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ANALYSIS OF RADIATION EXPOSURE FOR MANEUVER UNITS

Exercise Desert Rock V, Operation Upshot-Knothole

Science Applications International Corporation
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The radiation doses to maneuver units for Exercise Desert Rock V are reconstructed for each applicable shot of Operation Upshot-Knothole (1953). The maneuver troop units received the same initial radiation doses as calculated previously for troop observers at these shots. Residual doses are calculated by using an automated procedure to couple scenarios for troop activities to the radiation environment. Uncertainties are determined for each parameter. Possible internal doses are analyzed. The calculated total film badge equivalent gamma doses range from 0.04 rem (some Shot Grable elements) to 3.1 rem (some Shot Simon elements). Initial doses were less than 0.02 rem for any shot. The largest internal whole-body dose commitment is 0.05 rem (some Shot Grable elements).

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SECTION 1
INTRODUCTION

This report presents an analysis of the nuclear radiation dose for Army and Air Force participants in the troop maneuvers of the 1953 series of shots at the Nevada Test Site (NTS).* The series was designated Operation Upshot-Knothole.

Figure 1-1 shows the ground zero locations of the six shots in Operation Upshot-Knothole at which there were troop maneuvers. The maneuvers consisted of battalion combat teams (BCTs) that engaged in post-shot tactical exercises to test doctrine and tactics being developed for the nuclear battlefield. Army multiple-battalion exercises were conducted at Shots Annie, Nancy, Simon, Encore, and Grable. Air Force ground units also maneuvered at Shot Encore. The Marine exercise at Shot Badger is analyzed in Reference 21.

In addition to troop maneuver units, there were three other types of military participation in Exercise Desert Rock V, conducted at the Nevada Proving Grounds in conjunction with Operation Upshot-Knothole in the spring of 1953. One consisted of troop observers who were sent to Camp Desert Rock for the specific purpose of observing one or more nuclear shots (supported and controlled by personnel assigned to Camp Desert Rock). The radiation exposure to observers is analyzed in Reference 22. Another type of military participation centered around service equipment tests and operational training associated with the employment of nuclear weapons. A further category, distinct from the Exercise Desert Rock groups, consisted of technical projects and logistical support under the sponsorship of Field Command, Armed Forces Special Weapons Project.

In this report, Army and Air Force troop maneuver unit activities for each of five shots are traced from the pre-shot orientation and rehearsals through the shot activities to the post-shot equipment inspection. Time-dependent position information is presented in order that an exposure analysis can be performed to determine the

*The Nevada Test Site was known in 1953 as the Nevada Proving Grounds (NPG). In the remainder of this report it will be referred to as such.

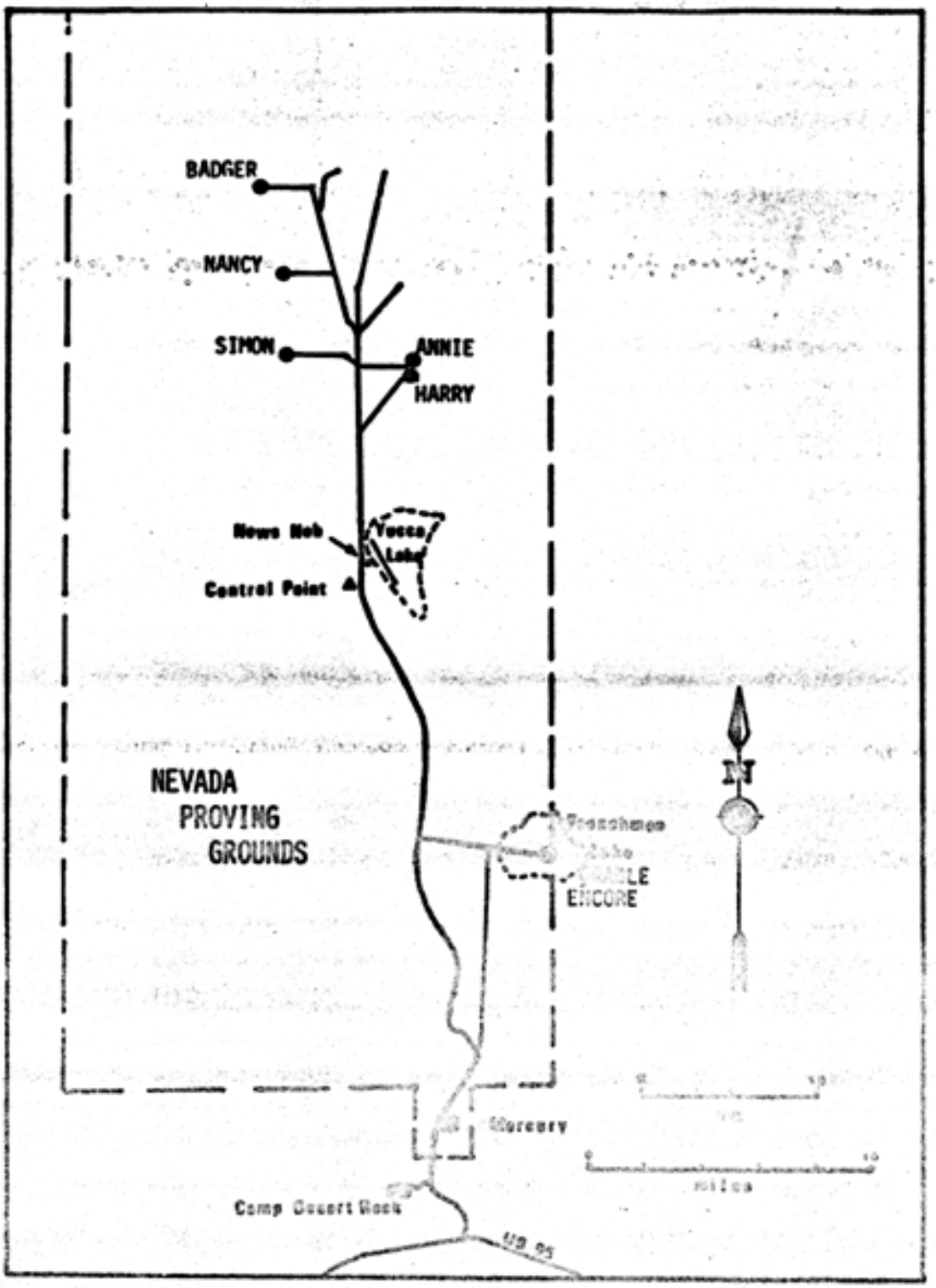

Figure 1-1. Selected shot locations, Operation Upshot-Knothole.

integrated dose from all contributing sources. These include the initial neutron and gamma radiation doses, and the external and internal doses due to residual radiation from the observed shot, as well as applicable preceding shots.

Section 3 provides a summary description of the initial radiation dose determination. The maneuver troops were in trenches at the same distances as the troop observers for the five shots covered in this report. No new calculations of initial radiation dose are therefore required, and the results derived in Reference 22 are summarized in Section 3.

The analysis described herein utilizes an automated procedure, described in Reference 23, for determining the external dose due to residual radiation. Radiological survey data are fit, in statistical regression analyses, to space-time models of residual radiation intensity, from which isointensity contours (isopleths) are then developed. Unlike Operation Teapot, the available AEC radiological survey reports for Operation Upshot-Knothole had no raw data, but only isopleths that were not fully time-resolved. Nevertheless, these isopleths were necessarily the source of information used to generate the reconstructed radiation fields with the automated methodology. However, in some cases it was possible to refine the assessment of intensities encountered by the troops with isolated values reported in Reference 1.

As in previous reports, the methodology considers the effect of soil activation in the residual radiation analysis. This is particularly important for Shots Encore and Grable, where the residual contamination at 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 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 inferred from the calculations for the observers (Reference 22). For a given shot, the maneuver troops' internal dose commitment is determined from that of the observers by adjusting for differences in ground contamination and duration of exposure.

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 readings is possible. The methodology for calculating personnel dose is not significantly different than that used in previous analyses (References 21, 24, 25) in which comparisons 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 calculation 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 troops of maneuver units participating in 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. Almost the entire dose received was from residual radiation.

- The residual radiation doses calculated for Upshot-Knothole maneuver troops range from 0.04 rem (troop elements at Shot Grable) to 3.1 rem (troop elements at Shot Simon).

- Except for BCT-B at Shot Grable, the inhalation of radioactive dust resulted in whole body dose commitments of less than 0.001 rem. The calculated whole-body dose commitment to the most-exposed elements at Shot Grable is 0.05 rem.

SECTION 2
OPERATIONS

2.1 SHOT DATA

A summary of the eleven test shots of Operation Upshot-Knothole is contained in Table 2-1. Although maneuver troop units participated in only six shots as indicated, all shots are considered for any residual radiation that might have contributed to total radiation dose.

2.2 PARTICIPATION

Desert Rock V exercise troops consisted of an estimated 18,000 DOD personnel who arrived at Camp Desert Rock to participate in testing and training programs. These exercise troops, unlike the Camp Desert Rock support troops, were assigned to Camp Desert Rock to participate in specific activities associated with a particular shot. These activities included the troop observer program, the volunteer officer observer program, tactical troop maneuvers, operational helicopter tests, and damage effects evaluation.

This report addresses only the Desert Rock V tactical troop maneuvers. Approximately 13,000 exercise troops took part in the tactical maneuvers conducted at Shots Annie, Nancy, Badger, Simon, Encore, and Grable. Units from the six continental Armies, Marine Corps, and Air Force traveled to the NPG specifically to participate in the maneuvers. In addition to these personnel, Camp Desert Rock support troops were utilized to form the maneuver elements for Shot Annie. Table 2-2 gives the planned personnel allocations and the total number of planned and actual participants in the maneuvers at each shot.

2.3 CONCEPT

In general, Exercise Desert Rock V was a continuation of the military exercises conducted in conjunction with the two preceding continental test operations. For Operation Upshot-Knothole, the US Army was given responsibility for radiological safety of participating Desert Rock V personnel. The Desert Rock V radiological safety plans were designed to minimize exposure to ionizing radiation while allowing

Table 2-1. Upshot-Knothole shot data.

SHOT DESIGNATION AEC	SHOT DESIGNATION DESERT ROCK	DATE Actual (Sched) 1953	LOCAL TIME (PST)(1)	LOCATION COORDINATES (UTM)	BURST HEIGHT(2) (ft)	YIELD (KT)
Annie(4)	V-1	17 March (17 March)	0520	Area 3 871004	300 T	16
Nancy(4)	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(4)	V-5	18 April (11 April)	0435	Area 2 784104	300 T	23
Simon(4)	V-7	25 April (25 April)	0430	Area 1 798009	300 T	43
Encore(4)	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(4)	V-10	25 May (21 May)	0830 (PDT)	Frenchman Flat 956728	524(3)	15
Climax		4 June (31 May)	0415 (PDT)	Area 7-3 872048	1334 A	61

(1) Pacific Standard Time, unless noted as Pacific Daylight Time (PDT).
(2) T - Tower; A - Air Drop
(3) Fired from 280 mm Cannon
(4) Maneuver Troop Participation

Source: References 1, 5, 6

Table 2-2. Planned personnel allocations and total actual participants for maneuvers at Exercise Desert Rock V.

Participating Service	ANNIE	NANCY	BADGER	SIMON	ENCORE	GRABLE	TOTAL
First Army	0	0	0	0	600	200	800
Second Army	0	800	0	800	0	400	2,000
Third Army	0	600	0	0	1,000	400	2,000
Fourth Army	0	0	0	600	400	600	1,600
Fifth Army	0	400	0	600	0	600	1,600
Sixth Army	0	600	0	400	0	200	1,200
Camp Desert Rock Army Support Troops	1,000	0	0	0	0	0	1,000
Marine Corps	0	0	2,100	0	0	0	2,100
Total Planned Participants	1,000	2,400	2,100	2,400	2,000	2,400	12,300
Total Actual	1,181	2,349	2,167	2,450	2,475[1]	2,670	13,292

[1] Includes 326 Air Force personnel.

Source: References 1, 4-7, 16-20.

participants to conduct more realistic military exercises within radiation limits. Subject to radiation constraints, troop maneuvers were allowed near ground zero as long as there was no interference with instrumentation or other experiments.

The purpose of the troop maneuvers was to instill confidence in soldiers operating on the nuclear battlefield, through indoctrination in the tactical employment of nuclear weapons, realistic training in essential protective measures, and observation of the effects of the explosion on test animals and assorted military equipment at various distances from ground zero.

At Camp Desert Rock, troop maneuver personnel were organized into composite Battalion Combat Teams (BCTs). There were two BCTs at each of the five shots covered in this report. Their activities involved the following phases:

- Orientation instruction and tours of display areas
- Rehearsal of shot day activities
- Observing the nuclear blast
- Conducting the tactical maneuvers
- Post-shot touring of the display area.

The four-hour orientation instruction included basic atomic theory, characteristics and effects of nuclear weapons, protective measures to employ against nuclear attack, tactical deployment of nuclear weapons, results of previous Desert Rock Exercises, and the plan of operation for the particular shot. Rehearsals included entering the trenches; reviewing protection methods, countdown, and post-shot procedures; departing the trenches; carrying out the attack; walking through the display area; and entrucking for the return to Camp Desert Rock.

After the shot, the BCTs were to attack an objective in accordance with the exercise plans. These troops were to be accompanied by radiological safety monitors and preceded by radiological survey teams who determined the limits of safe advance. After reaching their objective or approaching as close as radiation safety standards would permit, the maneuver was terminated. Under the direction of the Desert Rock Control Group, the BCTs were to inspect the display area. The BCTs and observer groups were then to be picked up by trucks and returned to Camp Desert Rock.

