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ANALYSIS OF RADIATION EXPOSURE, 4TH MARINE CORPS PROVISIONAL ATOMIC EXERCISE BRIGADE, EXERCISE DESERT ROCK VII, OPERATION PLUMBBOB

Science Applications, Incorporated
P.O. Box 1303
McLean, Virginia 22102

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

The radiation dose to Marine Brigade participants in Exercise Desert Rock VII (Operation Plumbbob, 1957) is reconstructed for each major brigade element. Although the exercise was centered primarily around Shot Hood after the Diablo misfire, there was limited participation in Shot Priscilla also. Moreover, the residual radiation from previous shots contributed to the total dose. Residual doses are determined through an automated procedure that utilizes raw survey data in modeling the radiation field, which is overlaid with specific troop activities to arrive at an integrated dose. Despite the lack of definitive troop activity

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20. ABSTRACT (Continued)

information, the automated procedure facilitates an iterative process to correlate possible activities with those inferred from available dosimetry.

The calculated doses to typical troops range from .58 rem to .66 rem. Other participants, notably officers, received higher recorded doses due to participation in Shot Priscilla. The calculated doses correlate well with available dosimetry. Rad-safe monitor teams were subjected to higher exposures due to their duties. This is evidenced by their total badge readings averaging 1.2 rem and ranging as high as 3 rem.

Initial radiation and internal residual radiation exposures were insignificant.

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SECTION 1
SUMMARY

This report presents an analysis of nuclear radiation exposure for personnel of the 4th Marine Corps Provisional Atomic Exercise Brigade during their participation in Exercise Desert Rock VII (Operation Plumbbob) at Nevada Test Site in 1957. The exercise consisted basically of a battalion combat team and helicopter airlift support units in a coordinated air-ground assault of an objective following a nuclear strike. These units were part of a brigade maneuver that was controlled by command and staff elements of a Marine division and brigade, the other maneuver units of which were simulated. The exercise took place over a period of slightly more than two weeks, during which time the brigade trained, rehearsed, conducted a command post exercise, experienced a misfire (Shot DIABLO), observed one nuclear burst (Shot PRISCILLA), observed the largest nuclear burst ever detonated in the United States up to that time (Shot HOOD), conducted maneuvers, and viewed the effects of a nuclear burst on typical military equipment.

The brigade activities are traced from arrival at Camp Desert Rock in late June 1957 until departure in early July. Figure 1-1 shows the major features of relevance to the brigade activities at Nevada Test Site. Although there were varying degrees of participation in only two actual bursts, the residual radiation from all previous bursts in Operation Plumbbob was examined to determine the dose contribution to the troops during all their activities. Time-dependent position information is determined and presented in order that a complete exposure analysis can be performed. External (and internal as appropriate) dose is reconstructed and the uncertainties associated therewith are calculated.

A major obstacle to the preparation of this report was the lack of reports from any source that would have described the events and activities in sufficient detail to facilitate straightforward analysis. Detailed and exhaustive searches of all likely holdings of such reports were fruitless, despite extra-

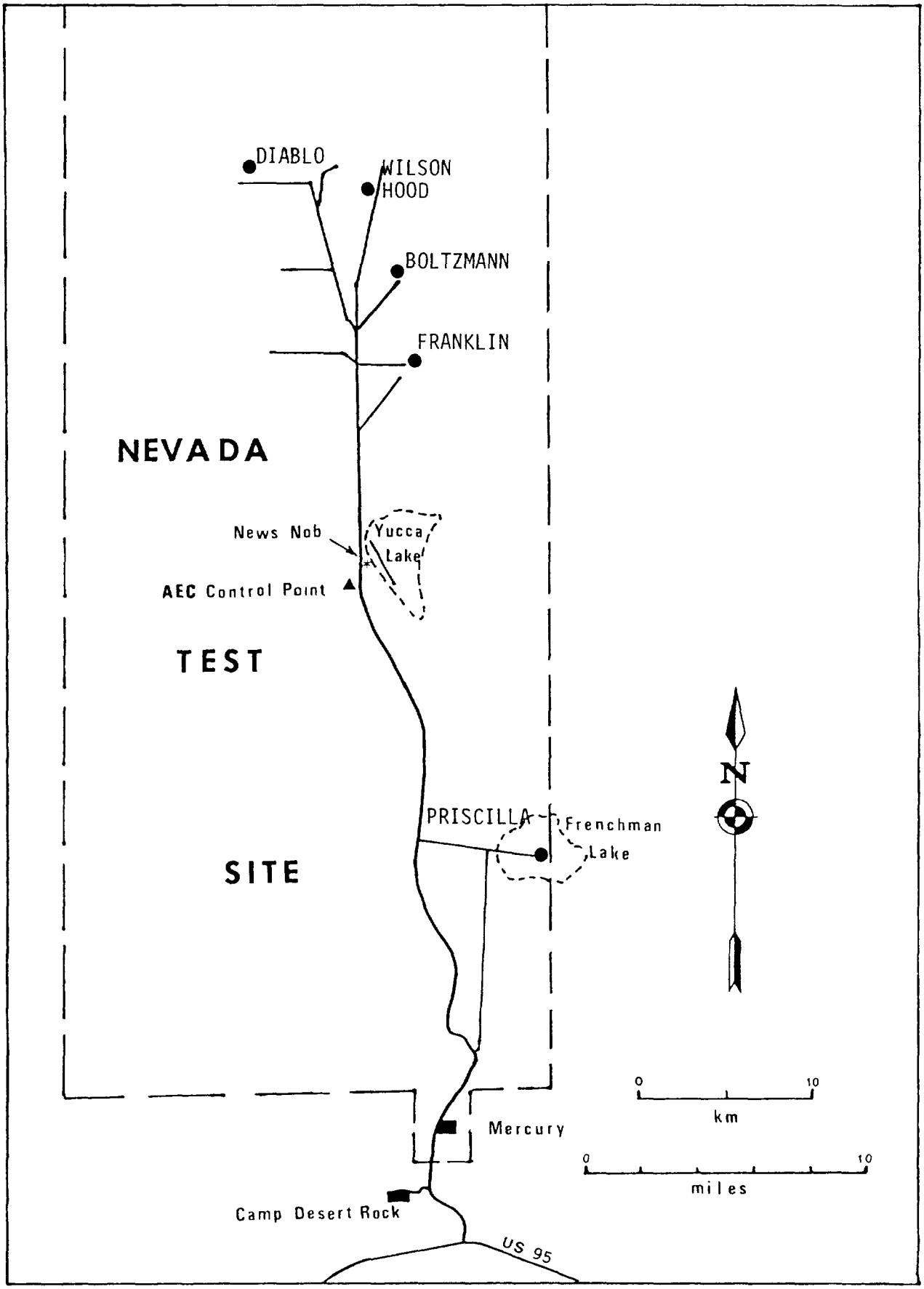


Figure 1-1 Selected Shot Locations, Operation Plumbbob

ordinary research efforts by several agencies. Several alternatives were therefore adopted. First, the three previous Marine Corps exercises, in 1952, 1953, and 1955, were studied to determine if any patterns of activities would emerge. Second, approximately a dozen participants were interviewed, both in person and by telephone, to determine significant (or memorable) elements of their experiences during the exercise. The participants interviewed were generally those in supervisory positions who could have had a broad perspective of the activities. Third, several official photographs from Army and Marine Corps files were obtained. These were most useful in determining activities, dates, and specific locations of the exercise elements to augment the information from other sources. These sources, supplemented with planning documents and military judgment, provide the basis for the descriptions of activities and the resulting exposure analysis. The lack of definitive reports, however, is reflected in the uncertainty analysis. Despite the uncertainties, there were no unresolved inconsistencies or contradictions in the various sources of information used in this report.

