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# ANALYSIS OF RADIATION EXPOSURE FOR TROOP OBSERVERS, EXERCISE DESERT ROCK V, OPERATION UPSHOT-KNOTHOLE


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

The radiation doses to observers, including volunteer observers, for Exercise Desert Rock V are reconstructed for each applicable shot of Operation Upshot-Knothole (1953). Initial neutron and gamma doses are determined from radiation transport codes. The several components of initial radiation are evaluated separately in order to consider the cloud dynamics and the effect of body positions on initial doses. Residual doses are determined through an automated procedure that utilizes raw data in regression analyses to fit space-time models. Observer activity data are combined with the refined radiological data to deter-

mine integrated dose. Uncertainties are calculated for each parameter. The relationship of internal dose to the radiological environment is also discussed.

The highest calculated doses received by volunteer observers was 14 rem gamma and 28 rem neutron at Shot Simon. The highest gamma dose received by other observers was 1.3 rem at Shots Badger and Harry. Neutron doses for all other observers was less than .02 rem at any shot.

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## Section 1

## INTRODUCTION AND SUMMARY

This is a continuation of the series of reports on the reconstruction of nuclear radiation dose for military participants in the atmospheric nuclear weapons program. This report on troop observers is the first of several pertaining to military participation in Operation Upshot-Knothole.

There were four types of military participation in Exercise Desert Rock V, conducted at Nevada Proving Grounds in conjunction with Operation Upshot-Knothole in the spring of 1953. The first consisted of troop observers, who were military personnel sent to Camp Desert Rock for the specific purpose of observing one or more nuclear shots. This is the military participation addressed in this report.

The second type of military participation consisted of battalion-size maneuver units that moved to Camp Desert Rock for the purpose of engaging in tactical exercises to test doctrine and tactics being developed for the nuclear battlefield. Several such exercises were conducted: a Marine Brigade Exercise at Shot Badger and Army multiple-battalion exercises at Shots Annie, Nancy, Simon, Encore, and Grable. Air Force ground units also maneuvered at Shot Encore. Each of these exercises, and the associated radiation exposure, are to be treated in a separate report.

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

Finally, there were the personnel assigned to Camp Desert Rock, usually for the entire exercise, who planned, supported, and administered the overall exercise. The activities of the Camp Desert Rock personnel and the associated radiation exposures will also be analyzed subsequently.

It should be noted that a fifth major category of military participation, not a part of the four Exercise Desert Rock groups described above, consisted of projects conducted under the sponsorship of Field Command, Armed Forces Special Weapons Project. These efforts, as well as the support provided by Department of Defense (DoD) personnel to other test groups and to the overall operation, are to be analyzed as necessary to supplement available film badge dosimetry.

Of the eleven nuclear shots (Figure 1-1) of the Upshot-Knothole series, Exercise Desert Rock observers participated to some degree in nine. This report addresses the radiation doses to observers during their activities at Nevada Proving Grounds in conjunction with these nine shots. The observer program is described and the observer activities for each of the 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 neutron and gamma radiation dose from the shot being observed and the external (and internal as appropriate) dose due to residual radiation from applicable preceding shots.

A major obstacle to the initial radiation dose determination was the lack of radiation output data for several of the atypical devices being tested in operation Upshot-Knothole. Two courses of action were adopted to solve this problem. First, when available, output data from related devices were used where similarities permitted. Second, for those shots when the first option was not viable, output calculations were performed on request by Los Alamos Scientific Laboratory. Procedures for specific shots are described in the section on initial radiation. A supporting appendix describes the extensive effort required to provide a more reliable estimate of the shielding effect of trenches from the several types of initial radiation examined in this report.

The analysis described herein utilizes an automated procedure, developed for the Teapot (Exercise Desert Rock VI) observer report, for determining the external dose due to residual radiation. Radiological survey data is fit, in

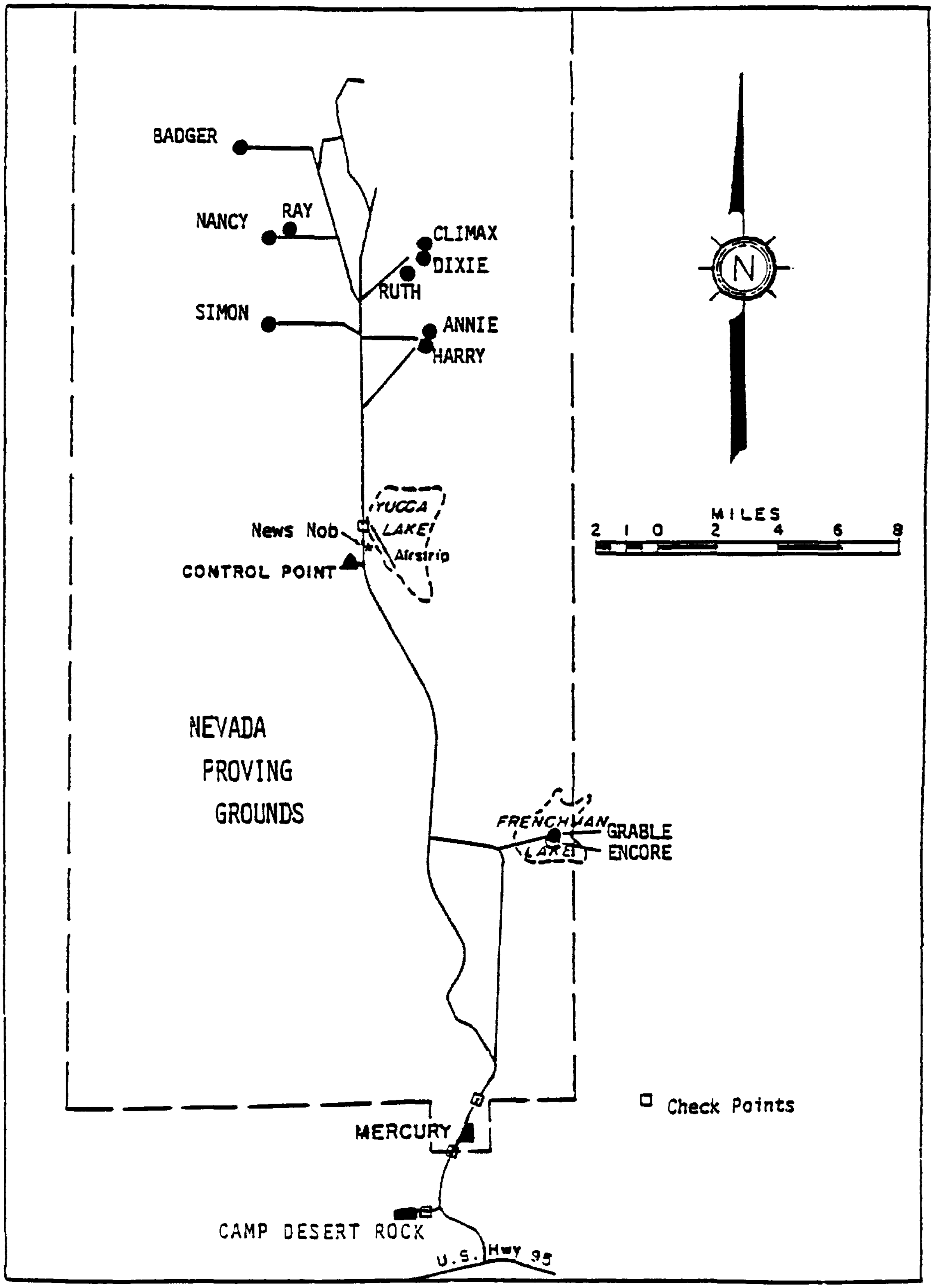


Figure 1-1 Shot Locations, Operation Upshot-Knothole

statistical regression analyses, to space-time models of residual radiation intensity, from which isointensity contours (isopleths) are then developed. A variance from the prior procedure is required for this analysis, because the available AEC radiological survey reports had no raw data, but only isopleths that were not fully time-resolved. Thus early surveys in particular (where time sensitivity is high) are unreliable for use in the regression analyses. This necessitates the use of isolated random data from Desert Rock activities to provide time resolution of AEC isopleths at corresponding locations, which narrows the time uncertainty of the AEC data at the coincident points while broadening the utility of the isopleths.

As in the previous report, the methodology also considers the effect of soil activation in the residual radiation analysis. This is particularly important for Shots Encore and Grable, where the residual contamination of the post-shot times of interest was primarily due to the induced activity of Manganese-56 and Sodium-24. For some other shots, the induced contribution was evident near ground zero, but at greater distances it was small compared to the contribution from fission products. In all cases, the decay model is representative of actual shot conditions, verified by correlations with available data.

The potential for an internal dose commitment from inhaled radionuclides is assessed for several situations encountered by Upshot-Knothole observers. An expanded methodology for internal dose determination considers induced activity as a source of contamination and allows for the possible mobility of airborne contamination. These are accomplished by relating measured gamma intensities and properties of the actual contaminants to other parameters of the observer activity scenarios.

Due to the lack of film badge dosimetry data for most personnel of Exercise Desert Rock V, only minimal comparison of calculated dose with film badge dose is possible. No personnel film badge data are used in the calculations. The methodology for determining personnel dose is not significantly different than that used in previous analyses (References 17, 18, 32), in which comparisions with dosimetric data established a high degree of confidence. The uncertainties in the results are due primarily to the uncertainties in both the radiological surveys and the time-position descriptions of troop activities. Automation of the dose estimation procedure facilitates the determination of confidence levels and aids in subsequent exposure analyses of other troop operations in the same radiologically contaminated areas.

Major findings of this report are:

- The troop (including volunteer) observers of nuclear shots in Operation Upshot-Knothole were exposed to initial radiation from neutrons and gamma rays, and residual gamma radiation from fallout and neutron-activated soil.

- Mean neutron doses of 0.63, 2.4, and 28 rem and mean initial gamma doses of 0.64, 3.9, and 9.8 rem are calculated for the in-trench positions of the volunteer observers at Shots Nancy, Badger, and Simon, respectively. Neutron and initial gamma doses for other observers in the troop trenches at greater ranges were all less than 0.02 rem.

- The typical scenario of service observer activities resulted in a dose far less than the maximum dose permitted for Desert Rock V participants. Only for Shot Badger, at which considerable time was spent near the rad-safe limit, and Shot Harry, for which the gamma intensity restriction on movement was removed, are the calculated mean film badge doses as high as 1.3 rem. The dose associated with other shots was significantly less.

- The inhalation of radioactive dust resulted in only a trivial addition to the dose of observers at Exercise Desert Rock V.

# Section 2

# OPERATIONS

## 2.1 SHOT DATA

A summary of the eleven test shots of Operation Upshot-Knothole is contained in Table 2-1. Exercise Desert Rock observers participated in only nine shots, as shown in Table 2-2. All shots, regardless of Desert Rock participation, are considered for any residual radiation that might have contributed to total radiation dose.

## 2.2 PARTICIPATION

During Operation Upshot-Knothole, there were four categories of observer personnel participating in Exercise Desert Rock V. In addition, other military and civilian observers, sponsored by the Atomic Energy Commission or the Armed Forces Special Weapons Project, witnessed shots but generally did not participate in shot activities to the same extent as those in Exercise Desert Rock. The categories of Desert Rock observers were as follows:

A. Service Observers. This group consisted of personnel selected from all four military services. They were sent to Camp Desert Rock from military bases throughout the United States, as well as from some overseas areas, to become familiar with nuclear weapons and their effects. They usually observed a shot, from close-in (3500-5000 yards) trenches if possible, and inspected the resulting damage to equipment exposed to the shot. The participation of the service observers is shown in Table 2-2. It should be noted that, due to possible participation in more than one shot, the numbers in each category are not necessarily additive. This is explained in Section 2.3. It should also be noted that the service observers did not engage in any maneuvers or other similar exercises while at Nevada Proving Grounds. Those troops who did are treated in a separate report.

Table 2-1. Upshot-Knothole Shot Data

| SHOT DESIGNATION AEC | SHOT DESIGNATION DESERT ROCK | DATE Actual (Sched) 1953 | LOCAL TIME (PST)* | LOCATION COORDINATES (UTM) | BURST HEIGHT** (ft) | YIELD (KT) |
|---|---|---|---|---|---|---|
| ANNIE | V-1 | 17 March (17 March) | 0520 | Area 3 871004 | 300 T | 16 |
| NANCY | V-2 | 24 March (24 March) | 0510 | Area 4 797056 | 300 T | 24 |
| RUTH | V-3 | 31 March (31 March) | 0500 | Area 7(5a) 868042 | 300 T | 0.2 |
| DIXIE | V-4 | 6 April (6 April) | 0730 | Area 7(3) 871045 | 6020A | 11 |
| RAY | V-6 | 11 April (18 April) | 0445 | Area 4a 806060 | 100 T | 0.2 |
| BADGER | V-5 | 18 April (11 April) | 0435 | Area 2 784104 | 300 T | 23 |
| SIMON | V-7 | 25 April (25 April) | 0430 | Area 1 798009 | 300 T | 43 |
| ENCORE | V-9 | 8 May (7 May) | 0830 (PDT) | Frenchman Flat 956726 | 2423 A | 27 |
| HARRY | V-8 | 19 May (2 May) | 0505 (PDT) | Area 3a 867996 | 300 T | 32 |
| GRABLE | V-10 | 25 May (21 May) | 0830 (PDT) | Frenchman Flat 956728 | 524*** | 15 |
| CLIMAX | | 4 June (31 May) | 0415 (PDT) | Area 7(3) 872048 | 1334 A | 61 |

*Unless noted as Pacific Daylight Time (PDT).
**T - Tower; A - Air Drop
***Fired from 280 mm Cannon

Source: References 1, 5, 6

Table 2-2
Observer Participation
Exercise Desert Rock V
Operation Upshot-Knothole

| | Army Observers | Navy Observers | Marine Corps Observers | Air Force Observers | Volunteer Observers | Camp Desert Rock Observers[1] | Civilians (DOD) | Total Observers |
|---|---|---|---|---|---|---|---|---|
| Annie | 303 | 152 | 9 | 41 | | | 30 | 535 |
| Nancy | 308 | 86 | 17 | 79 | 9 | | 16 | 515 |
| Ruth | | | | | | | | 0 |
| Dixie | | | 75 | | | 60 | | 135 |
| Ray | | 1 | 25 | 4 | | 33 | | 63 |
| Badger | 260 | 122 | 106 | 101 | 12 | | 10 | 611 |
| Simon | 198 | 13 | 1 | 340 | 8 | | 24 | 584 |
| Encore | 135 | 92 | 12 | 113 | | 180 | 21 | 553 |
| Harry | 99 | 14 | 2 | 255 | | 526 | 7 | 903 |
| Grable | 606 | 70 | 29 | 13 | | | 31 | 749 |
| Climax | | | | | | | | 0 |

[1] Camp Desert Rock personnel participated in the exercise as both observers and as maneuver troops. This column reflects only those who participated as observers. Other reports of maneuvers will address those CDR personnel who participated as maneuver troops.

[2] Includes 160 officers and enlisted personnel from the 9th Ordnance Battalion (SWS), Sandia Base, N.M. (Reference 13).

Source: References 1, 5, 6.

B. Volunteer Observers. For three shots (Nancy, Badger, Simon), volunteers were positioned in trenches well forward of other observers and troops. Officers from all services were represented in this category. Each volunteer had been trained to determine the effects of nuclear weapons. A safe distance from the burst was calculated and agreed on by the volunteer group. Calculations were based on standard military reference manuals (e.g., TM 23-200), using the highest expected yield of the particular device. For Shot Nancy, the trench was located 2500 yards from ground zero. For Shots Badger and Simon, the trenches were 2000 yards from the tower--the closest that any personnel had experienced a nuclear burst in a training situation. The number of volunteers for each applicable shot is shown in Table 2-2.

C. Camp Desert Rock (CDR) Observers. This group consisted of Army personnel assigned to Camp Desert Rock as the permanent party--that is, those who planned, administered, and supported the maneuvers and programs (including the observer program) that comprised Exercise Desert Rock V. Either in the course of their duties or when integrated with the service observers, they were permitted to observe one or more shots during their stay at Camp Desert Rock. Those who did so in connection with their duties (e.g., instructors, truck drivers) as well as those who participated as maneuver troops, will be treated in a separate report. Those shown in Table 2-2 thus represent only the CDR personnel who participated in the same manner as the regular service observers.

D. Civilian Observers. The number of observers in this category was relatively small (Table 2-2); these apparently represented civil service employees from the various army areas who were sent to Camp Desert Rock in the same manner as other military service observers. There were many other civilian observers at NPG, not sponsored by Desert Rock, who likely participated in various shot-related activities. Their participation is not addressed in this report.

## 2.3 CONCEPT

The purpose of Exercise Desert Rock V was to provide indoctrination and training in military operations featuring tactical employment of nuclear weapons; to demonstrate to participating troops and observers the effects of nuclear explosions on prepared positions, equipment, and animals; and to observe individual psychological effects resulting from nuclear explosions. The missions of Desert Rock V were a continuation of those of the four previous Desert Rock exercises. However, because several restrictions placed by the AEC on military participation in earlier operations were removed for Upshot-Knothole, more realistic training was conducted. This resulted in a number of changes for Desert Rock V. These included:

- Two Battalion Combat Teams were positioned in trenches 3500 yards from GZ - the nearest any large number of troops had been permitted to observe a nuclear burst.

- Volunteer observers were in trenches at 2000 yards from two shots, the closest any personnel had ever been in a training situation.

- The US Army had full responsibility for the radiological safety of Desert Rock-sponsored military participants.

- Troops were permitted to maneuver near ground zero, so long as such exercises did not interfere with other tests and scientific experiments.

The services were invited to send observers to the tests. Each service was informed of the reporting date for each shot as well as the records and equipment to be brought to Camp Desert Rock by individual observers. Army observer allocations were to be divided between commissioned officers and enlisted personnel.* When possible, the enlisted observers were to be formed into

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*Reference 4 suggests a 50/50 mix of personnel, but Reference 3 (which probably superseded the former) indicates that the observers were to be primarily officers, while enlisted personnel were to participate in the troop maneuver exercises.

provisional units by Army commanders for movement to Camp Desert Rock. This was to alleviate the administrative and logistical problems associated with the moves (Reference 4).

After arrival at Camp Desert Rock, the observers followed a scheduled routine that, while varying from shot to shot, included a series of standard activities. The schedule prepared for participating military personnel generally included the following:

- <u>Pre-shot classroom instruction.</u>
  Subjects included basic nuclear theory, characteristics and effects of nuclear weapons, protective measures to employ against a nuclear attack, tactical use of nuclear weapons, and a plan of operation for the upcoming shot. Eight hours of instruction were planned. For those observers who did not arrive at Camp Desert Rock in time for the instruction, a one-hour orientation was conducted on the evening preceding the shot.

- <u>Rehearsal of shot day activities.</u>
  Observers visited the trenches, had a "dry run" of the detonation, and then viewed the display area established for the shot. In some cases, they were taken to the display area of a previous test to see the post-shot effects.

- <u>Shot observation.</u>
  Approximately one hour before the scheduled shot, observers arrived at the trench area, were briefed on what to expect, and were checked for proper safety procedures. A few minutes before the shot, they entered the trenches and assumed a crouching position.

- <u>Guided tour through display area.</u>
  Under the direction of the Desert Rock control group, observers toured the equipment display area to see and have explained the effects of the detonation on animals, equipment, and prepared positions.

Circumstances altered this general schedule in many of the shots. In some instances, weather conditions or fallout contamination precluded the tour of the display area after the shot. In others, shot delays resulted in changes to some observer activities. For example, no observers were originally scheduled for Shot Ray, but when Shot Badger was postponed and Shot Ray was moved ahead one week, the Marine Corps advance party was able to take advantage of the situation and view the detonation from News Nob. In other cases, some observers may have had to return to their home station without having seen a shot.

Several procedures were established for the nine shots in which military personnel participated: observers remained in a group that facilitated control of their activities; prior to H-hour, all personnel were briefed on what to expect; at approximately H-10 minutes, all personnel entered the trenches (except for the two shots where the distance was sufficient to permit observers to remain above ground); after the shot, observers were permitted to tour the equipment display (if any), supervised by the control group and accompanied by rad-safe monitors.

## 2.4 ACTIVITIES

The test shots and attendant observer participation went as scheduled in the majority of the shots. Observers departed Camp Desert Rock for the trench areas in convoys of buses and trucks. With the exception of the volunteer observers, all observers occupied the same set of trenches at a given shot. When observers inspected post-shot equipment displays, their movement to and through the display area was accomplished as a single group. Ground zero locations, the approximate trench locations, and the display areas are identified on the figures accompanying the discussion of each shot. Significant distances of interest, as used in the exposure analysis, are summarized in Table 2-3. The following paragraphs describe the observer activities for each shot at which Desert Rock observers were present.

### 2.4.1 Shot Annie

The first shot in the series was witnessed by 535 observers (Table 2-2) from trenches located 3500 yards (3200 meters) south-southwest of ground zero on an

Table 2-3
Observer-Ground Zero Distance Summary
Exercise Desert Rock V

| Shot | Observer Distance | Post-Shot Approach |
|---|---|---|
| Annie (V-1) | 3500 yds (3200 m) | 700 yds (640 m) |
| Nancy (V-2) | 4000 yds (3660 m)<br>2500 yds (2300 m) | 1000 yds (910 m) |
| Dixie (V-4) | 10 mi (16 km) | None |
| Ray (V-6) | 11 mi (18 km) | None |
| Badger (V-5) | 4000 yds (3660 m)<br>2000 yds (1830 m) | 1000 yds (910 m) |
| Simon (V-7) | 4000 yds (3660 m)<br>2000 yds (1830 m) | 2000 yds (1830 m) |
| Encore (V-9) | 10,000 yds (9150 m) | GZ |
| Harry (V-8) | 4000 yds (3660 m) | 450 yds (410 m) |
| Grable (V-10) | 5000 yds (4570 m) | 1100 yds (1000 m) |

azimuth of 200 degrees. In addition to the observers noted above, there were other civilian observers present for this "open" (to selected civilians and news media) shot. Two battalion combat teams, comprised of troops from Camp Desert Rock, also observed the shot from adjacent trenches and performed an assault maneuver thereafter. This and other troop maneuvers are treated in a separate report.

The observers had arrived at Camp Desert Rock on 13 March 1953. A full dress rehearsal was held in the shot area on 14 March, observers and maneuver troops having departed Camp Desert Rock at 0800. They arrived at the trench area about 1½ hours later. The rehearsal consisted of assigning trenches to specific groups and having the participants practice the procedures, including the method of entering the trenches, the crouch for the shot, the rise to observe the fireball, and the exit from the trenches. They then toured the display area. This gave them the opportunity to view the equipment in its pre-shot condition for later comparison with its condition after the shot. The locations of the major observer activities are shown in Figure 2-1.

On 17 March, the morning of the test, the observer group departed Camp Desert Rock at 0230 and arrived at the trench area at 0400. The pre-shot orientation began at about 0420 (H-1 hour), during which safety instructions were repeated, communications were checked, and muster was taken. At H-10 minutes, the observers entered the trenches. At H-2 minutes, they crouched as the final countdown began for the 0520 shot.

Eight seconds after the shot, the shock wave passed and the observers were permitted to stand in the trench and observe the rising fireball. The rad-safe survey teams immediately set out to monitor the display area and to mark the iso-intensity lines of importance--the 1, 2, and 2.5 r/hr lines in particular. At approximately 0545, the observers began the tour of the display area under the direction of the control group. After walking east from the trench area to the 3500-yard display line, where they viewed the effects of the detonation, they proceeded north through the display area, stopping briefly (approximately five minutes) every 500 yards to note the progressively increasing effects on the displayed equipment. At 700 yards from ground zero they were halted due to rad-

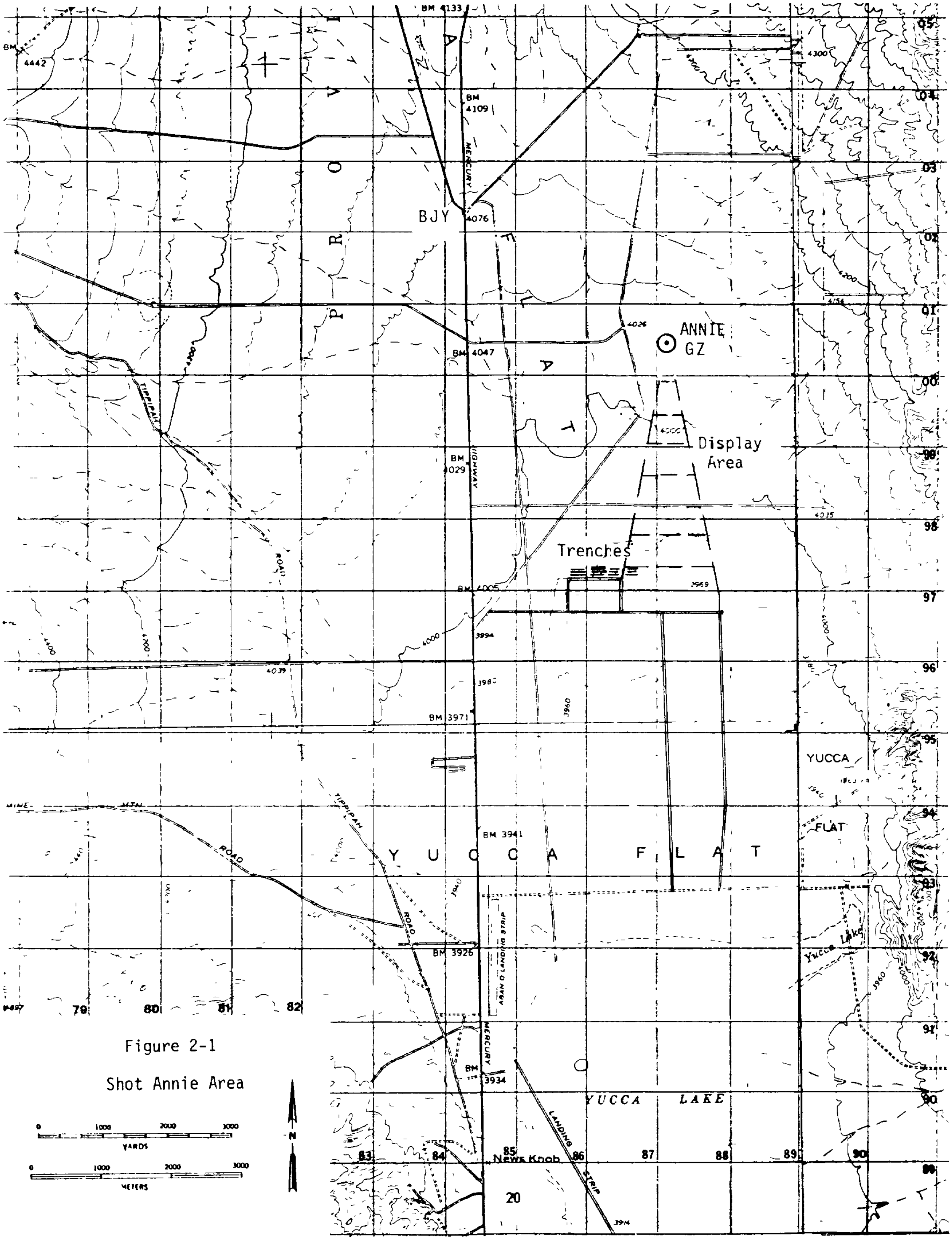


Figure 2-1

Shot Annie Area

safe criteria--they had reached the 2.5 r/hr line, which was not to be crossed (Reference 7). They then returned to the 1000-yard line, mustered, brushed off their clothes and loaded onto the vehicles, which had been brought up from the parking area. At about 0800 (H+2.7), they loaded up for the return trip to Camp Desert Rock.

### 2.4.2 Shot Nancy

Service observers, volunteer observers, and DoD civilians, totaling 515 personnel (Table 2-2), witnessed Shot Nancy from trenches south-southwest (azimuth 205$^{o}$) of ground zero as shown in Figure 2-2. The nine volunteer observers were in a trench 2500 yards (2290 meters) from ground zero. The other observers, as well as two battalion combat teams that maneuvered after the shot, were in trenches at 4000 yards (3660 meters) from the tower.

The observers had arrived at Camp Desert Rock on 20 March 1953. After classroom orientation the next day, they conducted a rehearsal in the shot area on 22 March. In a pattern similar to that of the previous shot rehearsal, they departed Camp Desert Rock shortly after 0800 and arrived at the trench area at 1045. After the simulated shot about an hour later, they viewed the equipment display to the north of the trenches. They then visited the Shot Annie display area to see the effects of the previous detonation, arriving there in the early afternoon, staying about an hour, and departing at about 1500. They arrived back at Camp Desert Rock at 1630. On the following day, 23 March, the remainder of the pre-shot instruction was held.

