Determination Procedure (Continued)

INC #	TIME AT INC END (HRS)	YARDS FROM START	ANGLE	YARDS FROM GZ	INC DOSE RATES (MR/HR)		CUM DOSE (MR)	ERROR FACTOR	CONFIDENCE LIMITS	
					START	END			LOWER	UPPER
1	1.09	10	235.0	1010	3891	3625	1448	1.719	830	2526
10	1.12	100	235.0	1100	2060	1920	1538	1.656	883	2677
20	1.15	200	235.0	1200	1018	949	1588	1.606	915	2760
30	1.19	300	235.0	1300	504	470	1614	1.578	930	2800
40	1.23	400	235.0	1400	250	233	1626	1.573	938	2820
50	1.26	500	235.0	1500	124	115	1632	1.592	942	2830
60	1.30	600	235.0	1600	61	57	1635	1.633	944	2835
70	1.33	700	235.0	1700	31	28	1637	1.695	945	2837
80	1.37	800	235.0	1800	15	14	1638	1.775	946	2838
90	1.40	900	235.0	1900	8	7	1638	1.873	946	2839
100	1.44	1000	235.0	2000	4	4	1638	1.988	946	2839
110	1.48	1100	235.0	2100	2	2	1638	2.118	946	2840
120	1.51	1200	235.0	2200	0	0	1638	0.000	946	2840
130	1.55	1300	235.0	2300	0	0	1638	0.000	946	2840
140	1.58	1400	235.0	2400	0	0	1638	0.000	946	2840

92

INTEGRATION ALONG THIS SEGMENT STOPPED WITH

DISTANCE FROM START IS 1400.0 YARDS

CURRENT POSITION IS 235.0 DEGREES  
2400.0 YARDS FROM GZ

MILITARY COORDINATE IS 826077

ENTER 1... TO SPECIFY STAY TIME AT THIS POINT  
2... TO SPECIFY THE NEXT SEGMENT OF THE TRACK  
3... TO END THIS TRACK

3

\*\*\*END OF TRACK\*\*\*

Figure A-1. Sample Computer Printout of Dose Determination Procedure (Continued)

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