The analysis utilizes an automated procedure (Reference 20) for determining dose due to residual radiation. All available radiological survey data are fit, through statistical regression, to space-time models of residual radiation intensity, from which isointensity contours (isopleths) are then developed. These data are stored for subsequent combination with the time and space factors associated with troop operations in contaminated areas. Derived parameters that characterize soil activation or fission product decay permit continuous adjustment of the radiation field, in order that an integrated radiation dose for a given operation can be determined. A major feature of the automated procedure is that variations in the time and space factors associated with troop operations can be introduced to determine the sensitivity of the calculated dose to the omissions and inconsistencies of the operational histories. It was only after this automated procedure was developed and thoroughly evaluated that there now exists the confidence to analyze an operation for which so few facts are available.

One very valuable category of data exists for this exercise, albeit in limited form. Of approximately 1900 on-site participants, film badge dosimetry records exist for over 600 individuals, representing to varying degrees all of the major categories of participants. These data are used to verify the calculations and to identify the degree of participation in various brigade activities.

Major findings of this report are:

- Troops of the 4th Marine Corps Provisional Atomic Exercise Brigade were exposed to initial radiation from Shots PRISCILLA and HOOD. The combined (neutron plus gamma) initial dose, however, was less than 0.01 rem for both shots.

- Exercise troops were exposed to residual radiation from Plumbbob shots detonated before their arrival at the test site. Only Shot WILSON residual was significant, primarily to the brigade staff, which accrued a dose from this source of no more than 0.16 rem.

- A limited number of brigade personnel observed Shot PRISCILLA from trenches and viewed the equipment display thereafter, resulting in an estimated gamma dose of 0.46 rem. For those maneuver elements of the brigade who entered the contaminated area after Shot HOOD, the calculated gamma dose from Shot HOOD, as well as residual from Shot WILSON, ranges from 0.58 to 0.66 rem. This is the dose that applies to the great majority of personnel (from the maneuver battalion) for whom dosimetry records have not been located.

- The 50-year whole body dose commitment due to possible inhalation of helicopter-lofted contamination during airlift operations, including rehearsals, was no more than 0.012 rem. The corresponding bone-dose commitment was approximately twice that to the whole body.

SECTION 2
OPERATIONS

2.1 SHOT DATA

The 4th Marine Corps Provisional Atomic Exercise Brigade (MCPAEB), which constituted the force for this exercise, completed its movement to the Nevada Test Site on 20 June 1957. Their plans called for participation in maneuvers in conjunction with Shot DIABLO, scheduled for 0430 hours, 27 June 1957. Prior to DIABLO, 311 personnel from the 4th MCPAEB participated as observers for Shot PRISCILLA, which was detonated at 0630 hours on 24 June 1957. On the afternoon of 26 June, a delay of DIABLO for 24 hours was announced (Reference 1). The shot subsequently misfired on 28 June. After the misfire, the decision was made to modify the plans of the 4th MCPAEB and perform the exercise in conjunction with Shot HOOD instead of DIABLO. HOOD was scheduled for 0440 hours, 3 July. It was subsequently postponed for 48 hours and was detonated on 5 July. The data for these shots are summarized as follows:

a. Shot PRISCILLA
   Date: 24 June 1957, 0630 hours
   Location: Frenchman Flat (coordinates 956728)
   Yield: 37 KT
   HOB: 700 feet (balloon)

b. Shot DIABLO (misfire--no detonation)
   Date: 28 June 1957, 0430 hours
   Location: Area T-2 (coordinates 794117)
   Expected Yield: 11-13 KT
   Planned HOB: 500 feet (tower)

c. Shot HOOD

Date: 5 July 1957, 0440 hours

Location: Area B-9 (a) (coordinates 852100)

Yield: 74 KT

HOB: 1500 feet (balloon)

2.2 PARTICIPANTS: PROJECT 52.1 MARINE BRIGADE EXERCISE

The brigade was organized as a standard Marine Corps air-ground task force. The headquarters, or brigade staff, of the 4th MCPAEB was a provisional organization of about 120 personnel from both the 1st Marine Division and 3d Marine Air Wing required to coordinate the ground and air maneuvers. The 1st Marine Division was represented by members of the division headquarters and the headquarters of the 5th Marine Regiment. The 3rd Marine Air Wing was represented by members of the Wing Headquarters Group and by Marine Air Groups 15 and 36. The 2nd Battalion, 5th Marine Regiment, of the 1st Marine Division constituted the infantry battalion assault force around which the brigade was organized. It was supported by normal combat support elements from the 1st Marine Division. The air support provided by the 3rd Marine Air Wing consisted of transport and observation helicopters from Marine Air Group 36 and, for close air support, 24 F9F aircraft from Marine Air Group 15. The helicopters were based with the ground troops at the test site while the fixed wing aircraft operated from the Marine Corps Auxiliary Air Station at Mojave, California. The complete brigade organization was as follows:

4th Marine Corps Provisional Atomic Exercise Brigade (4th MCPAEB)	Number of Personnel*	Number of Surviving Film Badge Records
1st Marine Division		
Det, Hq Co, Hq Bn	500	
Headquarters, 4th MCPAEB		120
Radiation Safety Monitor Teams Group		178
Observers		44
2nd Bn (reinf), 5th Marine Regiment	1100	120
H&S Co		
Company E		
Company F		
Company G		
Company H		
3rd Marine Air Wing	300	
Det, Marine Wing Hq Group		
Marine Air Group 36		171
Marine Helicopter Squadron 361		
Marine Helicopter Squadron 362		
Marine Helicopter Squadron 363		
Marine Observation Squadron 6 (-)		
Marine Air Base Squadron 36 (-)		
Headquarters & Maintenance Squadron 36 (-)		
Marine Air Group 15		
Marine Attack Squadron 223 (-)		

*As estimated from official unit diaries.

2.3 CONCEPT OF OPERATIONS

The purpose of the Marine Brigade Exercise was to provide command and staff training, emphasizing the evaluation of techniques relative to the exploitation of nuclear weapons, and to indoctrinate personnel in the effects of these weapons. Specific objectives were (1) to provide realistic training, particularly for command and staff personnel, in all phases of planning and conducting operations supported by nuclear weapons; (2) to test and evaluate doctrine for assault operations; (3) to develop new tactics and techniques for the utilization of nuclear weapons; (4) to familiarize personnel with the effects of nuclear weapons; and (5) to familiarize personnel with passive defense measures used for protection in a nuclear environment (Reference 3).