For radiological safety purposes, a maximum permissible dose of 6 rem was established for the entire exercise (or six month period) of which no more than 3 rem could be prompt, whole body radiation (Reference 3). Standard operating procedures for radiological safety in all operations were based on these criteria. For the five shots discussed in this report (except Grable) the rad-safe limits for the maneuver troops were the same (References 16-19). The 2.5 R/hr intensity line was the forward limit for the troops (see Section 4.1 for a discussion of this limit). The following instructions appear in References 16-19: "One radiological survey team consisting of one radiological safety monitor and one enlisted man, driver, from the 50th Chemical Service Platoon and one enlisted man, communications, from [Detachment A, 505th Signal Company] will station itself approximately 150 yards on the east (right) flank of the foremost elements of the maneuvering troops. It will proceed slightly in advance of the line, monitoring continuously as it moves forward. Upon noting increasing intensity (approaching 2 R/hr) of radiation the survey party will proceed obliquely to the northwest until the instrument records below that intensity. Right flank units of the maneuvering troops will conform to this movement by a similar change in direction." It should be noted that these instructions do not correlate to the maneuver path for Shot Encore (see Figure 2-4). However, evasive action was not required during any portion of Shot Encore activities, since only low levels of activity were anticipated and encountered. Apparently because radiological intensity limitations had been somewhat restrictive to movements around the displays, the BCT commanders at Shot Grable were given the responsibility, without a formally specified intensity limit, to see that participating troops did not receive a total dose in excess of 6 rem. The monitor team preceding the maneuver troops for Shot Grable was given the instruction to "direct discontinuance of the forward movement of the troops and/or movement to one or the other flank to avoid contaminated areas of high intensity" (Reference 20).

In addition to the Desert Rock monitors on the flank, unit CBR personnel were to precede the advance elements of the attacking force by 150 yards. For Shot Grable, these monitoring personnel were to be only 50 yards ahead. Prior to each shot, the Camp Desert Rock Radiological Safety Section conducted a school for these unit radiation monitors. They were to monitor continuously and report readings of 100 mR/hr (500 mR/hr for Shot Grable) or more. Company commanders were directed to report readings of 1 R/hr or more to their battalion commander.

Finally, a third survey team consisting of one radiological safety monitor and a driver from the 50th Chemical Service Platoon was assigned to each BCT commander. These teams were to check the unit CBR personnel by patrolling across the zone of attack, checking reported readings of 1 R/hr or more, and informing the BCT commander of their determinations.

In the display area, Desert Rock radiological survey teams denoted the limit of troop movement (except for Shot Grable) by marking the 2.5 R/hr isopleth with stakes and marking tape.

2.4 ACTIVITIES

The test shots and maneuver unit participation went as scheduled for two shots and with some deviations on the other three, as described below. For all shots, maneuver troops departed Camp Desert Rock for the trench areas in convoys of buses and trucks. All troops occupied the same set of trenches at a given shot. When a BCT made a post-shot inspection of equipment displays, movement to and through the display area was normally accomplished as a single group. Ground zero locations, the trench locations, and the display areas are identified on the figures accompanying the discussion of each shot. Shot-time distances and distances of closest approach to ground zero are summarized in Table 2-3. The following paragraphs describe the maneuver troop activities for each shot.

2.4.1 Shot Annie

For this shot, 1181 of the Army support troops at Camp Desert Rock participated in tactical maneuvers. The participating units provided personnel for the two BCTs as follows (Reference 16):

- BCT Able

23rd Trans Trk Co	505th MP Co
31st Trans Trk Co	762nd QM Subs Sup Co
38th Trans Hv Trk Co	6020th ASU
53rd Trans Hv Trk Co	371st Evac Hosp
77th Army Band	3623rd Ord Co
163rd QM Ldry Det	

Table 2-3. Maneuver troop ground zero distance summary, Exercise Desert Rock V.

Shot	Shot Time Distance	Closest Post-Shot Approach
Annie	3500 yds (3200m)	500 yds (460m)
Nancy	4000 yds (3660m)	1000 yds (910m)
Simon	4000 yds (3660m)	1400 yds (1280m)
Encore	10,000 yds (9150m)	0
Grable	5000 yds (4570m)	500 yds (460m)

- BCT Baker

  412th Engr Const Bn
  360th Engr Util Det
  705th Engr Fld Maint Plt
  505th Sig Co

Figure 2-1 shows the locations of ground zero, the trench area, the maneuver scheme, and the display area.

The orientation/rehearsal was held at the shot area on 14 March. The troops spent a total of about four hours in the shot area on this day, experiencing a simulated countdown and rehearsing the post-shot maneuver. The objective was about 1200 yards west of ground zero (Figure 2-1). For the rehearsal, the advances continued for only 1000 yards toward the objective. The troops then toured the equipment display area to observe the emplaced equipment, following which they returned to Camp Desert Rock.

Shot Annie was detonated on schedule at 0520 hours on 17 March. The troops were crouched in trenches 3500 yards from ground zero. After the blast wave passed, the troops were permitted to stand and watch the rising fireball. They climbed out of their trenches and started moving forward at 0535 hours (Reference 1).

Both BCTs reached their objectives at about 0630, where they remained for an estimated 5 minutes before departing for the display area (see Section 4.1.1 for discussion of the scenario). The troops would have followed the 2.5 R/hr contour around to the display area, reaching it before 0700. After visiting each display from 1000 yards to 3500 yards for an estimated 5 minutes, the BCTs reached the entrucking area (near the trenches) at about 0800. Following personnel decontamination and monitoring, the troops boarded the trucks and cleared the area by 0905 (Reference 8).

2.4.2 Shot Nancy

At Shot Nancy, Exercise Desert Rock V activities included troop maneuvers, the volunteer officer observer program, the troop observer program, an operational helicopter test, and damage effects evaluation. Of the approximately 2,860 personnel involved, 2,349 troops participated in the tactical troop maneuver. The origin of each BCT was as follows:

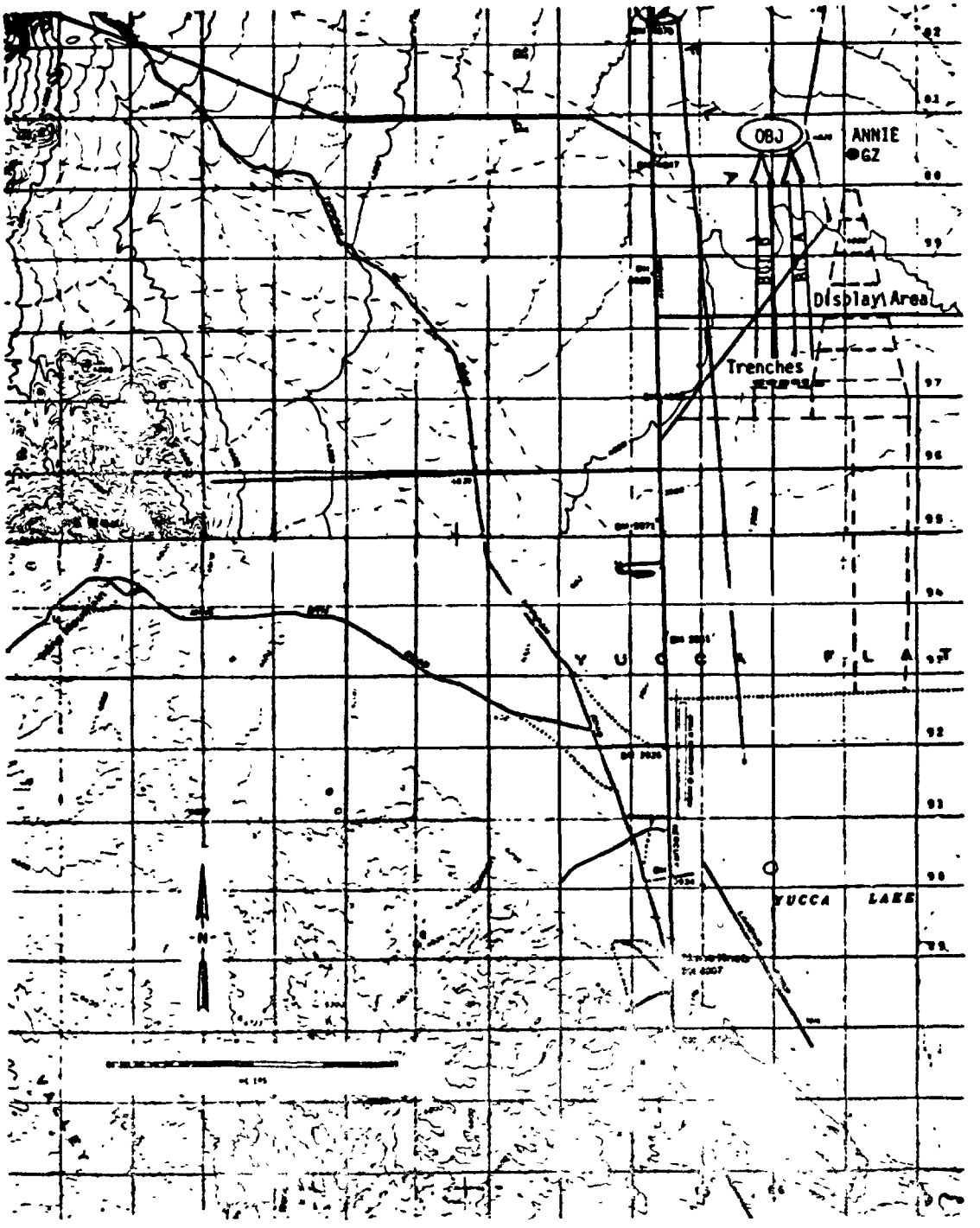

Figure 2-1. Shot Annie area and scheme of maneuver.

BCT-Able - Second Army, Fifth Army

BCT-Baker - Third Army, Sixth Army

The maneuver troops arrived at Camp Desert Rock on 20 March 1953. They underwent a four-hour orientation program, and on 22 March they participated in a full-dress rehearsal of the exercise in the actual shot area. Unlike the observer personnel, they did not visit the Shot Annie area.

At 0500 hours on 24 March, the exercise troops entered the trenches 4000 yards (3660 meters) south-southwest of ground zero (See Figure 2-2). At two minutes before the detonation, the troops were ordered to crouch low in the trenches and to remain in that position until after the detonation. The detonation occured on schedule at 0510 hours. At 0533 hours the BCTs began an attack on objectives 4000 yards (3660 meters) to the north. As the two BCTs headed toward their objectives, BCT-A had to sideslip its advance to the west because of radiation intensities. The troops were able to approach to within 500-700 yards (Reference 1 estimate) of their objectives before being halted by rad-safe personnel. According to References 1 and 9, some of the maneuver troops had exceeded the 2.5 R/hr rad-safe limit, up to 14 R/hr, before being halted. That BCT-A had sideslipped to the west with no reported violation of the rad-safe limit implies that BCT-A was well under the control of its rad-safe monitors. It is therefore assumed that the troops who entered the 14 R/hr radiation area were part of BCT-B. Commanders experienced some difficulty in withdrawing the troops from the high radiation area. However, according to Reference 1, "little time was spent in the area."

The troops withdrew from the high radiation area in what is estimated to have been 5 minutes, and the tactical phase of the maneuver was terminated. It is assumed that the troops followed the 2.5 R/hr contour to the display area, where they observed the effects of the shot on prepositioned equipment and test animals. The 1000-yard display was the closest display to GZ that the troops were able to visit, as deduced from the rad-safe data of References 1 and 13.

After touring the displays, the troops returned to the trench area and boarded trucks for the return to Camp Desert Rock. Shortly after 0800 hours, the units (observers first--Reference 17) began the return trip (Reference 1). The trench area was cleared by 0830 and all closed in Camp Desert Rock by 1032 hours (Reference 9).

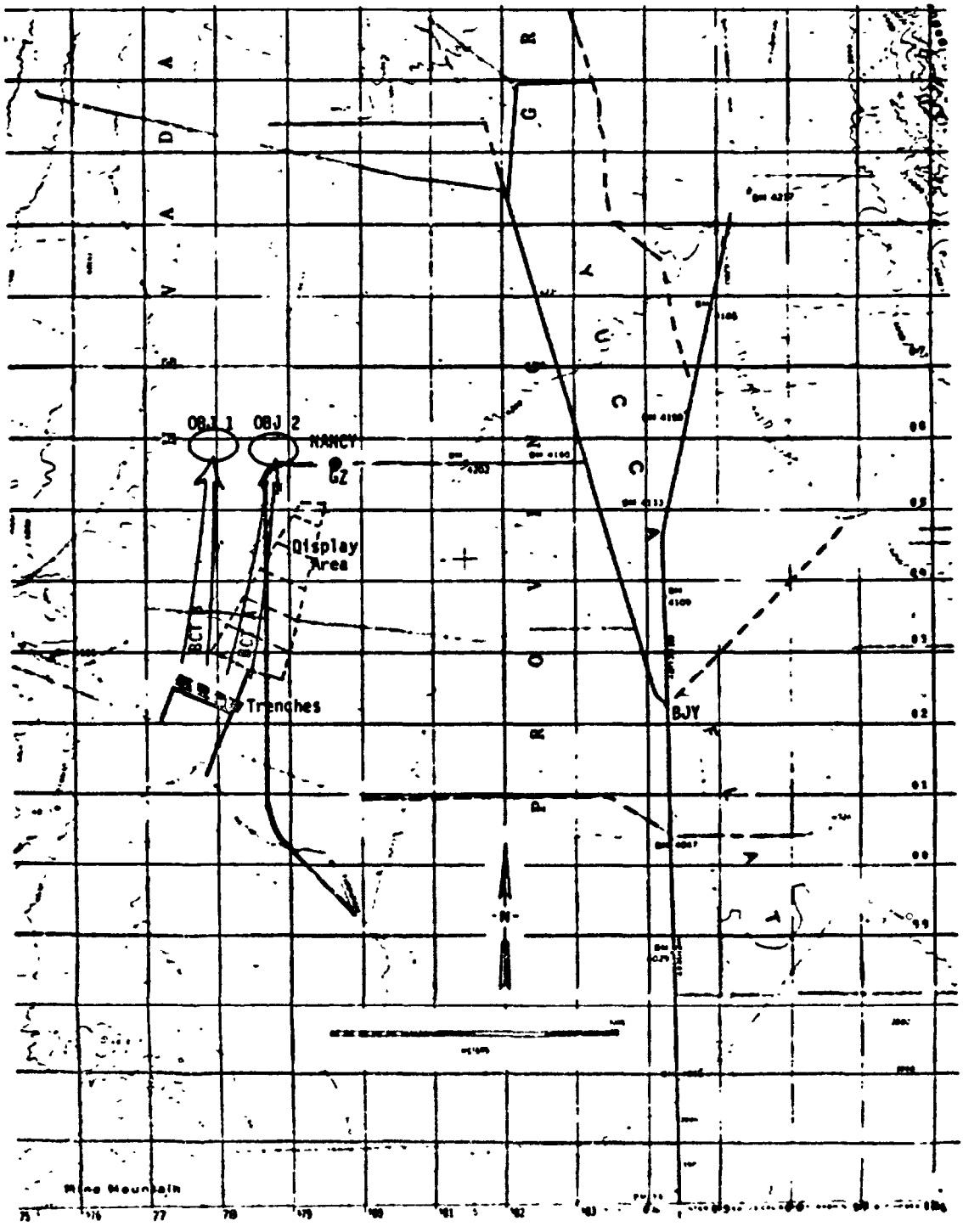

Figure 2-2. Shot Nancy area and scheme of maneuver.