On shot day, the observers departed camp after midnight and arrived in the trench area at 0340. The observers and maneuver troops were given their pre-shot orientation and safety checks shortly after 0400. The nine volunteer observers, who had previously agreed on the distance at which they would be positioned, were taken to their revetted trench, 1500 yards (1370 meters) closer to ground zero.

The location and dimensions of the volunteer observer trench are not well-documented. From an inspection of the display area and the graphic portrayal in

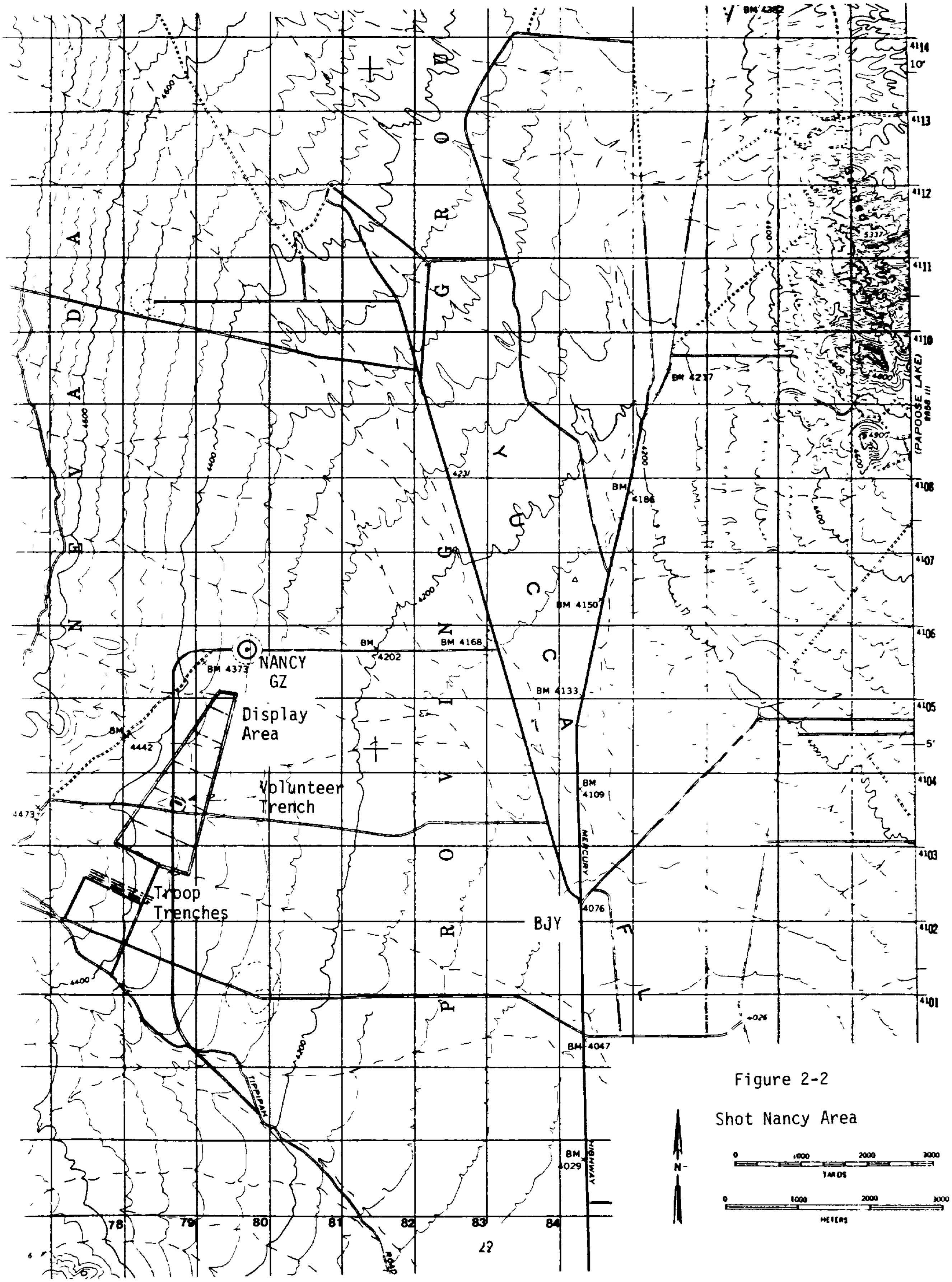


Figure 2-2

Shot Nancy Area

Reference 6, it appears that the trench was near Orange Road, a north-south road cutting through the display area. Its azimuth (from GZ) was therefore 205 degrees, not 200 as stated in the same reference. Moreover, the reference describes the trench variously as three and four feet in width. Photographs of the trench indicate the width as four feet. This width, as well as the azimuth of 205 degrees, is used in the analysis.

Following the pre-shot briefing and about ten minutes before detonation, the observers entered the trenches. The shot went off as scheduled at 0510. A portion of the cloud stem passed near the trenches, and resulted in detectable (18mr/hr) radiation levels in the main trench area for a brief period. This was apparently caused by a wind shift just before the shot that caused the slight wind to come from the north rather than the west, as it had previously (Reference 1).

The volunteer observers were able to view the rising fireball for only a few seconds before dust obscured their vision for the next minute. Gamma radiation levels noted in the volunteer trenches were as high as 1-2 r/hr on the floor of the trench and 4.5 r/hr at shoulder height, about a foot below ground level, at the entrance ramp. Seeing the approaching cloud, they decided to evacuate the trench and return to the main observer area to the rear. The intensity at that time was 90 mr/hr. After a walk of 500 yards, their vehicle met them and returned them to the control trench. The intensity at the time of pick-up (at the 3000-yard line) was 20 mr/hr.

At 0630, the observers (not including the volunteer observers) departed the trench area for a tour of the display area. They likely stopped for about five minutes at each 500-yard display line from 3500 yards to 1000 yards from ground zero. Because the rad-safe limit line (2.5 r/hr) was established at 850-1250 yards (depending on azimuth), it is unlikely that observers would have proceeded beyond the 1000-yard display line. After a brief stay of five minutes at this line, they would have returned to the main trench area, arriving there at about 0730. At 0800, the return trip to Camp Desert Rock began. The last unit reached camp at about 1030.

2.4.3 Shot Ruth

There was no Desert Rock observer participation in this event. The location of this shot is shown in Figure 2-3. There was no impact on subsequent Desert Rock operations due to this shot.

2.4.4 Shot Dixie

Originally, no observer participation was planned for this event. However, 75 Marine Corps officers and enlisted personnel (the advance party of Marines for the Shot Badger exercise) from Camp Pendleton, California, and 60 Camp Desert Rock personnel observed the shot from News Nob, 10 miles south of ground zero. There was no equipment display, and no post-shot inspection of the area. Within a half-hour after the shot, the observers departed for Camp Desert Rock. The location of the shot is shown in Figure 2-3.

2.4.5 Shot Ray

This shot, the fifth in the series, was originally scheduled as number 6. Because of the high residual radiation levels in the Shot 5 (Badger) area due to Shot Nancy fallout, shots 5 and 6 were interchanged. Some Marine Corps personnel who had already arrived at Camp Desert Rock to begin preparations for Shot Badger were thus afforded the additional opportunity to view this shot. Some 25 Marines, as well as other service personnel as shown in Table 2-2, observed Shot Ray from News Nob, 11 miles south of the tower. There was no equipment display for post-shot inspection. The location of the shot is shown in Figure 2-3.

2.4.6 Shot Badger

A total of 611 observers (Table 2-2) witnessed this shot from trenches south ($195^{\circ}$ azimuth) of ground zero. Of this group, 12 volunteers were in a trench 2000 yards (1830 meters) from the shot, while the other observers were in trenches 4000 yards (3660 meters) away. Figure 2-4 depicts the trench areas and the shot area. In addition to the observer program, a Marine exercise was conducted in conjunction with this shot, starting from trenches adjacent to the observer trenches. The exposure analysis of this maneuver unit, the Second Marine Corps Provisional Atomic Exercise Brigade, is treated in a separate report.

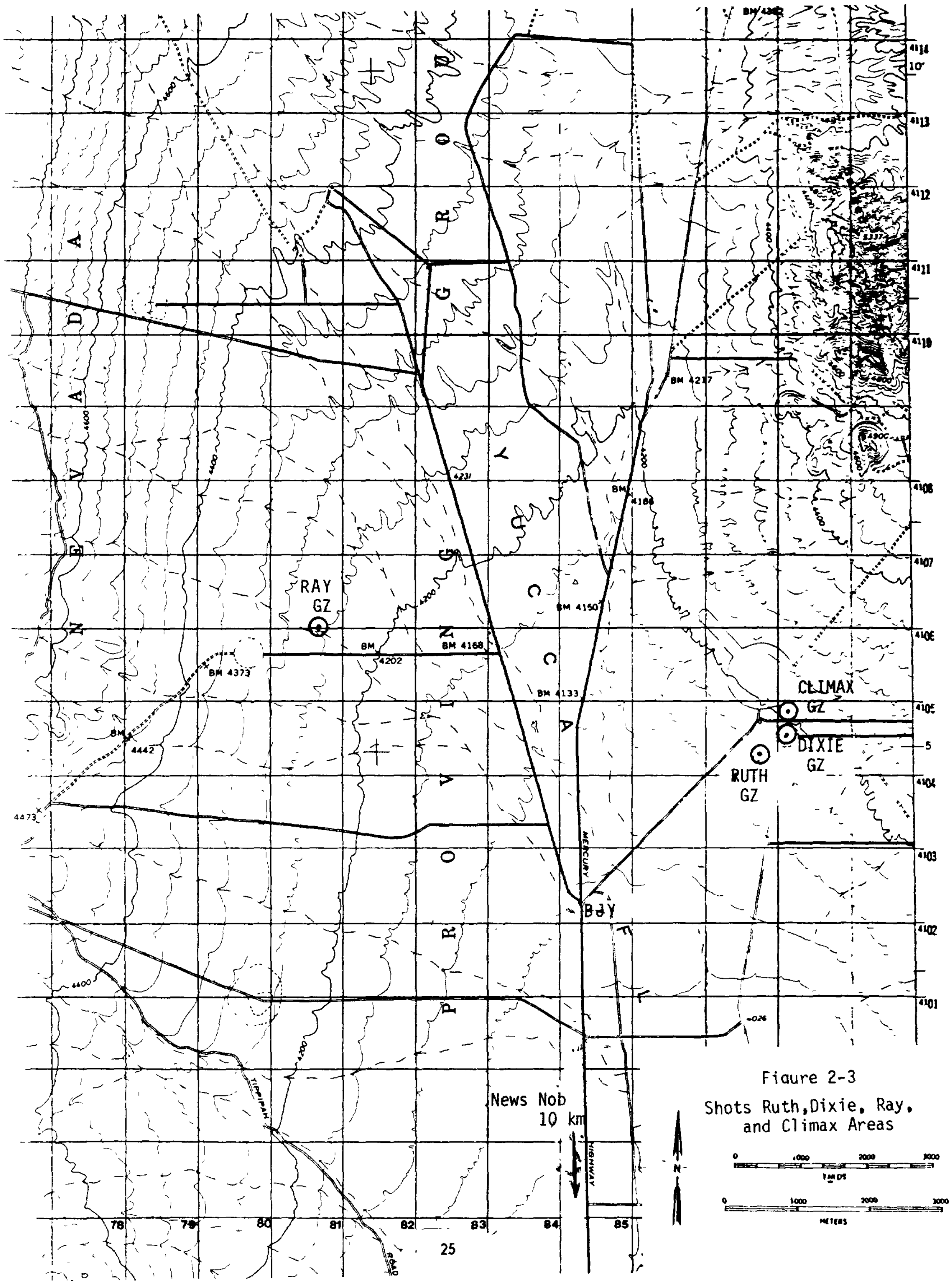


Figure 2-3
Shots Ruth, Dixie, Ray, and Climax Areas

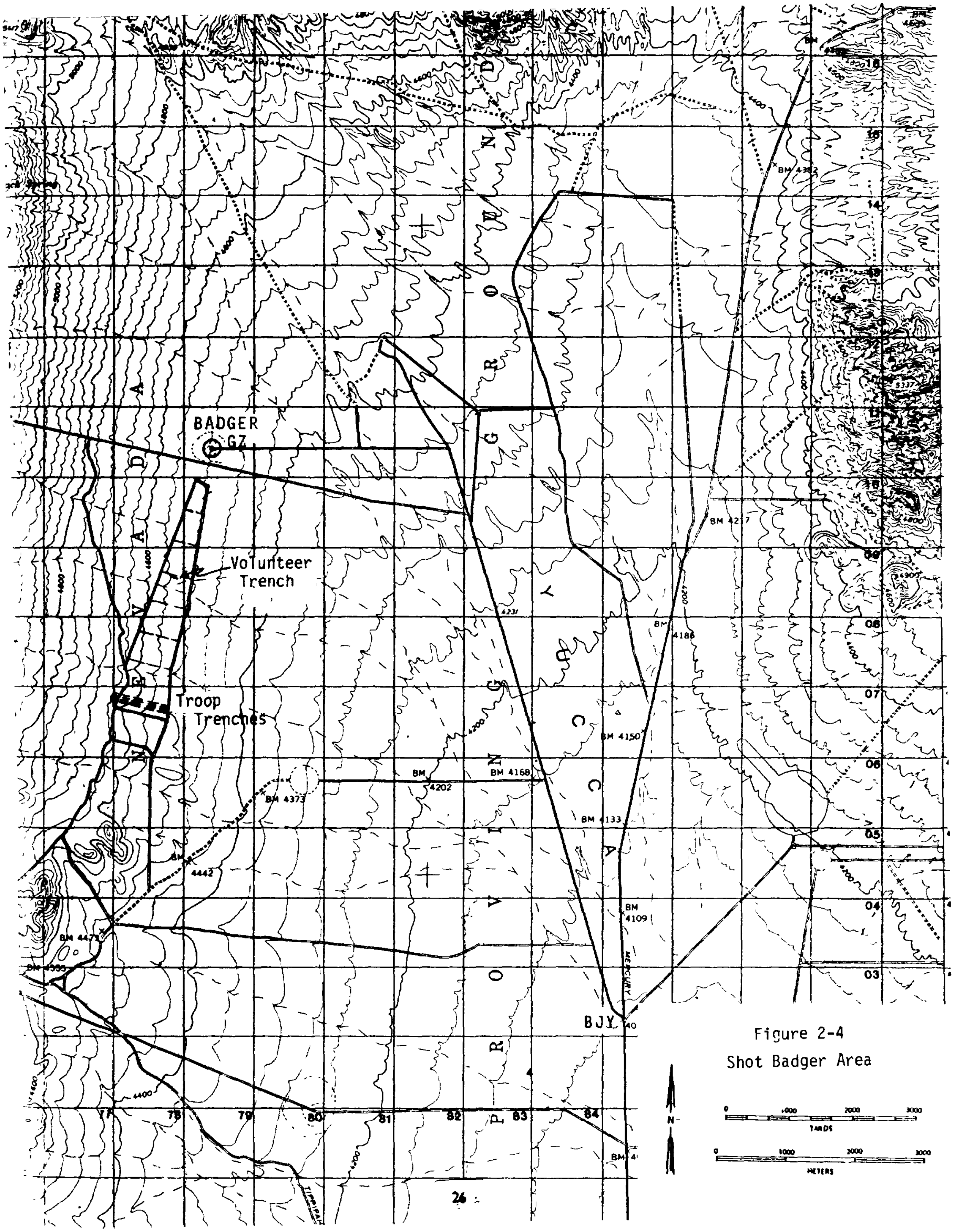


Figure 2-4
Shot Badger Area

The observers arrived between 13 and 17 April. Most were able to attend the rehearsal on 16 April, conducted in conjunction with the brigade maneuver rehearsal. For the rehearsal, they departed Camp Desert Rock shortly after 0700 and arrived at the trench area at about 1000 hours. Simulated H-hour was at 1051, and shortly thereafter the manuever units began their attack. At this time, the observers toured the display area to note the pre-shot condition of the equipment. Based on the plan, they were in the display area for about an hour after the simulated shot (Reference 9). They then boarded their vehicles at about 1200 hours and began their return trip to Camp Desert Rock. On the way, they stopped at the Shot Nancy display area to view the post-shot condition of that equipment. After an estimated stay of one hour, they re-boarded their vehicles and continued back to camp.

Observers were given a full day's instruction on 17 April, the day before the shot. Those who arrived too late were briefed in the evening. Just before midnight, the observers loaded up for the three-hour ride to the shot area. They arrived at the trench area about 0300 on the morning of 18 April. The usual pre-shot orientation was given about an hour before shot time, and at H-10 minutes the observers entered the trenches for the final countdown. The shot was fired at 0435 hours.

After the shot, the volunteer observers experienced radiation levels greater than 500 r/hr, as indicated by instruments that they were using (References 15 and 33). This level was sustained for 10-15 seconds, then began to drop. They decided to evacuate the position, and at about seven minutes after the burst they began walking toward the west radial road, about 200 yards away. The radiation intensity was about 50 r/hr at this time, but decreased to 1 r/hr by the time they reached the west radial, about two minutes later. They apparently waited there for a few minutes for transportation before starting toward the main trench area, 2000 yards to the south, where they arrived about 20 minutes later. It is unlikely that they joined the other observers in the post-shot inspection of the display area, since they were involved in interviews and tests relating to their experiences.

The service observers departed the trench area about 35 minutes after the shot. Because of the contamination on the east radial, they moved northward up the west radial. Both Desert Rock and Marine displays were located at varying distances from the shot, the first (outermost) at 3500 yards (3200 m) from ground zero. They proceeded up the west radial until they reached the 1000-yard display line (Reference 15), the last display before the rad-safe limit line. They moved eastward along the 1000-yard line to the east radial, where they turned south toward the trench area. They continued down the east radial as far as radiological conditions permitted, detouring to the west as necessary to avoid areas contaminated in excess of 2.5 r/hr. They reached the trench area shortly before 0700. Following the prescribed procedures, they underwent field decontamination before boarding their vehicles for the return trip to Camp Desert Rock. The observer vehicles departed the trench area at about 0735. Because of contamination on the planned return route, some rerouting of the convoy was necessary, likely to avoid that in the extended east radial. This also necessitated a final stop to check for contamination before leaving Yucca Flat. No decontamination was required, and the group reached camp at 1000 hours (Reference 1) approximately an hour behind schedule (Reference 9).

### 2.4.7 Shot Simon

The seventh shot produced the largest yield (43 kt) of any shot in Nevada up to that time. It was the fourth shot in which Desert Rock observers and maneuver troops participated from trenches. Approximately 584 observers witnessed the shot, as shown in Table 2-2. The eight volunteer observers were in two adjacent trenches 2000 yards (1830 meters) south of the shot at an azimuth of 180 degrees. All others were in trenches 4000 yards (3660 meters) south, as shown in Figure 2-5. Maneuver units, who would perform a tactical exercise after the shot, were in adjacent trenches. Their activities are treated in a separate report.

The observers arrived at Camp Desert Rock during the period 21-24 April. Pre-shot instruction was conducted on 22 April, although less than half of the observers had arrived. On 23 April, a full scale dress rehearsal was held in the shot area. This was primarily for the benefit of the tactical maneuver troops, but those observers who had arrived also participated. The observers departed Camp

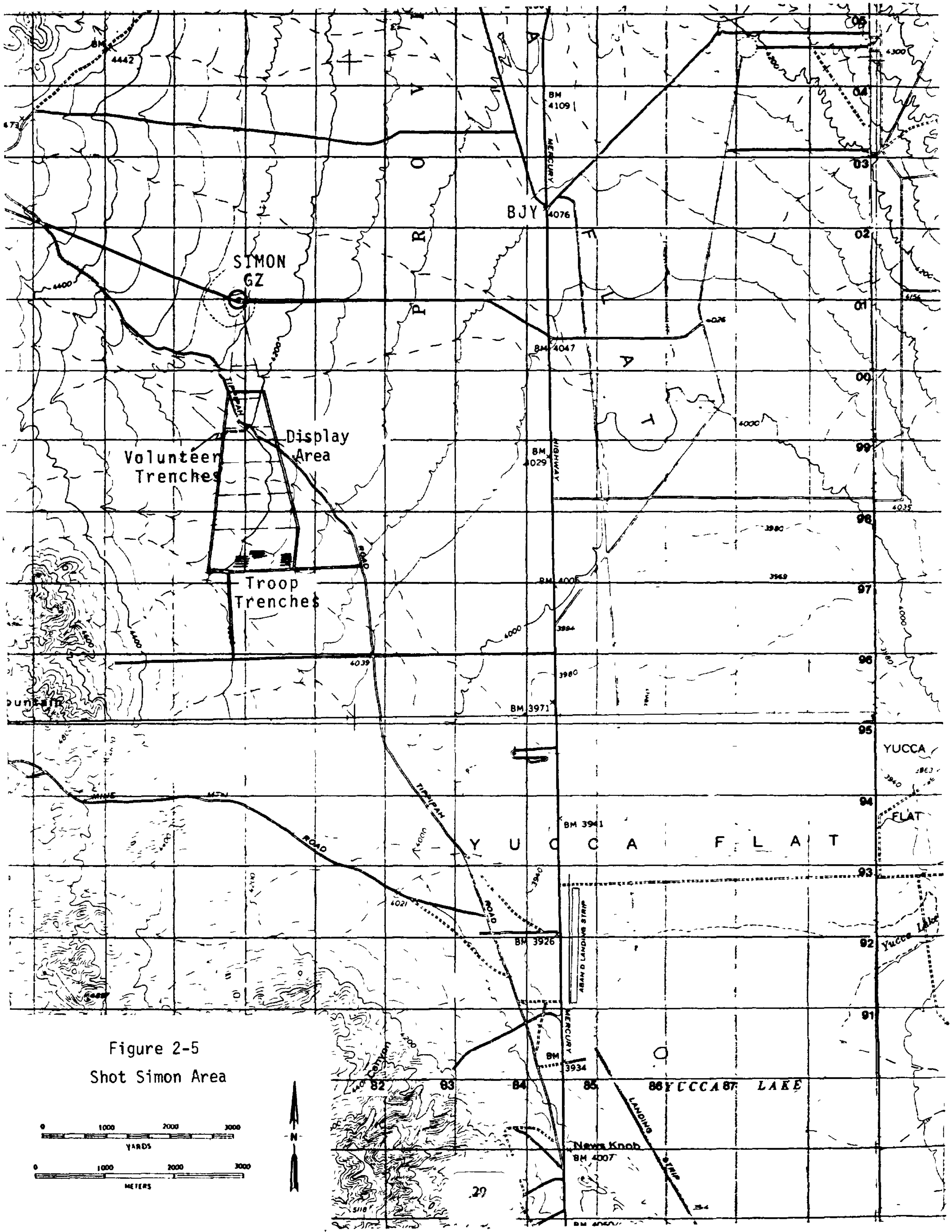


Figure 2-5
Shot Simon Area

Desert Rock shortly after 0800 (the first work unit, comprised of the control group, had begun the trip at 0700) and arrived at the trench area at 0945 hours. During the pre-shot orientation, it was explained that the display area might be contaminated on shot day to the extent that displays closer than 1500-2000 yards from the tower may be denied. After the simulated shot at 1030 and the beginning of the tactical maneuver five minutes later, the observers began their walk-through of the display area to note the pre-shot condition of the equipment and animals. This activity lasted from about 1100 hours to just before noon, at which time the observers loaded onto their vehicles for the trip north to the display area for Shot Badger, fired five days earlier. At approximately 1315 hours, they departed the Badger area for the return trip to Camp Desert Rock, arriving there shortly after 1500 (Reference 1).

On 24 April, the observers received the final four-hour segment of their instruction. That evening, late arrivals were given a four-hour orientation briefing on what to expect the next day. It was anticipated that these late arrivals would receive assistance from those who had attended the full orientation and the rehearsal (Reference 1).

On 25 April, the observers departed Camp Desert Rock at 0135 hours (Reference 10) and arrived at the trench area at 0315. The volunteer observers probably arrived at their trenches, 2000 yards (1830 meters) closer to the shot tower, a few minutes later. Five volunteers occupied a revetted trench (4 feet wide, 6 feet deep), while three chose to occupy an unrevetted trench (same dimensions) having only a sandbag parapet. Constant telephone communication was maintained with the control group at the main trench area. After the standard pre-shot orientation, all observers entered the trenches at H-15 minutes, where they stayed for the 0430 shot.

After the shot, the volunteer observers experienced radiation intensity levels of 100 r/hr. This was probably a few seconds after the burst, when the light level had subsided. The observed intensity dropped rapidly to 50 r/hr, then to 20-25 r/hr in another minute. They decided to exit the trenches. In the next four minutes, they examined some of the animal positions nearby, as the intensity again increased to about 50 r/hr. They then moved toward the planned vehicle pick-up point, 200 yards to the west (Figure 2-5). When they reached the west radial road, they turned south and met their vehicle at the 2500-yard line (500 yards south of their trenches). As they continued south in the vehicle, the intensity dropped to about 1 r/hr by the time they had travelled another 500 yards (References 1 and 16).

At the main trench area, the initial radiation transient was noted to be about 5 r/hr at a few seconds after the shot. Later, as the cloud stem passed, the level rose to 120 mr/hr before dropping again to about 30 mr/hr. The total early dose was reported to be less than 25 mr (Reference 1), which probably indicates no discernable reading on a pocket dosimeter.

Thirty minutes after the shot, the service observers began the walk-through of the display area. Their route likely followed the path of the maneuver troops, who had previously begun their attack to the northwest. After reaching the western boundary of the display area, the observers proceeded toward ground zero until stopped by the rad-safe limit (2.5 r/hr) at the 2000-yard line. After a brief description of the close-in damage (as observed by control personnel from a vehicle), the observers returned to the trench area, probably by way of the east radial, arriving at the vehicle loading area at 0600, ninety minutes after the shot. Within a half hour, they mustered, loaded up, and began the return trip to Camp Desert Rock. The convoy stopped enroute for final rad-safe monitoring and personnel brushing-off; this routine procedure was not accomplished at load-up due to low level contamination in the shot area, but occurred enroute to Camp Desert Rock and resulted in an overall delay in the return trip of about an hour (Reference 1). Arrival at camp was at about 0900 hours rather than at 0800 as planned.

### 2.4.8. Shot Encore

This shot was witnessed by 553 observers, including 180 observers from the Camp Desert Rock permanent party. Shot Encore was the first of the series to be conducted at Frenchman Flat, the site of the major military effects experiments. Because of the uncertainties associated with air-delivery of the weapon, the observer trenches were located 10,300 yards (9,420 meters) south-southwest ($200^{\circ}$

azimuth) from intended ground zero. As in several previous shots, a post-shot tactical maneuver was conducted. This is the subject of a separate report. Figure 2-6 shows Frenchman Flat, the intended and actual burst points, the display area, and the observer trenches.

Observers arrived at Camp Desert Rock during the period 2-6 May. Maneuver troops, who would conduct the post-shot exercise, arrived during the same period. A rehearsal of shot day activities was held on 5 May, although not all observers had yet arrived. As in previous shots, late arrivals were apparently assisted by those who had attended all pre-shot activities. The rehearsal began at Camp Desert Rock when the troops and observers entrucked after 0600 for the short ride (7 miles) to the trench area. By 0755, all participants had arrived at the trenches. After the simulated shot at 0830, the maneuver elements began their attack while the observers were transported to the display area. From about 0900 to 1040, observers inspected the equipment, fortifications, and animal positions located from ground zero out to 3500 yards to the south. Shortly after 1100, they began the 13-mile trip back to Camp Desert Rock, arriving there before noon.

The next day, 6 May, the observers received classroom instruction in preparation for the shot, scheduled for the following day. A 24-hour shot postponement due to unfavorable meteorological conditions was filled by another day of instruction on 7 May.