The exercise consisted of two major elements, both of which were planned for execution in conjunction with Shot DIABLO. The first was a command post exercise (CPX) starting the day before and ending an hour or two before the scheduled shot. The CPX was to be held at a forward Command Post in the Syncline Ridge area of the Nevada Test Site (Figure 2-1). The CPX was designed to familiarize the brigade staff with the planning requirements necessary for employing a nuclear weapon in support of ground operations. After the final steps leading to the decision to employ the weapon, some of the brigade staff (forward element) would move into the trenches and, along with the maneuver units who had already been positioned there, observe the shot. After the shot, the forward element would return to the CP to monitor the field maneuver that constituted the second phase of the exercise. Afterwards, all the brigade staff would be transported to the shot area to view an equipment display.

The equipment display was designed to demonstrate, evaluate and record the effects of a nuclear detonation on a representative sample of items of Marine Corps clothing and equipment. These items were divided into 15 groups according to type and level of damage expected and were placed at 11 distances from ground zero that (for the DIABLO Shot) varied from 230 yards to 2500 yards (Reference 8).

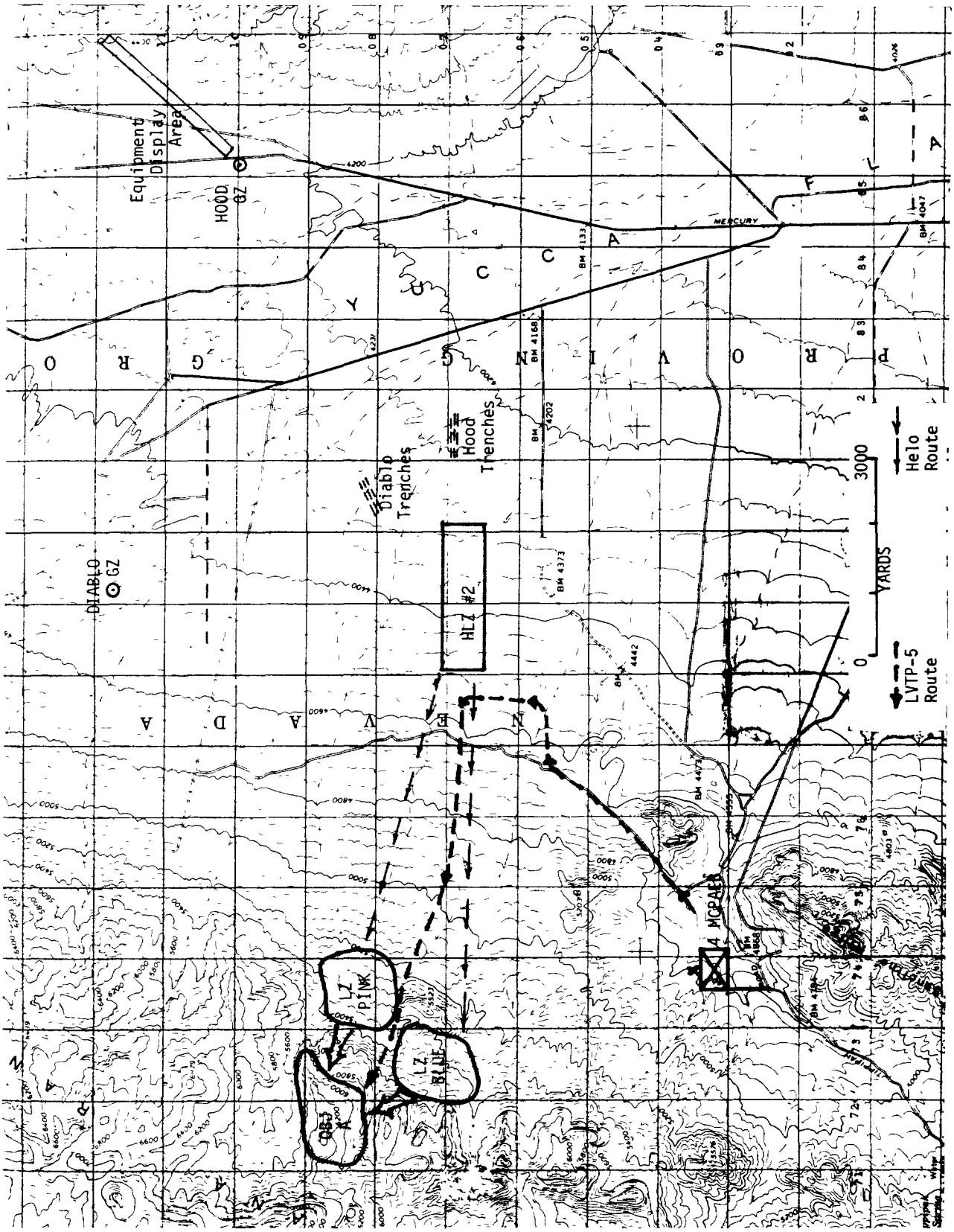


Figure 2-1. Exercise Area, 4th Marine Corps Provisional Atomic Exercise Brigade

The post-shot troop maneuver consisted of a coordinated air-ground battalion landing team assault on an objective. For safety reasons, the objective was some distance removed from the actual shot area. The assault was to be accomplished using helicopters and tracked vehicles (LVTP-5) for movement to the objective and would be supported by tactical aircraft. Personnel from the supporting artillery battery would accompany the battalion during the entire period and participate in the exercise. The battalion and its supporting units would observe the shot from either trenches or other vantage points to the rear. Immediately following the shot, two infantry companies would be air lifted by helicopter to Landing Zones Pink and Blue, while a third company would move overland to the landing zone area in the LVTP-5's. The movement to the landing zones would be followed by a ground assault of the nearby objective (Figure 2-1). During this period, the fourth company of the battalion would march from the trench area toward ground zero until they reached the radiation safety limit (that point where the radiation intensity reached 5 r/hr). At this point, they were to return to the trench area to board helicopters for the airlift to Landing Zone Pink, where they would act as the battalion reserve. At the conclusion of the maneuver, the entire battalion and supporting units would board trucks and proceed to the equipment display near ground zero. After viewing the display, they would return to Camp Desert Rock (Reference 10).

2.4 PRE-SHOT OPERATIONS

All of the 4th MCPAEB troops arrived at Camp Desert Rock by 20 June 1957 for maneuvers that were to be held on 27 June in conjunction with Shot DIABLO. Operations were designed to avoid exceeding Department of Defense nuclear radiation safety criteria, which limited maximum whole body gamma exposure to 5 rem at any one test, of which no more than 2 rem would be from prompt radiation (Reference 4). Marine Corps radiation safety personnel from Camp Lejeune were employed in 16 monitor teams, to accompany every separate element of the brigade during each phase of the exercise (Reference 10). In order to assess the exposure to ionizing radiation of all personnel, film badges were issued to each individual. After a detonation, monitor teams erected red

cones connected by white engineer tape at the 5 r/hr line. Teams then surveyed back to the 20 mr/hr line and marked it with yellow cones to indicate the forward limit for buses and personnel vehicles. The periphery of areas of high-intensity contamination within display areas was marked by tape and red cones (References 4-7).

2.4.1 DIABLO Rehearsal

A full rehearsal of all events planned for Shot DIABLO was held on 20-21 June in the exercise area. The brigade staff, a provisional organization of about 120 men from the 1st Marine Division and the 3rd Marine Air Wing, departed Camp Desert Rock at approximately 1200 hours on 20 June and went directly to the Command Post area (Figure 2-1) where rehearsal of the command post exercise commenced at approximately 1500 hours. The CPX rehearsal was probably completed between 0200 and 0300 hours on 21 June. At that time, the forward element of the staff was trucked to the DIABLO trench area to "witness" the simulated detonation scheduled for 0430 hours. The trenches were located about 4200 yards southeast of GZ. The rear element remained at the CP. Shortly after the simulated detonation, the forward element returned to the CP to monitor the maneuver rehearsal and subsequent movements until about 1100 hours. The entire brigade staff then proceeded to the display area to view equipment that was to be exposed to the shot (Reference 9).