2.4.3 Shot Simon

At Shot Simon, troop activities involved more than 3,000 personnel in tactical maneuvers, troop observer and volunteer officer observer programs, operational helicopter tests, and damage effects evaluation. The tactical troop maneuver, the largest Desert Rock program, engaged 2,450 Army personnel. The origin of each BCT was as follows:

BCT Able - Second Army, Sixth Army

BCT Baker - Fourth Army, Fifth Army

The rehearsal of the tactical maneuver was conducted in the shot area on 23 April. The planned maneuver consisted of an attack by BCT-A and BCT-B on an objective beyond and to the west of ground zero (GZ) immediately following the detonation (Figure 2-3). The troops spent approximately 4½ hours going through the attack and viewing the equipment display area. BCT-A was on the right (east) and BCT-B was on the left (west). Following seizure of the objective, the maneuver was to be terminated and the troops were to return to the display area to observe the damage to field fortifications positioned at 500-yard increments from 500 to 3500 yards from GZ.

Shot Simon (43 KT) was detonated at 0430 hours on 25 April 1953 from a 300-foot tower. At that time, BCTs A and B were crouched in trenches 4000 yards from GZ. The BCTs started their attack at 0444. BCT-A reached the 2.5 R/hr rad-safe limit before having advanced 2000 yards. As discussed in Section 4, a westward sideslip was likely attempted. Nonetheless, radiation intensities prevented reaching its objective, and a halt was called at 0600 hours. BCT-B was able to attain its objective (Reference 6) without encountering excessive radiation levels. Both BCTs then moved to the display area, where radiation levels permitted viewing of displays at 2000 yards and farther from GZ (Reference 1). They returned to the trench area and boarded trucks, which departed by 0815 hours (Reference 10). Because there was low-level residual radiation in the trench area, personnel and vehicle monitoring had to be performed elsewhere. Enroute to Camp Desert Rock, troops and vehicles stopped at the decontamination station near Yucca Pass for field decontamination and monitoring. Arrival at Camp Desert Rock was at about 1000 hours.

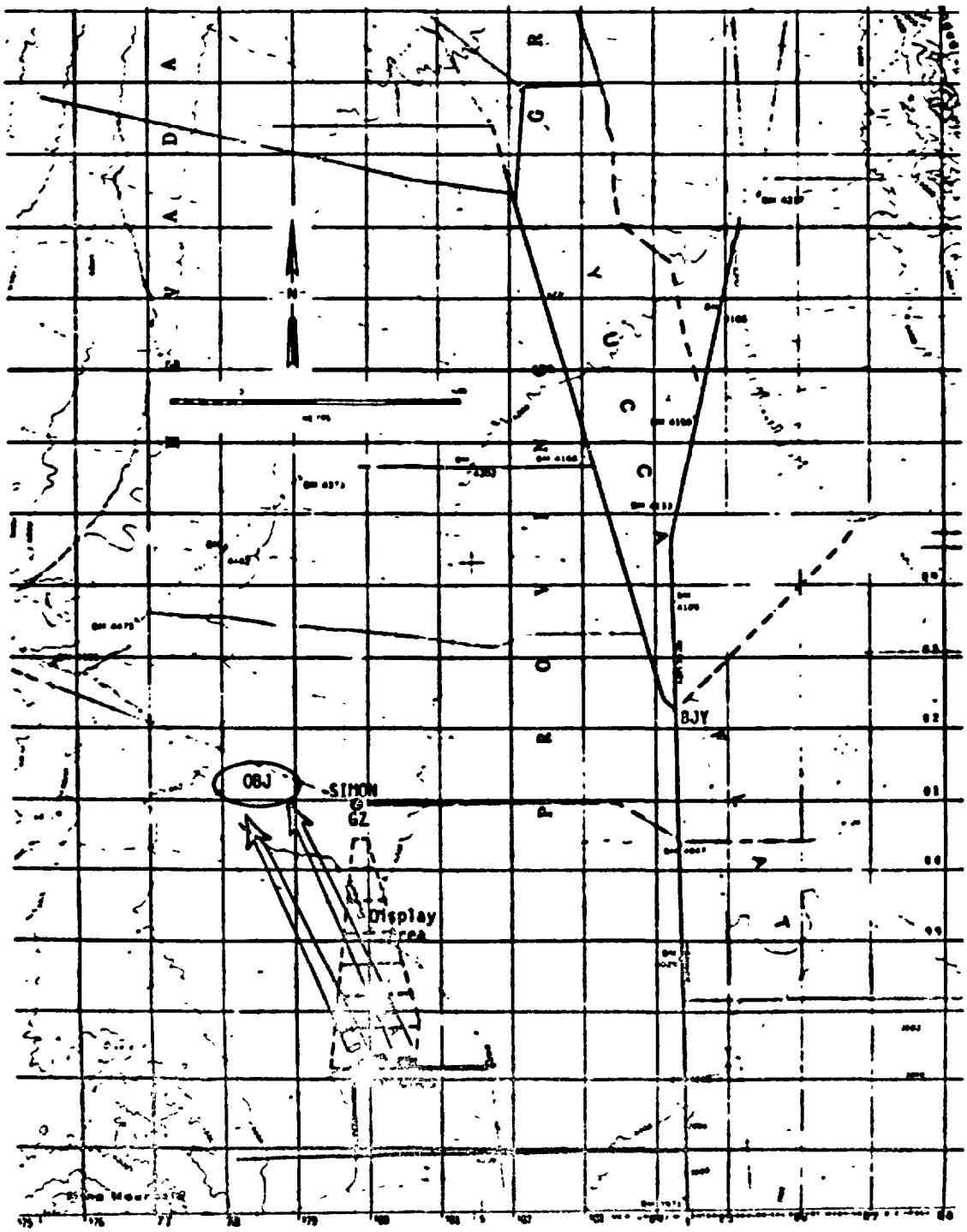

Figure 2-3. Shot Simon area and scheme of maneuver.

2.4.4 Shot Encore

At Shot Encore, more than 3,000 individuals took part in the troop observer program, troop maneuvers, operational helicopter tests, and damage effects evaluation. Desert Rock troop maneuvers, the largest single program conducted at Encore, involved 2,475 men, including 326 Air Force participants. Participants were organized into two BCTs. The origin of each BCT was as follows:

BCT Able - First Army, Fourth Army

BCT Baker - Third Army, Air Force

Most of the troops arrived at Desert Rock between 2 and 4 May. A full-scale rehearsal was conducted on 5 May in Frenchman Flat. Actual shot day procedures were followed during the rehearsal. The locations of ground zero, the troop trenches, the maneuver area with Objectives 2 and 4, and the equipment display area are shown in Figure 2-4.

The airdropped nuclear device detonated at 0830 hours on 8 May 1953 at a height of 2423 feet above Frenchman Flat and some 280 yards south of the intended GZ. Its yield was 27 KT. At shot time, BCTs Able and Baker were in the trenches 10,300 yards (9420 meters) southwest of the intended ground zero. Five minutes after the shot, the BCTs began their attack towards Objectives 2 and 4 with BCT-A on the right and BCT-B on the left. At 0843 hours, seven helicopters arrived at the trench site to begin the airlift of two platoons (60 men) to the landing zone at Objective 4. This move was conducted in two lifts and was completed by 0912 hours. Upon arrival at the landing zone, the platoons deployed and moved toward the intended ground zero, arriving there at 0932. They noted that radiation levels were 260 mR/hr (Reference 1). Meanwhile, the BCTs were moving towards their objectives. They reached Objective 2 at 0943 hours and secured Objective 4 at 1045 hours. This concluded the tactical phase of the exercise (Reference 1).

Following the maneuver, the BCTs began their tour of the display area to observe the post-shot condition of the equipment that had been subjected to the effects of the nuclear detonation. They reached the 500-yard line (from the intended GZ) at 1115 hours (Reference 11) and moved through the display area to the 2000-yard line,

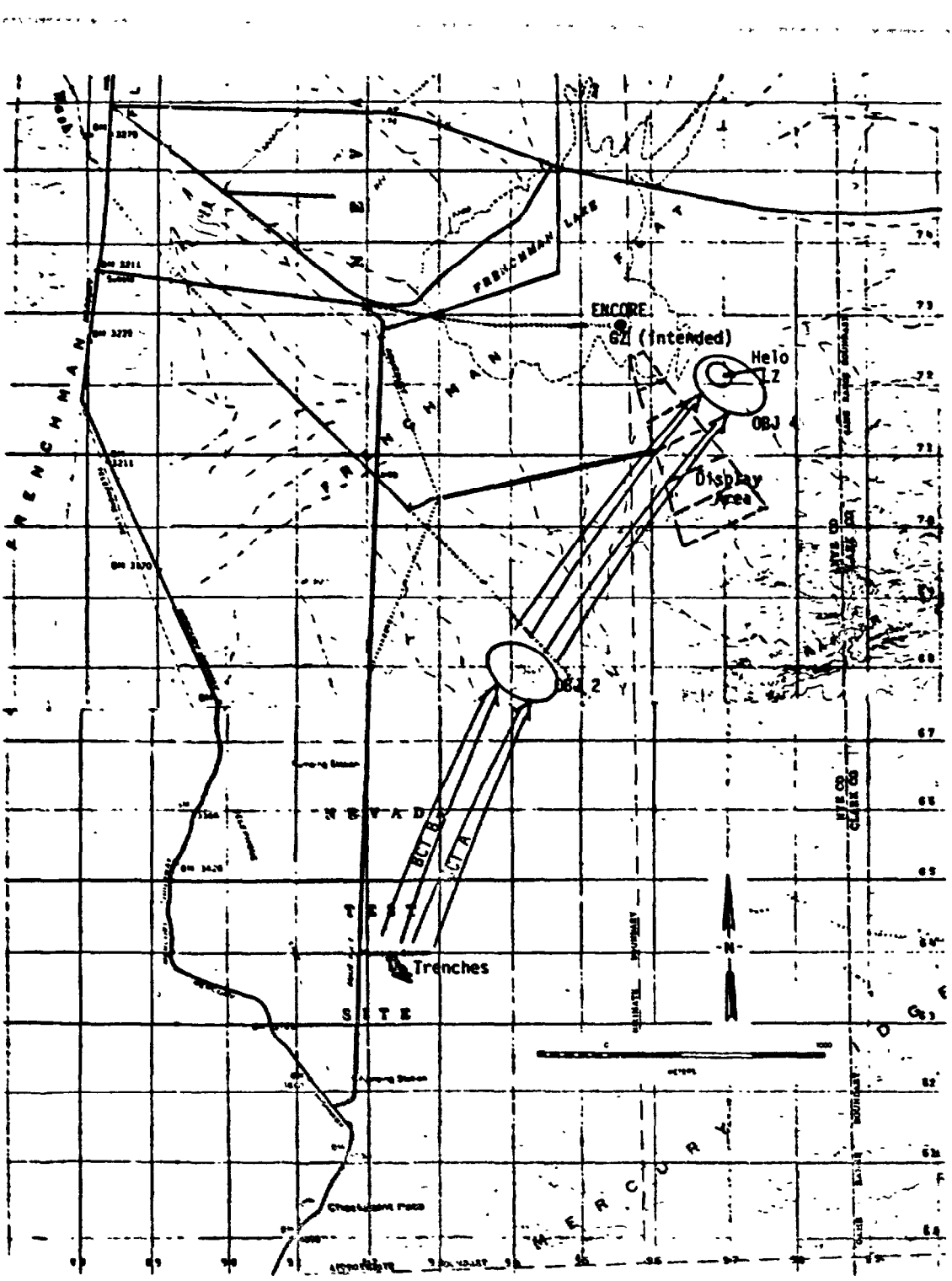

Figure 2-4. Shot Encore area and scheme of maneuver.

where the trucks were waiting to return them to Camp Desert Rock. The truck ride back took about an hour; all units were back in camp by 1414 hours (Reference 1).

2.4.5 Shot Grable

This concluding shot with Desert Rock V involvement had nearly 3400 personnel participating in tactical troop maneuvers, the troop observer program, and damage effects evaluation. The troop maneuver activities involved 2670 personnel in two BCTs. The origin of each BCT was as follows:

BCT Able - Third Army, Fourth Army, Sixth Army

BCT Baker - First Army, Second Army, Fifth Army

The troops arrived at Camp Desert Rock on and shortly after 18 May 1953, and were given an orientation on 20 and 21 May (Reference 1). The BCTs conducted a full-scale rehearsal on 23 May. The troops were transported from Camp Desert Rock to the trench area in Frenchman Flat (a distance of approximately 12 miles) shown in Figure 2-5. There they rehearsed the shot day procedures, including trench procedures, and the maneuver toward objectives to the southeast of the shot area. Afterwards, the troops moved into the equipment display area, but severe dust conditions limited the movement through the area.

Reference 2 notes that the troops also visited another display area--the damage area of Shot Harry, a 32 KT device fired in Area 3 on 19 May. Due to their other commitments, described above, the troops could have inspected the Harry post-shot display no earlier than 22 May. This date is used to provide the highest residual radiation intensity in the Harry display area (see Section 4.1.5). The reference states that they approached to within 500 yards of GZ; it is estimated that they stayed in the Harry area no more than 2 hours.