On 8 May, the observers departed Camp Desert Rock at 0640 and arrived at the trench area shortly after 0700. After the usual pre-shot orientation, the observers entered the trenches for the shot. The B-50 aircraft released the bomb, and detonation occurred at 0830 hours, 2423 feet (740 meters) above Frenchman Lake, about 280 yards (250 meters) south of the aim point. Five minutes later, the maneuver troops began their attack toward ground zero. When the troops had cleared the trench area, the observers loaded onto their vehicles and were transported to the display area. They dismounted at the left (west) boundary radial, near the 2000-yard display line, about 45 minutes after the burst. Their tour through the display area likely would have included an inspection of each 500-yard line from the dismount point to (intended) ground zero, then back out to

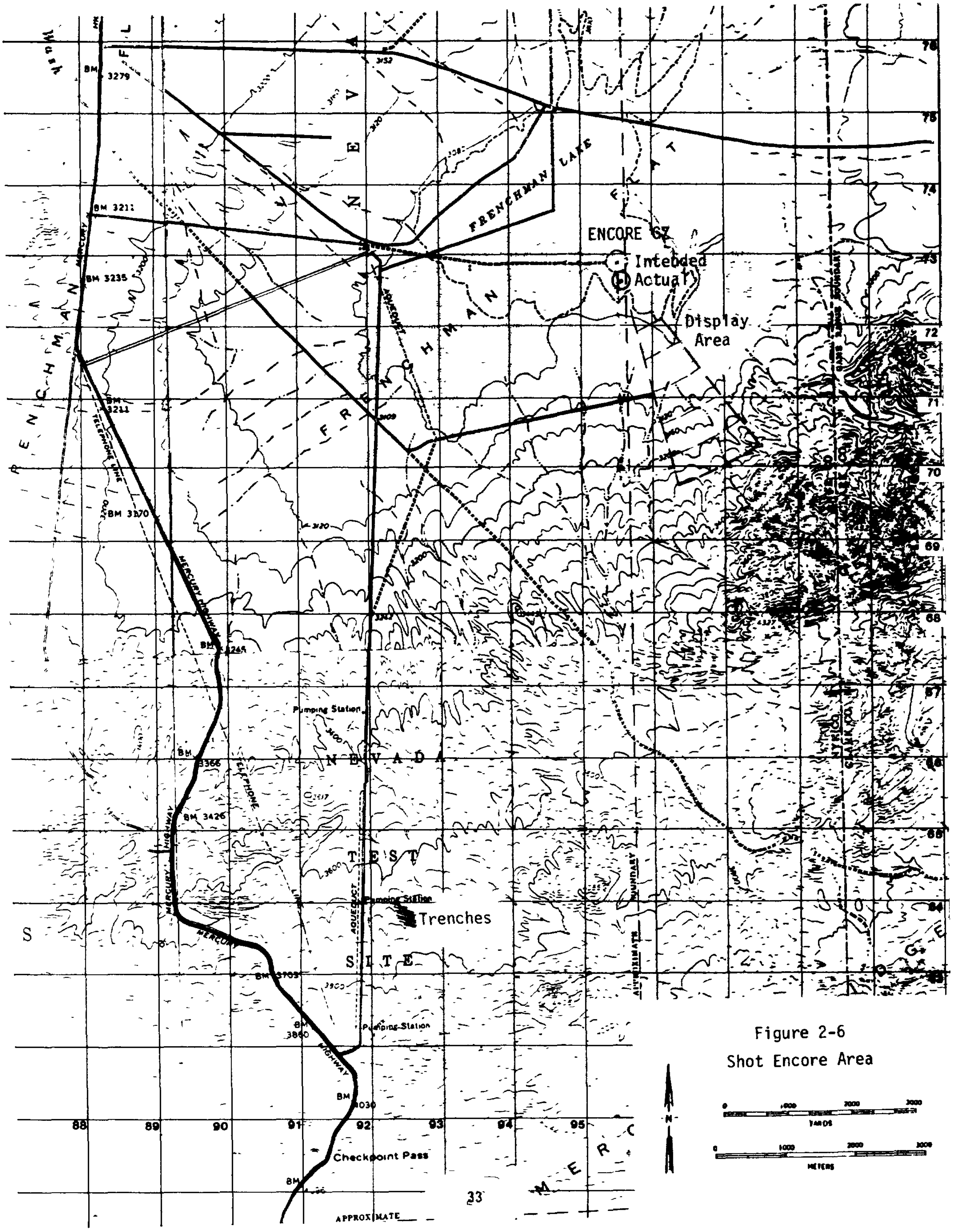


Figure 2-6
Shot Encore Area

the waiting vehicles. After muster and decontamination, the observers loaded up and departed for Camp Desert Rock shortly after 1100 hours, arriving back at camp an hour later.

### 2.4.9 Shot Harry

Over 900 observers witnessed this shot from trenches 4000 yards (3660 meters) from the tower, as shown in Table 2-2. The display area was located south of the burst while the trenches were more to the west (Figure 2-7).

Due to contamination from Simon fallout, Shot Harry was postponed two weeks from its scheduled date of 2 May. Other delays due to unfavorable meteorological conditions caused further postponements, resulting in a shot date of 19 May. Except for those from the Camp Desert Rock permanent party, the observers arrived during the period 12-15 May. Because there was no troop maneuver for this shot, there were no rehearsals and no pre-shot inspection of the display area. During the postponements, observers were provided additional orientation and classroom instruction. Some were also afforded the opportunity on 15 May to observe the first registration firing of the 280 mm cannon that was to be used for Shot Grable in Frenchman Flat.

On the morning of Shot Harry, observers departed Camp Desert Rock at 0145 and arrived at the trench area two hours later. Shortly after 0400, the usual pre-shot indoctrination was conducted, after which the observers entered the trenches for the final countdown. The shot went off at 0505 hours. Within 15 minutes, the vehicles had arrived at the trench area to transport the personnel to the display area, at its nearest about a mile away. Because of the limited time allowed (Reference 1), they likely were transported up the left (west) side of the area to the 1000-yard line, where they continued on foot to the 500-yard line. The actual limit of advance was 450 yards from ground zero, where the radiation intensity was reported to be 6 r/hr (Reference 1). It should be noted that this was the first shot at which Desert Rock rad-safe criteria did not provide for an intensity limitation. The 5 r/hr line was used as a caution, but the only substantive limit was 6r total dose as indicated by pocket dosimeters.

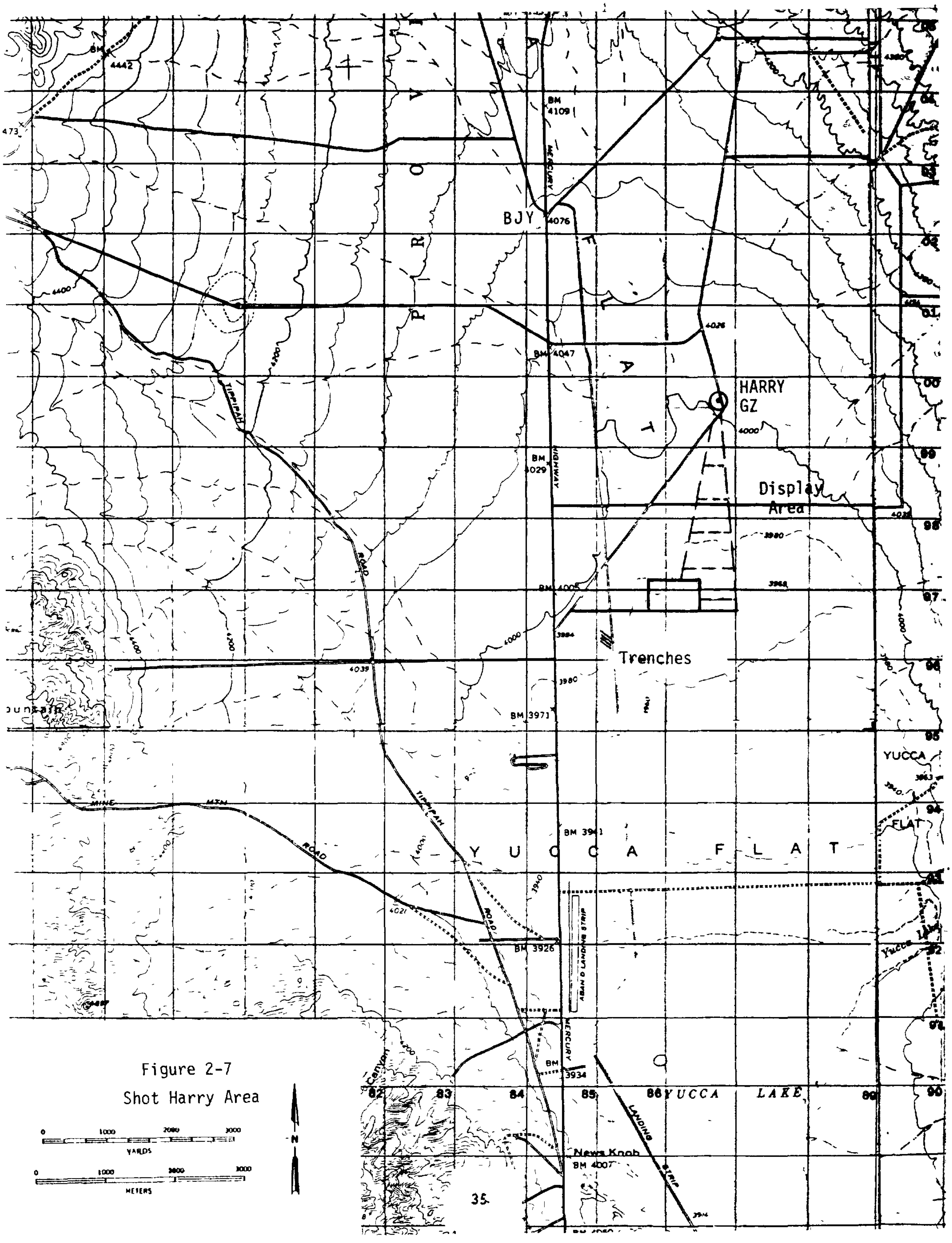


Figure 2-7

Shot Harry Area

At this point, about 45 minutes after the shot, the observers proceeded back toward the outer areas of the display, stopping briefly at each 500-yard line until they reached the 2500-yard display at about 0630 hours. There, they mustered and loaded up for the return trip to Camp Desert Rock. They departed the shot area at 0651 hours and arrived back at camp at 0900.

### 2.4.10 Shot Grable

Shot Grable was the first (and last) atomic projectile fired by the 280 mm cannon, "Amazon Annie" (Figure 2-8). Many high-level officials, including the Secretary of Defense, were on hand for the shot. Two battalion combat teams, comprised of troops from the six continental armies, maneuvered after the shot. This and other troop maneuvers are treated in a separate report.

Observers sponsored by Desert Rock arrived during the period 18-24 May. Pre-shot orientation was provided on 22 May. This included four hours of classroom instruction, a trip to the gun position to watch registration firing, and a trip to the display area for Shot Harry, fired three days earlier. This inspection likely occurred during the afternoon of 22 May, and would have taken about two hours in the shot area, ranging from 2500 to 500 yards from ground zero.

A full dress rehearsal of the shot activities was held on 23 May in Frenchman Flat. The troops and observers were in the trenches, 5000 yards (4570 meters) from ground zero, for the 1000 hours simulated shot, after which the tactical exercise began. The observers were then transported to the display area shown in Figure 2-9. However, due to a severe sandstorm, the time spent in the display area was limited. Within 1½ hours after the simulated shot, the observers were returning to Camp Desert Rock. The next day was D-1. Shot preparations continued and orientation was provided for late arrivals and high-level officials.

On shot day (25 May), the observers departed Camp Desert Rock at 0610 and arrived in the trench area (Figure 2-9) at 0700. The pre-shot orientation, conducted from 0735 to 0810 hours, included an address by the Army Chief of Staff. Meanwhile, the 280 mm cannon continued to register with conventional

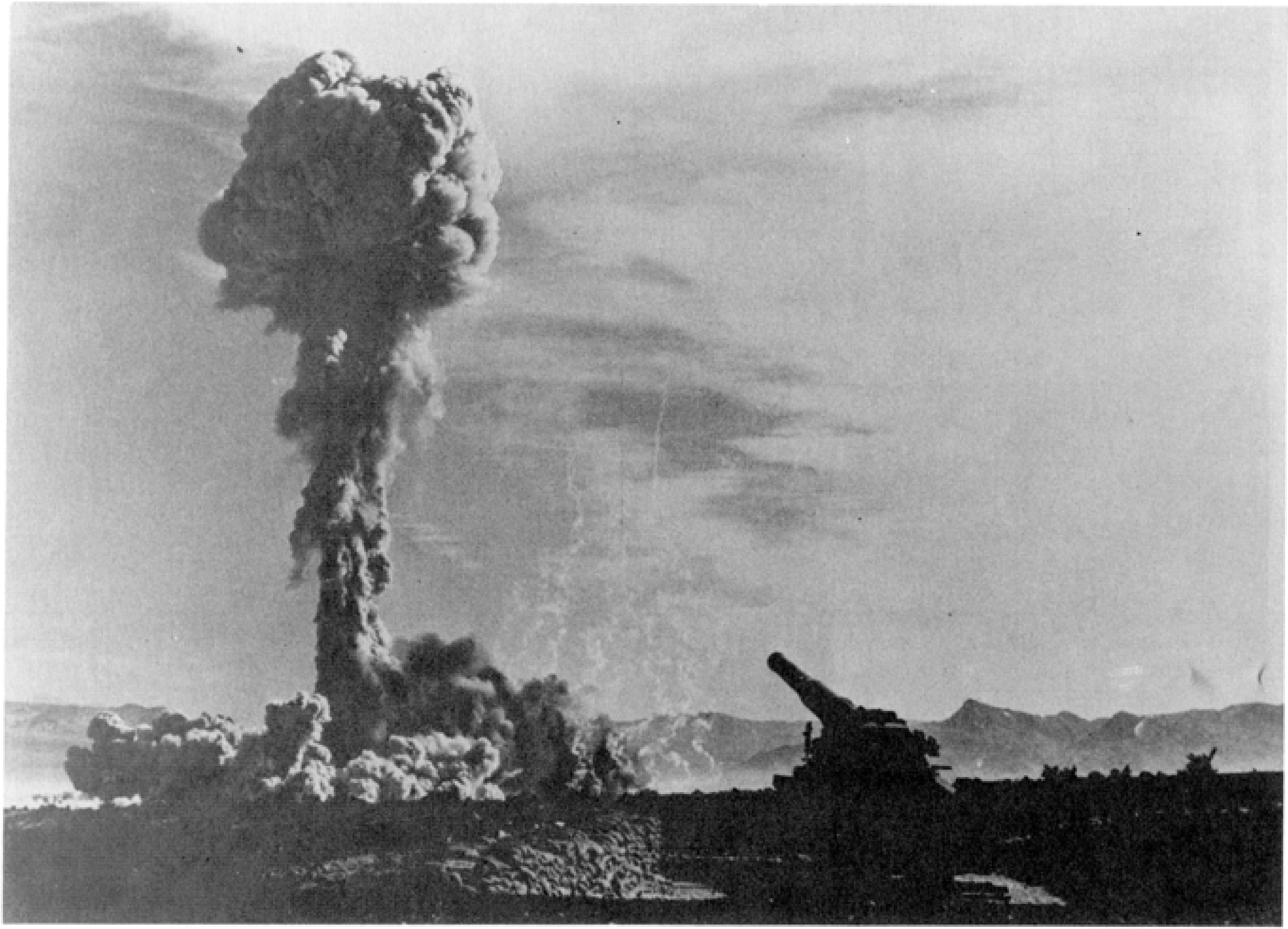

Figure 2-8 Shot Grable and the 280mm Cannon "Amazon Annie"

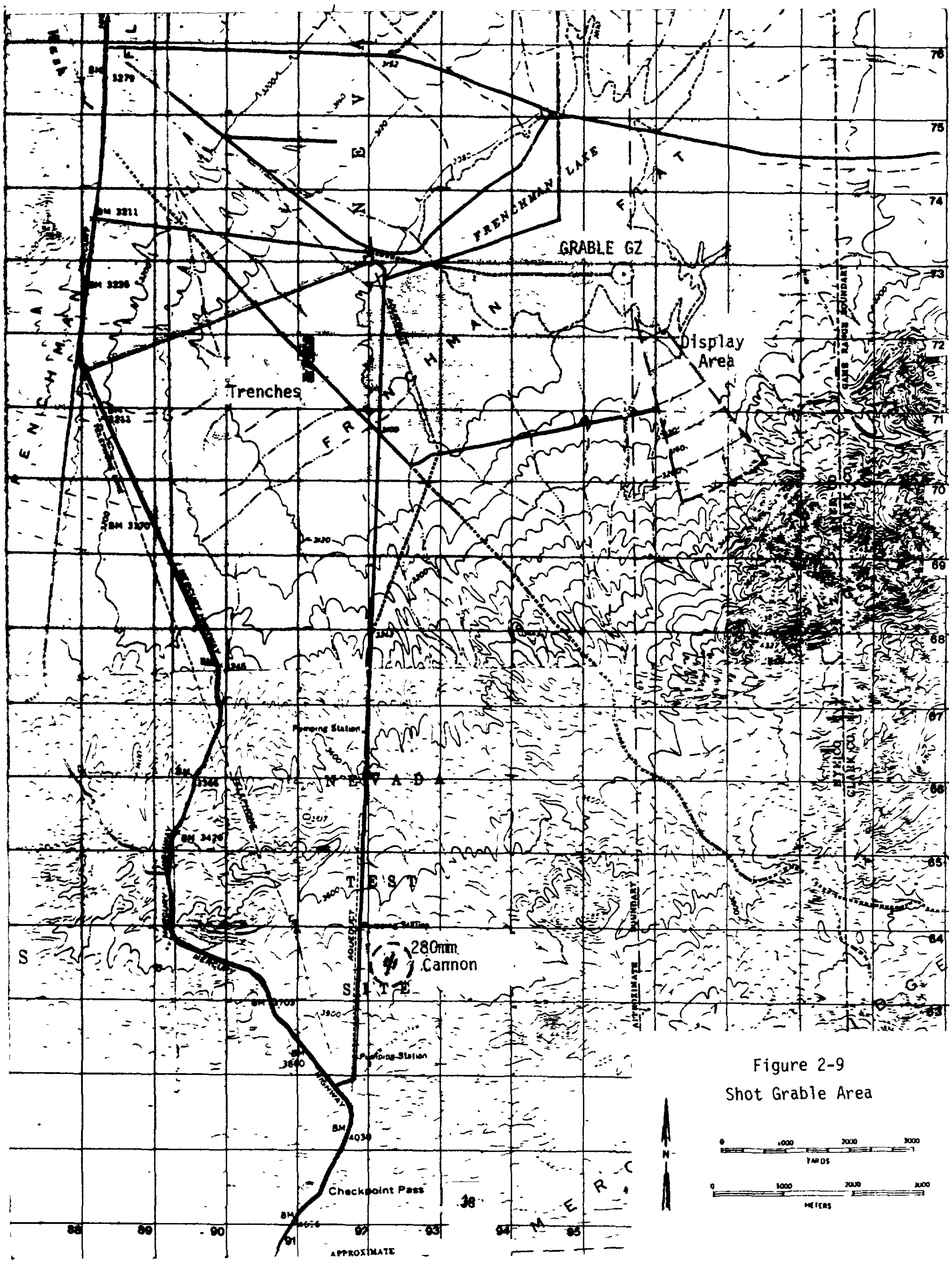


Figure 2-9
Shot Grable Area

ammunition. Nineteen seconds before H-hour, the nuclear projectile was fired; it detonated on schedule at 0830 hours, only 54 yards (49 meters) short of its target (Reference 34).

After the shot, the maneuver troops begain their attack. The observers then loaded onto their vehicles and were transported to the display area, the same one used previously for Shot Encore. At 45 minutes after the burst, they reached the dismount point near the 2000-yard line. They inspected the 2000- and 1500-yard lines before severe dust conditions caused the inspection to be terminated, possibly as close as 1100 yards (1000 meters) from ground zero. They returned to their vehicles near the 2000-yard line, where they waited for almost an hour before it was decided at 1100 hours to return to Camp Desert Rock.

### 2.4.11 Shot Climax

There was no Desert Rock participation in this event. It may be noted that, at 61 KT, Shot Climax was the largest shot fired in the continental United States up to that time. Figure 2-3 depicts the shot area.

## Section 3
## INITIAL RADIATION

Of the eleven shots in the Upshot-Knothole series, six are investigated to determine the dose resulting from possible exposure to initial gamma and neutron radiation. These shots are Annie, Nancy, Badger, Simon, Harry, and Grable, the details of which are given in Table 2-1. For the remaining five shots, observers were not present, or were at distances such that initial radiation doses were insignificant. 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 personnel were located in trenches at the times of detonation, the calculation of the radiation doses for volunteer and service observers 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 gamma and prompt neutron radiation environment is determined with computer codes ATR4 (Reference 19) and ATR4.1 (Reference 20). These codes, developed from two-dimensional discrete ordinates radiation transport calculations, predict free-field neutron and gamma doses in the vicinity of a nuclear detonation. The first code contains provisions to correct for the presence of Nevada soil at the air-ground interface; the second, although based on a West German soil type, contains improved source-energy-dependent air-ground correction factors. Hence, ATR4 is generally used to calculate prompt neutron and neutron-induced gamma radiation, which are sensitive to the hydrogen (water) content of the soil (Reference 21), while ATR4.1 is used to calculate fission product gamma and prompt gamma (emitted directly from the fission reaction) radiation, neither of which is sensitive to the presence of hydrogen in the soil. Neutron doses are calculated from (Ritts) tissue kerma factors, while the Henderson tissue response function is used to determine gamma doses (Reference 19).

Several adjustments are applied to the neutron doses calculated with ATR4. Improved methods of cross-section weighting and grouping, developed since the ATR data base was compiled, are incorporated, and allowance is made for a representative air moisture content (humidity). The numerical correction factor is derived by comparing infinite air calculations of the one-dimensional discrete ordinates code ANISN (Reference 26), which incorporates these improvements, with ATR-generated infinite air calculations. This factor varies approximately from 0.8 to 1.5 over the distances of interest. The second adjustment to the ATR neutron doses corrects for inaccuracies in the air-ground correction factor used in ATR for ranges greater than 1500 meters (the factors used in ATR are considered accurate at smaller ranges). Recent transport calculations with the discrete ordinates code DOT (Reference 29) provide the best estimate of these correction factors in the range 1500-3300 meters. This correction results in a reduction in calculated neutron doses at ranges greater than 1500 m, with the magnitude of the reduction increasing with range.

Required input to the ATR code includes the neutron output spectrum of the device, and geometric and meteorological data. For each of the six shots of interest, the general source of neutron spectral information for the device is given in the detailed discussion for the shot. Meteorological and geometric (e.g., height of burst, ground zero elevation) data are taken from References 40 and 41. The output of ATR-- neutron and gamma doses as a function of range--can be compared with existing dose measurements for each shot to gauge the accuracy of the results. Unfortunately, insufficient neutron activation foil measurements were made during this nuclear test series to allow experimental confirmation of calculated neutron doses. Generally, only gold foils (to measure low energy neutrons, <0.3 eV), sulfur foils (to measure fast neutrons, >3 MeV), and various experimental materials (e.g., iodine, plutonium, tantalum, and zirconium) were used as neutron detectors (References 42, 43, 44). There is an abundance of free-field gamma dose data available (References 45, 46, 47, 1), however, and these are utilized to verify the ATR results.

For certain devices the prompt neutron output was strongly suppressed by absorption within the device itself. In these cases, the delayed neutrons, which are emitted by the fission products after the device disassembles and are not subject to such absorption, may deliver doses that are comparable to the doses due to prompt neutrons. It must be emphasized that this effect was important only for specific devices (e.g., those with a thick layer of high explosives surrounding the fissile material), and that, for most devices of this and later series, the delayed neutron dose was negligible compared to that of prompt neutrons. Moreover, the air attenuation of neutrons is such that delayed neutrons were significant only for locations fairly close to ground zero (e.g., at the volunteer observer trenches). Computer code NUIDEA (Reference 49) is used to calculate the delayed neutron environment in the vicinity of the volunteer observer trenches for Shots Nancy, Badger, and Simon.

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. Brief discussions of the derivations of the various trench factors are presented in Appendix I.

For the shots of interest, two trench sizes were utilized. The volunteer observers (shots Nancy, Badger, and Simon) were in trenches approximately four feet wide and six feet deep, and at ranges of 2000-2500 yards from ground zero. The service observers (all six shots) were in trenches approximately two feet wide and five feet deep, and at ranges of 3500-5000 yards. The in-trench free-field neutron and gamma doses are calculated at depths of four feet in the four-foot wide trench and 2.33 feet in the two-foot wide trench. These depths correspond approximately to the mid-torso depths of personnel crouched in each of the trenches. It is coincidental that the fractions of solid angle subtended by the trench openings, when viewed from the referenced depths, are nearly the same for these two cases. Consequently, most of the factors are similar. The following trench factors are used in this report:

| Radiation Type | Volunteer Observer Trenches | Service Observer Trenches |
|---|---|---|
| Neutron | 0.25 | 0.25 |
| Secondary gamma | 0.019-0.025* | 0.015 |
| Local gamma | 0.08 | 0.08 |
| Debris gamma | ** | ** |

The in-trench dose (in rads) is converted to an equivalent tissue dose (in rem) using the quality factors and methods prescribed in Reference 22. The rad-rem conversion factor for neutrons, derived from calculations utilizing computer codes DOT and MORSE (Reference 23), 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 chest-worn film badge readings were developed from calculations utilizing the adjoint mode of the computer code MORSE. These film badge conversion factors are strongly dependent on the posture and orientation of the personnel in the trench; the ranges of values shown below reflect extreme variations in individual posture and orientation. The conversion factor for the standing position is based on a badge depth of 1.5 feet centered in a 4-foot wide trench and 0.5 feet centered in a 2-foot wide trench. The geometric means of these ranges, where applicable, are used to determine best-estimate film badge doses.

| Radiation Type | Film Badge Conversion Factors Range | Mean |
|---|---|---|
| Neutron | NA | NA |
| Secondary gamma | 0.34-0.83 | 0.53 |
| Local gamma | ~0.7 | 0.7 |
| Debris gamma, crouched position | 0.26-0.81 | 0.46 |
| standing position | 0.95 | 0.95 |

*Dependent on range.

**The debris gamma trench factors are time and orientation-dependent; they are discussed in detail in Appendix I.

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 prompt 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 delayed neutron dose, of importance only for the volunteer observers, is accrued during the first few seconds after detonation and before any significant reorientation is likely to have occurred. The debris gamma dose, however, is delivered over a period of many seconds, as illustrated in Figure 3-1 for Shot Badger. 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. For the volunteer observers (Shots Nancy, Badger, and Simon), this occurred at approximately five to seven seconds after detonation. Therefore it is likely that, by fifteen seconds after detonation, most of the volunteers 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 at times $t < t_o$, and standing upright in the center of the trench facing the rising cloud at times $t > t_o$, his film badge dose due to debris gamma is calculated by:

$$D_d(t_o) = F_c \int_0^{t_o} T_c(t) I_d(t) dt + F_u \int_{t_o}^{\infty} T_u(t) I_d(t) dt,$$

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 $T_u(t)$ are discussed in Appendix I; these functions are shown in Figure I-1 for Shot Badger. Intensities $I_d(t)$ are calculated with computer

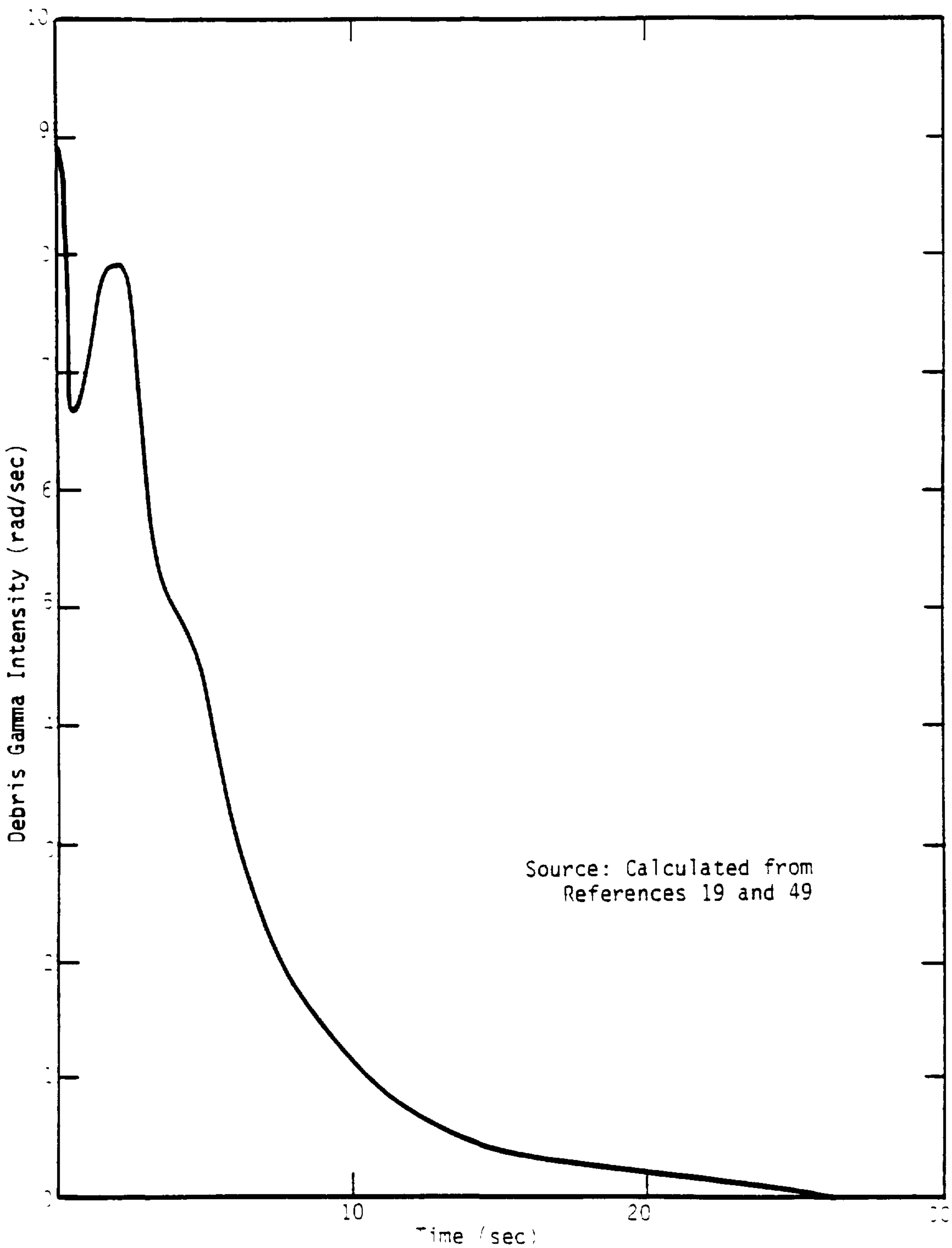


Figure 3-1   Debris Gamma Intensity at 2000 Yards
as a Function of Time, Shot Badger

codes NUIDEA (Reference 49) and ATR4 for the shots of interest; this is plotted in Figure 3-1 for Shot Badger. The film badge conversion factors $F_c$ and $F_u$ were discussed previously.