The maneuver troops from the 2nd Battalion, 5th Marines, departed Camp Desert Rock at approximately 2230 hours on 20 June and, with the exception of G Company, went directly to the trench area. Most of G Company stopped at Loading Zone #1, near the Control Point and News Nob (Figure 1-1), and joined three helicopter squadrons from MAG-36 that had flown up from Camp Desert Rock earlier that evening. The remaining elements of G Company went directly to the trench area. The supporting units for the exercise were positioned in the vehicle assembly area near the CP.

Immediately after the simulated detonation at 0430 hours, E Company began marching towards ground zero. During E Company's march, elements of G Company were airlifted from Loading Zone #1 to LZ Blue. Concurrently, F and H&S Companies marched to Loading Zone #2 and from there were airlifted to LZ Pink following the G Company movement. It is not clear how far forward E Company went toward GZ during the rehearsal prior to returning to the trench area and Loading Zone #2, where they boarded helicopters and were airlifted to LZ Pink. Immediately after the helicopter lift was completed, F and G Companies began their ground assault on the objective and the helicopters returned to Camp Desert Rock. While the airlift and subsequent ground assault were in progress, troops from H Company were being transported to the objective via armored personnel carriers (LVTP-5's), where they joined F and G Companies in their ground assault. During their mechanized movement, H Company was preceded by five Ontos (a light anti-tank vehicle) that supported the attack. Close air support was provided throughout the rehearsal by 24 F9F aircraft from Marine Attack Squadron 223. These aircraft operated out of the Marine Corps Auxiliary Air Station at Mojave, California.

It is estimated that the tactical exercise rehearsal was completed by 0900 hours, at which time the maneuver troops, including the LVTP and Ontos crews, began moving by trucks to the equipment display area set up for Shot DIABLO. Here, the 2nd Battalion, 5th Marines, viewed the various equipment and material displays to be exposed to DIABLO's scheduled detonation on 27 June. The tour through the display area was probably completed by 1200 hours, at which time the brigade began the trip back to Camp Desert Rock.

2.4.2 Shot PRISCILLA

On 24 June, some of the brigade witnessed Shot PRISCILLA, a 37 KT device suspended from a balloon 700 feet above Frenchman Flat (Figure 2-2). The PRISCILLA shot was to provide, for selected brigade officers and enlisted men, additional orientation and indoctrination in the effects of atomic weapons. Some of these personnel were from the maneuver battalion; others were probably

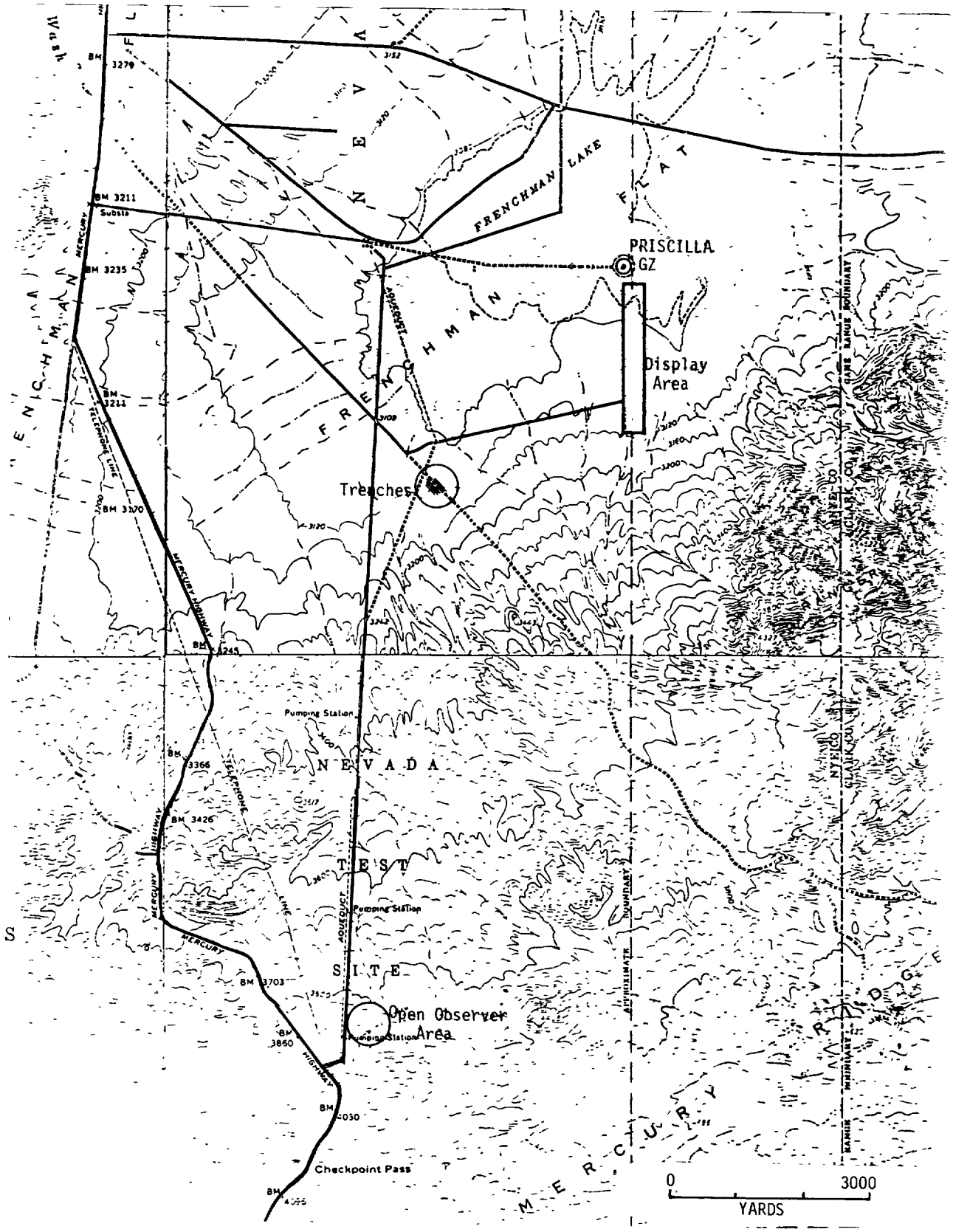


Figure 2-2. Shot Priscilla Area Frenchman Flat

from the brigade staff. This test involved no troop maneuvers, but served to familiarize troop leaders with the effects of an actual detonation. An eight-hour orientation in nuclear weapons was presented to observers prior to the shot. The participants observed PRISCILLA from trenches 4250 yards to the southwest of Ground Zero (Reference 4). Detonation was at 0630 hours. There were reports of some trenches caving in, but no serious injuries were reported. Because of persistent dust, the observers remained in the trenches for nearly two hours before moving forward in trucks to the equipment display area, 250 to 2500 yards south of GZ (see Figure 2). The observers toured the display area until about 1030 hours, then they were trucked back to Camp Desert Rock. Their walking tour was limited by rad-safe restrictions to displays at least 600 yards from GZ (5 R/hr line).