At shot time, 0830 hours on 25 May, BCTs A and B were in trenches 5000 yards (4570 meters) west of ground zero, having arrived there from Camp Desert Rock several hours before the shot (Reference 1). All personnel were permitted to rise and observe the fireball 3 seconds after the detonation and prior to the arrival of the blast wave. Ten minutes after the shot, the BCTs began their attack, proceeding from the

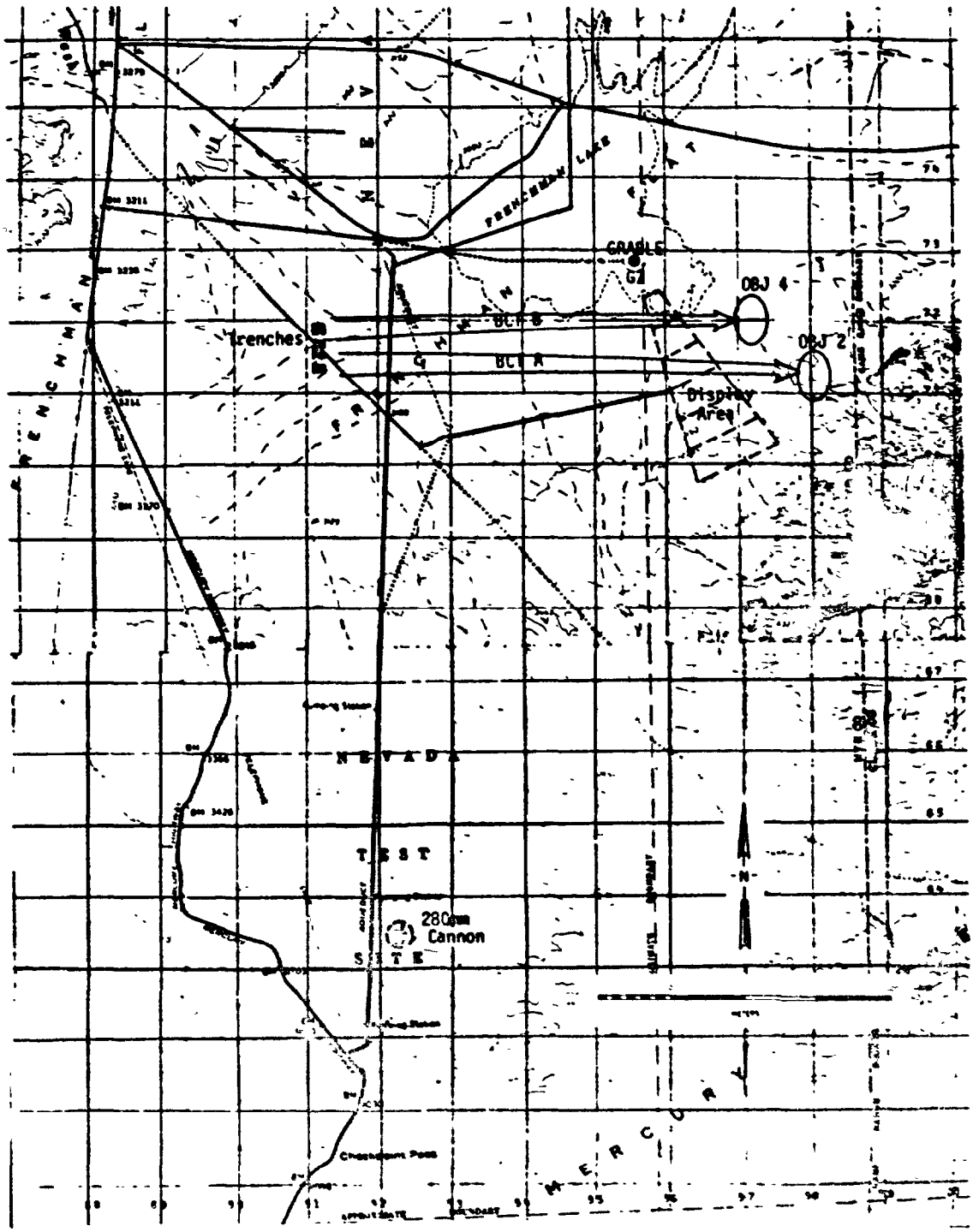

Figure 2-5. Shot Grable area and scheme of maneuver.

trench area toward Objectives 2 and 4 (Figure 2-5). BCT-B, on the left (north), passed 800 yards to the south of ground zero (Reference 2), while BCT-A, on the right, passed further south at about 1600 yards from GZ, as shown in the figure.

Due to the reported high winds and the resultant surface dust conditions, the attack was halted at 0950 hours, as the troops arrived at the display area (Reference 1). Personnel from BCT-B were taken through a portion of the equipment display area, but BCT-A was unable to proceed into the display area due to the intense dust conditions. Some portion of BCT-B visited the 500-yard display (Reference 1). The vehicles were brought to the predesignated pick-up point where the troops loaded up for the return to Camp Desert Rock. Departure from Frenchman Flat was at 1225 hours (Reference 12), although BCT-A could have departed as early as the observers, 1100 hours (References 1, 20). In any case, all troops would likely have returned to Camp Desert Rock before 1300 hours. Departure for home stations was on the following day (Reference 2).

SECTION 3
INITIAL RADIATION

Shots Annie, Nancy, Simon, and Grable are investigated to determine the dose resulting from possible exposure of maneuver troops to initial gamma and neutron radiation. For Shot Encore, the troop distance at the time of detonation was so great that initial radiation doses were insignificant. This section discusses the general method used to compute the initial radiation dose to personnel. The specific doses received at each of the shots of interest are the same as for the troop observers (Reference 22), which are summarized.

3.1 COMPUTATIONAL METHOD

Because the personnel were located in trenches at the times of detonation, the calculation of the radiation doses for maneuver troops 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 26) and ATR4.1 (Reference 27). 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 28), 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 26).

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 29), which incorporates these improvements, with ATR-generated infinite air calculations. This factor varies approximately from 1.0 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 30) 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 as well as geometric and meteorological data. For the shots of interest, the general source of neutron spectral information for the device is given in Reference 22. Meteorological and geometric (e.g., height of burst, ground zero elevation) data are taken from References 32 and 33. 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 measurements were made during this nuclear test series for precise confirmation of calculated neutron doses (References 34, 35, 36). There is an abundance of free-field gamma dose data available (References 31, 37, 38), however, and these are utilized to verify the ATR results.

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 to Reference 22.

Maneuver troops were in trenches approximately two feet wide and five feet deep, and at ranges of 3500-5000 yards (3200-4570 meters). The in-trench free-field neutron and gamma doses are calculated at depths of 2.33 feet. This depth corresponds approximately to the mid-torso depths of personnel crouched in the trenches. The following trench factors are used in this report:

Radiation Type	Trench Factors
Neutron	0.25
Secondary gamma	0.015
Local gamma	0.08
Debris gamma	*

*The debris gamma trench factors are time-dependent; they are discussed in detail in Reference 22.

The in-trench dose (in rads) is converted to an equivalent tissue dose (in rem) using the quality factors and methods prescribed in Reference 39. The rad-rem conversion factor for neutrons, derived from calculations utilizing computer codes DOT and MORSE (Reference 40), 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 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
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

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 debris gamma dose, however, is delivered over a period of many seconds. Therefore, the possibility of individual reorientation (e.g., standing up) in the trench must be considered. For an individual crouched in the trench at times $t < t_o$ and standing upright in the center of the trench facing the rising cloud at times $t > t_o$, the film badge dose due to debris gamma is calculated by:

$$D_d(t_o) = F_c \int_o^{t_o} T_c(t) I_d(t) dt + F_u \int_{t_o}^{\infty} T_u(t) I_d(t) dt, \quad (1)$$

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.
t_o = standup time

The trench factors $T_c(t)$ and $T_u(t)$ are discussed in Appendix I to Reference 22. Intensities $I_d(t)$ are calculated with computer codes NUIDEA (Reference 41) and ATR4 (Reference 26) for the shots of interest. The film badge conversion factors F_c and F_u were discussed previously. For Shots Annie, Nancy, and Simon, t_o is assumed to be 3 seconds after passage of the blast wave. This is the same assumption that was made for the troop observers in Reference 22. For Shot Grable, the troops were allowed to rise and observe the fireball at H+3 seconds, prior to the arrival of the blast (Reference 1).

3.2 RESULTS

For each shot, the maneuver troops occupied the same trench system as did the troop observers. The same assumptions are made for stand-up times and crouch positions. Thus, the initial radiation doses for maneuver troops are calculated to be the same as for the observers. Previously reported in Reference 22, these doses are summarized in Table 3-1.

Table 3-1. Summary of initial radiation doses.

Shot	Tissue Dose Above Trench (mrad)		Dose Equivalent in Trench (mrem)	
	Neutron	Gamma	Neutron	Gamma
Annie	5	300	16	11
Nancy	<1	90	<1	4
Simon	1	200	3	11
Grable	<1	4	<1	<1

SECTION 4
RESIDUAL RADIATION

4.1 RESIDUAL GAMMA EXPOSURE

Gamma doses are reconstructed for maneuver troops, based on their activities in the fallout and neutron-induced activity fields of Shots Annie, Nancy, Simon, Encore, and Grable. A computerized methodology, described in Reference 23, 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.

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 24: 1 R/hr → 0.7 rem/hr (the calculated film badge dose is identical to the "film badge equivalent dose" of Reference 24). 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 maneuver troop 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.

Dose calculations are categorized by the shot in which each maneuver troop unit participated. In one instance, there is a contribution from a previous shot to the dose—when the BCTs visited an old display area. Rehearsals were on essentially uncontaminated terrain. No prior shots of Upshot-Knothole had resulted in fallout on maneuver areas; the neutron-induced activity from Encore had nearly all decayed in the 15 days before the Grable rehearsal.

Because of limited data concerning the details of troop location and the timing involved, estimates are required for various parameters. Rates of movement are estimated from planned times or the few reported times, the locations of attack

objectives, 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 70 yds/min walking speed and 5 minutes at the objectives (or where maneuvers were halted) and at each display. The stay time allows for some lateral movement of the troops at each display arc.

Gamma intensities are calculated primarily from radiation survey data obtained by the AEC Rad-Safe Unit (Reference 13). Few specific measurements by Desert Rock rad-safe personnel are available. However, reported locations of rad-safe limits and other 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 too sparse to define an intensity field, comparisons with the AEC data are possible at specific locations. Thus, if the AEC data insufficiently define the intensity field in the Desert Rock display sector, Desert Rock data can supplement the AEC data to assist in characterizing the environment.

Radiation safety limits for maneuver troops were specified in References 16-20. The references identify the 2.5 R/hr iso-intensity line as being the forward limit of observer and troop movement through the display area. In the maneuver area, the BCTs were to change their direction of advance upon approaching 2 R/hr. It is presumed that subsequent movement to the 2.5 R/hr level was permitted. Movements from the objectives to the display areas are not specified, but must have required indirect routes in some cases because of rad-safe limits. For these cases, it is assumed that the BCTs minimized their march distances by keeping close to the 2.5 R/hr limit until the displays were reached. Late in Operation Upshot-Knothole, the limits on radiation intensity were discarded, but the limit on total dose of 6 rem for Desert Rock V continued in force. Only at Shot Grable did this change influence the movement of maneuver troops.

4.1.1 Shot Annie

The time/location scenario used in this analysis for BCTs A and B at Shot Annie is developed from several sources. Reference 1 states that the objective was reached at 0700 hours, personnel entrucked at 0800, and all units closed at Camp Desert Rock at 1040. However, the first two times are incompatible with the distance covered and the assumed march speed (70 yds/min) for the maneuver troops. A minimum of 1

hour would be required at this march speed just to move from the objective area to the truck area, even if there were no stopping at the objective area or at any of the displays. If the 70 yds/min march speed is assumed for both the attack and the walk-through, the objective would have been reached at about 0625 and the entrucking area at about 0800, with 5-minute stay times assumed at the objective area and at each of the display lines. This allows time for departure from the area prior to 0905 (Reference 8 states that the area was cleared by 0905) and arrival at CDR prior to 1040. This scenario also extends the time that the troops were in the fallout area, and thus tends to high-side the doses. It is likely that the entrucking time of 0800 marked the start of entrucking activity, which stretched over some period of time and initially involved only observer personnel (in accordance with Reference 16).

Figure 4-1 shows the attack and walk-through routes of BCT-A and BCT-B with residual radiation contours for H+1 hour (0620 hours) superimposed. Using the scenario and march rates described in Section 2.4.1, the BCTs arrived at the display area at about 0700. By this time, the 10 R/hr contour for H+1 would have decayed to 9 R/hr (neutron-induced activity dominated this portion of the radiation field). Figure 4-1 thus indicates that the 500-yard display could not be visited. Despite their maneuver, the BCTs would have reached the innermost displays in advance of the observers, who were halted by rad-safe personnel in the display area at 700 yards from GZ (Reference 1). However, Reference 1 also states that Desert Rock rad-safe monitors reached one corner of the 500-yard display at the 2.5 R/hr limit in their initial survey. If this value is correct (in contrast to the AEC data), the halt of the observers suggests that there were no displays in that corner. For the present calculation, it is assumed that the BCTs halted for 5 minutes at the 2.5 R/hr line in the display area before proceeding to the 1000-yard display.

Calculated film badge doses are 800 mrem for BCT-A and 690 mrem for BCT-B, almost all from the movement to and through the display area.