When calculating the dose for Upshot-Knothole volunteer observers, it is assumed that they stood upright in the trenches at 10 seconds ($t_o$ = 10) after detonation. The calculated dose is sensitive to the value of $t_o$, as indicated in Figure 3-2, which gives a gamma dose adjustment factor as a function of $t_o$ for the volunteer observers at Shots Nancy, Badger, and Simon. To determine the gamma dose equivalent (film badge dose) for standup time $t_o$, the gamma dose equivalent reported in the following section (for $t_o$ = 10 seconds) is multiplied by the appropriate adjustment factor. Because the service observer trenches were located significantly farther from ground zero than the volunteer observer trenches, the shock wave took longer to pass these positions. It is assumed in these calculations that the service observers stood upright in their trenches at three seconds after passage of the blast wave. The incremental dose due to this action was only a few millirem.

## 3.2 RESULTS

The results of the computations are discussed in the following subsections for each of the six shots of interest.

### 3.2.1 Shot Annie

A suitable neutron output spectrum for this shot is available in Reference 24. Project 6.8a and Desert Rock free-field gamma dose measurements, taken from References 45 (as modified in Reference 47) and 1, respectively, are plotted in Figure 3-3 together with the ATR-derived gamma dose curve. The quality of the Desert Rock (Reference 1) data is uncertain; deviations from the Project 6.8a data may be due to differences in film type, film holder configuration, and/or calibration procedure.

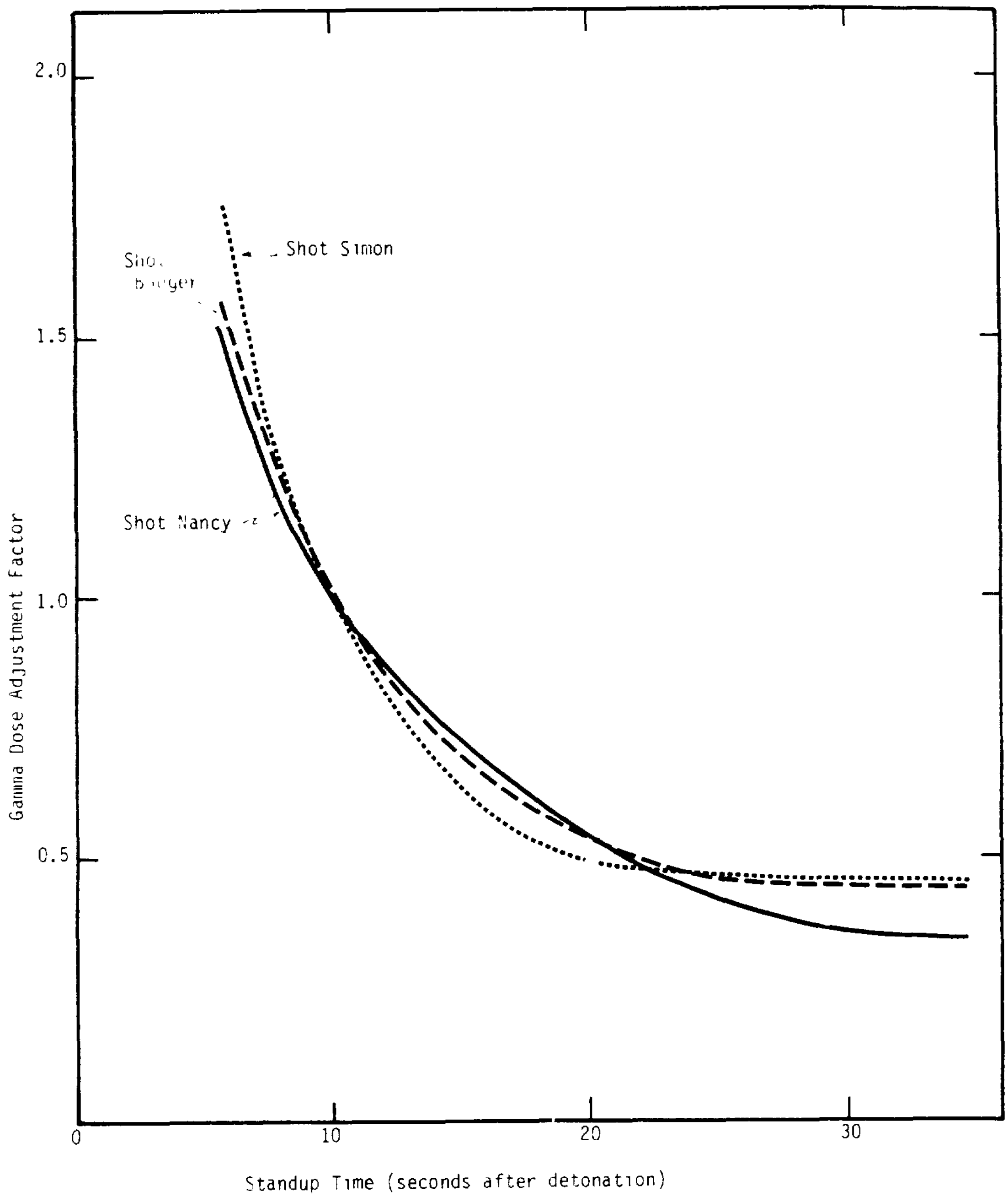


Figure 3-2 Gamma Dose Adjustment Factors for Volunteer Observers

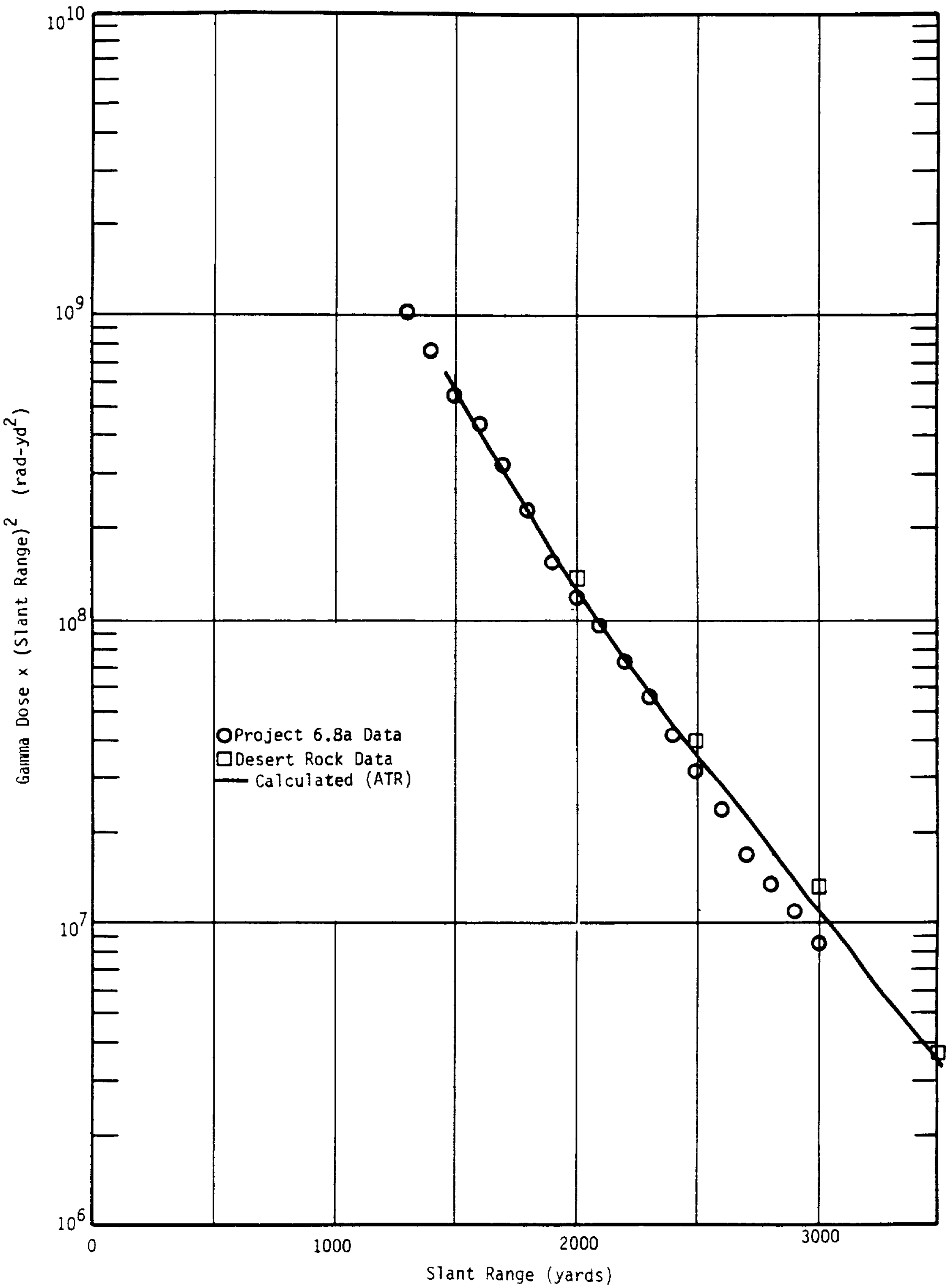


Figure 3-3 Shot Annie Gamma Dose

For this shot, where service observers were located in trenches 3500 yards from ground zero, the doses are as follows:

| | Neutron | Gamma |
|---|---|---|
| Tissue dose above trench (mrad) | 5 | 300 |
| Dose equivalent in trench (mrem) | 16 | 11 |

### 3.2.2 Shot Nancy

The Nancy device was asymmetrical, with the axis in the north-south direction. Volunteer observer trenches at 2500 yards and service observer trenches at 4000 yards from GZ, were oriented approximately $20^{\circ}$ west of the south axis, as shown in Figure 3-4. The device was shielded on the east side by a thick limonite shield placed on the tower platform. In an apparent oversight (Reference 45), the Project 6.8a film badges were placed along the east axis, in the shadow of the shield. Thus, the applicability of the gamma data is questionable. Using a neutron output spectrum suggested by the sponsoring laboratory (Los Alamos Scientific Laboratory), the ATR code produces the gamma dose curve shown in Figure 3-5. The discrepancy between this and the Project 6.8a data is probably due to the presence of the shield.

The estimated radiation doses at the trench locations for Shot Nancy are as follows. Delayed neutrons contribute approximately 9 percent of the volunteer observer neutron dose.

| | Volunteer Observer Trenches | | Service Observer Trenches | |
|---|---|---|---|---|
| | Neutron | Gamma | Neutron | Gamma |
| Tissue dose above trench (mrad) | 180 | 10500 | <1 | 90 |
| Dose equivalent in trench (mrem) | 590 | 570 | <1 | 4 |

### 3.2.3 Shot Badger

A neutron output spectrum for Shot Badger was developed by Los Alamos Scientific Laboratory (LASL) (Reference 25) for use in these calculations. The calculated gamma dose-range curve is shown in Figure 3-6, along with data from

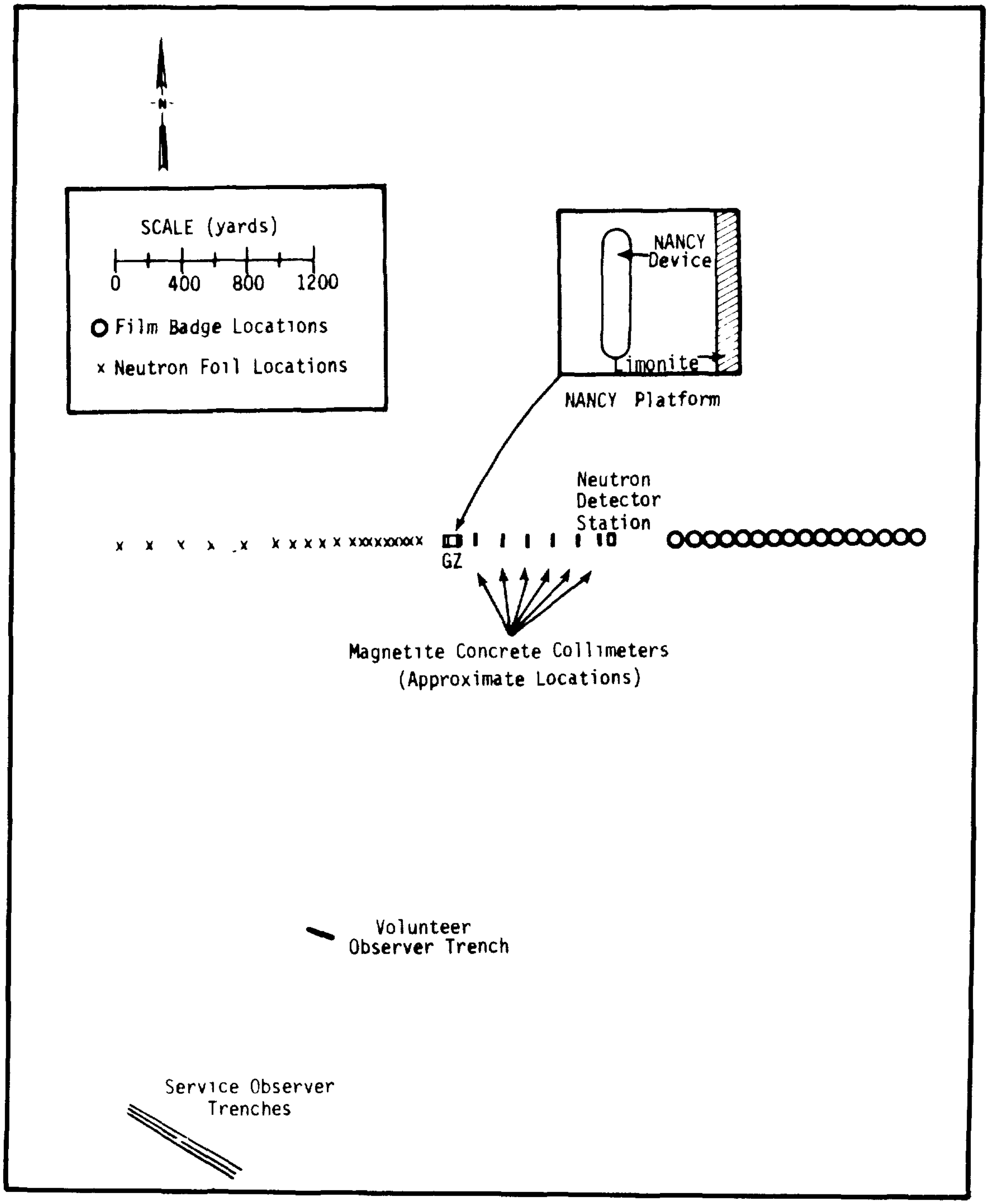


Figure 3-4 Site Layout, Shot Nancy

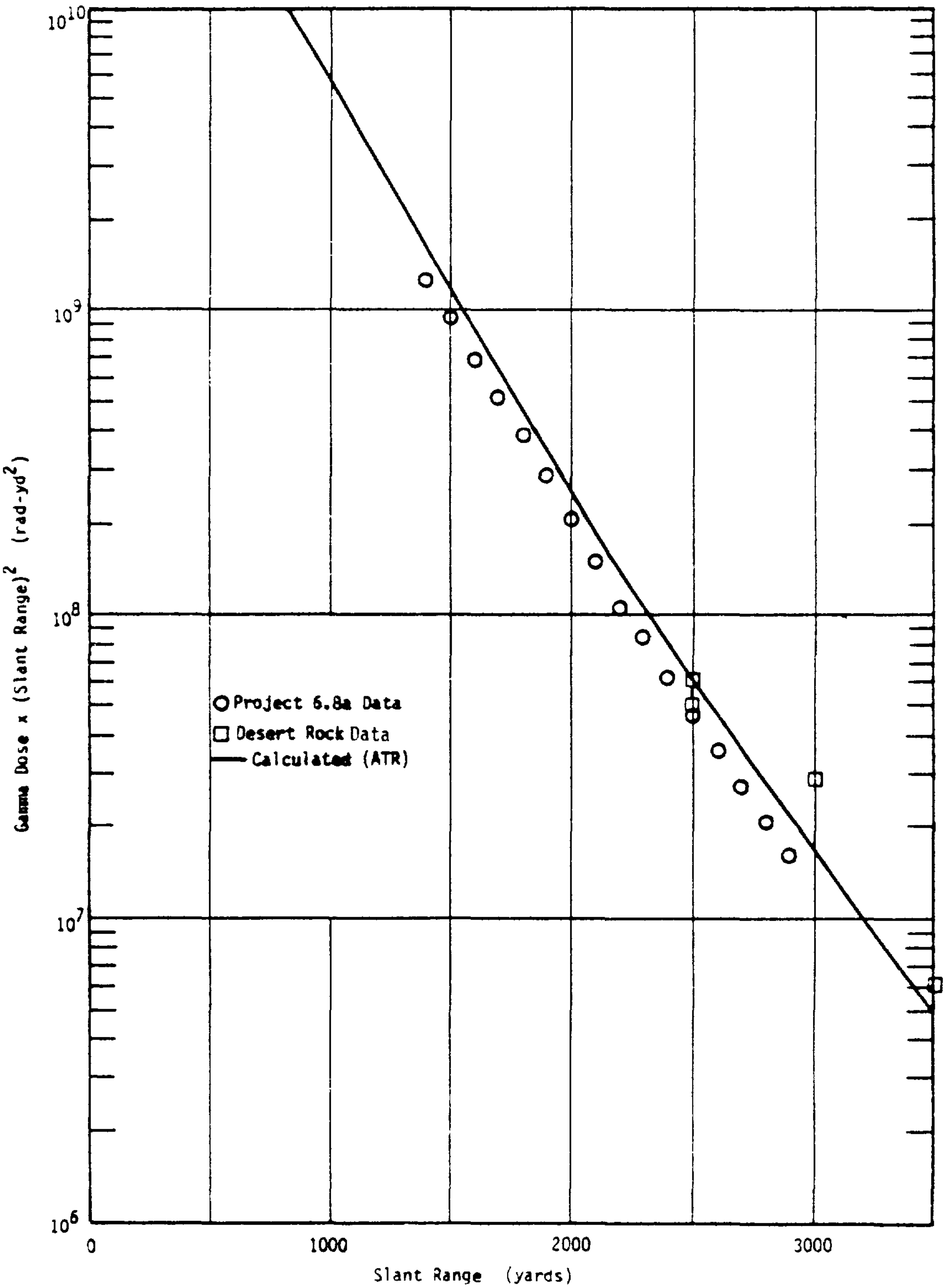


Figure 3-5 Shot Nancy Gamma Dose

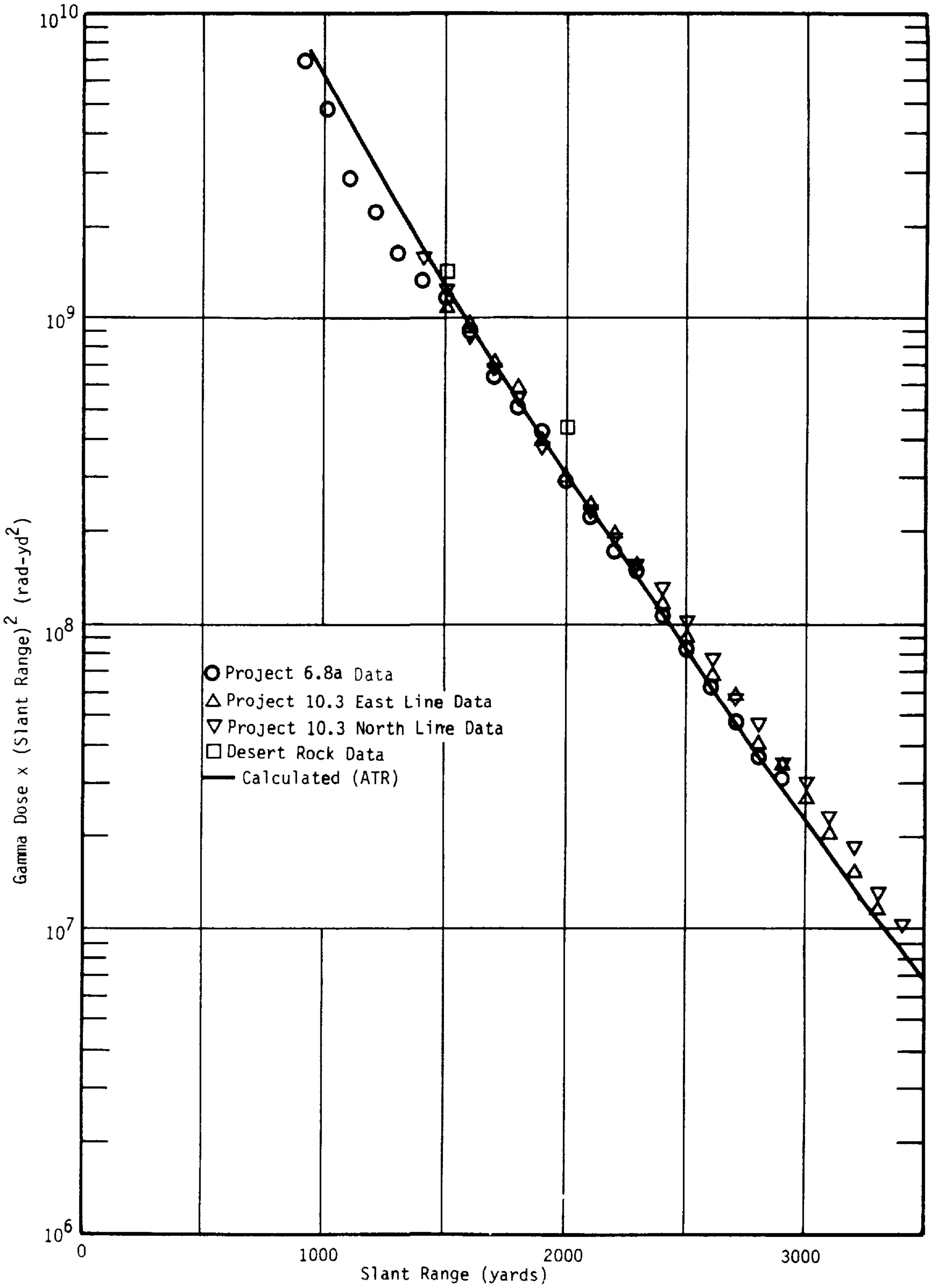


Figure 3-6 Shot Badger Gamma Dose

References 45, 46, 47, and 1. It is seen that the calculated dose curve agrees well with the Project 6.8a data beyond 1500 yards, but that the general trend of the data indicates that the calculated curve may underpredict at the range of the service observer trenches (4000 yards). Therefore, the gamma dose for the range of these trenches is developed by extrapolating from the Project 10.3 data, thereby insuring a conservative (high-sided) estimate.

The estimated radiation doses at the locations of the volunteer observer trenches (2000 yards) and service observers trenches (4000 yards) are presented below. Delayed neutrons contribute approximately 44 percent of the volunteer observer neutron dose.

| | Volunteer Observer Trenches | | Service Observer Trenches | |
|---|---|---|---|---|
| | Neutron | Gamma | Neutron | Gamma |
| Tissue dose above trench (mrad) | 720 | 78000 | <1 | 150 |
| Dose equivalent in trench (mrem) | 2300 | 3700 | <1 | 6 |

### 3.2.4 Shot Simon

The unique design of the Simon device produced rather unusual initial radiation characteristics. The neutron output from part of the device was strongly suppressed, resulting in a large ratio of gamma dose to neutron dose at points external to the weapon. The device axis was in the general direction of the observer trenches (Figure 3-7). Due to device asymmetry, two neutron output spectra were calculated by LASL (Reference 27). The first (spectrum L1) represents neutron output, perpendicular to the device axis, in the direction of largest case thickness; the second (spectrum L2) is of the bare device, without case material. The actual case thickness in the direction of the observers was between these two extremes (the unusual case design prevented an exact determination of the case thickness in the relevant direction). Therefore, each spectrum was used in the ATR4 computer code to calculate the prompt neutron and secondary gamma doses at the trench locations (2000 yards for volunteer observers, 4000 yards for service observers), and a mean value taken as the representative dose. The neutron doses derived for the two spectra, and the mean

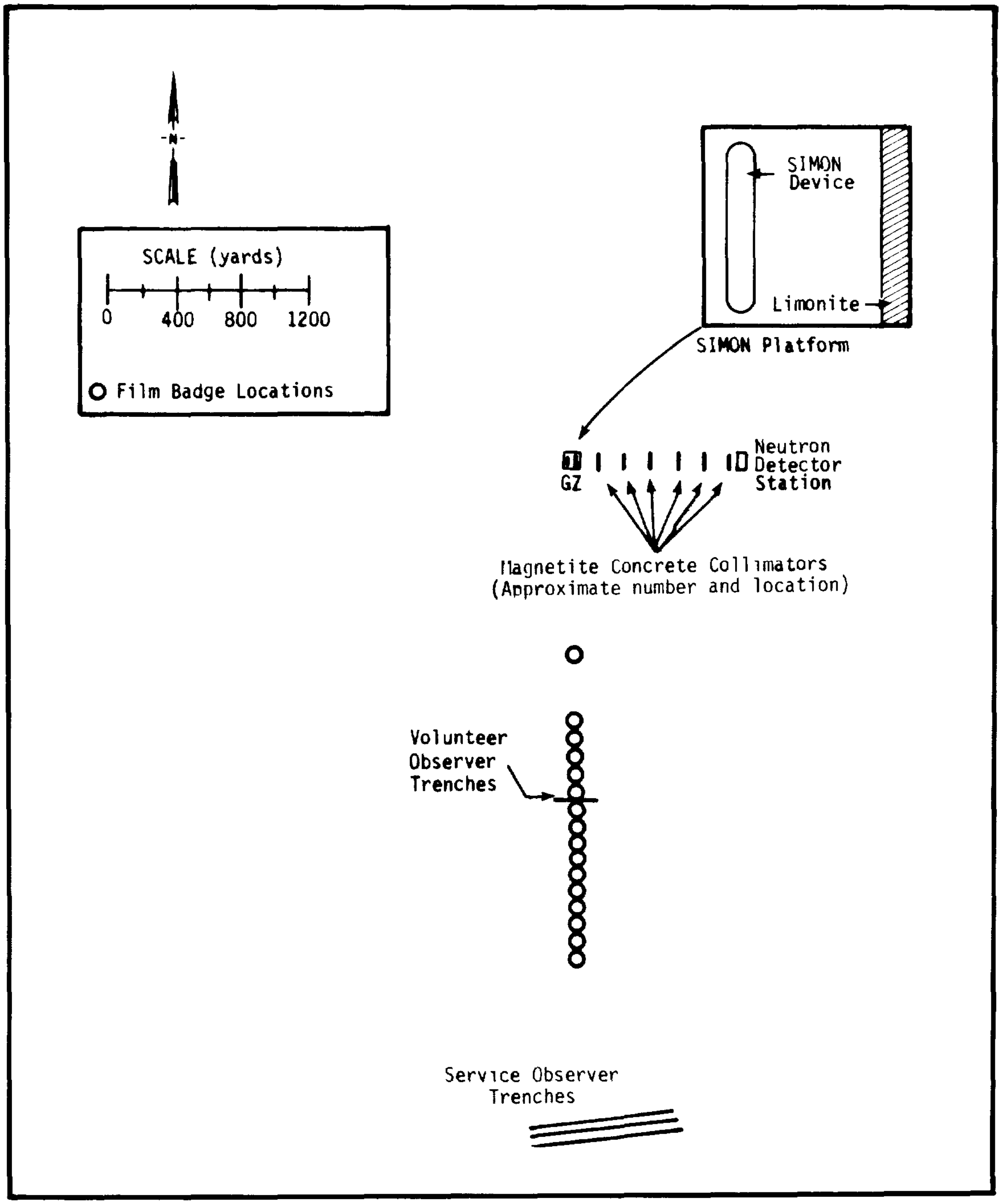


Figure 3-7 Site Layout, Shot Simon

dose, are presented below for the volunteer observers. The neutron foil measurements taken at the detector station east of the tower are insufficient to resolve this uncertainty.

| Spectrum | Free-Field Prompt Neutron Doses (2000 yards) Above-trench dose (rads) | In-trench dose (rads) | In-trench dose equivalent (rem) |
|---|---|---|---|
| L1 | 3.2 | 0.8 | 10.4 |
| L2 | 10.1 | 2.5 | 32.5 |
| Mean | 6.7 | 1.7 | 21.5 |

Delayed neutrons contribute an additional 1.0 rad to the free-field neutron dose. The gamma doses calculated from the two spectra are virtually identical, since the total gamma dose was dominated by debris gamma radiation, which is independent of neutron output spectrum. The ATR-calculated gamma dose-range curve is shown in Figure 3-8, together with gamma doses measured with film badges along a line in the direction of the trenches (Reference 45). The limonite shield in the tower perturbed the gamma and neutron fields to the east of ground zero, but should have had a negligible effect on doses at the observer locations.