Other personnel witnessed PRISCILLA in the open from the slope overlooking Frenchman Flat, about 12 km from GZ. These personnel did not go forward after the burst and were not exposed to nuclear radiation. The 311 Marine participants cited in Reference 4 presumably include both these as well as those in the trenches, mentioned previously.

2.4.3 DIABLO Misfire

On 26 June, the 4th MCPAEB troops were informed that Shot DIABLO was postponed for 24 hours and had been rescheduled for 0430 hours, 28 June.

The brigade staff departed Camp Desert Rock at approximately 1200 hours, 27 June, destined for the CP area. The CPX began at 1400 hours and was completed at approximately 0300 hours on 28 June. At that time, the forward CP element was trucked to the trenches to observe Shot DIABLO.

As in the rehearsal, the remainder of the troops assigned to the 4th MCPAEB departed Camp Desert Rock at approximately 2230 hours on 27 June and, with the exception of some of G Company, went directly to the DIABLO trench area to witness the detonation. Elements of G Company joined the

MAG-36 helicopter squadrons at Loading Zone #1, near the Control Point and News Nob, 15 miles south of the DIABLO tower (Reference 10). At 0430 hours on 28 June, DIABLO failed to detonate with all troops in position. After a 30-minute delay, the exercise was terminated and all 4th MCPAEB troops returned to Camp Desert Rock.

2.4.4 Modification of Plans for Shot HOOD

Shot DIABLO was rescheduled for 12 July 1957; therefore, in order to save time, a decision was made to have the 4th MCPAEB conduct maneuvers in conjunction with Shot HOOD, set for 0440 hours on 3 July. During the period between shots, most of the troops were granted weekend liberty in Las Vegas.

The planning for Shot HOOD required only a few changes to the Shot DIABLO plan. Trenches for Shot SHASTA could be used for Shot HOOD without changing other elements of the maneuver plan (see Figure 2-1). The equipment display, however, did require some major changes because the yield for Shot HOOD was to be much larger than that for DIABLO. The distances from GZ for the various groups of equipment were scaled up for the higher yield. Because of the hilly area to the east, the most distant displays were placed close to the trenches. On 2 July, forecast weather conditions precluded the detonation of HOOD on 3 July; the shot was rescheduled for 0440 hours on 5 July 1957.

2.5 SHOT HOOD SCENARIO

At approximately 2230 hours on 4 July 1957, the entire brigade departed Camp Desert Rock for the exercise areas. Because the CPX had been completed in conjunction with Shot DIABLO, this element of the tactical exercise was not repeated for Shot HOOD (Reference 3). Therefore the forward element of the brigade staff was trucked directly to the HOOD trenches to observe the detonation. The rear element of the brigade staff went to the CP area.

Troops and vehicles from the supporting units went directly to the tracked vehicle assembly area in the vicinity of the CP (Figure 2-1), where they remained until the post-shot maneuvers began.

In a virtual repeat of the events for Shot DIABLO, the maneuver troops, with the exception of G Company, were trucked to the HOOD trench area, where they remained until H-hour. Most of G Company stopped at Helicopter Loading Zone #1 (HLZ #1) at the Yucca Lake airstrip (Figure 1-1), where they joined the helicopter crews from MAG-36 who had moved their helicopters to the forward area before dark. The helicopter crews and part of G Company witnessed Shot HOOD from that location.

The nuclear device for Shot HOOD was suspended from a balloon 1500 feet above Yucca Flat. The troops were crouched in trenches, five and a half feet deep (Reference 16), located 5360 yards (from inspection of USGS topographic map, Yucca Flat, 1:24,000) to the southwest of GZ. Everyone was issued a gas mask to counter the heavy cloud of dust (non-radioactive) expected to be raised by the blast wave from the shot (Reference 16).

Shot HOOD was detonated on schedule at 0440 hours, 5 July 1957. Figure 2-3, taken from News Nob, 13 miles away, shows the rising cloud a few seconds after the 74 KT burst. Blast from the detonation caused cave-ins in a few of the trenches, but no injuries to the men in the trenches were reported. Dust raised by the blast was extremely heavy in the vicinity of the trenches, as expected. Numerous small fires were noted in the vicinity of the trenches.

By 0455 hours, the dust had subsided sufficiently for the troops to move out of the trenches. The forward element of the brigade staff returned to the CP while E Company, preceded and flanked by rad-safe monitors, began marching northeast toward ground zero in two columns. H&S Company and F Company marched westward to HLZ#2, where they would be airlifted to LZs Pink and Blue. Company H, which joined in the march to HLZ#2, was met there by the LVTP-5s and Ontos that had departed the CP area immediately after the