4.1.2 Shot Nancy

Figure 4-2 shows the attack route of BCT-A and BCT-B with residual radiation contours for H+1 hour (0610 hours) superimposed. The assumed scenario has BCT-A encountering intensities of 2.0 - 2.5 R/hr at about 0610 hours. BCT-A then sideslipped to the west, at or near the rad-safe limit, apparently halting when BCT-B was

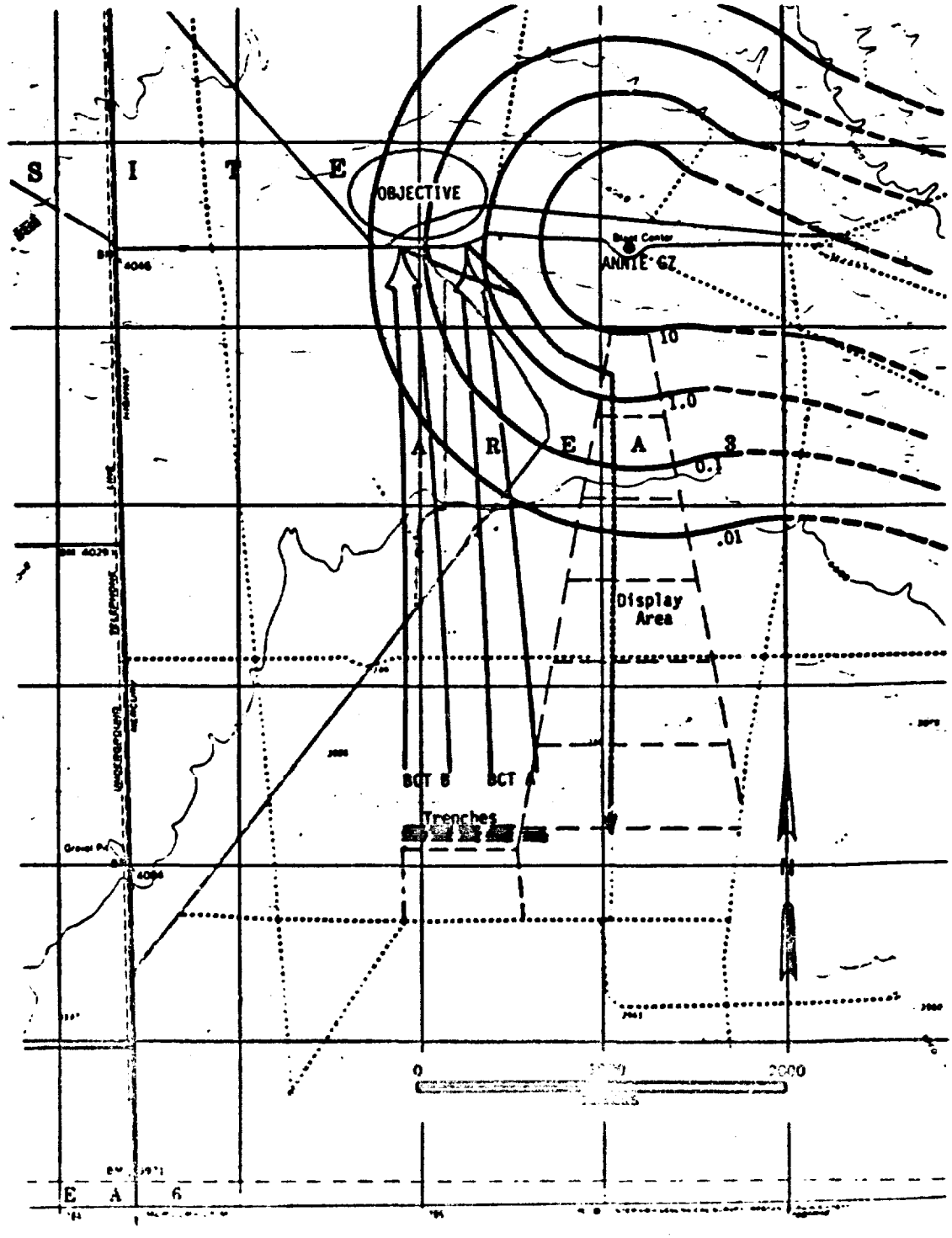

Figure 4-1. Shot Annie residual radiation (R/hr @ H+1) and maneuver troop routes.

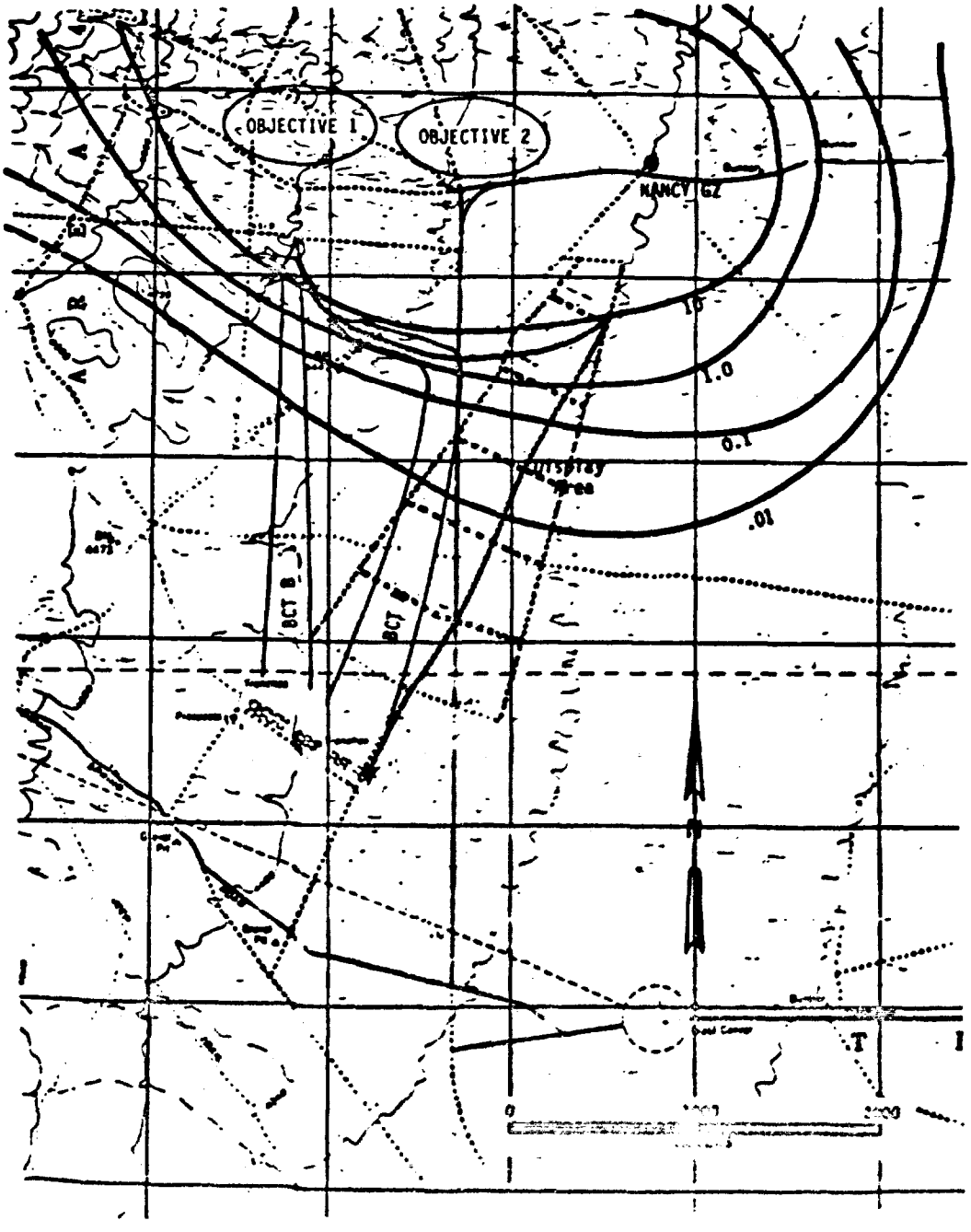

Figure 4-2. Shot Nancy residual radiation (R/hr @ H+1) and maneuver troop routes.

approached. As discussed in Section 2.4.2, some elements of BCT-B went beyond the 2.5 R/hr limit to an intensity of 14 R/hr. Therefore, three cases are assessed: BCT-A, BCT-B (forward--went to 14 R/hr), and BCT-B (rear). In the second case, the troops are assumed to have withdrawn toward the rad-safe limit after a stay time of 5 minutes at 14 R/hr. In the third case, the troops are assumed to have maintained an estimated 300-yard battalion depth and, after a 10-minute stay, followed in formation toward the display area.

The rest of the scenario is based on the assumption that both BCTs followed the 2.5 R/hr contour to the east until reaching the 1000-yard display. Reference 1 states that Desert Rock rad-safe monitors reached the 2.5 R/hr limit in the display area at 850 yards on the east and 1250 yards on the west. The AEC rad-safe data also indicate that a portion of the 1000-yard display was available to the BCTs within the rad-safe limit. For the assumed march speed and stay times, return to the trench area would have been at about 0800, which is consistent with the 0830 departure for Camp Desert Rock.

Despite the availability of rad-safe data from several surveys of the Shot Nancy residual radiation field, the initial survey alone is used for dose calculations. This is the survey that best reflects the unusually steep intensity gradient that the troops encountered (Reference 9 indicates that monitors in advance of the BCT reached 40 R/hr). The impact of later survey data is discussed in Section 5. In the display area, the initial survey is in essential agreement with intensities obtained from analysis of all the data (compare to Reference 22).

Calculated doses are as follows: BCT-A, 1.3 rem; BCT-B (forward), 2.2 rem; and BCT-B (rear), 1.0 rem. In each case, nearly 1 rem was accrued during movement toward and through the display area.

4.1.3 Shot Simon

The radiological survey data for Shot Simon are somewhat limited. The few surveys and lack of survey lines on isointensity contour plots by the AEC Rad-Safe Unit increase the uncertainty in the radiation field. However, some Desert Rock data are useful. The initial survey of the display area by teams of the 50th Chemical Platoon began at H+15 minutes (0445). Jeep-mounted teams proceeded northward on the radial roads bounding the area (165° and 185° from GZ) until 5 R/hr was reached. (Desert Rock

rad-safe personnel in vehicles were authorized this intensity.) Lesser intensities, including the 2.5 R/hr points, were marked enroute. It is assumed that the 5 R/hr and 2.5 R/hr intensities, whose locations are reported in Reference 1, were measured at about H+30 minutes.

The residual radiation contours established by the AEC initial survey are shown on Figure 4-3. The survey began at 0450 hours and was completed at 0715 hours. Despite the radiological decay during this interval, the contours were based on raw readings rather than on readings normalized to a common time base. Reference 13 indicates that high intensities east of GZ delayed access to the survey lines north of GZ. Evidently, the southern part of the shot area was surveyed in the usual time, by about H+1 hour.

Direct comparison of the two initial surveys, without adjustment for the timing of survey measurements, is as follows:

Radial	50th Chemical Platoon	Rad-Safe Unit (Interpolated to Same Distances)
165°	5 R/hr at 2000 yards	4 R/hr
	2.5 R/hr at 2200 yards	2 R/hr
185°	5 R/hr at 2100 yards	2.8 R/hr
	2.5 R/hr at 2500 yards	0.8 R/hr

The agreement along the 165° radial suggests that the Rad-Safe Unit surveyed along this radial at about the same time as did the 50th Chemical Platoon. The disagreement along the 185° radial suggests that the Rad-Safe Unit surveyed this radial later than did the Desert Rock team, or merely interpolated from other radials.

Dose calculations are performed using the initial survey of the Rad-Safe Unit, taken to be at H+1 hour. Uncertainties in dose from the uncertain timing are discussed in Section 5. With insufficient surveys to determine actual radiological decay, the standard $t^{-1.2}$ relationship is used. Based on low-level wind data, fallout at troop locations began about H+15 minutes; for high-siding the calculations, fallout deposition is taken to be complete at that time. Although there was low-level residual radiation in the trench area at the time of departure from the area, essentially no additional dose was accrued after the troops boarded the trucks at the end of their walk through the display area.

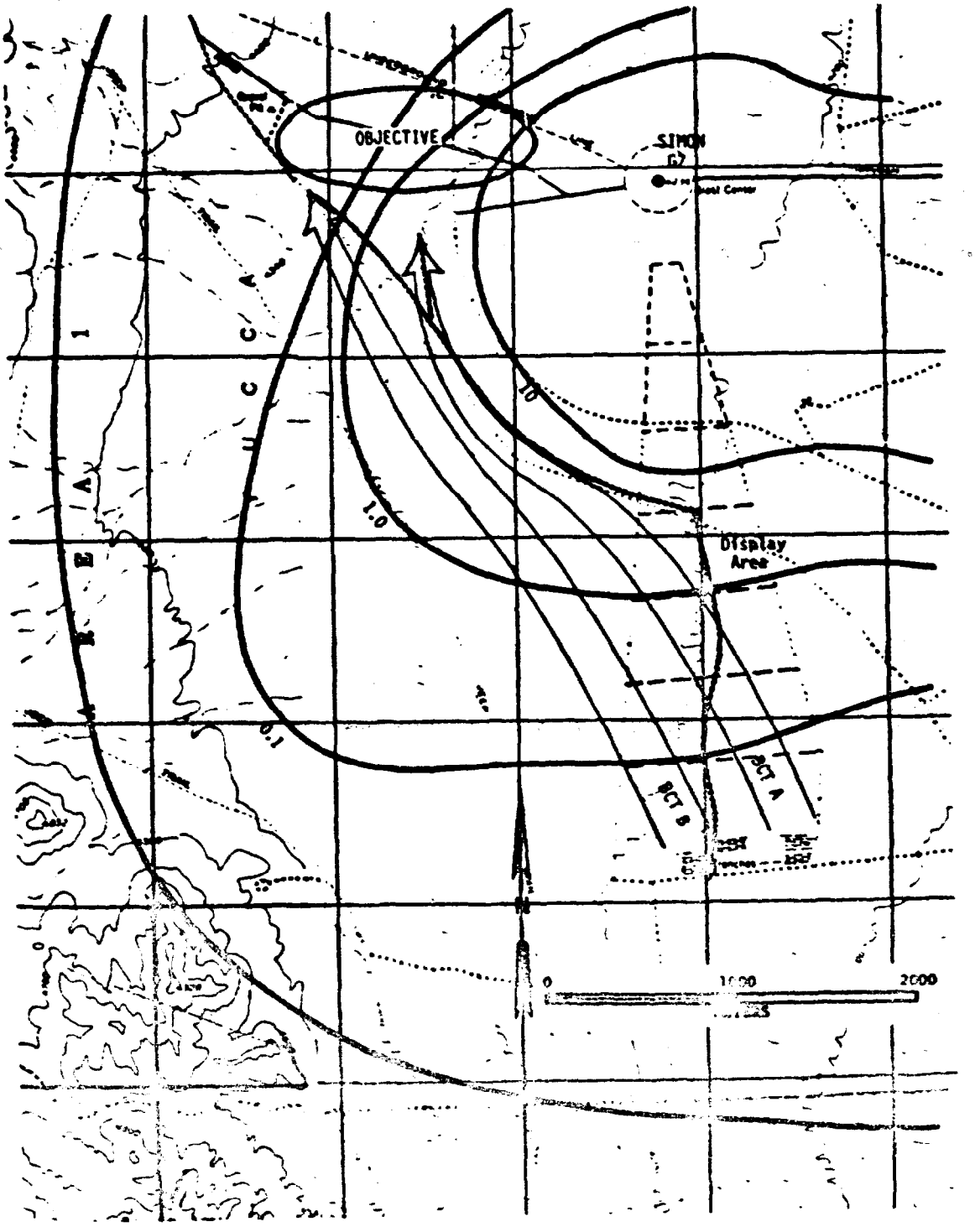

Figure 4-3. Shot Simon residual radiation (R/hr @ H+0:20 to 2:45) (Ref. 13) and maneuver troop routes.