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

| | Volunteer Observer Trenches | | Service Observer Trenches | |
|---|---|---|---|---|
| | Neutron | Gamma | Neutron | Gamma |
| Tissue dose above trench (mrad) | 7700 | 160000 | 1 | 200 |
| Dose equivalent in trench (mrem) | 25000 | 9000 | 3 | 11 |

### 3.2.5 Shot Harry

The neutron output spectrum from a similar device was used to calculate the neutron and gamma doses at the observer trench location, 4000 yards from ground zero. The results of these calculations are presented below. The ATR-derived gamma dose curve and data from Reference 47 are shown in Figure 3-9. Although the fit is apparently not as good as for other shots, ATR does tend to overpredict the dose. Moreover, the prediction tends to converge with the data of the ranges of interest.

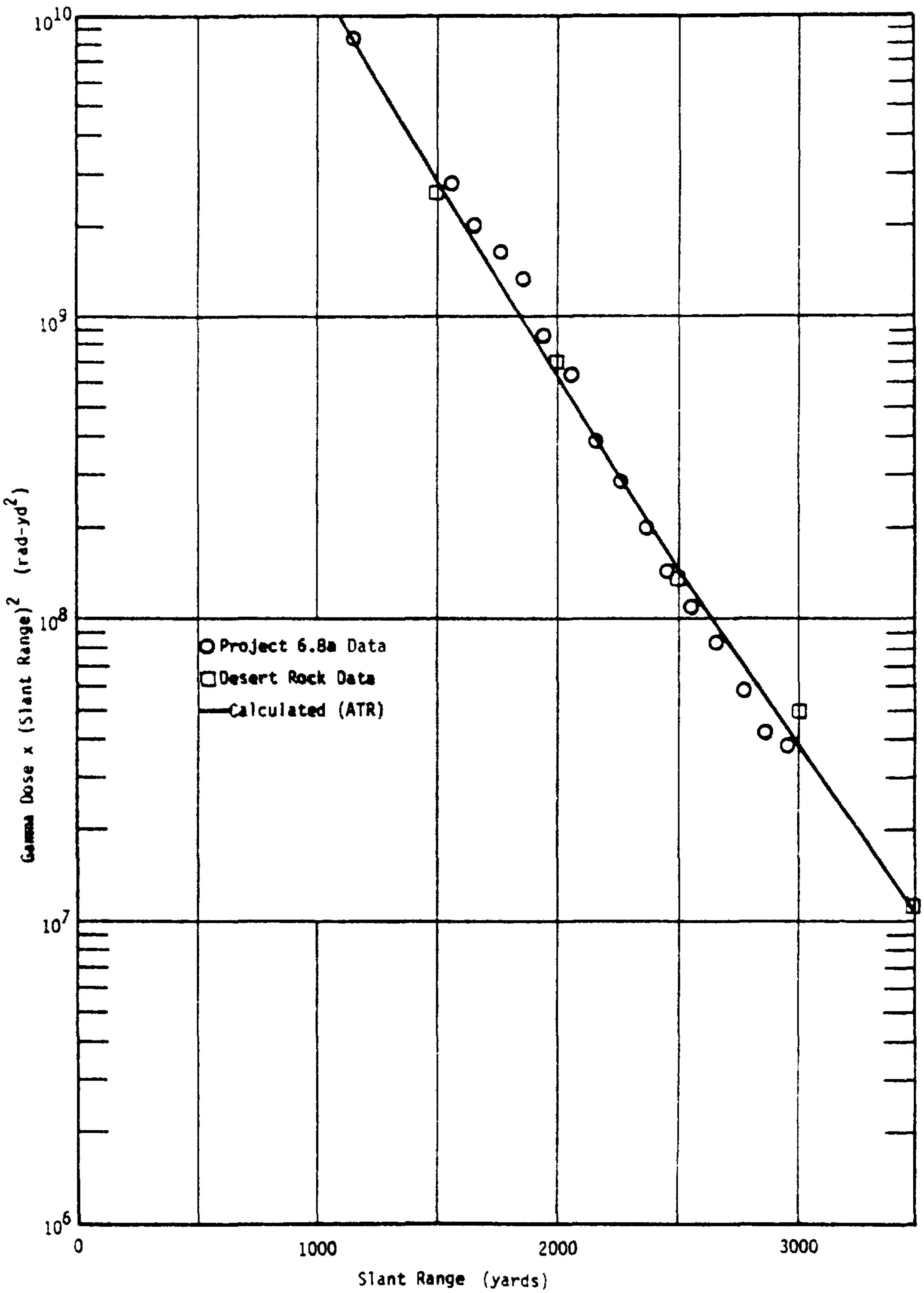


Figure 3-8 Shot Simon Gamma Dose

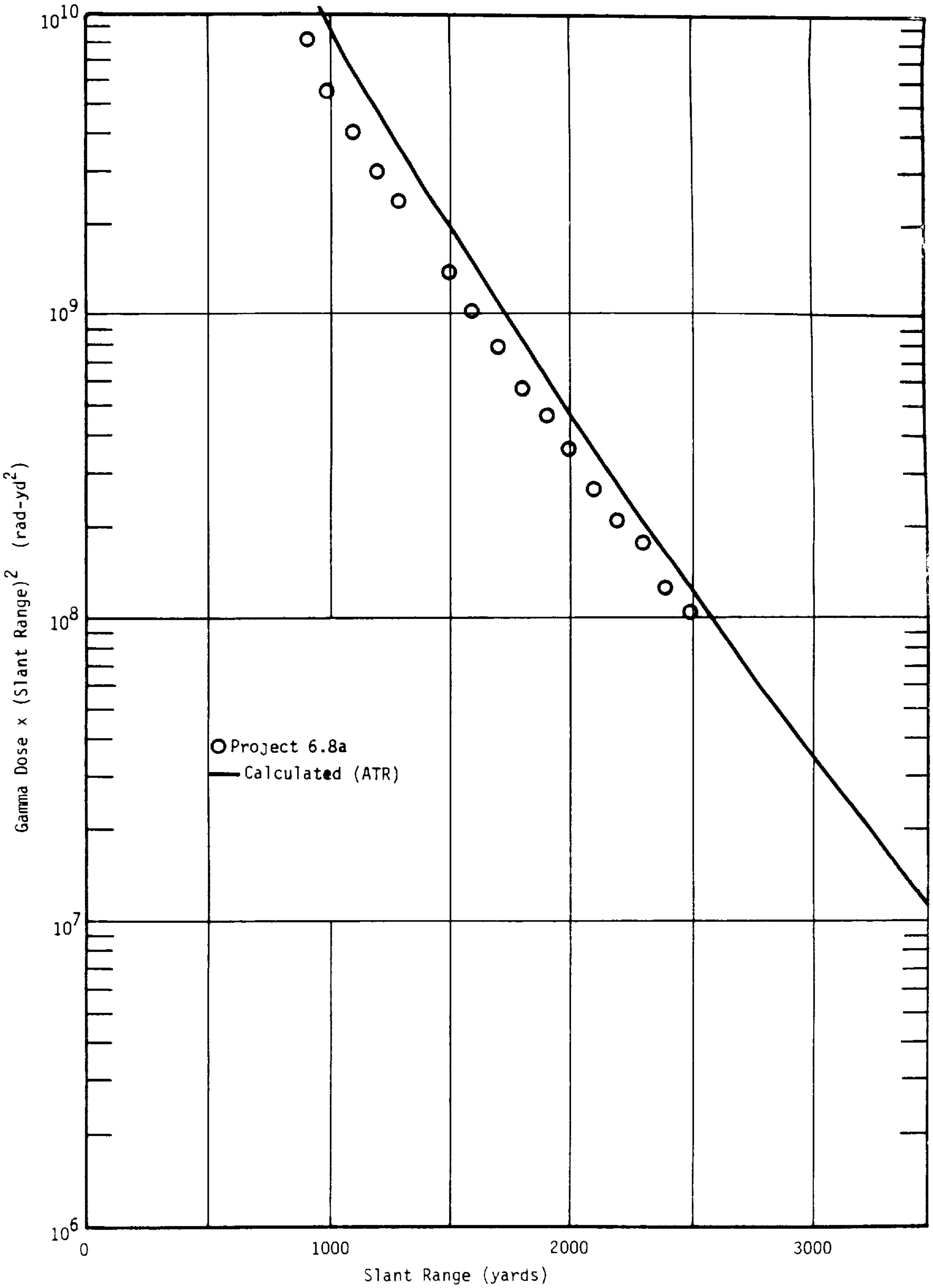


Figure 3-9 Shot Harry Gamma Dose

| | Neutron | Gamma |
|---|---|---|
| Tissue dose above trench (mrad) | <1 | 210 |
| Dose equivalent in trench (mrem) | <1 | 8 |

### 3.2.6 Shot Grable

The neutron output spectrum for Shot Grable, a gun-assembly device, was obtained from Reference 28. The ATR-generated gamma dose curve and the gamma film badge data from References 46 and 47 are shown in Figure 3-10. The estimated radiation environment at the trench location, 5000 yards from ground zero, is given below.

| | Neutron | Gamma |
|---|---|---|
| Tissue dose above trench (mrad) | <1 | 4 |
| Dose equivalent in trench (mrem) | <1 | <1 |

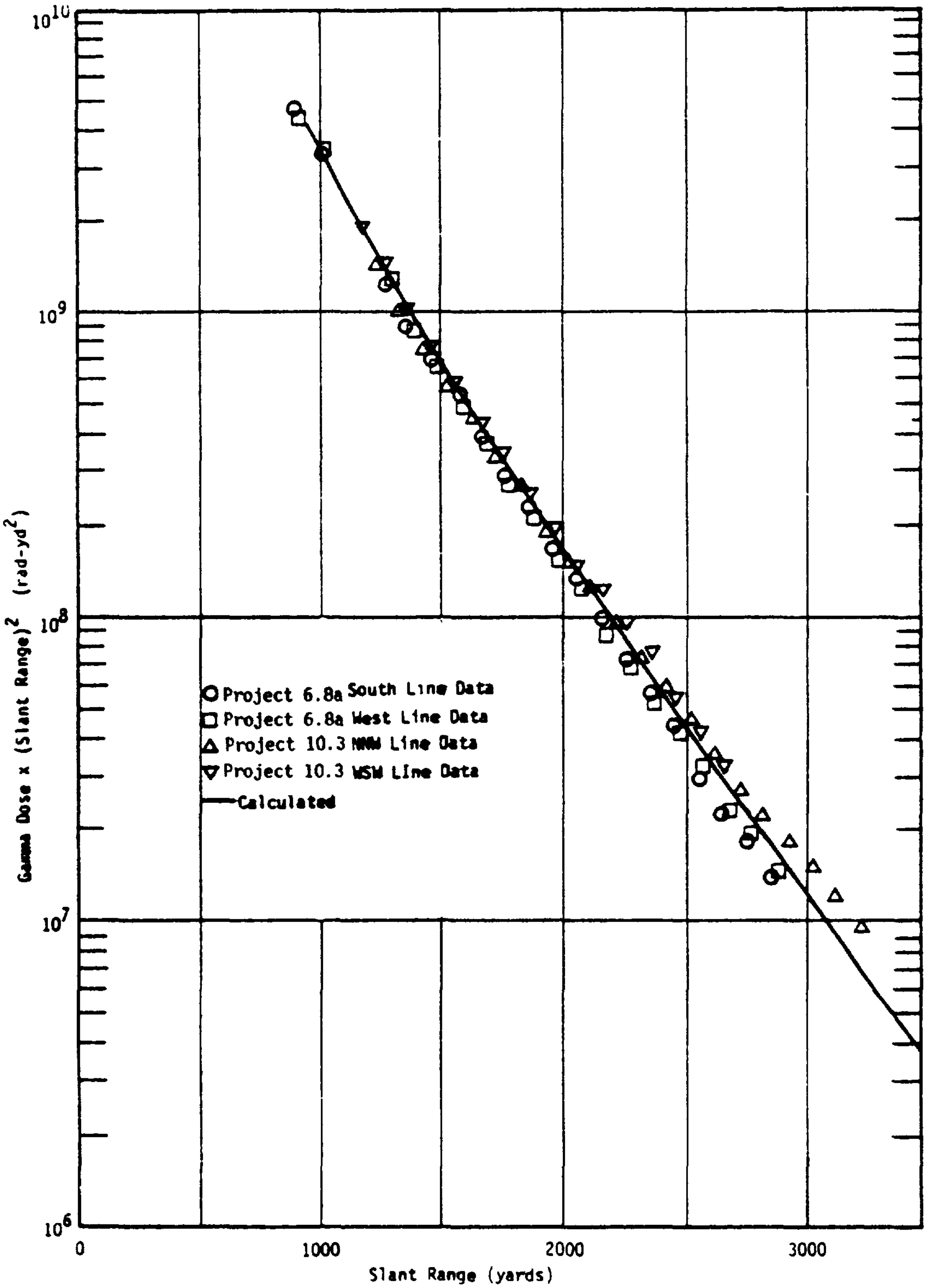


Figure 3-10 Shot Grable Gamma Dose

# Section 4

# RESIDUAL RADIATION

## 4.1 RESIDUAL GAMMA 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 Upshot-Knothole. A computerized methodology, described in Reference 32, determines the radiological environment for each shot of interest. From this, doses are calculated based on the scenario of troop activities. Iso-intensity contours with superimposed troop tracks are displayed for Shots Annie, Nancy, Badger, Simon, Encore, Harry, and Grable. Other shots, which did not contribute to observer doses, have gamma fields depicted to show their relationship to the observer positions.

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 calculated film badge dose rate is related to the free-field gamma intensity through the conversion factor developed in Reference 17: 1 r/hr $\rightarrow$ 0.7 rem/hr (the calculated film badge dose is identical to the "film badge equivalent dose" of Reference 17). 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 observer scenarios except that there are intensity gradients in the gamma fields. These gradients have a negligible effect on film badge readings for randomly-oriented personnel.

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

Because of limited data concerning the details of display inspection and the timing involved, estimates were required for various parameters. Rates of movement were estimated from planned times or the few reported times, the number of displays viewed, the calculated or reported position of radiological safety limits, and the consequent distance to be traversed. A reasonable and consistent set of parameters is 50 yds/min walking speed between displays (including the starting and stopping of troops), 5 minutes at each display and at the limit of march toward GZ, and 70 yds/min on the return. Motor movements in the display area are taken to be at 15 mph. Unless otherwise specified, the walk-through route is assumed to be on the same azimuth as the trenches for shots in Yucca Flat. The stay time at each display arc allows for some lateral spread of the observer group to see a variety of equipment. For the military effects shots in Frenchman Flat, the greater number of displays would have warranted walking the length of each display arc. For these, a slow walking rate of 50 yds/min is assumed along display arcs, without stops, and a faster pace of 70 yds/min is assumed between arcs.

The radiation surveys from which the gamma intensity field is calculated were performed by the Rad-Safe Unit under the AEC (Reference 2), and thus had no connection with the Desert Rock rad-safe effort. Few data reflecting specific radiation measurements by Desert Rock personnel are available. However, reported locations of rad-safe limits and other random mentions of intensities in Reference 1 are sometimes sufficiently coupled with position/time data to be of use in dose reconstruction. While the Desert Rock data are far too few to define an intensity field, they do permit comparisons with the AEC data at specific locations. Lack of agreement can result where the latter must be interpolated. Consequently, if the AEC data insufficiently resolve the intensity field in the Desert Rock display sector, Desert Rock data are used to the extent possible to refine the reconstructed doses.

### 4.1.1 Shot Annie

Observers of Shot Annie (see Figure 4-1) are estimated to have reached the prescribed radiation safety limit of 2.5 r/hr at about two hours after the shot. Along the western edge of the display sector (the planned route of advance), this

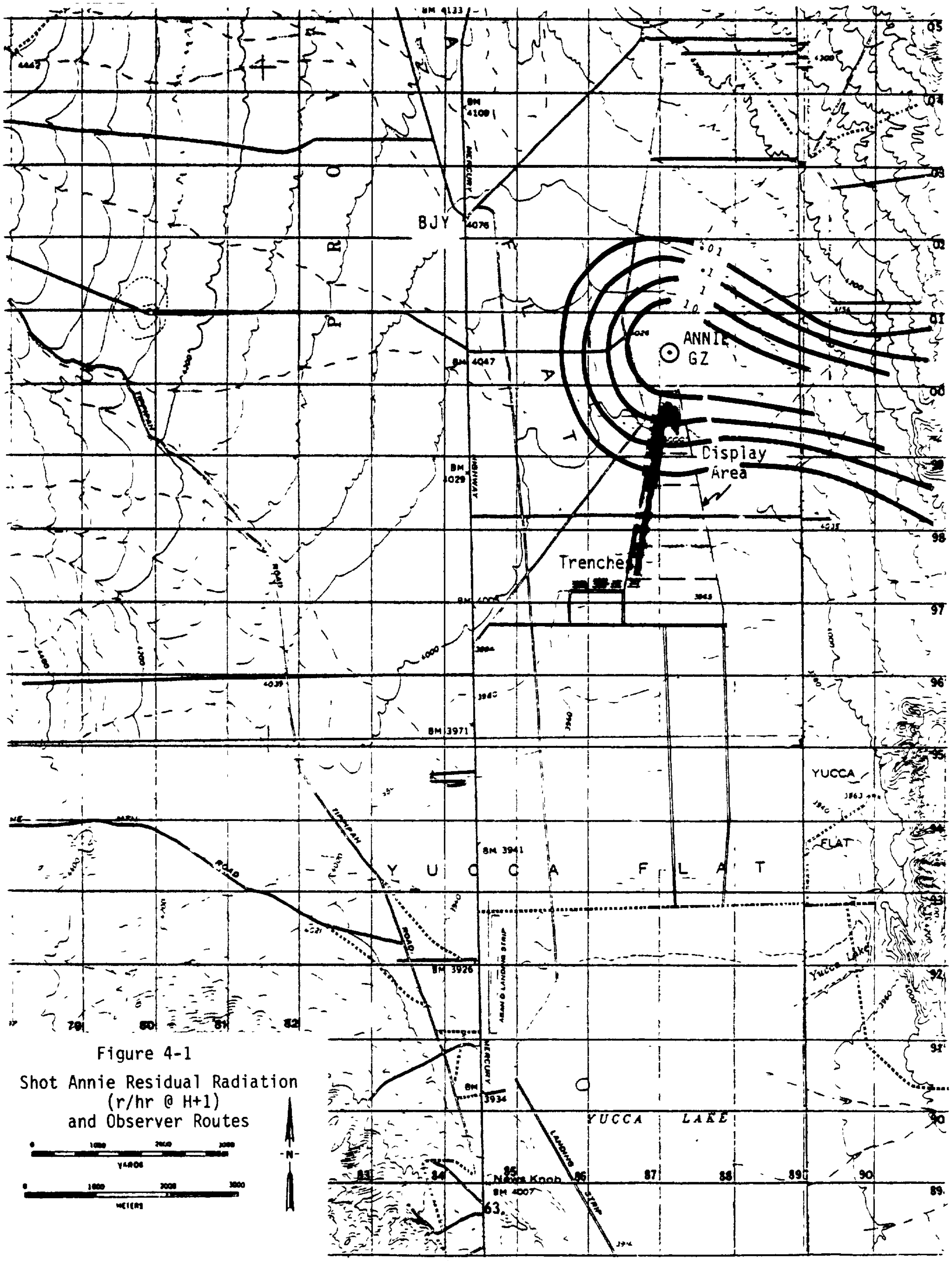


Figure 4-1
Shot Annie Residual Radiation
(r/hr @ H+1)
and Observer Routes

is calculated to have been at 710 yards from GZ. According to Reference 1, the closest approach to GZ was 700 yards, at the rad-safe limit. The reference is internally inconsistent--it also refers to rad-safe limits at 500 yards on the west and 700 yards on the east side of the display sector. The only satisfactory explanation is that these directions are reversed. An inverted (south at top) map of the planned rad-safe monitoring movement in Reference 7 is the likely source of the error.

A rad-safe limit at 700 yards at both the time of early monitoring (some 20 minutes post-shot) and when the observers reached it (after 2 hours) indicates only slight radiological decay in the interval. This could be true only if the radiation encountered was from neutron-induced activity. If the activity were from fallout, the 2.5 r/hr line would have receded some 250 yards. In this case, the accompanying monitors could have overruled the previously posted rad-safe limit and permitted the observers to view the equipment display at 500 yards from GZ. Comparisons of day-to-day rad-safe survey data do indicate better agreement with the induced activity model. The resulting displacement of the 2.5 r/hr line would have been only about 30 yards for the interval in question. There would have been no motivation to cross the early rad-safe line, where the intensity would have decreased only to 1.9 r/hr. Under these conditions, the calculated film badge dose for the Annie observers is 0.50 rem.

### 4.1.2 Shot Nancy

The volunteer observers were exposed to residual radiation in addition to the initial radiation described in Section 3. Because the fallout had not yet been deposited when they evacuated their trench, the subsequent radiation surveys cannot be used in reconstruction of the volunteers' residual radiation dose. The only relevant data are given in Reference 1, which cites a 90 mr/hr reading as the cloud approached and a 20 mr/hr reading when the volunteers were picked up after a 500-yard walk to the rear. The former is presumed to have been a peak reading at about five minutes after detonation; the latter would have been about five minutes later. Consequently, the total residual radiation dose to the volunteer observers was less than 0.01 rem.

Prior to Shot Nancy, the service observers were exposed to residual radiation when they viewed the Annie equipment display. By five days after Annie, significant contamination was limited to within a few hundred yards of GZ. Since there was virtually nothing to see closer than 500 yards from GZ, it is presumed that the observers did not walk any closer. Their dose from this excursion would have been less than 0.01 rem.

While in the Nancy equipment display area (see Figure 4-2), the service observers were exposed to residual radiation primarily from fallout. The early rad-safe limits posted by the Desert Rock monitors were at 1250 yards from GZ on the west boundary of the display sector and at 850 yards on the east (Reference 1). By the time the observers approached these limits, the 2.5 r/hr line would have receded some 200 yards. Whether or not the early survey would have been superseded in practice should not have affected the observers' closest approach to GZ. In either case, they would have been able to view (at least part of) the 1000-yard display, but not the 500-yard display. Consequently, the observers are assumed to have reached the 1000-yard display while approximately maintaining their original azimuth from GZ. The calculated film badge dose for the Nancy service observers is then 0.32 rem. A reading of 18 mr/hr at their trench area during cloud passage (Reference 1) would have been too short in duration to contribute more than negligibly to the dose. Fallout deposition in the display area should have been complete by the time that the observers left the trenches.

### 4.1.3 Shots Dixie and Ray

Shots Dixie and Ray were observed from News Nob, more than 10 miles distant. In neither case did the observers advance toward the shot area. No exposure resulted from fallout because Dixie had no measurable fallout and because fallout from Ray passed to the west of the control point (Reference 2), and therefore also west of News Nob (see Figures 1-1 and 4-3). Consequently, no dose was accrued by observers of those shots.

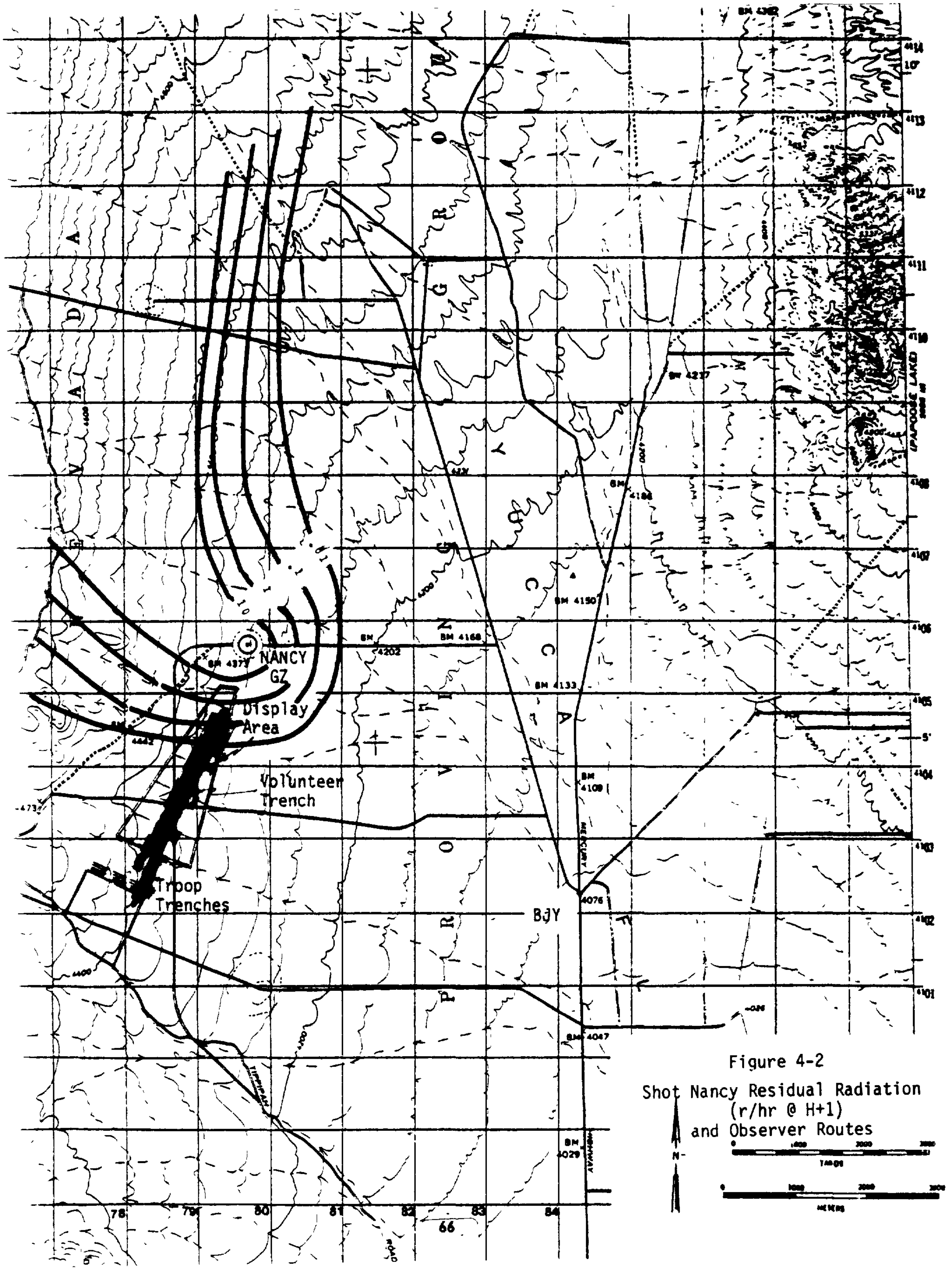


Figure 4-2

Shot Nancy Residual Radiation
(r/hr @ H+1)
and Observer Routes

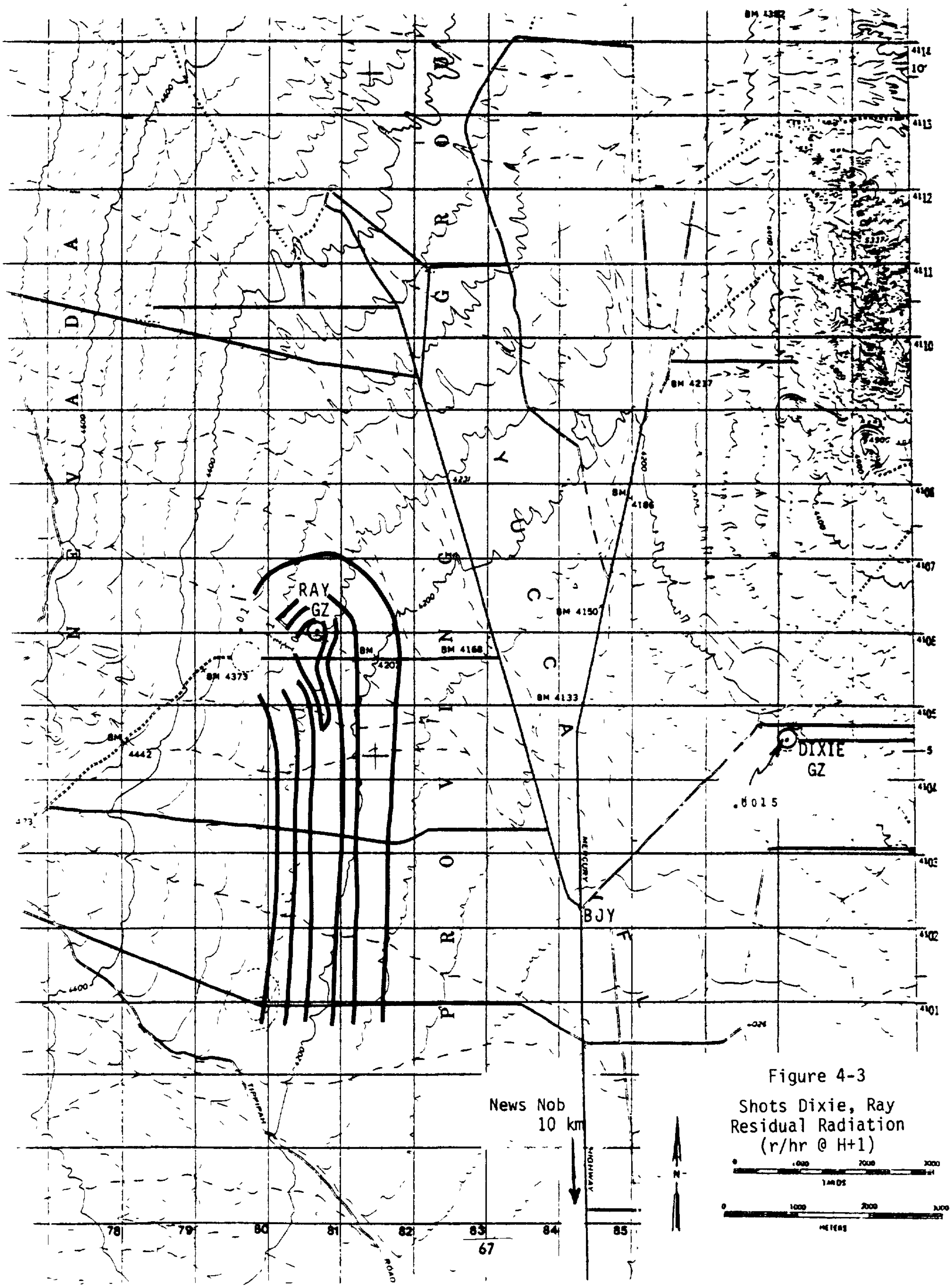


Figure 4-3

Shots Dixie, Ray
Residual Radiation
(r/hr @ H+1)