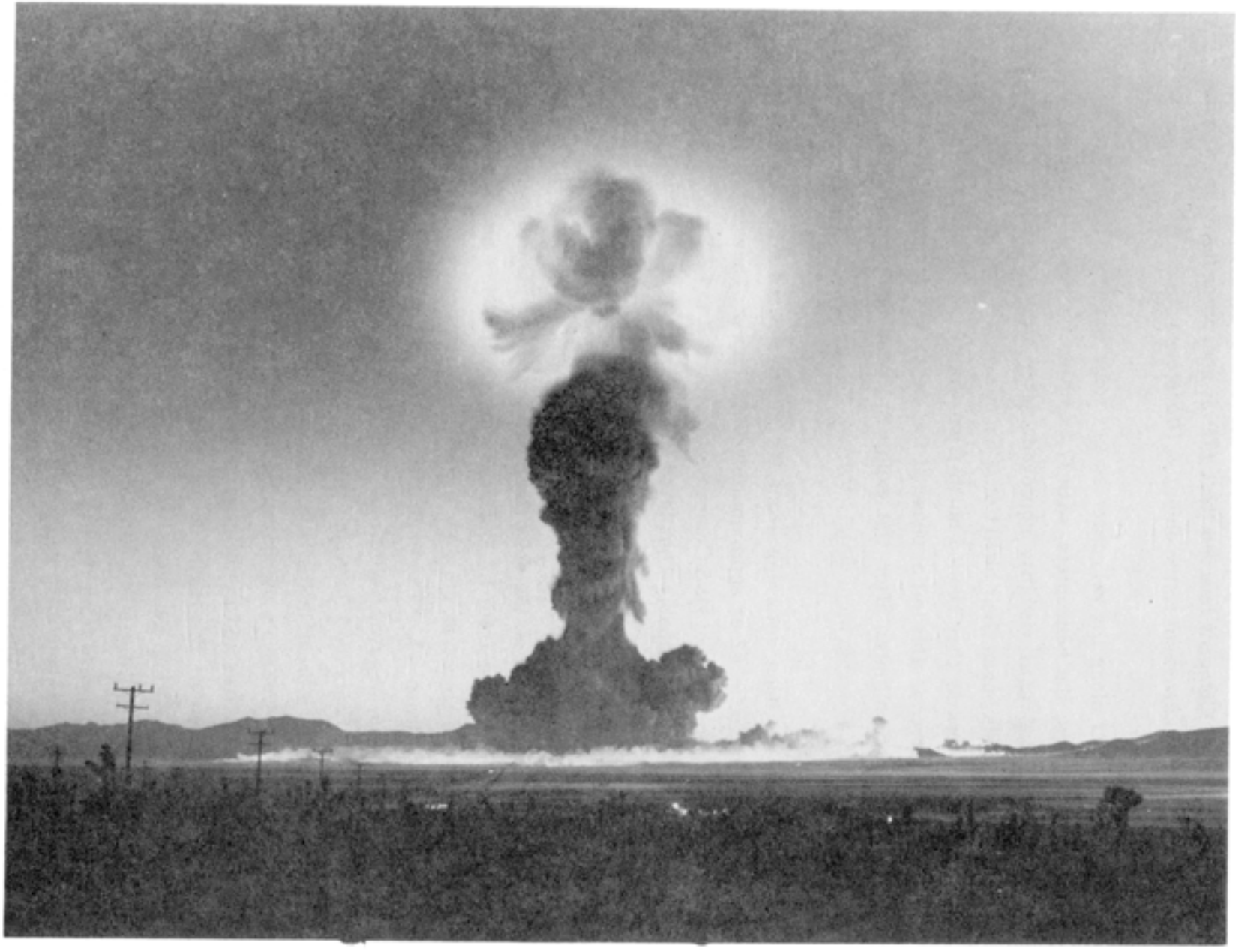


Figure 2-3 Shot Hood (U S Army Photograph)

detonation. Here, H Company boarded the LVTP-5s and, preceded by the Ontos, began a mechanized movement to the objective (Reference 10).

Because dust along the helicopter assault route between HLZ#1 and LZ Blue was very heavy, the helicopters, with G Company on board, remained at HLZ#1 (Yucca Lake) until visibility improved. After approximately an hour's delay, the helicopters began their airlift of G Company to LZ Blue. Figure 2-4 shows the helicopters as they headed north from Yucca Lake, with the HOOD cloud dissipating beyond. This initial phase of the airlift was completed at 0620, one hour and forty minutes after the explosion. The subsequent airlift of personnel from HLZ#2 began immediately thereafter.

Company E, upon returning from its march toward GZ, moved to Helicopter Loading Zone #2 at approximately 0700 hours. They joined in the heli-lift with the remainder of H&S Company and proceded to LZ Pink. The final phase of the airlift was probably completed by approximately 0830 hours; the helicopters then returned to Camp Desert Rock.

Upon reaching LZ Pink, F Company linked up with H Company (LVTP-5s) and began a ground assault on the objective. Simultaneously, G Company troops marched on the objective from LZ Blue. During the heli-lift and subsequent ground attack on the objective, close air support was provided by 24 F9F aircraft from Marine Air Group 15. These aircraft staged from the Marine Corps Auxiliary Air Station, Mojave, California. The objective area was occupied at approximately 1100 hours on 5 July, and the battalion exercise was terminated. The troops then took a break in the objective area and ate a lunch consisting of combat rations. The LVTP-5's and Ontos returned to the vehicle assembly area near the CP. Their crews and the brigade staff were trucked to the equipment display area northeast of the HOOD GZ, arriving at about 1200 hours. After approximately one hour in the display area, these troops departed for Camp Desert Rock. The 2nd Battalion, 5th Marines and the remaining supporting elements marched eastward from the objective areas to the nearest road, where they were picked up at about 1230 hours and trucked to the display area. They

Figure 2-4. Marine Helicopters over Yucca Lake after Shot Hood (U S Army Photograph)

would have arrived at the display area at about 1300 hours. After viewing the effects of the detonation on the displayed equipment, the troops departed for Camp Desert Rock at about 1400 hours. Company E evidently did not view the display, but was trucked back to Desert Rock after the conclusion of the battalion exercise.

Later that day, the majority of the exercise participants departed from Desert Rock for the return trip to Camp Pendleton. The Marine Brigade exercise was officially terminated.

Section 3
INITIAL RADIATION

Both shots of Operation Plumbbob involving Marine Brigade participation are investigated to determine the possible exposure to initial neutron and gamma radiation. This section discusses the general method used to compute the initial radiation dose to personnel and then treats specifically both shots of interest.

3.1 COMPUTATIONAL METHOD

The calculation of the radiation dose to personnel (in trenches in both cases) is accomplished in two steps: (1) calculate the radiation environment above the trench, (2) determine from this the radiation environment in the trench.

In the first step, the neutron and gamma radiation environment above the trench is determined with computer codes ATR4 (Reference 23) and ATR4.1 (Reference 24). ATR4 contains provisions to correct for the presence of Nevada soil at the air-ground interface; ATR4.1, although using West German soil, contains improved source energy-dependent ground correction factors. Hence, ATR4 is used to calculate neutron and neutron-induced gamma radiation, which is sensitive to the hydrogen (water) content of the soil (Reference 25), 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.

A required input to the ATR codes is the weapon neutron output spectrum, or source spectrum. When this spectrum is not known, it may be estimated by first choosing a trial neutron spectrum based on specific weapon design characteristics (e.g., boosting, high explosive thickness) and known spectra for

similar weapons. This trial spectrum is used in ATR4 to calculate neutron dose as a function of range, and a comparison is made with the dose-range curve derived from neutron fluence measurements for the specific shot of interest. These fluence measurements were made with fission (neptunium, uranium, and plutonium) and activation (sulfur and gold) foils. If necessary, the neutron distribution in the trial spectrum is then adjusted to obtain agreement with the observed data. It is important to note that the fluence data are not sufficient for dose reconstruction since they were obtained at ranges closer to GZ than the trenches. Hence, ATR codes, calibrated to fluence data, are used for extrapolation to the trench location.

Initial gamma doses are then calculated in the manner described previously, using ATR4 for neutron-induced (secondary) gamma and ATR4.1 for prompt and fission product gamma, and the total calculated gamma doses compared with gamma dose measurements. Because a significant gamma component is due to secondary gamma from radiative capture and inelastic scattering of neutrons, the low-energy portion of the neutron spectrum may be adjusted somewhat to obtain better agreement between the calculated and observed gamma dose curves. This adjustment does not significantly alter the neutron dose curves in the ranges of interest. The neutron source spectrum (adjusted, if necessary, as described above) is used in ATR4 and ATR4.1 to determine the neutron and gamma doses, evaluated for the locations of the trenches.

The second step of the calculation uses the free-field radiation environment to determine the dose within the trench. It is convenient to define a trench factor as the ratio of dose (neutron or gamma) in the trench to dose (neutron or gamma) above the trench. These factors must be calculated for each of the major components of radiation--neutron, secondary gamma (created by neutron capture or inelastic scattering in the atmosphere and ground), local gamma (created locally by neutron capture in the trench walls), and fission product (debris) gamma. It is found that the trench factors depend also on ground range, height of burst, weapon yield, trench dimensions, and depth in the

trench. For the shots of interest, the participants were in trenches approximately two feet wide and at a minimum of five feet deep (Reference 4). The in-trench free-field neutron and gamma doses for personnel in a crouched position are calculated at a depth of 2.33 feet below the lip of the trench, which corresponds approximately to the mid-torso depth for personnel in this position. For personnel standing upright in the trench, as probably occurred soon after passage of the shock wave, free-field doses are calculated at a point six inches below the lip at the mid-trench position; this corresponds approximately to the location of a properly-worn film badge for a standing observer. Brief discussions of the derivations of the various trench factors are presented in Appendix I of Reference 21.