Available references provide some description of the BCT movements. References 1 and 10 state that BCT-A advanced to within 2000 yards of GZ at 0600 hours, and that the attack was halted there due to a reading of 2.5 R/hr. While the location of the halt is unspecified, its timing of H+1½ hours suggests that BCT-A had nearly reached its portion of the objective. As calculated from the AEC survey contours, the halt may have been as close as 1400 yards to GZ. The rad-safe limit of 2.5 R/hr would have been reached on a direct approach, but skirting to the west (Reference 18) to avoid excessive intensities would have brought BCT-A near the objective without exceeding the limit. Caution during this part of the advance would have reduced the rate of march and makes the 0600 halt time reasonable for being near the objective. The return to the display area would have nearly retraced the attack path along the 2.5 R/hr isopleth. All display area intensity data are consistent with the statement in Reference 1 that the 2000-yard display was the closest (to GZ) that the troops visited. For the normal rates of movement, arrival at the trench area would have been at about 0730, consistent with the departure from the area of all units by 0815 (Reference 10).

Reference 6 states that BCT-B reached the attack objective, and Reference 1 indicates that no radiological difficulties were encountered. Although the attack route was west (farther from GZ) of BCT-A, BCT-B apparently approached maximum permissible radiation intensities late in its attack (see Figure 4-3). In seeking a direct route from the objective to the display area, the rad-safe limit would have been soon encountered. A southward detour, keeping to 2.5 R/hr, has BCT-B just ahead of BCT-A on its return track.

With these attack and walk-through scenarios, the calculated doses are 3.1 rem for BCT-A and 2.2 rem for BCT-B. While most of the BCT-B dose was from the return to the display area, the additional dose to BCT-A resulted from its proximity to the rad-safe limit during much of the attack as well.

4.1.4 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 and indicate that the actual GZ was approximately 280 yards to the

south (see Figure 4-4). Several readings at the intended GZ, from different sources, are used to determine the relative intensity of gamma radiation from Mn^{56} and Na^{24} for all times. Figure 4-4 is used in conjunction with this radioactive decay function to determine the intensities encountered by the troops during their attack and their inspection of the displays.

Dose calculations are made for the troop maneuver and tour of the display area for the three elements of the maneuver force: i.e., the helilifted platoons, BCT-A, and BCT-B. For each element, the tour of the display area is as shown in Figure 4-4, with a 5-minute halt assumed at each display line. The greater number of displays for the military effects shots in Frenchman Flat led to this type of walkthrough.

The helilifted platoons departed Objective 4 at 0912 and arrived at the intended GZ at 0932 (Reference 1). In walking to the intended GZ (where a 5-minute wait is assumed) and then to the display area, the platoons passed near the actual GZ, where the radiation intensity was about 300 mR/hr. Because of the considerable height of burst, the intensities were fairly uniform from the intended GZ through the 500-yard display line (about 200 yards from the actual GZ). The platoons viewed displays at least to the 2000-yard line, which was the truck loading area for the return trip. They would have arrived at the loading area after 1100 hours. The radiation dose calculated for the helilifted platoons is 130 mrem.

BCT-A encountered peak residual radiation of less than 1 mR/hr as it advanced through the display area at about the 2000-yard line and halted at Objective 4 at 1045 hours. Although passing closer to GZ while approaching Objective 4, BCT-B encountered radiation levels that were still insignificant. It is assumed that the troops then moved straight to the 500-yard display, in order to arrive there at about 1115 hours (Reference 11). Viewing the displays through the 2000-yard line would have led to an arrival at the loading area by 1230 hours. This time is consistent with the 1414 hours return to Camp Desert Rock. The calculated dose for both BCTs is 60 mrem.

4.1.5 Shot Grable

Residual radiation was encountered by the BCT troops in two locations: Area 3 on 22 May to view the Harry post-shot damage, and Frenchman Flat on 25 May when maneuvering and subsequently inspecting the equipment display following Shot Grable.

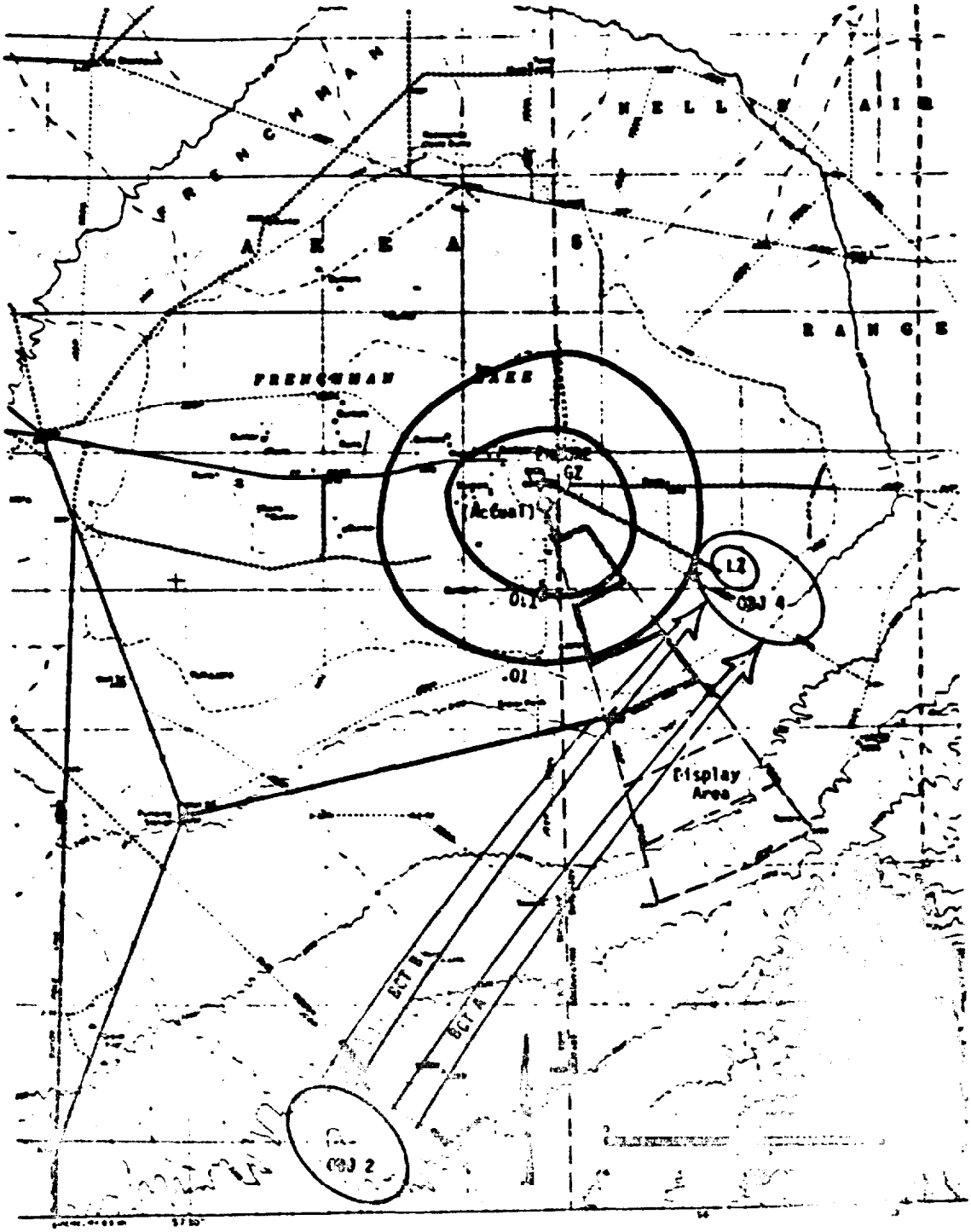

Figure 4-4. Shot Encore residual radiation (R/hr @ H+1) and maneuver troop routes.

The Shot Harry residual radiation at H+80 hours, as determined in Reference 22, is shown in Figure 4-5, together with the display area. The H+80 intensities are used to determine the dose accrued by the BCT troops on the afternoon of D+3, the day that they visited the Shot Harry display. Comparison of survey data (Reference 13) clearly shows the residual radiation in the display area to be primarily due to soil activation. For activated Nevada soil, the major source of contamination on D+3 is Na-24 ($t_{1/2}$=15 hours). Intensities are high-sided by assuming no H+1 contribution from the faster-decaying Mn-56. Therefore, D+3 (H+80) intensities are less than the intensities shown in the figure by a factor of 40. The same scenario as for the maneuver troops was applied to Grable observers at Harry in Reference 22; the resulting film badge dose of 0.03 rem is equally applicable to the BCTs.

Figure 4-6 shows the residual radiation contour lines for Shot Grable at H+1 hour. Normalization to actual times used in the analysis is based on the decay rates of Na-24 and Mn-56, the activation products that produced the gamma intensity during the period of the initial survey. These two radioisotopes are taken in the proportion that leads to the composite decay best fitting all survey data (through the automated procedure).

The Grable maneuver was terminated at the time that the BCTs were near their closest proximity to GZ--1600 yards for BCT-A and 800 yards for BCT-B. The maximum radiation intensity experienced by BCT-A was 0.04 R/hr, leading to less dose than was accrued at Harry. BCT-B happened to approach the 2.5 R/hr rad-safe limit that was no longer current. The elements of BCT-B that reached the 500-yard display, where the calculated intensity was 14 R/hr, were exposed to the same radiation levels as some elements at Shot Nancy. Calculated film badge doses, including the Shot Harry contribution, are 0.04 rem, 0.47 rem, and 1.9 rem for BCT-A, BCT-B, and BCT-B (500 yard), respectively.

4.2 INTERNAL RADIATION EXPOSURE

While operating in residual radiation fields, troop maneuver personnel were subject to an internal dose commitment from the inhalation of airborne radionuclides. Internal dose commitments for volunteer and service observers were investigated and reported in Reference 22, and shown to be on the order of 1 mrem or less. The internal dose pathways for maneuver troops were the same as some of these pertinent to

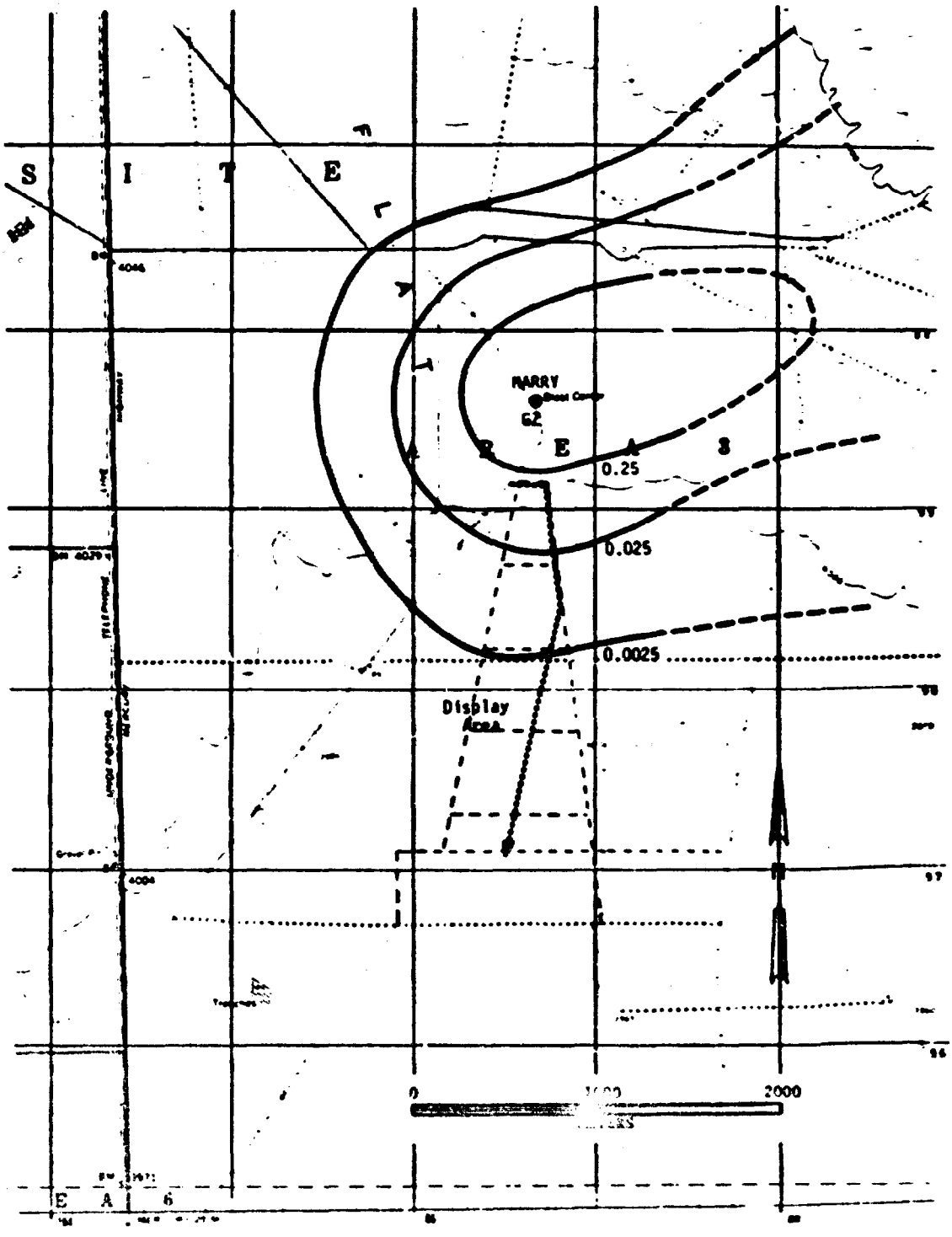

Figure 4-5. Shot Harry residual radiation (R/hr @ H+80) and troop route.