### 4.1.4 Shot Badger

The residual radiation dose to the volunteer observers of Shot Badger was from the nuclear cloud passage and early fallout; therefore, the later radiation surveys are not required for dose reconstruction. The two available sources of pertinent information (References 15 and 33) are somewhat contradictory and internally inconsistent. For the portion of the accounts involved with residual radiation (defined as radiation at least one minute after burst), a reasonably consistent version is as follows. The gamma intensity, which had been at least 500 r/hr in the early seconds after burst, would have reached its miminum reported value of 30 r/hr by the end of the first minute (at which time the volunteers were likely out of their trenches). As the radioactive stem of the nuclear cloud approached and passed over, the intensity rose to 50 r/hr, presumably at about seven minutes, at which time they evacuated the trench area. As they walked westward along the 2000-yard arc of the display area, the intensity dropped rapidly. After a walk of about 200 yards to the junction with the boundary road of the display area, the volunteers waited four minutes, recording intensities averaging just under 1 r/hr. While subsequently walking to the rear, they also recorded readings of 0.5 r/hr at H+14 min, 0.32 r/hr at H+19 min, and 0.12 r/hr at H+25 min. With a power-law relationship between intensity and time used to fit these data, the volunteer observers' film badge dose resulting from residual radiation is calculated to be 3.7 rem prior to leaving the trench area, 0.3 rem while walking along the 2000-yard display arc, and 0.1 rem thereafter, totaling 4.1 rem.

Service observers of Shot Badger were exposed to residual radiation on two occasions before the shot. While rehearsing the shot-day operation, personnel were in the 23-day old Nancy fallout field. With gamma intensities of no more than 30 mr/hr, the calculated film bage dose from this activity is less than 0.03 rem for the observers. The observers also visited the Nancy equipment display on the same day. Because there was little to see closer to GZ than 500 yards, the observers are assumed not to have proceeded any closer. At this distance, the intensity was less than 100 mr/hr, including a contribution from Shot Ray, fired five days previously. The calculated film badge dose for this excursion is about 0.01 rem.

On shot day, residual radiation exposure first occured as the nuclear cloud stem approached and passed to the east. A 1 r/hr transient was reported "at the trench area", probably by rad-safe personnel at or near the central command trench. Because the observer trenches were also in the central portion of the trench area, the intensity is considered appropriate for calculation of the observers' dose. For an assumed three-minute exposure to the peak intensity, the calculated film badge dose is 0.035 rem.

Reconstruction of the additional dose to the service observers on shot day is encumbered by the condition of the AEC rad-safe data, which consist merely of drawn contours for each survey; there is no indication of the roads along which the data were taken. The absence of time data also complicates the interpretation of the initial survey, which required some three hours to complete (Reference 2). The reference states that six roads were intended for survey use around GZ. In order to utilize the AEC data, photographs of the shot area in 1953 were examined to determine tracks along which the surveys might have been taken. This estimation introduces an additional, unquantifiable uncertainty into the iso-intensity contours calculated for Shot Badger (Figure 4-4).

From remarks regarding the radiological situation in the Desert Rock display area for Shot Badger (References 1, 15, 33), it is evident that the rad-safe contours (and therefore Figure 4-4) do not sufficiently define the intensity field to justify its use in dose reconstruction. Along the western boundary of the display area, gamma intensities were low, as evidenced by the volunteer observer data and the ability of the regular observers to proceed to within 1000 yards of GZ. Near the eastern boundary, however, intensities were so high as to require withdrawal of a Marine battalion (of the troop exercise) at 3500 yards from GZ. Film badges in emplacements at 2500, 3000, and 3500 yards from GZ, in the eastern half of the display area, recorded large doses from fallout. However, at 1000 yards, the observers were able to view displays on the eastern boundary. The AEC survey plots do indicate high intensities toward the southeast corner of the display area that are reasonably consistent with the Marine withdrawal, but they considerably overpredict intensities in areas traversed by the volunteer and service observers.

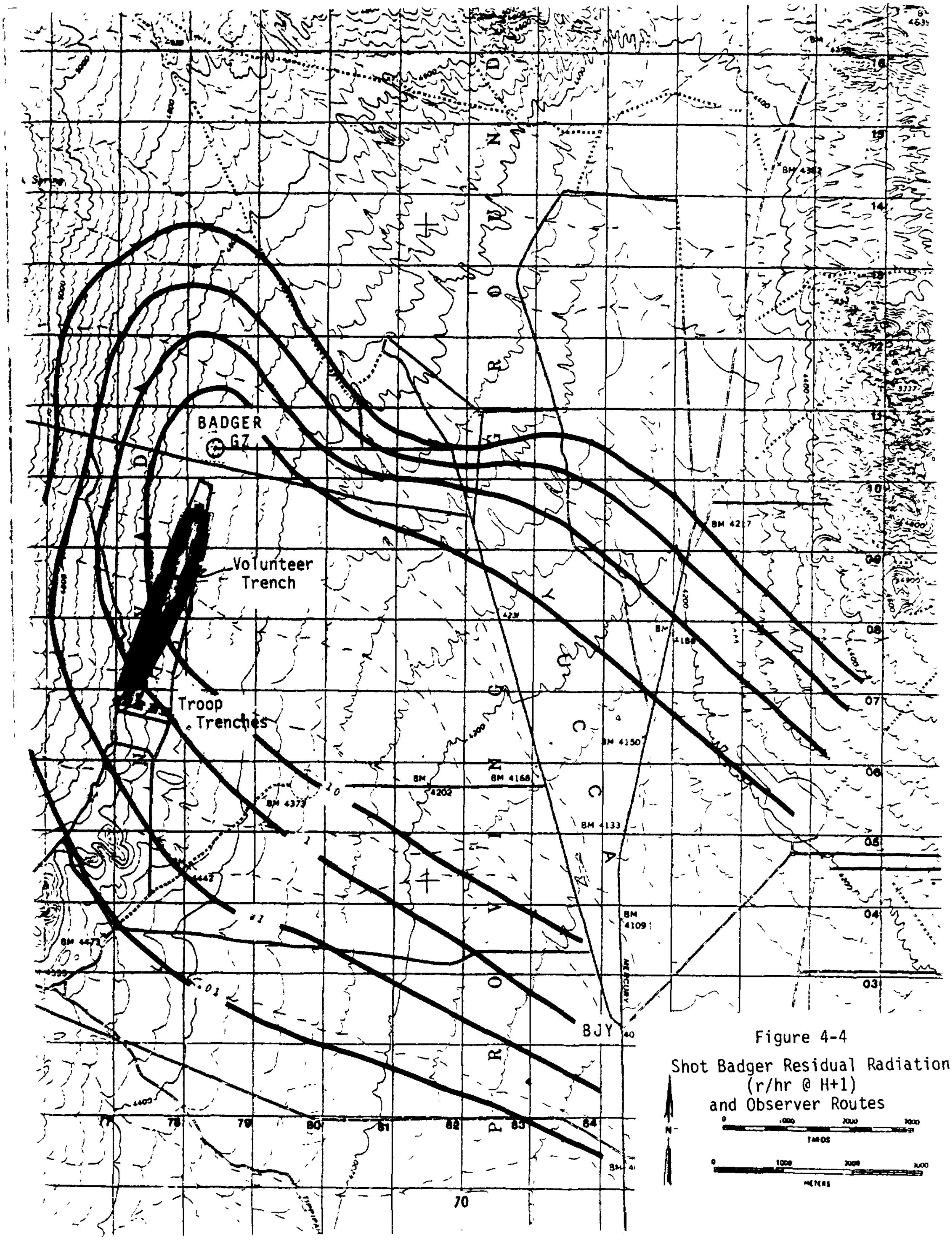


Figure 4-4

Shot Badger Residual Radiation
(r/hr @ H+1)
and Observer Routes

Although there is considerable uncertainty concerning the time of the initial AEC survey, there are adequate Desert Rock data upon which to base dose calculations for observers and others whose activities in the display area correspond to the general times at which the data were obtained. The traditional decay rate of $t^{-1.2}$ is used to adjust for the small time differentials involved.

The gamma dose to observers during their walk through the display area is estimated as follows. Along the western boundary of the display, values of the intensity are obtained from the volunteer observer data and the average spacing of contours on the survey plots at appropriate distances and azimuth. The H+25 minute, 3000-yard reading of 0.12 r/hr is most useful because fallout deposition is more likely to have been complete than at the times of earlier readings. Along the boundary road, the intensity appears to have increased tenfold in 1200 yards. Based on the above, observers would have been able to keep within the 2.5 r/hr rad-safe limit upon their arrival at the 1000-yard display (within 90 minutes after the shot). Even if the permissible limit of advance had been recently adjusted for the decaying fallout, observers would not have been able to view the innermost displays. Because of the tight scheduling for the walk-through, it is assumed that the observers did not attempt to advance closer to GZ than 1000 yards. On the return, they saw the displays along the eastern boundary road until the gamma intensity reached the rad-safe limit at an estimated 2000 yards from GZ. It is assumed that the observers then followed the 2.5 r/hr contour cross-country until they reached the vicinity of the trenches. The service observers' film badge dose, calculated in accordance with these assumptions, is 1.4 rem.

Another possible exposure to residual radiation occurred during the return trip to Camp Desert Rock. Reference 33 states that the level of contamination forced a detour from their planned route and required an unscheduled stop for personnel monitoring. Reference 1, however, states that the return movement to camp was completed without incident. The greatest level of contamination encountered on the planned route of return would have been near the eastern end of the trenches. However, even the AEC survey data do not suggest intensities approaching the 5 r/hr limit for vehicular movement. It is therefore unlikely that the observers accrued a dose while in trucks that was of any significance in comparison to their previous dose.

### 4.1.5 Shot Simon

The volunteer observers of Shot Simon encountered residual radiation in the same manner as did the Badger volunteers--from nuclear cloud passage and early fallout. Again, the later radiation surveys are not relevant to the dose reconstruction. Reference 16, an eyewitness account, provides some data from which a dose can be calculated. The volunteers exited the trenches at approximately one minute after the shot. The intensity, then 40 r/hr, increased to 50 r/hr in the next four minutes as they moved to the west before they began walking away from GZ. These high intensities may be ascribed to the approach of the nuclear cloud stem and the onset of fallout deposition. Fallout continued as they walked from the 2000-yard to the 2500-yard line, where the intensity was 10 r/hr. The volunteer observers were trucked to the rear from this point, and on the way they noted an intensity of 1 r/hr at the 3000-yard line (Reference 1). With a power-law relationship between intensity and time used to fit these data, the volunteer observers' film badge dose resulting from residual radiation is calculated to be 2.1 rem for the time along the 2000-yard line, 1.6 rem for the walk away from GZ, and less than 0.1 rem for the truck ride, totaling 3.8 rem.

Prior to Shot Simon, the service observers were exposed to residual radiation when they viewed the Badger equipment display. No details are available regarding the equipment seen. Because of the short time available for the visit (see Section 2.4.7), any walk-through would have been limited. A reasonable excursion within the time constraint, that involved the most comprehensive view of equipment, would have been a loop around the 500 and 1000 yard display lines. The gamma intensities would have been sufficiently low five days after Badger to permit vehicle and personnel movement to these distances from GZ. Based on the intensities deduced in Section 4.1.4 and fallout decay behaving as $t^{-1.05}$ (the exponent computed from the fit of the AEC data), the observers would have been exposed to about 30 mr/hr maximum and received a film badge dose of approximately 0.01 rem.

The AEC radiation survey data for Shot Simon are so inadequate as to introduce considerable uncertainty as to their reliability. The survey lines are not specified on the isointensity contour plots and the initial survey required over two hours to complete. However, Desert Rock rad-safe monitors reported intensities of 2.5 r/hr at 2500 and 2200 yards from GZ on the west and east boundary roads of the display area, respectively, and 5 r/hr at 2100 and 2200 yards. A reasonable estimate of the time of this survey is about one-half hour after the shot. The distances, the implied gradients, and the weak azimuthal dependence are supportive of the AEC survey, particularly if it is assumed that the southern sectors were surveyed before the less accessible northern area. A second AEC survey, taken on the afternoon of shot day, yielded contours not compatible with those from either the initial AEC survey or the Desert Rock survey. Moreover, there is no evidence in Reference 2 that any subsequent surveys were conducted in Yucca Flat until 20 days later. Consequently only the initial AEC survey (see Figure 4-5), as augmented by Desert Rock data, is utilized for dose reconstruction.

An early rise in intensity at the trench area (4000 yards from GZ) to 120 mr/hr (Reference 1) resulted from the approach of the cloud stem. This transient exposure resulted in a dose inconsequential when compared with the observers' subsequent dose. Fallout from the stem resulted in a more persistent 30 mr/hr intensity, subject only to radioactive decay. It is estimated that fallout deposition in the trench area occurred about 15 minutes after the shot.

Reference 1 reports that the observers could not view displays closer to GZ than 2000 yards because of the rad-safe limit. At this distance, the intensities originally measured were at least 5 r/hr. However, by the time observers reached the area, the fallout had decayed sufficiently so that the earlier rad-safe limit line could be bypassed. For an arrival time of about one hour after the shot, the observers would have encountered intensities on the 2000-yard line of at least 2.2 r/hr. The AEC data, for approximately the same time, indicate roughly 3 r/hr along that line. The service observers' dose is calculated from the time of fallout deposition in the trench area until they left the shot area in trucks; the total film badge dose from residual radiation is 0.50 rem.

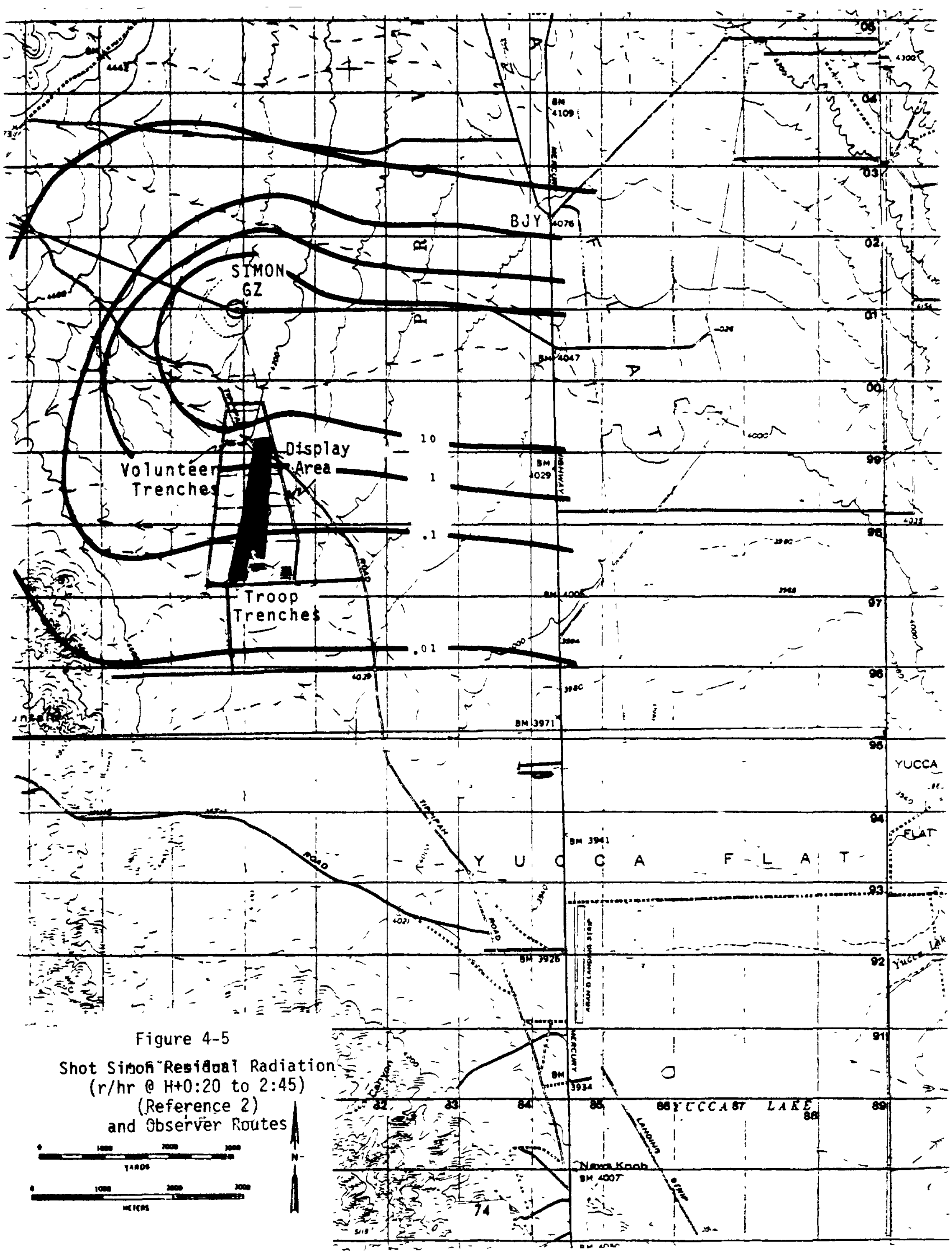


Figure 4-5
Shot Simon Residual Radiation
(r/hr @ H+0:20 to 2:45)
(Reference 2)
and Observer Routes

### 4.1.6 Shot Encore

The radiation levels from Shot Encore were sufficiently low (due to the height of burst) to warrant only one AEC radiation survey. The nearly circular isointensity contours, indicative of the neutron-induced soil activation, were offset from the intended GZ; the actual GZ was 280 yards to the south. Several readings at intended GZ, from different sources, are used to determine the relative intensity of gamma radiation from $Mn^{56}$ and $Na^{24}$ for all times. The one survey plot (see Figure 4-6) is used in conjunction with this radioactive decay function to determine the intensities encountered by the observers during their inspection of the display. Even though the observers passed near the actual GZ, they never exceeded one-tenth of their rad-safe limit. Their calculated film badge dose is 0.10 rem.

### 4.1.7 Shot Harry

The observers (both the service observers and Camp Desert Rock observers followed virtually the same scenario) for Shot Harry reportedly walked to 450 yards from GZ, at the 6 r/hr line (Reference 1). Because the 6 r/hr line had no official status under the revised rad-safe procedures, this intensity is open to question. The total dose limit remained at 6 rem, but the maximum permissible intensity consistent with this dose limit was up to the discretion of the officer-in-charge. While it is possible that the Control Group chose to halt upon encountering 6 r/hr, it is also possible that the above reference mistakenly ascribed the numerical value of the dose limit to an intensity limit.

As for Badger and Simon, the AEC radiation survey data for Harry are deficient. After shot day and the following day, there is no evidence of surveys (at least in Reference 2) for ten days. With unmarked survey roads on an insufficient number of plots, which also have serious inconsistencies, statistical analysis is impossible. The inconsistencies appear to result from the mixed nature of the radiation field and the liberties taken in sketching the intensity contours. The area upwind of GZ, in which the observers operated, was subject to neutron-induced activity. Only this region of Figure 4-7 is drawn with any confidence. The considerable winds which blew heavy fallout offsite appear,

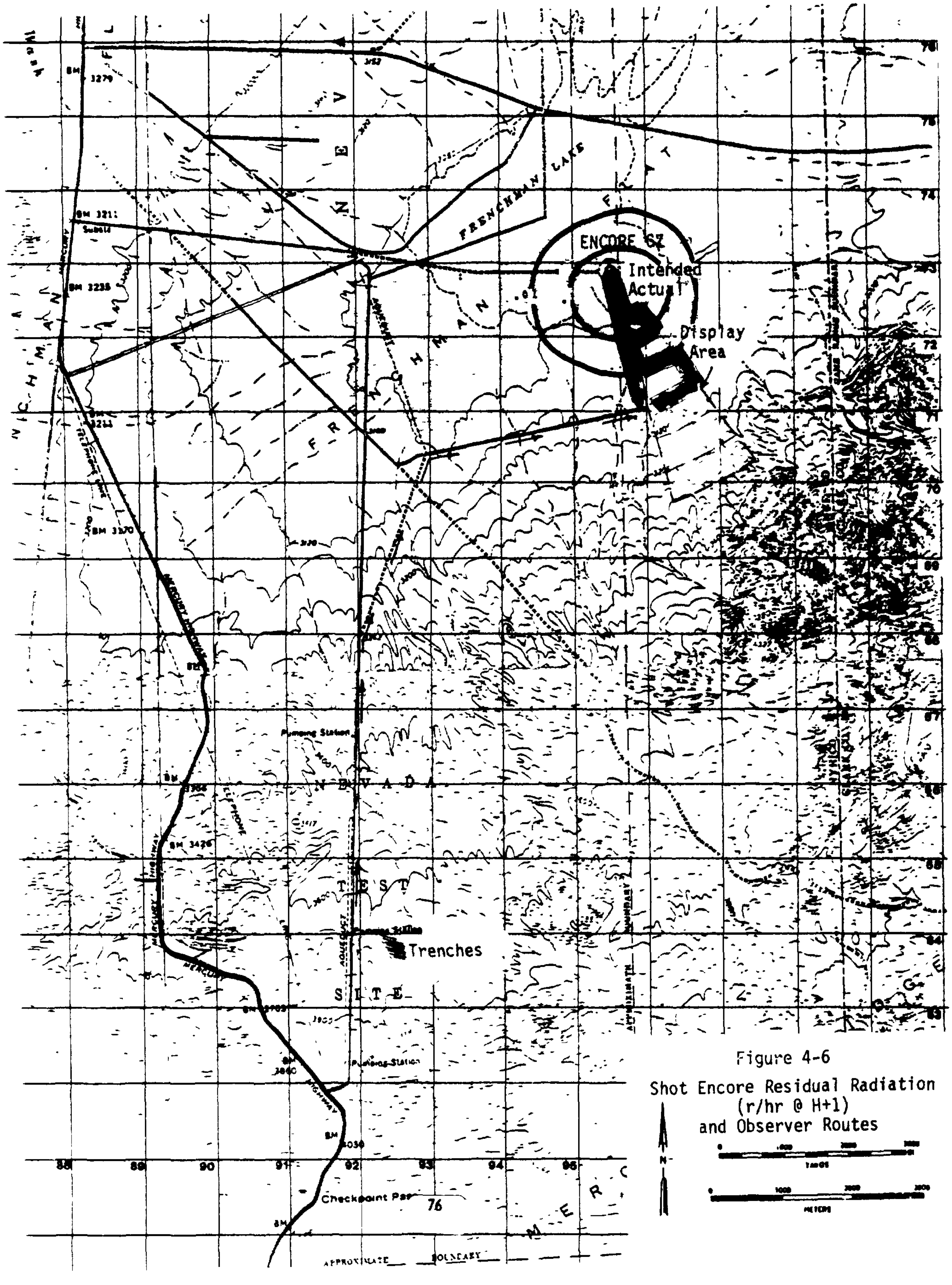


Figure 4-6
Shot Encore Residual Radiation
(r/hr @ H+1)
and Observer Routes

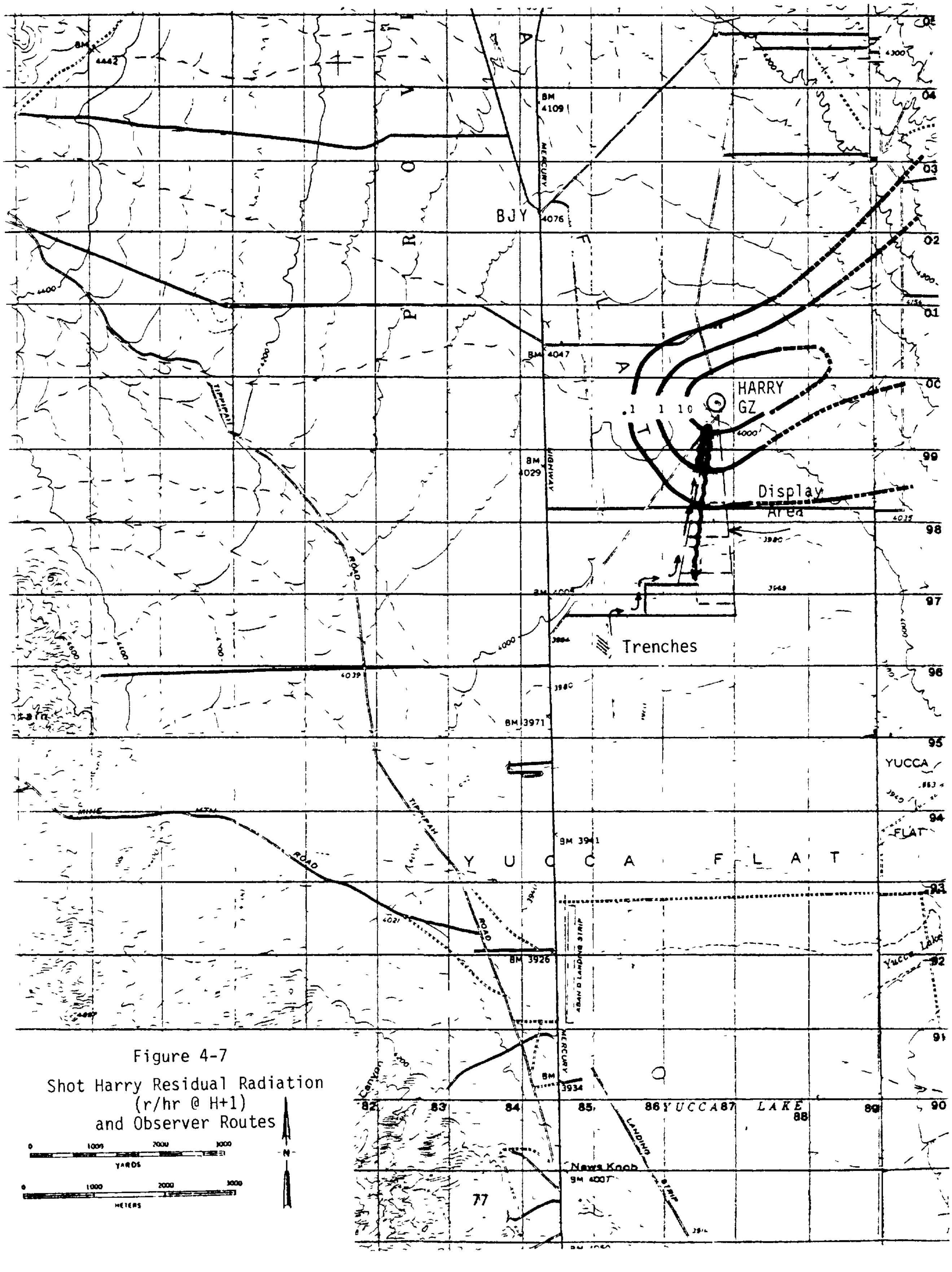


Figure 4-7

Shot Harry Residual Radiation (r/hr @ H+1) and Observer Routes from the plots, to have spared the Desert Rock display area from this form of contamination.