The in-trench dose (in rads) is converted to an equivalent tissue dose (in rem) using the quality factors and methods prescribed in Reference 26. The rad-to-rem conversion factor for neutrons, derived from calculations utilizing computer codes DOT (Reference 27) and MORSE (Reference 28), 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; mean values of these parameters were determined from MORSE calculations involving extreme variations in individual posture and orientation. The "dose equivalent in trench" values reported for each shot in Section 3.2 are the equivalent tissue dose for neutron radiation and the film badge dose for gamma radiation.

The neutron, secondary gamma, and local doses are accrued rapidly (essentially within the first second) after detonation. Thus, the posture in a trench could not be altered significantly during this exposure. The debris gamma dose, however, is delivered over a period of many seconds. Therefore, the possibility of individual reorientation (e.g., standing up) in the trench must be

considered. It is unlikely that a person crouched in the trench at the time of detonation would have attempted any significant movement until after the shock wave had passed and the blast winds had subsided. Within a few seconds after passage of the shock wave, most of the troops would have stood upright in the trench to watch the rising cloud. This reorientation changes both the trench factors and film badge conversion factors for such an individual. The methodology used to determine the debris gamma contribution to personnel film badge doses is described in References 20 and 21. It is assumed in these calculations that the participants stood upright in the trenches at three seconds after the shock wave passed their positions.

3.2 RESULTS

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

3.2.1 Shot PRISCILLA

A good approximation of the neutron source spectrum is available for the PRISCILLA device. Neutron foil data are taken from Reference 29, and gamma dose data from Reference 30. The neutron and gamma doses derived from these data and the ATR dose-range curves are displayed in Figures 3-1 and 3-2, respectively. No spectrum adjustment was necessary to obtain the neutron dose fit; however, an adjustment of low-energy neutrons was required for the gamma doses.

The results of the calculations, for a midpoint trench location of 4250 yards from ground zero, are presented below.

	Neutron	Gamma
Tissue dose above trench (mrad)	.6	76
Dose equivalent in trench (mrem)	2	3