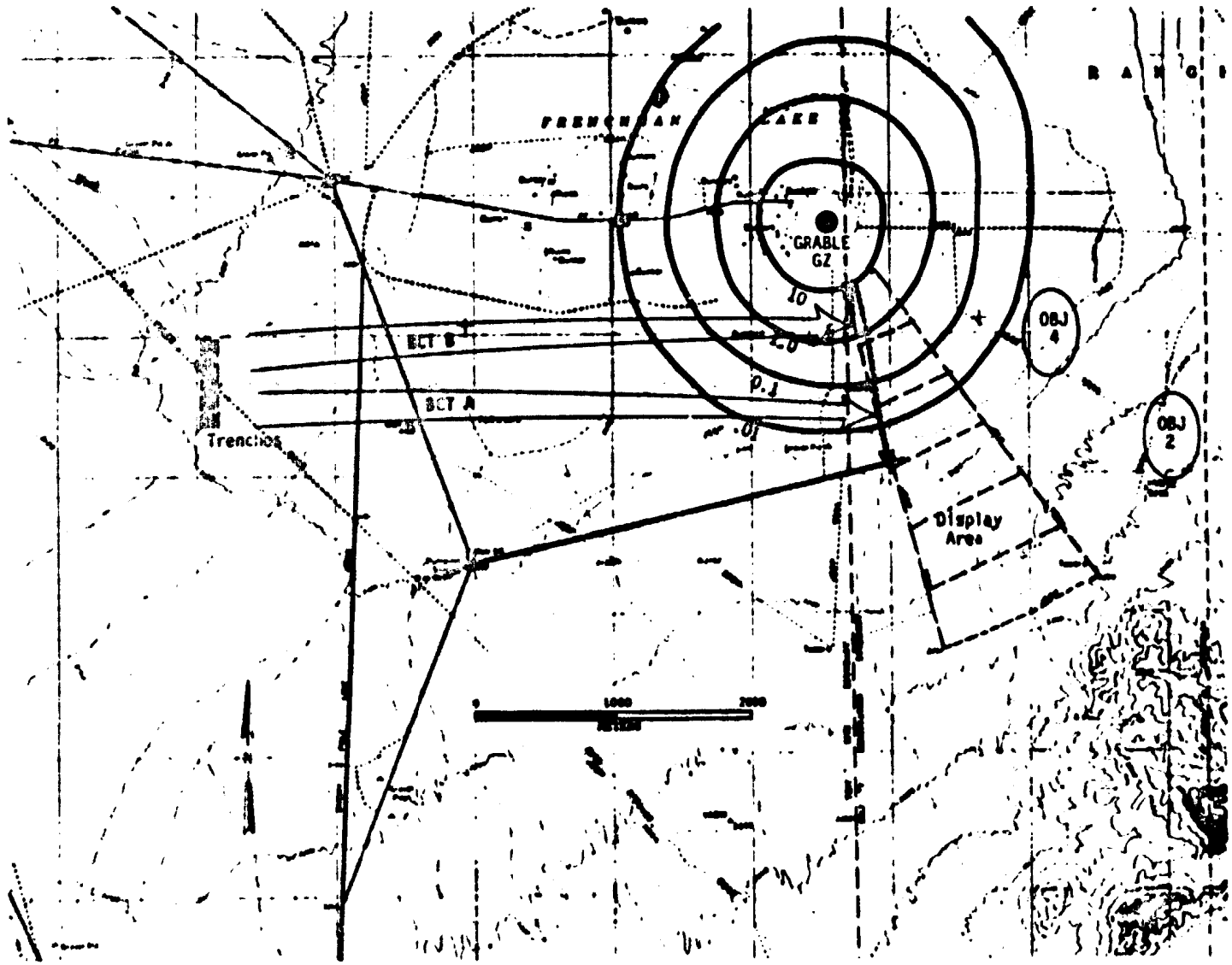

Figure 4-6. Shot Grable residual radiation (R/hr @ H+1) and maneuver troop routes.

observers: resuspension of fresh fallout while marching and suspension of neutron-activated soil in a dust storm. As the time after burst of exposure was similar for observers and maneuver elements, the internal dose commitment is directly proportional to the external dose; thus, the results of Reference 22 may be used directly for corresponding situations. As the calculated external doses for the maneuver troops (for all shots except Grable) are within an order of magnitude of those of the service observers, the internal doses are similarly insignificant. All are less than 0.001 rem, with all internal emitters included.

At Shot Grable, some maneuver elements went closer considerably to GZ than did the observers. Although it may be construed that dust conditions were less severe for these elements than for the observers, the same high-sided suspension factor of 10^{-2} Ci/m^3 per Ci/m^2 is used. For severe dust conditions, the top centimeter of the soil is assumed to be available for suspension. Experiments in Operation Plumbbob (Reference 14) correlate the intensity of the gamma radiation field with the distribution of activation products (mainly Mn-56 and Na-24) in the soil for a shot similar to Grable. As calculated in Reference 22, the (external) film badge dose of 0.04 rem for the observers after Shot Grable implied a 50-year internal dose commitment (whole body and bone) of 0.001 rem. Proportionally, the corresponding internal dose commitments to BCT-A, BCT-B and BCT-B (500 yard) are <0.001 rem, 0.01 rem, and 0.05 rem, respectively. Corresponding upper limit doses, also as determined in Reference 22, are about 0.002 rem, 0.10 rem, and 0.4 rem, respectively.

4.3 RESIDUAL RADIATION DOSE SUMMARY

The calculated film badge doses (rem) to maneuver troops from residual gamma radiation at applicable shots are summarized as follows:

Associated Shot:	Annie	Nancy	Simon	Encore	Grable
BCT A	0.80	1.3	3.1	0.06	0.04
BCT B	0.69	2.2*	2.2	0.06	0.47
		1.0**		0.13***	1.9****

* Forward elements that went to 14 R/hr.
** Rear elements
*** Helilifted platoons.
**** Troops that went to the 500-yard display.

For all maneuver troop activities in conjunction with all shots except BCT-B at Grable, the 50-year dose commitment to the whole body or bone from inhaled radionuclides is derived from Reference 22 to be less than 0.001 rem. During the dust storm at Grable, BCT-B troops could have inhaled neutron-activated dust, resulting in a whole-body commitment of 0.01 rem, or 0.05 rem to those elements that visited the 500-yard display. Almost all of the commited dose would have been accrued within a few days after 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 unit of maneuver troops. For initial radiation, the uncertainty analysis corresponds to that of Reference 22, as the conditions of exposure were the same as for troop observers; for residual radiation, the analysis reflects the distinct maneuver scenarios.

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 are 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 the radially symmetric Annie device. 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 1.4 at 3500 yds to 1.3 at 5000 yds. The uncertainty in the calculation of neutron trench factors results in an error factor of 1.2 for the 2-foot wide trenches.

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
Simon	1.3	1.9	1.4	1.2	2.2
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 the 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 Shot 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 Reference 22. The error in interpolation/extrapolation techniques used to determine the gamma doses at trench locations is range-dependent, with estimated values of 1.3-1.4. It is estimated that the uncertainty in the gamma trench factors, which relate the above-trench dose to the in-trench dose, introduces an error factor of 1.2. 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 troops is estimated to be 1.5.

The final uncertainty in initial gamma dose results from the probability that the troops stood up in the trenches to observe the rising cloud soon after the blast

effects of the weapon had subsided. As discussed in Section 3.1, the assumption is made for Shots Annie, Nancy, and Simon that the troops stood up 3 seconds after passage of the blast wave. For Grable, the troops were allowed to rise and observe the fireball at H+3 seconds, prior to blast wave arrival. The times of arrival of the blast waves at the maneuver troop trenches, and the assumed stand-up times are as follows:

Shot	Trench Distance (yards)	Time of Arrival of Blast Wave (seconds)	Assumed Stand-up Time (sec)
Annie	3500	7.6	11
Nancy	4000	8.7	12
Simon	4000	8.4	11
Grable	5000	11.6	3

No error is assigned for Grable. For the other shots, the 90-percent confidence limits in the stand-up times are estimated at ±3 seconds. The associated error factor in dose is about 1.3 in each case.

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

Shot	Source of Uncertainty					Combined Error Factor
	Experimental Data	Extrapolation/ Interpolation	Trench Factor	Trench Posture	Standup Time	
Annie	1.4	1.3	1.2	1.5	1.3	2.0
Nancy	1.8	1.4	1.2	1.5	1.3	2.3
Simon	1.4	1.4	1.2	1.5	1.3	2.0
Grable	1.2	1.4	1.2	1.5	1.0	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 facilitated through parametric studies using the automated procedure (described in Reference 23) 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 Shot Grable). Uncertainties exist with regard to the times and locations of the maneuver troops during the attack phases of their activities. In one case (see Section 4.1.1) a reported arrival time had to be reinterpreted because it was inconsistent with other reported information. As there is no indication of violation of rad-safe limits, except for BCT-B at Shot Nancy, the assumption that troops kept close to the limits when detouring is necessarily high-sided in terms of dose; however, a 2.5 R/hr intensity is taken to apply without error under these conditions. The uncertainty is in the duration and path length of a detour. In the display areas, the limits of advance were not always reported. When the references do not report which equipment display lines were inspected, the assumption is made that all of the displays within rad-safe limits were inspected. The dose accrued within the display area is maximized if the innermost display visited is coincident with the rad-safe limit. Within the uncertainty of the radiation field, this is often a possibility.

The timing of the troops' march is generally based on the reported time of attack, time of arrival at the objective, and arrival at the pickup point. Reasonable march speeds and display area stay times are assumed, in order 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(s) of greatest gamma intensity. Uncertainties based on timing are high-sided by coupling stay times (all upper limits are considered together) and by ignoring the overall time constraint on the combination of long stay times and slow march speeds.

The various sources of error are combined approximately; they cannot be combined rigorously due to the disparity of their associated distributions. While some distributions are normal as expressed (e.g., a march speed ± 20 yds/min or a halt point ± 100 yards from GZ), they imply a more lognormal distribution in dose. For each source of uncertainty, the limits on dose are interpreted in terms of error factors on the best-estimate doses from Section 4. Uncertainties are combined as for lognormal distributions. The overall uncertainties permit determination of 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 entered as an individual's assigned gamma dose. Ninety-percent confidence limits are estimated for each calculated dose.

5.2.1 Shot Annie

For both BCTs at Shot Annie, the uncertainty in dose stems predominantly from two sources: (1) time spent at the first two displays (the intensity dropped off such that there was essentially no dose received at the other displays), and (2) the marching speed, especially that near the 2.5 R/hr limit. The stay times are assumed to be 5 minutes, with an error factor of 2. The marching speed is assumed to be 70±20 yds/min. Because most of the dose was accrued near the 2.5 R/hr limit, not at a specified distance, the uncertainty in the radiation field contributes little to that in dose. The calculated film badge doses, with errors, are:

	(1)	(2)	Combined
BCT-A	$0.80^{+0.17}_{-0.08}$	$0.80^{+0.24}_{-0.14}$	$0.80^{+0.31}_{-0.16}$ rem
BCT-B	$0.69^{+0.16}_{-0.08}$	$0.69^{+0.21}_{-0.12}$	$0.69^{+0.27}_{-0.14}$ rem

5.2.2 Shot Nancy

The uncertainties in dose associated with the maneuvers at Shot Nancy stem from three basic sources: (1) stay times at the halt points (short of the objective) and at the 1000- and 1500-yard displays (the contribution to dose was negligible at the other displays), (2) marching speeds, especially in the higher-intensity areas, and (3) the radiation field intensity, in particular the gradient of intensity near the halt point for BCT-B. The stay time and marching speed assumptions are the same as for Shot Annie, except that an error factor of 2 is applied to a stay time of 10 minutes at the halt point for rear elements of BCT-B. Unless the march speed was far from constant, the upper limit on dose from this source of uncertainty is unrealistic; the BCTs could not have marched as slow as 50 yds/min and still have reached the entrucking area in time to clear the shot area by 0830 hours (see Section 2.4.2).

The intensity gradient near the halt point of BCT-B affects the calculated dose to both forward and rear elements. A high gradient would have minimized the dose to forward elements during their approach to 14 R/hr and reduced the intensity to the rear elements at their spacing behind the front. The highest gradient is depicted in the initial survey contours used for the dose calculation; therefore, the calculated dose also

represents a lower dose limit on the basis of uncertainty in gradient. An upper dose limit is obtained from also utilizing later survey readings in the vicinity of the halt point. While these may not have fully captured a localized gradient, they nevertheless imply that the rear elements did not exceed the rad-safe limit.

The calculated film badge doses, with uncertainties, are:

	(1)	(2)	(3)	Combined
BCT-A	$1.3^{+0.3}_{-0.2}$	$1.3^{+0.4}_{-0.2}$	—	$1.3^{+0.5}_{-0.2}$ rem
BCT-B (forward)	$2.2^{+1.0}_{-0.5}$	$2.2^{+0.5}_{-0.3}$	$2.2^{+0.4}_{-0}$	$2.2^{+1.3}_{-0.5}$ rem
BCT-B (rear)	$1.0^{+0.2}_{-0.1}$	$1.0^{+0.3}_{-0.2}$	$1.0^{+0.4}_{-0}$	$1.0^{+0.6}_{-0.2}$ rem

5.2.3 Shot Simon

For both BCTs at Shot Simon, the uncertainty in dose is dominated by that in the time spent at radiation intensities near the 2.5 R/hr rad-safe limit. The uncertainty in that duration follows mostly from that in (1) marching speed (70±20 yds/min) and (2) stay times (5 minutes at each display or halt point, with an error factor of 2). Despite the uncertainty in timing of the initial rad-safe survey, the significant gradients in the radiation field ensure that the isopleths are accurate to within a few hundred yards for any time during the BCT movements. For the few kilometers of presumed marching at 2.5 R/hr, the uncertainty in path length at this intensity is thus small.