Because the initial survey was made at about an hour after the shot, at roughly the same time the observers were in the display area, the dose estimate is relatively insensitive to radioactive decay rates. Therefore, the determination of the relative intensity from $Na^{24}$ and $Mn^{56}$, which requires multiple surveys, is not as important in this case. For both service observers and Camp Desert Rock observers, the calculated film badge dose is 1.2 rem. The calculated maximum intensity encountered at 450 yards is 8.9 r/hr, within the uncertainty of which the alleged 6 r/hr of Reference 1 falls.

4.1.8 Shot Grable

The observers for Shot Grable are presumed to have visited the Shot Harry display area, as did the maneuver troops (Reference 14). The timing most consistent with their activities reported in Reference 1 places them in the Harry area three days after that shot. It is assumed that they walked only to the display line at 500 yards from GZ, for there was virtually nothing to see at closer ranges (it is not apparent why the Shot Harry observers moved any closer). Even if the original induced activity had all been $Na^{24}$, the intensity encountered by the Shot Grable observers at any given range would have been about one-fortieth of that for the Shot Harry observers. The film badge dose to the Grable observers in the Harry area is calculated to be 0.03 rem; it would be less if the contribution to the original activity from $Mn^{56}$ could be considered.

Because of the dust (not fallout-bearing) at Shot Grable, the observers were not able to view equipment at any range closer than 1500 yards from GZ (see Figure 4-8). Even if they had been turned back from a position arbitrarily close to the next display, say at 1100 yards from GZ, their calculated film badge dose (from induced activity) is only 0.04 rem. Thus, with these high-sided assumptions, the total film badge dose to the Shot Grable observers is estimated as 0.07 rem.

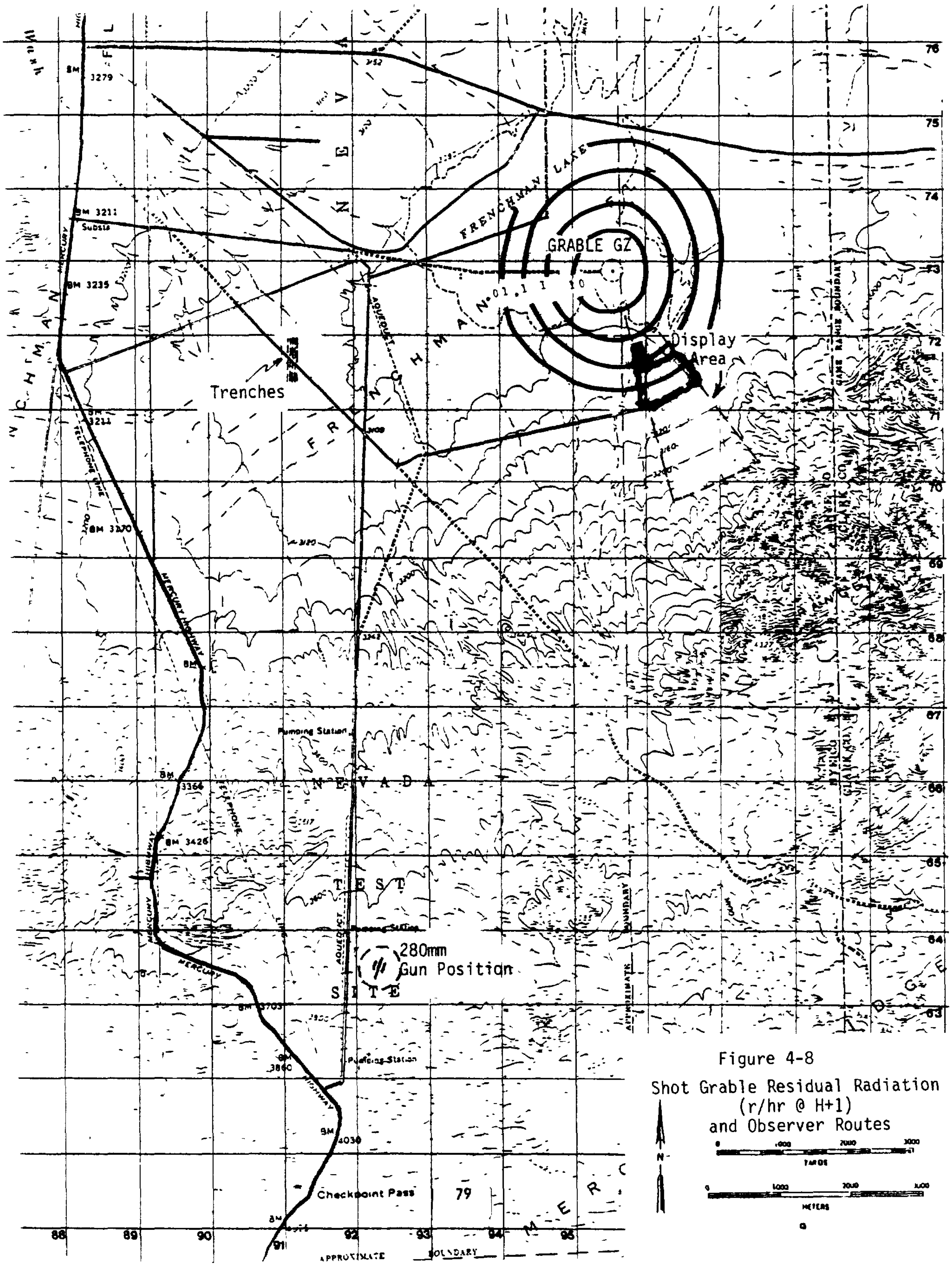


Figure 4-8

Shot Grable Residual Radiation
(r/hr @ H+1)
and Observer Routes

## 4.2 INTERNAL RADIATION EXPOSURE

While operating in residual radiation fields, personnel were subject to an internal dose commitment from the inhalation of airborne radionuclides. The scenarios for Desert Rock V observers indicate several different situations in which airborne contamination was encountered. Each situation is analyzed for the case that results in the greatest dose. Dose commitments to the whole body and bone are considered, as these are of current interest with regard to radiologically-induced disorders.

The basic methodology used for calculating internal dose commitments is that used in Reference 18, which is based on the following expression:

$$D_j = GC \times K \times BR \times T \times \sum_i P_i DF_{ij}$$

where:

| | | |
|---|---|---|
| $D_j$ | = | Dose commitment (rem) to organ j |
| GC | = | Ground Contamination ($Ci/m^2$) |
| K | = | Resuspension Factor ($Ci/m^3$ per $Ci/m^2$, or $m^{-1}$) |
| BR | = | Breathing Rate ($m^3/hr$) |
| T | = | Duration of Exposure (hr) |
| $P_i$ | = | Activity fraction of isotope i |
| $DF_{ij}$ | = | Dose Factor (rem/Ci) for organ j resulting from an intake of isotope i |

Variations of this expression are developed as required for utilization of the measured radiological parameters. Except where noted, the particle size distribution of airborne contamination is assumed to be consistent with that for which the dose factors were developed. This distribution provides a more nearly optimal particle retention than does any distribution likely encountered by Desert Rock observers; thus, the calculated dose commitments are high-sided.

### 4.2.1 Volunteer Observers During Fallout Deposition

The primary example of personnel being showered by fallout was at Shot Simon, where the volunteer observers noted fallout deposition especially at 2000 to 2500 yards from GZ at about 5 to 10 minutes after burst. In order to arrive so rapidly, these fallout particles must have been too large to be respirable. Consequently, no internal dose would have resulted.

### 4.2.2 Volunteer Observers Walking in Fresh Fallout

The Simon volunteers provide the best example of personnel walking in an intense gamma field from fresh (and presumably the most resuspendable) fallout. Although the fallout particles were large during their descent, some would have fragmented or liberated small scavenged particles on impact with the ground. Reference 37, for example, reports that particles of respirable size were detected much nearer to ground zero than was compatible with their own fall rates. Although the fraction of activity associated with respirable particles was small, the following calculation assumes all particles as respirable in order to upper-bound the dose commitment.

Because of the effort involved in weighting the dose factors for all fission product isotopes by the time-dependent activity fractions for each, a computer code was developed to provide these data for the common fissile materials. Reference 38 provides the relationship between 50-year dose commitment to various organs and (external) gamma intensity for various times after burst. The mix of Simon fission products and unfissioned weapon debris is used to determine that the relationship at approximately 0.1 hour after burst is 0.3 mrem (whole body) per mr/hr for unit resuspension factor ($m^{-1}$), breathing rate ($m^3$/hr), and time of exposure (hr). The gamma intensity and time factors may be combined in the form of a time-integrated intensity, which for the volunteers' evacuation was 5.4 r (corresponding to the film badge dose of 3.8 rem). For a resuspension factor of $10^{-5} m^{-1}$ (used in Reference 18 for walking) and a breathing rate of 1.3 $m^3$/hr, the 50-year whole body dose commitment for Simon volunteers is calculated as:

$$D = (0.3)(5400)(1.3)(10^{-5}) = 0.02 \text{ mrem}.$$

The bone dose commitment is about the same.

### 4.2.3 Service Observers Walking in Aged Fallout

The 25-day Nancy field in which the Badger observers operated was the oldest Upshot-Knothole shot area revisited by observers. Although gamma intensities in the area had decreased markedly since shot day, the potential for internal dose had not. The total time-integrated intensity from Nancy fallout encountered by the Badger observers on Badger shot day and during the rehearsal two days previous was about 100 mr. From Reference 38, the relationship between 50-year dose commitment and gamma intensity at 25 days is: 1010 mrem (whole body) per mr of integrated intensity for unit resuspension factor ($m^{-1}$) and breathing rate ($m^3$/hr). Despite the aging of the fallout, the resuspension factor is still taken as order $10^{-5}m^{-1}$. The whole body dose commitment is then:

$$D = (1010)(100)(1.3)(10^{-5}) = 1.3 \text{ mrem}$$

The corresponding bone dose commitment is 2.8 mrem.

### 4.2.4 Service Observers in an Induced Field

A neutron-induced field would not ordinarily be considered as a potential internal radiation hazard because the activated soil is distributed to a depth of several inches. However, in circumstances of extreme dust lofting, significant contamination could conceivably be inhaled. Such was the case at Shot Grable, where a dust storm curtailed the observer activities.

The observers at Grable are calculated to have received a film badge dose of 40 mrem, for which the corresponding time-integrated intensity is 58 mr. At the time of the observers' principal exposure, about one hour after burst, $Mn^{56}$ and $Na^{24}$ contributed about equally to the intensity (as determined from the Grable radiation survey data using the methodology of Reference 32). Thus, the time-integrated intensity from $Na^{24}$, (trivially) adjusted to zero time after burst, would be about 30mr.

The quantitative relationship between the gamma intensity and internal dose is developed in Appendix III. For the indicated soil composition, the 50-year dose commitment to the whole body is principally from intake of $Na^{24}$, with small contributions from $K^{42}$ and $Mn^{56}$. A ten percent additional dose commitment to bone results from $Ca^{45}$ and $P^{32}$. The whole body commitment for exposure at one hour after burst is 2.6 mrem per mr of time-integrated intensity for unit suspension factor ($m^{-1}$) of activity in the top centimeter of soil and unit breathing rate ($m^3$/hr). During the dust storm, the suspension factor may conceivably have been as great as $10^{-2}m^{-1}$, the upper limit of measured lofting for any activity. The whole body dose commitment is then given as:

$$D = (2.6)(30)(1.3)(10^{-2}) = 1.0 \text{ mrem}$$

It is tacitly assumed in the above that the dust remained in the vicinity where lofted. If dust had instead been transported from areas of greater intensity, the internal dose commitment would be correspondingly greater. However, any approaching contamination would have been detectable by virtue of its addition to the local gamma intensity.

The radiation surveys for Grable (Reference 2) indicate that there was no significant redistribution of induced activity. For all surveys, the roughly circular isointensity contours indicative of the original neutron activation are present. Because the initial survey was performed at about the time the observers were in the area, even the remote possibility of highly contaminated dust passing by the observers (to be deposited only in offsite areas where it might not be detected) may be discounted. The minor irregularities that do exist in the Grable intensity plots from survey to survey could include some contribution from transported contamination. However, the magnitude of these irregularities makes it most unlikely that more than half of the intensity encountered at any location could result from transient airborne contamination.

For an upper-limited internal dose calculation, it is assumed that half (about 30 mr) of the observers' time-integrated intensity resulted from airborne activity. In Appendix II, a relationship is developed between the concentration of activity in the air and the associated gamma intensity. The airborne activity concentration is then related to internal dose. With these expressions combined, the internal dose is the product of the time-integrated intensity, the breathing rate, and a composite (activity-averaged) dose factor, all divided by the average gamma energy per radiological decay. With the activity concentration data, dose factor data, and units as in Appendix II, the 50-year whole body dose commitment is given (in the limit of time zero) as:

$$D = \frac{(1.7)(1.27)+(0.35)(0.65)+(3.7)(0.066)}{(1.7)(4.12)+(0.35)(0.28)+(3.7)(1.68)} (1.3)(30) = 8 \text{ mrem},$$

where 4.12, 0.28, and 1.68 are the average gamma energies (MeV) per decay of $Na^{24}$, $K^{42}$, and $Mn^{56}$, respectively. The bone dose commitment, from $Ca^{45}$ and $P^{32}$ in addition, is 9 mrem.

### 4.2.5 Volunteer Observers in an Early Induced Field

Because of their proximity to nuclear bursts, the volunteer observers were exposed to radiation from an additional radionuclide, $Al^{28}$ ($t_{1/2}$=2.3 min), which decayed to insignificance before other personnel reached comparable distances from ground zero. The dose commitment from $Al^{28}$ (and all other activated nuclides) was negligible, however, even at high suspension (as from the shock wave), largely because the volunteers were at the fringes of the induced fields (which were quickly masked by fallout). Even in the lung, where the aluminum would decay before distribution throughout the body, the dose was far less than 1 mrem.

## 4.3 RESIDUAL RADIATION DOSE SUMMARY

The calculated film badge doses (rem) to Operation Upshot-Knothole observers from residual gamma radiation are summarized as follows:

| Associated Shot: | Annie | Nancy | Dixie | Ray | Badger | Simon | Encore | Harry | Grable |
|---|---|---|---|---|---|---|---|---|---|
| Service Observers | 0.50 | 0.32 | 0 | 0 | 1.4 | 0.50 | 0.10 | 1.2 | 0.07 |
| Volunteer Observers | -- | <0.01 | -- | -- | 4.1 | 3.8 | -- | -- | -- |

For all observer activities in conjunction with shots other than Grable, the 50-year dose commitment to the whole body or bone from inhaled radionuclides is calculated to be less than 0.003 rem. During the dust storm at Grable, observers could have inhaled neutron-activated dust, resulting in a commitment of from 0.001 rem to possibly as high as 0.008 rem to the whole body and 0.009 rem to bone. Almost all of the dose would have been accrued within a few days following exposure.

## 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

The sources of error in the calculation of neutron dose include: (1) uncertainty in the neutron output (magnitude and spectrum) of the device, (2) deviations from radial symmetry in the neutron output due to device asymmetry, (3) error in neutron transport from the burst point to a location above the trench, and (4) uncertainties in neutron trench factors. For the shots of interest, error factors representing 90-percent confidence limits are estimated for each of these sources.

The error factors for neutron output are based on the estimated reliability of the calculations and/or assumptions made to model the output characteristics of the device. The asymmetry error factors were developed by considering the degree of device asymmetry and the orientation of the device with respect to trench locations. Two devices (those for Shots Nancy and Simon) were highly asymmetric in design and therefore have large factors. An asymmetry error factor of 1.0 is assigned for radially symmetric devices. The transport error factor reflects the uncertainty in calculating the neutron dose at a trench location for a given neutron output of a symmetric device. This range-dependent factor varies from 1.3 at 2000 m to 1.5 at 5000 m. The uncertainty in the calculation of neutron trench factors results in error factors of 1.2 for service observer trenches (2-foot wide) and 1.3 for volunteer observer trenches (4-foot wide).

Neutron dose error factors are displayed below. The combined neutron error factors for the shots of interest range from 1.6 to 2.2.

| Shot | Source of Uncertainty: Neutron Output | Asymmetry | Transport | Trench Factor | Combined Error Factor |
|---|---|---|---|---|---|
| Annie | 2.0 | 1.0 | 1.4 | 1.2 | 2.2 |
| Nancy | 1.3 | 1.6 | 1.4 | 1.2 | 1.9 |
| Volunteers | 1.3 | 1.5 | 1.3 | 1.3 | 1.8 |
| Badger | 1.3 | 1.0 | 1.4 | 1.2 | 1.6 |
| Volunteers | 1.4 | 1.0 | 1.4 | 1.3 | 1.7 |
| Simon | 1.3 | 1.9 | 1.4 | 1.2 | 2.2 |
| Volunteers | 1.3 | 1.8 | 1.3 | 1.3 | 2.1 |
| Harry | 1.4 | 1.0 | 1.4 | 1.2 | 1.7 |
| Grable | 1.2 | 1.1 | 1.5 | 1.2 | 1.6 |

### 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 estimated to be approximately 1.4 when data were taken along one radial line, and 1.2 when consistent film badge data were obtained along multiple radial lines by two different experimental groups, as for Shots Badger and Grable. For Shot Nancy, the large error factor (1.8) reflects the uncertainty in the experimental data due to shielding in the direction of the experimental line, as discussed in Section 3.2.2. The error in interpolation/extrapolation techniques used to determine the gamma doses at trench locations is range-dependent, with estimated values of 1.1-1.4. 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 service observer trenches and 1.3 for volunteer observer trenches. 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. For volunteer observers, it is considered unlikely that anyone stood up before eight seconds after detonation, since the blast effects and fireball luminosity would have been significant prior to this time (Reference 16). It is also considered probable that most volunteer observers were standing by 15 seconds after the shot. The values of eight and 15 seconds are therefore considered the 90-percent confidence limits on standup time for volunteer observers. Compared to the ten-second standup time assumed in Section 3, an eight-second standup time results in a gamma dose 20 percent greater while that for a standup time of 15 seconds is 26 percent less (Figure 3-2). In order to combine the uncertainty in standup time with other uncertainties, a lognormal distribution, consistent with the 90-percent confidence limits, is assumed. The associated error factor is about 1.3 and reflects a median standup time near eleven, rather than ten, seconds (the volunteer observer doses shown in Table 5-1 reflect this lognormal distribution).

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 |
| Annie | 1.4 | 1.3 | 1.2 | 1.5 | | 1.9 |
| Nancy | 1.8 | 1.4 | 1.2 | 1.5 | | 2.2 |
| Volunteers | 1.8 | 1.1 | 1.3 | 1.5 | 1.3 | 2.2 |
| Badger | 1.2 | 1.2 | 1.2 | 1.5 | | 1.7 |
| Volunteers | 1.2 | 1.1 | 1.3 | 1.5 | 1.3 | 1.8 |
| Simon | 1.4 | 1.4 | 1.2 | 1.5 | | 1.9 |
| Volunteers | 1.4 | 1.2 | 1.3 | 1.5 | 1.3 | 2.0 |
| Harry | 1.4 | 1.4 | 1.2 | 1.5 | | 1.9 |
| Grable | 1.2 | 1.4 | 1.2 | 1.5 | | 1.8 |

## 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 Reference 32. 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 that limited troops to intensities of less than 2.5 r/hr (with the exception of Shots Harry and Grable). Troop positions are well known except, in some cases, with regard to the limit of advance in the display areas. When 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 that maximizes the time spent at or near the rad-safe limit.

Except for 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 all shots from operation plans, shot area maps, and shot area photographs. For all shots except Badger, the uncertainty in angle of troop position within the display sectors has a minor 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 movement from the trenches and arrival 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. The uncertainty of doses of 0.01 rem or less is not discussed.

Each shot for which the observers encountered residual radiation is considered separately. The various sources of error are combined approximately; they cannot be combined rigorously due to disparity of their associated distributions. These distributions may be normal (e.g., a stay time ± 5 minutes), lognormal (as for the gamma intensity), or truncated (due to the rad-safe limit). The best-estimate doses from Section 4 are used together with the error distributions to determine the mean dose from residual radiation for each shot. Only for significantly skewed distributions is the mean much different from the best estimate. For multiple exposures, the means may be legitimately added to find the mean total dose, which may be compared to film badge data or entered as an individual's assigned gamma dose. Ninety-percent confidence limits are estimated for each calculated dose. Confidence limits for totaled doses can only be approximated; they are obtained as for normal distributions, except that upper and lower confidence intervals are considered separately.

### 5.2.1 Shot Annie

The observers apparently went to the rad-safe limit although there was no display at that position. The only uncertainty of consequence is the time spent at the rad-safe limit. An error factor of 2 is estimated for the assumed stay of 5 minutes. The contribution to dose at that position is $0.14^{+0.14}_{-0.07}$ rem. The uncertainties in stay time at the displays and in walking speed affect the remaining dose estimate by roughly 10 percent, or 0.36 ± 0.04 rem. The calculated total film badge dose is then $0.50^{+0.15}_{-0.08}$ rem.

### 5.2.2 Shot Nancy

For the service observers, both the available survey data and calculations indicate that part of the 1000-yard display line was outside the rad-safe limit. Because the radiation intensity was not constant along that display line, there is greater than usual uncertainty in the time the observers spent at the rad-safe limit. An error factor of 3 is estimated for that time to reflect the possibilities that the observers briefly skirted the radiation-restricted area before reaching the display line, or that most of their time on the 1000-yard display line was spent at levels well below the rad-safe limit. The calculated total film badge dose at Nancy is then $0.32^{+0.27}_{-0.09}$ rem. Other uncertainties are negligible in comparison.

### 5.2.3 Shot Badger

The most significant uncertainties in the volunteer observers' residual radiation dose were the time spent and the intensity at the trench area. Based on the reported position-time data for the volunteers' evacuation, the time of leaving the trenches is estimable to the nearest minute. To that time, the residual film badge dose is then 2.9 ± 0.3 rem. Uncertainty with regard to gamma intensity, with the reported residual values of 30 to 50 r/hr at the trenches and a probable average over the interval within 5 r/hr of that estimated, results in an estimate of about 2.9 ± 0.4 rem. These uncertainties combined, with the other contributions to the volunteer observers, give a total residual radiation film badge dose of 3.3 ± 0.5 rem.

The service observers' dose estimate is dominated by the time spent at or near the rad-safe limit. This time would have been less than assumed if the observers headed toward the western boundary road upon reaching the rad-safe limit; it would have been more if they encountered the limit at the 1000-yard display and had remained near the limit line for their entire return walk. The resulting uncertainty in the film badge dose is about $1.4^{+0.4}_{-0.8}$ rem.

### 5.2.4 Shot Simon

The Simon volunteer observers had substantial contributions to their residual radiation dose from walking along the 2000-yard display line and from walking to the rear. Along the display line, the dominant uncertainty is the reported time. If correctly reported to the nearest minute, the resulting dose contribution is 2.1 ± 0.3 rem. For the walk to the rear, the average intensity might be in error by a factor of as much as 1.3 because of the substantial intensity gradient and the continuing fallout deposition. The uncertainty in walking speed, even without an end-time constraint, should be within a factor of 1.2. With the uncertainties combined, the dose contribution from the walk to the rear is $1.6^{+0.6}_{-0.4}$ rem. The total residual film badge dose for the Simon volunteer observers is then calculated as $3.8^{+0.7}_{-0.5}$ rem.

Despite the lack of sufficient rad-safe survey data to associate uncertainties with the Simon radiation field, the calculated dose to the service observers is not highly uncertain. All pertinent evidence indicates that the observers must have been very close to an updated rad-safe limit line to reach the 2000-yard display. The dominant uncertainty affecting dose is the time spent there. With the same uncertainty estimation as for Shot Annie, the observers' total film badge dose is computed to be $0.50^{+0.15}_{-0.08}$ rem.

### 5.2.5 Shot Encore

The observers accrued most of their dose in the portion of the display area near GZ, where the radiation field was nearly uniform over a considerable spatial extent. Intensity measurements during the early hours after burst at the intended GZ are consistent to within 20 percent (after accounting for decay); the calculated dose should be similarly accurate for the given scenario. Because approximately one-half hour was spent in the area of highest intensity, the uncertainty in timing cannot introduce much additional error. The estimated film badge dose to the observers is $0.10 \pm 0.03$ rem.

### 5.2.6 Shot Harry

Because the movement of the observers was no longer constrained by a maximum gamma intensity, the uncertainty in the calculated radiation field cannot be reduced with auxiliary information. With respect to gamma intensity, the calculated dose is uncertain to within a factor of 2.1, or $1.2^{+1.3}_{-0.6}$ rem. A factor of 2 uncertainty in the time spent at the innermost display that was viewed implies a dose of $1.2^{+0.4}_{-0.2}$ rem. The overall uncertainty in the observers' film badge dose is $1.2^{+1.4}_{-0.6}$ rem.

5.2.7 Shot Grable

The dose calculated for the Grable observers is high-sided because the intensity at the Harry area is based on the presumption of $Na^{24}$ as the sole contributor at early times and because of the presumption that the observers went forward from the 1500-yard display at Grable. The range of possible film badge dose to the Grable observers is about 0.02 to 0.07 rem.

## 5.3 TOTAL DOSE SUMMARY

The reconstructed neutron and gamma doses for Operation Upshot-Knothole observers are presented in Table 5-1. From the best-estimate doses of Sections 3 and 4 and the error distributions of Section 5, the mean neutron and gamma doses for each observer group are calculated. These are presented along with estimated 90-percent confidence limits.

Table 5-1. Observer Dose Summary

| Shot | Neutron Dose (rem) | Initial Gamma* Dose (rem) | Residual Gamma* Dose (rem) | Total Gamma* Dose (rem) |
|---|---|---|---|---|
| Annie | $0.018^{+0.017}_{-0.011}$ | 0.012** | $0.51^{+0.14}_{-0.09}$ | $0.52^{+0.14}_{-0.09}$ |
| Nancy | < 0.001 | 0.004 | $0.35^{+0.24}_{-0.12}$ | $0.35^{+0.24}_{-0.12}$ |
| Volunteers | $0.63^{+0.43}_{-0.30}$ | $0.64^{+0.61}_{-0.38}$ | < 0.01 | $0.64^{+0.61}_{-0.80}$ |
| Badger | < 0.001 | 0.006 | $1.3^{+0.5}_{-0.7}$ | $1.3^{+0.5}_{-0.7}$ |
| Volunteers | $2.4^{+1.5}_{-1.0}$ | $3.9^{+2.8}_{-1.8}$ | $3.3 \pm 0.5$ | $7.2^{+2.8}_{-1.9}$ |
| Simon | 0.001 | 0.012 | $0.51^{+0.13}_{-0.08}$ | $0.52^{+0.13}_{-0.08}$ |
| Volunteers | $28^{+25}_{-16}$ | $9.8^{+8.2}_{-5.3}$ | $3.8^{+0.7}_{-0.5}$ | $13.6^{+8.2}_{-5.3}$ |
| Encore | < 0.001 | < 0.001 | $0.10 \pm 0.03$ | $0.10 \pm 0.03$ |
| Harry | < 0.001 | 0.008 | $1.3^{+1.3}_{-0.7}$ | $1.3^{+1.3}_{-0.7}$ |
| Grable | < 0.001 | < 0.001 | $0.04 \pm 0.02$ | $0.04 \pm 0.02$ |

* Reconstructed film badge dose
** Uncertainties less than 0.01 rem not displayed

## Section 6

## FILM BADGE DOSIMETRY

Because dosimetry records for Desert Rock V have not been located, few data are available with which to compare reconstructed doses. An occasional dose report has been found in Marine Corps medical records; however, none of these appear to be for service observers. Volunteer observer doses, either individually or en masse, are recorded in several references because of their greater interest.

The volunteer observer doses are compared to calculated mean doses and dose ranges. A range of film badge readings is expected largely because of the likely variation in body position among the observers in a trench. The error factors of 1.5 for original trench posture and 1.3 for standup time, estimated for volunteer observers in Section 5.1, are applied to the calculated initial gamma dose (in Section 3, as modified for standup time in Section 5.1) to obtain the range in which 90 percent of the film badge readings are expected to lie.

For Shot Nancy, Reference 1 indicates that the range of film badge readings for the volunteers was from 0.3 to 0.545 rem. However, an individual volunteer's medical records indicate a dose of 0.787 rem. As the exposure to the Nancy volunteers was almost entirely from initial radiation, these data may be compared to the calculated range of initial gamma dose, 0.26 to 1.25 rem.

The Badger volunteer observers are known to have worn several sets of film badges. Reference 1 places greatest credibility on a set of recorded doses from 5.2 to 9.5 rem. Reference 6 lists individual readings ranging from 4.1 to 9.6 rem and averaging 6.1 rem. It cannot be determined which set is more representative; neither source indicates where on the body each set was worn. The calculated film badge dose range of 5.3 to 10.0 rem (including 3.3 rem from residual gamma) is similar to the range of both sets of film badge readings. The calculated mean dose of 7.2 rem is also consistent with these readings.

Reference 15 provides pocket dosimeter readings taken during and after the exercise. These could be used to check the relative contributions of initial and residual radiation, except that the reference does not clarify the times at which the intermediate readings were taken.

Volunteer observers at Shot Simon also wore multiple film badges, but Reference 16 provides chest readings for everyone. These range from 9.5 to 17.5 rem, with a mean of 12.7 rem. The range of calculated doses, 8.3 to 21.8 rem, (including 3.8 rem residual) and the calculated mean of 13.6 rem both indicate a fortuitous level of agreement.

These results establish confidence in the calculation of initial gamma doses, but are insufficient to provide correlation with neutron and residual gamma doses.

## Section 7

## CONCLUSIONS

Exercise Desert Rock V observers participated in nine of the eleven test shots of Operation Upshot-Knothole. Of the nine, seven were observed by significant numbers of observers from trenches as close as 3500 yards (3200 meters) from ground zero. For three shots, officer volunteers observed from as close as 2000 yards (1830 meters).

From the standpoint of initial radiation, neutron dose was insignificant for all but the volunteer observers at Shots Nancy, Badger, and Simon. Upper confidence limits for neutron dose are 1 and 4 rem for Shots Nancy and Badger, respectively, and as high as 53 rem (28 rem calculated mean) for Shot Simon (due in part to its higher-than-expected yield). Initial gamma doses were again significant only for the volunteers, the upper confidence limits for initial gamma calculated to be 1.25. 6.7, and 18 rem for Shots Nancy, Badger, and Simon, respectively.

Residual gamma radiation was more apparent from the tower shots than from the air bursts, likely due primarily to the increased burst height of the latter. The troop observers were exposed to the highest residual radiation at Shots Badger and Harry, where upper limit doses are calculated to be 1.8 and 2.6 rem, respectively. For volunteers at Shots Badger and Simon, the corresponding doses are 3.8 and 4.5 rem, respectively.

Despite high dust levels in contaminated areas, causing troop activities to be curtailed, the inhalation and ingestion hazard was not significant. At early times, an internal dose hazard in a residual radiation field would be accompanied by a corresponding external dose hazard. This is not the case for later times. The slower-decaying nuclides that contribute significantly to internal dose can present a hazard of inhaled or ingested, even when routine radiological surveys would indicate no significant external hazard.

Of all Desert Rock observers who participated in Operation Upshot-Knothole, only the volunteer observers at Shot Simon received a total radiation dose that exceeded established criteria. Their calculated mean doses were 13.6 rem gamma and 28 rem neutron, considerably exceeding the 10 rem volunteer observer limit mainly because of the neutron exposure, which was not recorded on their film badges. No regular observers exceeded their dose limit of 6 rem.

Although film badge dosimetry is not available for most observers, the volunteer observer film badge data correlates well with calculated gamma doses for all three shots at which the volunteers participated.

## REFERENCES


1. "Final Report, Exercise Desert Rock V," Headquarters, Camp Desert Rock, Nevada, 16 July 1953.

2. "Radiological Safety Operation," Report to the Test Director, Operation Upshot-Knothole, Nevada Proving Grounds, WT-817, Headquarters, Field Command, AFSWP, June 1953.

3. "Directive for Exercise Desert Rock V," Office of the Chief of Army Field Forces, Ft. Monroe, Virginia, 5 February 1953.

4. "Letter of Instruction No. 1," Exercise Desert Rock V , Headquarters, Sixth Army, Presidio of San Francisco, 5 January 1953.

5. "Operational Summary, 1 March - 9 June 1953," Operation Upshot-Knothole, Nevada Proving Grounds, Headquarters, Field Command, AFSWP, August 1953.

6. "Report of the Deputy Test Director," Operation Upshot-Knothole, Nevada Proving Grounds, WT - 816, Los Alamos Scientific Laboratory, June 1954.

7. Operations Order No. 1 (Shot Annie), Exercise Desert Rock V, Headquarters, Camp Desert Rock, Nevada, 9 March 1953.

8. Operations Order No. 2 (Shot Nancy), Exercise Desert Rock V, Headquarters, Camp Desert Rock, Nevada, 16 March 1953.

9. Operations Order No. 3 (Shot Badger), Exercise Desert Rock V, Headquarters, Camp Desert Rock, Nevada, 14 April 1953.

10. Operations Order No. 4 (Shot Simon), Exercise Desert Rock V, Headquarters, Camp Desert Rock, Nevada, 11 May 1953.

11. Operations Order No. 5 (Shot Encore), Exercise Desert Rock V, Headquarters, Camp Desert Rock, Nevada, 3 May 1953.

12. Operations Order No. 6 (Shot Harry), Exercise Desert Rock V, Headquarters, Camp Desert Rock, Nevada, 11 May 1953.

13. Operations Order No. 7 (Shot Grable), Exercise Desert Rock V, Headquarters, Camp Desert Rock, Nevada, 17 May 1953.

14. "Operational Report, 7 May - 3 June 1953," Headquarters, First Army Desert Rock V Battalion (Provisional "Y"), Ft. Totten, NY, 3 June 1953.

15. "Observers' Report of Desert Rock V," Marine Corps Educational Center, Quantico, VA, 1 May 1953.

16. "Report of Participation in Selected Volunteer Program of Desert Rock V-7," Headquarters , Armed Forces Special Weapons Project, 25 April 1953.

17. "Analysis of Radiation Exposure for Task Force WARRIOR, Shot Smoky," Exercise Desert Rock VII-VIII, Operation Plumbbob, DNA 4747F, Defense Nuclear Agency, 31 May 1979.

18. "Analysis of Radiation Exposure for Task Force BIG BANG, Shot Galileo," Exercise Desert Rock VII-VIII, Operation Plumbbob, DNA 4772F, Defense Nuclear Agency, 9 April 1980.

19. "Version 4 of ATR (Air Transport of Radiation)," DNA 3995, Defense Nuclear Agency, January 1976.

20. "Energy Dependent Air/Ground Correction Factors for the ATR (Air Transport of Radiation) Code," BRL Report No. 345, U.S. Army Ballistic Research Laboratory, August 1977.

21. "Radiation Environments from Tactical Nuclear Weapons," DNA 4267F, Defense Nuclear Agency, July 1976.

22. "Protection Against Neutron Radiation," NCRP Report No. 38, January 1971.

23. "The MORSE Monte Carlo Radiation Transport Code System," ORNL 4972, Oak Ridge National Laboratory, February 1975.

24. "DNA Nuclear Weapons Output Handbook," Defense Nuclear Agency, (unpublished).

25. "Preliminary Neutron and Gamma-Ray Output for (Badger)," Letter from Los Alamos Scientific Laboratory, 15 October 1980.

26. "A User's Manual for ANISN, A One-Dimensional Discrete Ordinates Transport Code with Anisotropic Scattering," Union Carbide Corporation, 1967.

27. "(Simon) Output", letter from Los Alamos Scientific Laboratory, 6 June 1980.

28. "Capabilities of Nuclear Weapons," EM-1, Defense Nuclear Agency, December 1977.

29. "The DOT III Two-Dimensional Discrete Ordinates Transport Code," ORNL-TM-4290, Oak Ridge National Laboratory, September 1973.

30. "The MISC Code and Marrow Dose in an Initial Radiation Environment," SAI-78-967-LJ, Science Applications, Inc., November 1978.

31. "Compilation of Local Fallout Data from Nuclear Test Detonations, 1945-1962," Volume I - Continental U.S. Tests, DNA 1251-1-EX, Defense Nuclear Agency, 1 May 1979.

32. "Analysis of Radiation Exposure for Troop Observers," Exercise Desert Rock VI, Operation Teapot, Draft Final Report, Science Applications, Inc., McLean, VA, 15 July 1980.

33. "Marine Corps Report on Exercise Desert Rock V," Headquarters, 2d Marine Corps Provisional Atomic Exercise Brigade, Camp Pendleton, CA, 19 May 1953.

34. "Activities of the Artillery Test Unit," Operation Upshot-Knothole, Nevada Proving Grounds, WT-709, U.S. Army Artillery Center, Ft. Sill, OK, September 1953.

35. "Soil Activation by Neutrons," Project 2.1, Operation Plumbbob, WT-1410, Field Command, AFSWP (DASA), May 1960.

36. "Test Director's Report on Operation Plumbbob," Nevada Test Site, UCRL 5166, November 1957.

37. "Distribution Characteristics and Biotic Availability of Fallout, Operation Plumbbob," Projects 37.1, 37.2, 37.2A, 37.3, and 37.6, Nevada Test Site, WT-1488, Civil Effects Test Group, July 1966.

38. "Fallout Inventory and Inhalation Dose to Organs (FIIDOS)," Science Applications, Inc., 1981.

39. "ORIGEN Isotope Generation and Depletion Code--Matrix Exponential Method," CC-217, Oak Ridge National Laboratory, June 1977.

40. "Summary of Preliminary Results of the Diagnostic Measurements Performed on Operation Upshot-Knothole," Los Alamos Scientific Laboratory (unpublished).

41. "Air Weather Service Participation," Operation Upshot-Knothole, WT-703, Air Force Special Weapons Center, July 1953.

42. "Neutron Flux Measurements," Project 2.3, Operation Upshot-Knothole, WT-720, Naval Research Laboratory, December 1953.

43. "External Neutron Measurements with Threshold Detectors," Project 17.1, "Operation Upshot-Knothole, WT-826, Los Alamos Scientific Laboratory, March 1955.

44. "Physical Measurements of Gamma and Neutron Radiation in Shelter and Instrumentation Evaluation," Project 24.2, Operation Upshot-Knothole, WT-789, U.S. Atomic Energy Commission, August 1953.

45. "Initial Gamma Exposure Versus Distance," Project 6.8a, Operation Upshot-Knothole, WT-756, Signal Corps Engineering Laboratories, April 1955.

46. "Gamma Radiation as a Function of Distance," Project 10.3, Operation Upshot-Knothole, WT-827, Los Alamos Scientific Laboratory, February 1956.

47. "Initial Gamma Data from Nuclear Weapons Tests, 1948-1962," NDL-TR-53, U.S. Army Nuclear Defense Laboratory, July 1965.

48. "A Methodology for Calculating Radiation Doses from Radioactivity Released to the Environment," ORNL-4992, Oak Ridge National Laboratory, March 1976.

49. "NUIDEA--A Computer Code for the Prediction of Radiation, Blast, and Thermal Environments from Nuclear Weapons," Science Applications, Inc., 19 November 1975.

# APPENDIX I
# CALCULATION OF TRENCH FACTORS

Trench factors are used to predict an in-trench radiation environment from a known or calculated above-trench radiation environment. It is necessary to calculate trench factors for each major component of radiation--neutrons, secondary gamma (produced by neutron capture and inelastic scattering in the atmosphere and ground) local gamma (produced by $(n,\gamma)$ reactions in the trench walls), and debris (fission product) gamma. The factors are found to depend on weapon yield, height of burst, range of trench from GZ, trench dimensions, and depth in the trench. This appendix provides brief descriptions of the methods used to calculate the various trench factors. The calculations are currently in a preliminary state; therefore, factors used in this report are tentative.

## A. Neutron Trench Factors

The neutron trench factor is defined as the ratio of the neutron dose in the trench to the neutron dose above the trench. Two-dimensional air-over-ground transport of neutrons is calculated by the discrete ordinates code DOT (Reference 29). The DOT calculations predict the angular neutron fluences above the ground. The neutron dose in the trench can be calculated either by a selection of the uncollided (from above-trench to detector location) angular rays which contribute to the dose, or by coupling the output of the Monte Carlo adjoint transport code MORSE (Reference 23) with the DOT results through a MISC program (Reference 30). The first method determines the dose in the trench from each angular neutron fluence ray. Scattered contributions to the dose are not included. This method underpredicts the neutron trench factor by about 0.07 compared to that obtained from a MORSE-MISC-DOT coupling. The MORSE adjoint calculation includes the scattered neutron dose contribution, which accounts for most of the difference.

B. Secondary Gamma Trench Factors

Two-dimensional air-over-ground transport of the secondary gamma radiation is also calculated by the discrete ordinates code DOT (Reference 29). To calculate the dose in the trench from secondary gamma radiation, a proper selection of the downward DOT gamma angular fluence is made. This selection depends on the dimensions of the trench. The gamma radiation above the trench is transmitted into the trench by performing special tests to select that portion of the angular distribution that contributes to the dose inside the trench and, when necessary, to determine the attenuation of the gamma radiation through the ground material surrounding the trench. Gamma scattering off of the trench walls contributes only a few percent to the dose in the trench and is thus not included in the calculation of the trench factor. The secondary gamma trench factor is, then, the ratio of the gamma dose inside the trench (due to secondary gamma above the trench) to the total secondary gamma dose above the trench.

C. Local Gamma Trench Factors

To calculate the dose in the trench from gamma radiation produced locally by the $(n,\gamma)$ reaction in the trench soil, an output of the Monte Carlo adjoint transport code MORSE is again coupled with the DOT neutron results using the MISC program. This MISC coupling is successful with the neutron fluences because they are nearly isotropic. (However, MISC coupling with gamma fluences cannot be used because the gamma fluence computed by DOT is more directional than the MORSE angular responses.) Thus, the local gamma trench factor is defined as the ratio between the gamma dose inside the trench from $(n,\gamma)$ reactions in the surrounding soil to the neutron dose above the trench.

D. Debris Gamma Trench Factors

One-dimensional atmospheric transport of radiation, known as infinite air calculations, are performed accurately by the discrete ordinates code ANISN (Reference 26). In calculating the free-field doses above the trench from debris gamma radiation, the presence of the soil material may be taken into account by utilizing a proper set of air-over-ground correction factors, such as those used in the ATR4 (Reference 19) computer code. Furthermore, by properly selecting the ANISN downward angular fluence, an estimate of the doses inside the trench may be made, noting that the angular fluence along some paths would suffer attenuation while traversing the soil material surrounding the trench. A set of trench factors, defined as the ratios of the doses inside to those above the trench, may then be calculated as a function of range for a given source height and spectrum.

Because the height of the debris gamma radiation source is increasing with time, it is necessary to calculate these trench factors as a function of fireball height. The debris gamma radiation spectrum is assumed to be constant during the period of initial fireball rise. The fireball rise model utilized in computer code NUIDEA (Reference 49) is then used to develop trench factor-versus-time curves for the shots of interest. In order to allow for personnel reorientation (i.e., standing up) in the trench during the output of debris gamma radiation, trench factor-time curves are determined for two locations within the trench, one corresponding to the film badge location of a person crouching in the trench, and the second at the film badge position of an observer standing upright in the trench, facing the rising cloud. The resulting curves for Shot Badger are shown in Figure I-1.

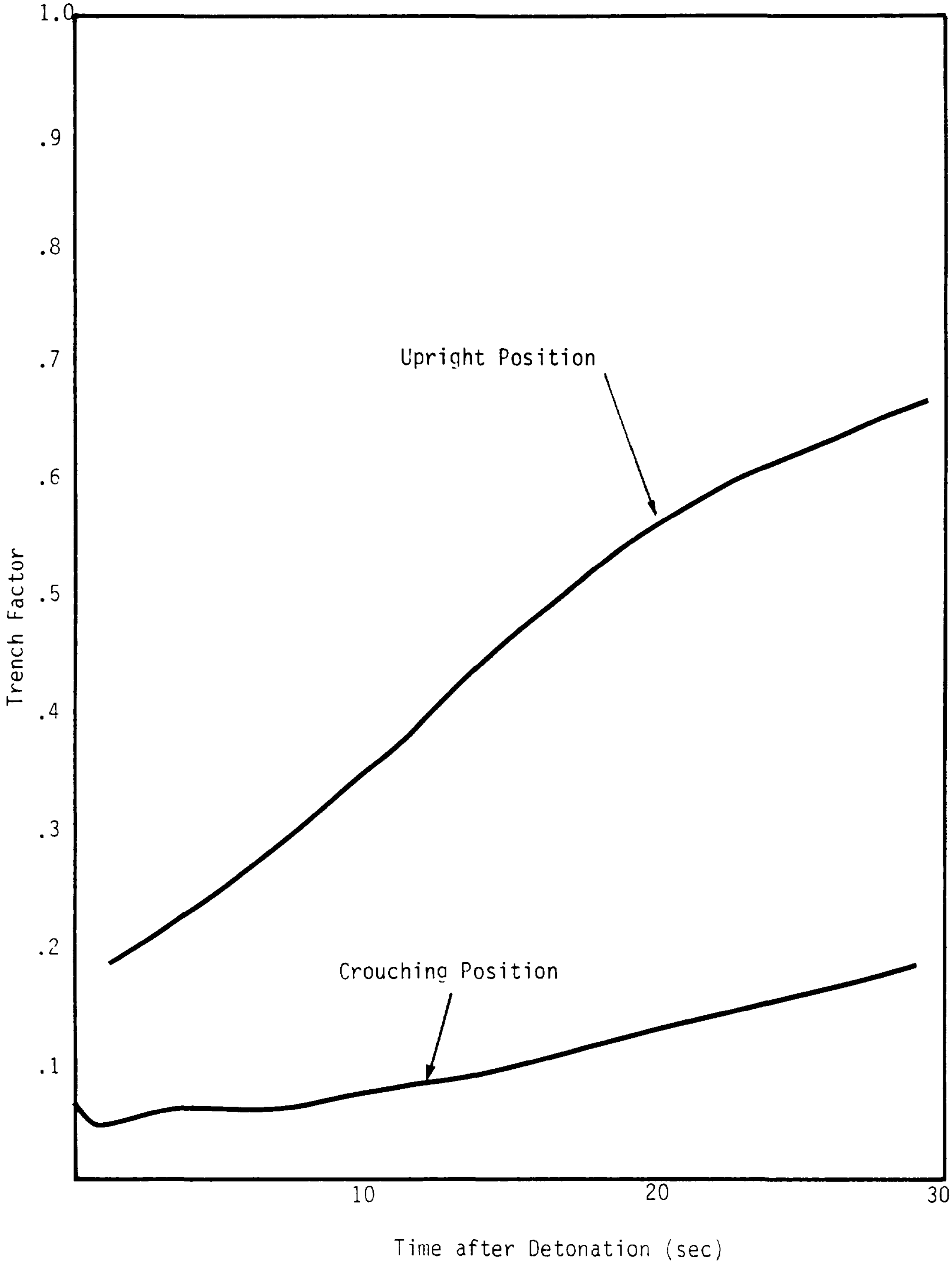


Figure I-1 Debris Gamma Trench Factors for Volunteer Observer Trench, Shot Badger

## APPENDIX II

## THE RELATIONSHIP OF INTERNAL DOSE TO EXTERNAL DOSE FROM AIRBORNE CONTAMINATION

Airborne contamination that may result in an internal dose from inhaled radionuclides also results in an external dose from gamma emitters (if any). Because radiation monitoring at Nevada Proving Grounds (also known as Nevada Test Site) concentrated primarily on surveys of gamma radiation intensity, it is useful to be able to determine inhalation doses from the gamma intensity environment.

Internal and external dose are most simply related if the airborne contamination is of uniform concentration over an effectively infinite distance (large compared to the mean free path of the gamma radiation). In this case, the volumetric rate of energy emission equates to that of energy absorption. The former may be expressed as:

$$\left(C\left[\frac{\mu Ci}{m^3}\right]\right)\cdot\left(3.7\times10^4\ \frac{dis/sec}{\mu Ci}\right)\cdot\left(E\left[\frac{MeV}{dis}\right]\right)\cdot\left(1.6\times10^{-6}\ \frac{erg}{MeV}\right)\cdot\left(3600\ \frac{sec}{hr}\right) = 213\cdot C\cdot E\left[\frac{erg/hr}{m^3}\right]$$

where C is the airborne activity concentration and E is the mean energy of gamma emissions per disintegration. For absorption,

$$I\left[\frac{mr}{hr}\right]\cdot 84\left(\frac{erg/g\ air}{r}\right)\cdot\left(\frac{1r}{1000mr}\right)\cdot\left(1293\ \frac{g\ air}{m^3}\right) = 109\cdot I\left[\frac{erg/hr}{m^3}\right]$$

where I is the gamma intensity from airborne contamination, and the air density is at standard temperature and pressure. Combining these expressions results in:

$$I(mr/hr) = 2.0\ C(\mu Ci/m^3)\cdot E(MeV/dis).$$

For an effectively infinite source of airborne contamination over a ground surface, it may be considered at ground level that half of the energy source is effectively absent, and thus that

$$I\,(mr/hr) = 1.0\ C\ (\mu Ci/m^3) \cdot E\ (MeV/dis).$$

This is a useful approximation for ground personnel if the airborne activity concentration is sufficiently uniform. The computation of the general case is much more complex, involving radiation transport computer codes that effectively provide weighting factors for all gamma emission energies. A separate computer study would be required for each activity distribution of interest.

A basic expression for internal dose from some radioisotope to some organ is:

$$D(mrem) = C(\mu Ci/m^3) \cdot BR(m^3 inhaled/hr) \cdot T(hr) \cdot DF(mrem/\mu Ci\ inhaled)$$

where BR is the breathing rate, T is the duration of exposure, and DF is the dose factor relating the specific radioisotope and organ. In terms of the airborne intensity, which may vary with time, the expression may be recast as:

$$D(mrem) = \frac{DF(mrem/\mu Ci)}{E(MeV/dis)} \cdot BR(m^3/hr) \cdot \int Idt\ (mr)$$

Each radioisotope j contributes a factor $c_j E_j / \sum_i c_i E_i$ to the total airborne intensity (only relative activity concentrations (c) need be considered). Thus, the total internal dose to some organ is expressed as:

$$D(mrem) = \frac{\sum_i c_i DF_i(mrem/\mu Ci)}{\sum_i c_i E_i(MeV/dis)} \cdot BR(m^3/hr) \cdot \int Idt\ (mr)$$

For other than standard conditions, the above should be modified by a factor of actual density/standard density. In practice, the breathing rate at altitude may change so as to roughly compensate for any density correction.

The preceding expression may be used for fission products in conjunction with a computer code such as ORIGEN (Reference 39), which provides the gamma energy data and relative activities for any time of interest. For neutron-induced activity, relative concentrations in the air may be assumed proportional to those in the ground, the determination of which is described in Appendix III. The time-integrated intensity in the expression is found from correlation of personnel movement data with applicable rad-safe surveys or can be related to film badge readings resulting from airborne contamination.

# APPENDIX III

## RELATIONSHIP OF INTERNAL DOSE TO GAMMA INTENSITY FROM INDUCED ACTIVITY

Estimates are made of the ground concentration of neutron activation products in Nevada Test Site soil from measured gamma intensities. Experimental data are used in both the construction and validation of the methodology. The induced radioisotopes that are the largest potential contributors to whole body and bone doses are identified.

The relationship between activity in soils and gamma intensity is developed from the dependence of each on the thermal neutron fluence. Soil activity is computed theoretically from the thermal neutron capture cross-sections and the radiological decay rates of the soil constituents. Correlation between gamma intensity and thermal neutron fluence can be found from data reported in Reference 35. The best correlation is obtained by considering only the gamma intensity from $Na^{24}$, the predominant contributor at Nevada Test Site from about one through five days after the burst. The direct readings of intensity from $Na^{24}$, extrapolated to time zero, are found to imply, for a thermal neutron fluence of $10^9 n/cm^2$ (measured at the surface), 1.0 mr/hr for each 2 percent by weight of sodium in the soil. In this form, the correlation is applicable to most soils of density similar to the typical NTS value of 1.3 $g/cm^3$.

For the radioisotopes calculated to be of significance as potential whole body and bone dose contributors, the relationship between soil activity and $Na^{24}$ intensity at time zero is shown below. Values in the preceding columns are multiplied to obtain these results. The highest values of weight fraction from References 28, 35, and 36 are used for each soil constituent.

| Radio-isotope | Specific Activity ($\mu$Ci/g of the isotope) | Thermal Neutron Cross-Section of Parent ($cm^2$) | Isotopic Fraction of Parent | Weight Fraction in Soil | Thermal Neutron Fluence ($n/cm^2$) for 1 mr/hr $Na^{24}$ at $t_o$ | Activity ($\mu$Ci/g of soil) for 1 mr/hr $Na^{24}$ at $t_o$ |
|---|---|---|---|---|---|---|
| $Na^{24}$ | 8.71 + 12* | 5.3 - 25 | 1 | 2 - 2 | 1.0 + 9 | 9.2 - 5 |
| $P^{32}$ | 2.85 + 11 | 1.9 - 25 | 1 | 4 - 4 | 1.0 + 9 | 2.2 - 8 |
| $K^{42}$ | 6.02 + 12 | 1.5 - 24 | 6.9 - 2 | 3 - 2 | 1.0 + 9 | 1.9 - 5 |
| $Ca^{45}$ | 1.76 + 10 | 1.2 - 24 | 2.1 - 2 | 6.7 - 2 | 1.0 + 9 | 3.0 - 8 |
| $Mn^{56}$ | 2.17 + 13 | 1.3 - 23 | 1 | 7 - 4 | 1.0 + 9 | 2.0 - 4 |

Data from Reference 35 permit comparison with the calculated activity-intensity (from $Na^{24}$) ratio for $Na^{24}$, $Mn^{56}$, and $K^{42}$. The measured activity was about 30 percent greater for $Na^{24}$ and about 50 percent greater for $Mn^{56}$. These discrepancies exist because of a build-up of thermal neutrons within the soil and a minor contribution to activation from higher-energy neutrons. The presence of $K^{42}$ in roughly the predicted amount is evidenced by spectra. Although unidentified in the reference, the peak corresponding to the gamma energy of $K^{42}$ is consistent with the calculated activity of $K^{42}$ for different soils and different times after burst. $P^{32}$ and $Ca^{45}$ do not appear in the spectra because they are not gamma emitters.

It is concluded that for NTS soils, correlations involving thermal neutron fluences and capture cross-sections are of use in determining levels of induced activity. A correction factor of 1.4, applied to match selected data, should be roughly applicable to activated nuclides in general.

*Read as $8.71 \times 10^{12}$

The calculated activity-intensity ratios are converted below to the form used for internal dose calculations in the main body of the report (a soil density of 1.3 g/cm$^3$ and the correction factor of 1.4 are included). Dose factors for 50-year dose commitments to the whole body or bone are given. The product of these two items provides normalized values of dose commitment. The relative importance of the listed radionuclides varies with the time after burst through their radiological decay. Half-lives are presented in the last column.

| Radio-isotope | Surface Activity ($\mu$Ci/m$^2$ in top cm)* | Dose Factor (mrem/$\mu$Ci inhaled)*** | | Normalized 50-Year Dose Commitment (mrem/m$^2$)*,** | Radiological Half-Life |
|---|---|---|---|---|---|
| $Na^{24}$ | 1.7 | 1.27 | WB | 2.2 | 15.0 h |
| $P^{32}$ | 4.0-4 | 1.65+2 | B | 0.066 | 14.3 d |
| $K^{42}$ | 3.5-1 | 6.53-1 | WB | 0.23 | 12.4 h |
| $Ca^{45}$ | 5.5-4 | 3.65+2 | B | 0.20 | 163 d |
| $Mn^{56}$ | 3.7 | 6.6 - 2 | WB | 0.24 | 2.58h |

*per 1 mr/hr from $Na^{24}$ at time zero

**mrem per unit resuspension factor (m$^{-1}$), per unit breathing rate (m$^3$/hr), per unit time (hr)

*** Reference 48

WB = whole body

B = bone

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