BCT-A spent about 1½ hours along the rad-safe limit. Because of the known halt time, only the time of first arrival at the rad-safe limit and the duration of the return to the display area are uncertain. The upper-limit march speed (not applied during the attack along the rad-safe limit) implies 6 minutes sooner for the former and 8 minutes shorter for the latter; the lower-limit speed implies 10 minutes later and 14 minutes longer, respectively. Thus, unless the march speed varied considerably between these two phases, the calculated dose is relatively insensitive to march speed. Stay times at the halt point and the displays (especially at 2000 yards from GZ), which are taken to be coupled, lead to a greater uncertainty in dose.

BCT-B spent about 1 hour along the rad-safe limit, including the apparent grazing of the limit during the attack phase. As no reference states the arrival time at the objective, the dose to BCT-B is more dependent on the assumed march speed. Only at the 2000-yard display did BCT-B stay where the intensity was near the rad-safe limit.

The resulting uncertainties in the calculated film badge doses are:

	(1)	(2)	Combined
BCT-A	$3.1^{+0.12}_{-0.06}$	$3.1^{+0.27}_{-0.13}$	$3.1^{+0.3}_{-0.2}$ rem
BCT-B	$2.2^{+0.8}_{-0.4}$	$2.2^{+0.12}_{-0.06}$	$2.2^{+0.8}_{-0.4}$ rem

5.2.4 Shot Encore

For the maneuvers at Shot Encore, the sources of uncertainty in dose are limited to: (1) stay times at the displays, and (2) march speeds. Despite the use of a single rad-safe survey in the calculations, the radiation field is well established. Several independent and consistent measurements were made of the intensity at the intended GZ, the displacement of the actual GZ is known, and the neutron-induced activity decayed minimally during the survey. For the helilifted platoons, the stay time dose and uncertainty include the delay at the intended GZ. The same stay time (5 minutes, error factor of 2) and march speed (70±20 yds/min) assumptions as for the other shots are made. The calculated film badge doses, with errors, are:

	(1)	(2)	Combined
BCT A/B	$0.06^{+0.015}_{-0.008}$	$0.06^{+0.017}_{-0.009}$	$0.06^{+0.02}_{-0.01}$ rem
Helilifted platoons	$0.13^{+0.035}_{-0.018}$	$0.13^{+0.037}_{-0.021}$	$0.13^{+0.05}_{-0.03}$ rem

5.2.5 Shot Grable

The uncertainty in dose for the BCTs at Shot Grable stems from four sources: (1) the radiation field intensity, (2) the distance south of GZ of the maneuver halt, (3) the stay time at the halt point (and at the 500-yard display for the element of BCT-B), and

(4) march speeds. For the gamma intensity, the calculated error factors are approximately 2.0 for the area in which most dose was accrued. The halt locations are estimated to be accurate to within 100 yards for each BCT, which implies an error factor of 1.9 in intensity at each location, based on the radiation field gradient. The stay time and march speeds assumed are as on the previous shots: 5 minutes within a factor of 2 and 70±20 yds/min. As the halt time calculated using 70 yds/min is in accord with that reported in Reference 1, only subsequent march speeds have an associated uncertainty. The calculated film badge doses, with errors, are:

	(1)	(2)	(3)	(4)	Combined
BCT-A	<0.01 error	<0.01 error	<0.01 error	<0.01 error	<0.01 rem
BCT-B	$0.44^{+0.33}_{-0.19}$	$0.44^{+0.33}_{-0.17}$	$0.44^{+0.14}_{-0.07}$	$0.44^{+0.12}_{-0.07}$	$0.44^{+0.61}_{-0.24}$ rem
BCT-B to 500 yds	$1.9^{+2.0}_{-1.0}$	$1.9^{+0.3}_{-0.2}$	$1.9^{+1.0}_{-0.5}$	$1.9^{+0.3}_{-0.2}$	$1.9^{+2.5}_{-1.1}$ rem

For the inspection of the Shot Harry displays on 22 May, the scenario and uncertainties are the same as indicated for observer personnel in Reference 22. The dose of 0.03 rem was stated to be high-sided because sodium-24, to which the troops were predominantly exposed, was assumed to account for the shot-day survey intensities as well; actually, the faster-decaying manganese-56 would have contributed to those readings. The 0.03 rem is added without quantified error to the dose for each Grable observer category.

5.3 TOTAL DOSE SUMMARY

The reconstructed neutron and gamma doses for Operation Upshot-Knothole maneuver troops 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 unit are calculated. These are presented along with estimated 90-percent confidence limits.

Table 5-1. Maneuver troops mean dose summary.

Shot	BCT	Neutron Dose (rem)	Initial Gamma Dose (rem)(1)	Residual Gamma Dose (rem)(1)	Total Gamma Dose (rem)(1)
ANNIE	A	$0.018^{+0.017}_{-0.011}$	0.012(2)	$0.80^{+0.31}_{-0.16}$	$0.81^{+0.31}_{-0.16}$
	B	$0.018^{+0.017}_{-0.011}$	0.012	$0.69^{+0.27}_{-0.14}$	$0.70^{+0.27}_{-0.14}$
NANCY	A	<0.001	0.004	$1.3^{+0.5}_{-0.2}$	$1.3^{+0.5}_{-0.2}$
	B(3)	<0.001	0.004	$2.4^{+1.5}_{-0.7}$	$2.4^{+1.5}_{-0.7}$
	B(4)	<0.001	0.004	$1.1^{+0.5}_{-0.3}$	$1.1^{+0.5}_{-0.3}$
SIMON	A	0.003	0.012	$3.1^{+0.3}_{-0.2}$	$3.1^{+0.3}_{-0.2}$
	B	0.003	0.012	$2.2^{+0.8}_{-0.4}$	$2.2^{+0.8}_{-0.4}$
ENCORE	A/B	—	—	$0.06^{+0.02}_{-0.01}$	$0.06^{+0.02}_{-0.01}$
	Helilifted Platoons	—	—	$0.13^{+0.05}_{-0.03}$	$0.13^{+0.05}_{-0.03}$
GRABLE	A	<0.001	<0.001	0.04	0.04
	B	<0.001	<0.001	$0.54^{+0.54}_{-0.31}$	$0.54^{+0.54}_{-0.31}$
	B(5)	<0.001	<0.001	$2.2^{+2.2}_{-1.4}$	$2.2^{+2.2}_{-1.4}$

(1)Reconstructed film badge dose.
(2)Uncertainties less than 0.01 rem not displayed.
(3)Forward elements.
(4)Rear elements.
(5)Elements that visited the 500-yard display following Shot Grable.

SECTION 6
FILM BADGE DOSIMETRY

Film badge dosimetry data for Army maneuvers in Exercise Desert Rock V are unavailable, with one exception. One of the listings sent from Camp Desert Rock to a home station of participants has survived, furnishing doses to 82 troops from Fort Benning. The date of the listing, 9 April 1953, and the Third Army affiliation of Fort Benning establish that these troops were in BCT-B at Shot Nancy.

The range of doses and the variety of units represented on the list suggests a useful comparison to the doses calculated for the forward and rear elements of BCT-B. Almost all of the readings fall into one of the following categories: 2.2 rem ± 10 percent, 0.9 rem ± 10 percent, and a uniform distribution from 1.1 to 1.6 rem. Although the Fort Benning participants formed less than 10 percent of BCT-B, their range of dose levels may nearly represent that of the BCT as a whole. The high-dose group consists almost entirely of personnel from airborne units, who would be expected to lead. Infantry units dominated the middle-dose groups, and field artillery and truck units the low-dose group.

The comparisons between calculated doses and the dosimetry data for the forward and rear elements of BCT-B are excellent. This is in part due to the known peak intensities reached and their domination of the dose (14 R/hr and the movement along the 2.5 R/hr rad-safe limit). In addition, the agreement reflects well on the judgement of time and space factors for all maneuver units as well as on the characterization of the residual radiation field.

SECTION 7
CONCLUSIONS

Exercise Desert Rock V maneuver troops participated in six of the eleven test shots of Operation Upshot-Knothole, and were exposed to nuclear radiation as a result. Exposure assessment for the marines at Shot Badger is provided in Reference 21. In each of the five shots covered by this report (Annie, Nancy, Simon, Encore, Grable), maneuver troops were divided into two Battalion Combat Teams (BCTs). At shot times, the troops crouched in trenches located 3500 (Annie) to 10000 (Encore) yards from ground zero (GZ). Following the shots, the troops engaged in maneuvers to simulate attacks on objectives offset from GZ. In some cases (Nancy, Simon, and Grable) one or both of the BCTs were unable to reach the objectives due to excessive radiation or lack of visibility. Following the maneuvers, the BCTs walked through the display areas to view the animals and equipment. In some cases (Nancy, Simon, and possibly Annie) it was not possible to visit all the displays because of high radiation levels. At Shot Grable, visibility was a problem, and only a portion of one of the BCTs visited the 500-yard display.

Initial radiation doses were very low for the maneuver troops for all five shots, the neutron dose ranging from less than 1 mrem (Nancy, Encore, Grable) to 18 mrem (Annie). The initial gamma dose ranged from less than 1 mrem (Encore, Grable) to 12 mrem (Annie, Simon). These doses were the same as for the service observers, since their trenches were collocated.

Residual radiation doses ranged from 0.04 rem (Shot Grable, BCT-A) to 3.1 rem (Shot Simon, BCT-A). Doses of about 2 rem were accrued by BCT-B, Shot Simon, elements of BCT-B, Shot Grable, and lead elements of BCT-B, Shot Nancy. In the latter instance, the 2.5 R/hr limit on gamma intensity was inadvertently exceeded (to 14 R/hr), but withdrawal to permissible levels was achieved quickly enough that a substantial dose was avoided. The Grable elements, for whom there were no intensity restrictions, were also exposed to 14 R/hr, at an equipment display line briefly visited.

The 50-year dose commitment to the whole body or bone from inhaled radionuclides was derived from Reference 22 to be less than 0.001 rem, except for BCT-B at Shot Grable. Calculated commitments are 0.01 and 0.05 rem for elements of this BCT.

Of all Desert Rock maneuver troops who participated in the five subject shots, none were calculated to have received a total film badge dose that exceeded the exercise limit of 6 rem.

SECTION 8

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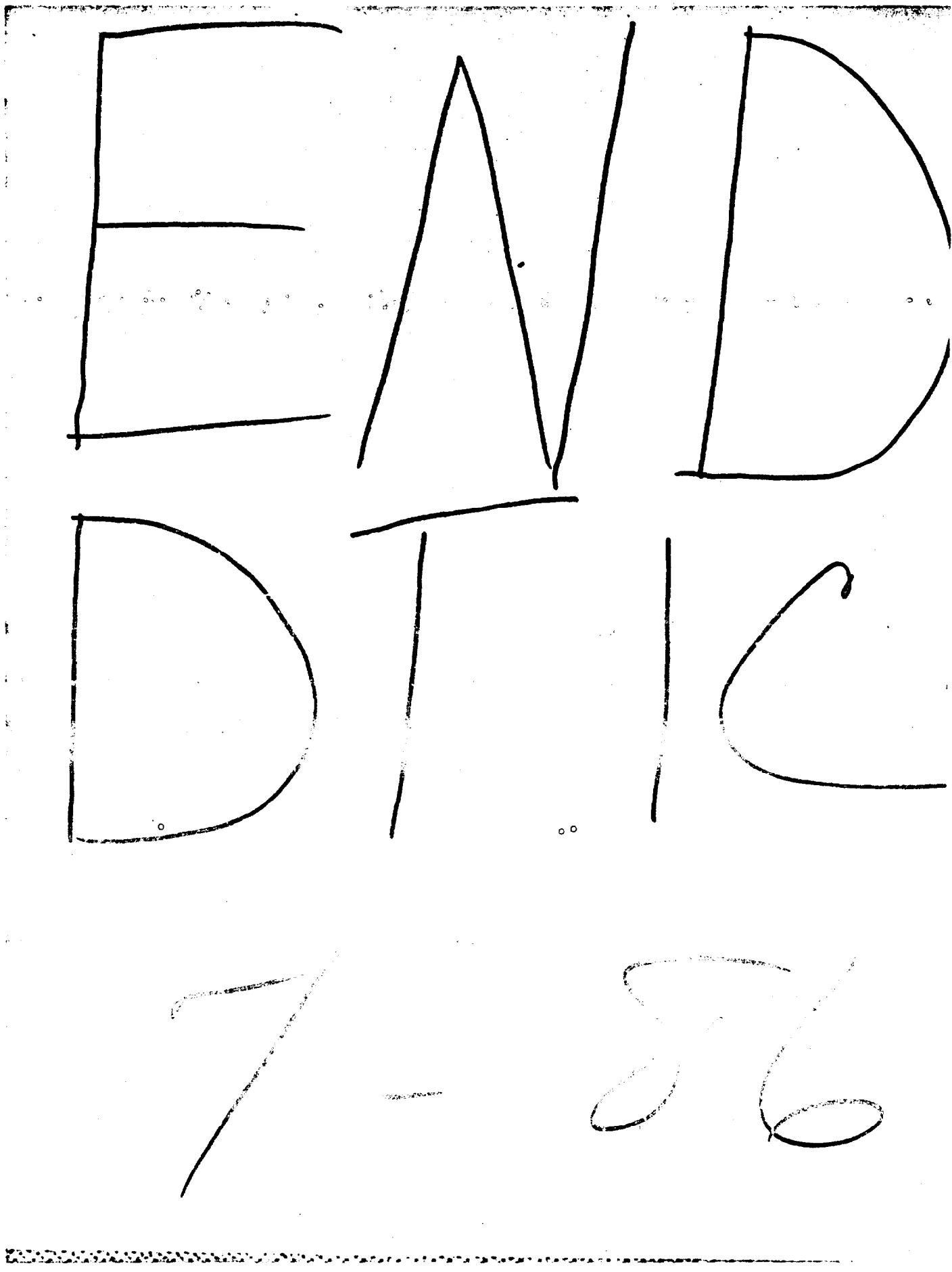
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