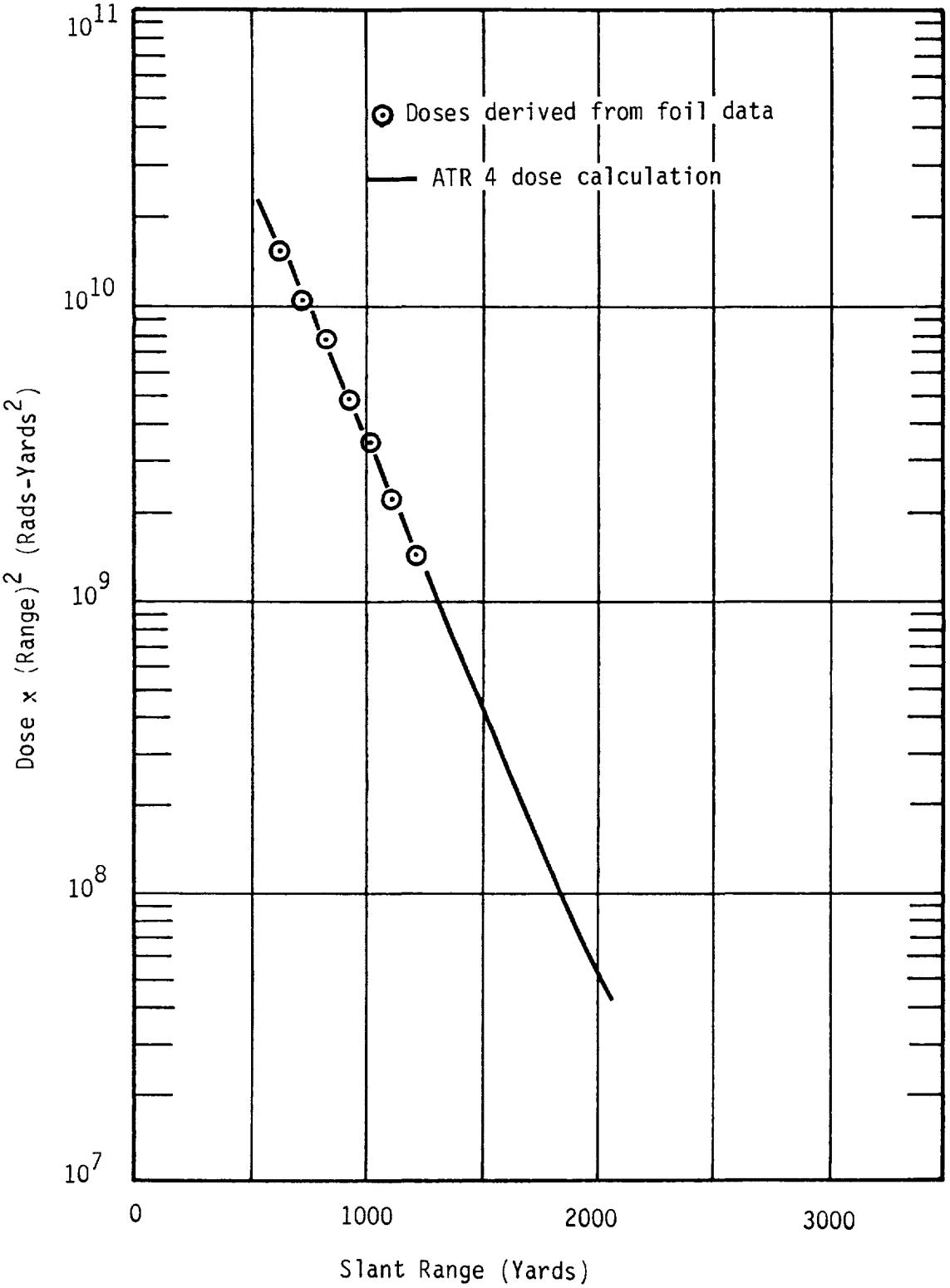


Figure 3-1. Shot Priscilla Neutron Dose

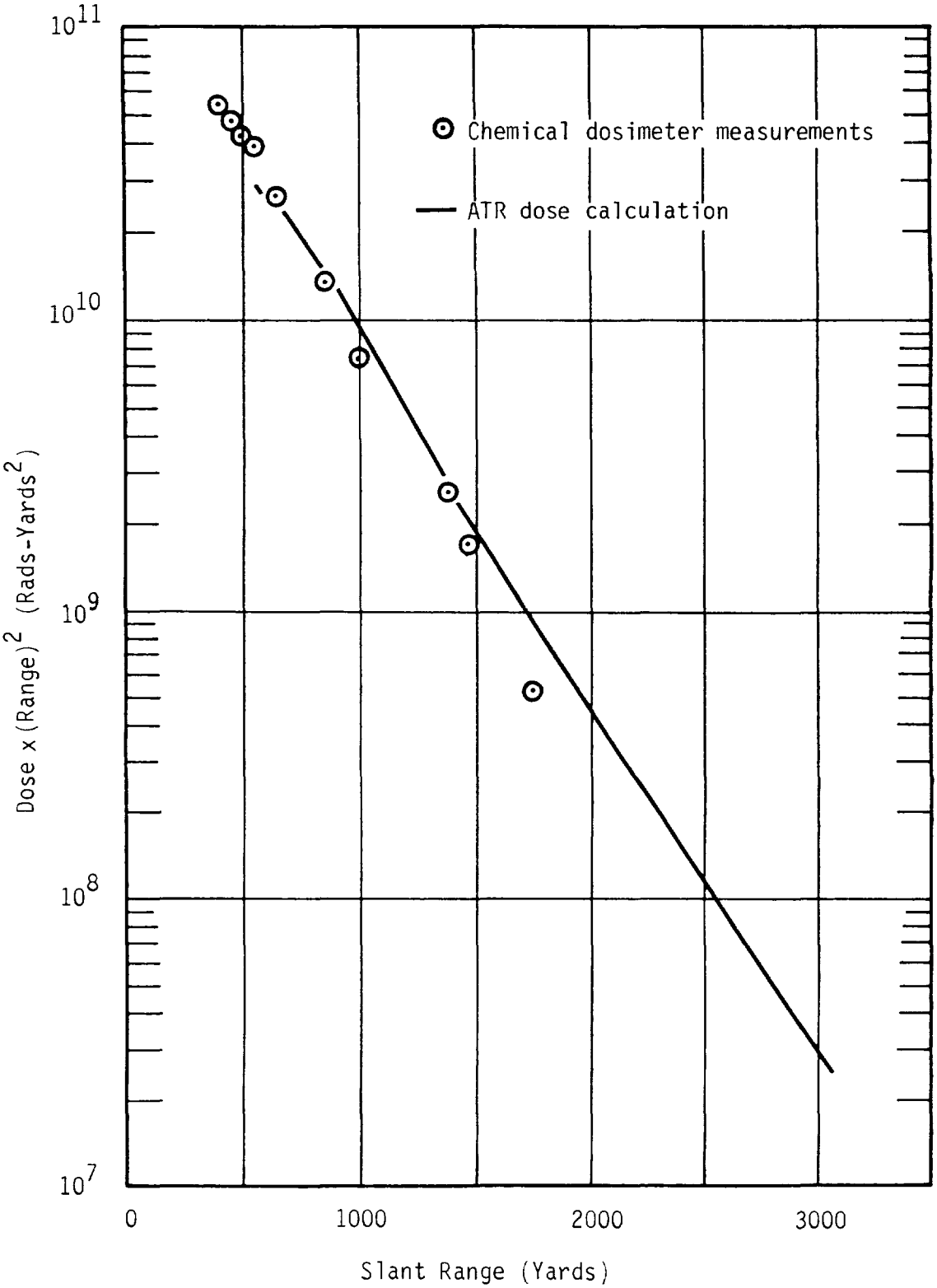


Figure 3-2. Shot Priscilla Gamma Dose.

3.2.2 Shot HOOD

The neutron source spectrum for the HOOD device has been calculated by the sponsoring laboratory and is used in this calculation. Neutron foil data are taken from Reference 31, and gamma dose data from Reference 30. Shown in Figures 3-3 and 3-4 are the neutron and gamma doses derived from these data and the ATR dose-range curves. No spectrum adjustment is used for either fit.

The results of the calculations, for a midpoint trench location of 5360 yards from ground zero, are given below.

	Neutron	Gamma
Tissue dose above trench (mrad)	<1	29
Dose equivalent in trench (mrem)	<1	<1

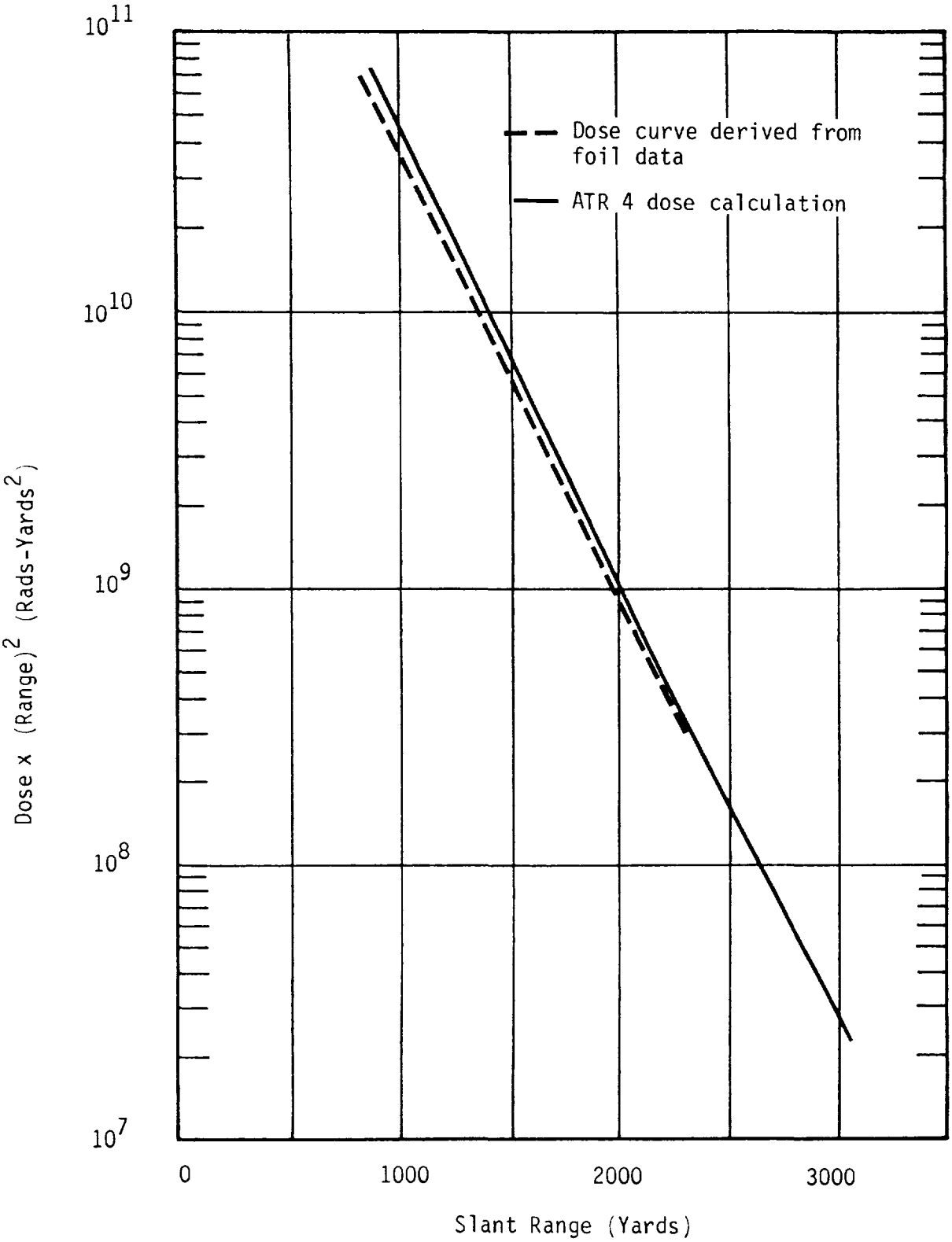


Figure 3-3. Shot Hood Neutron Dose.

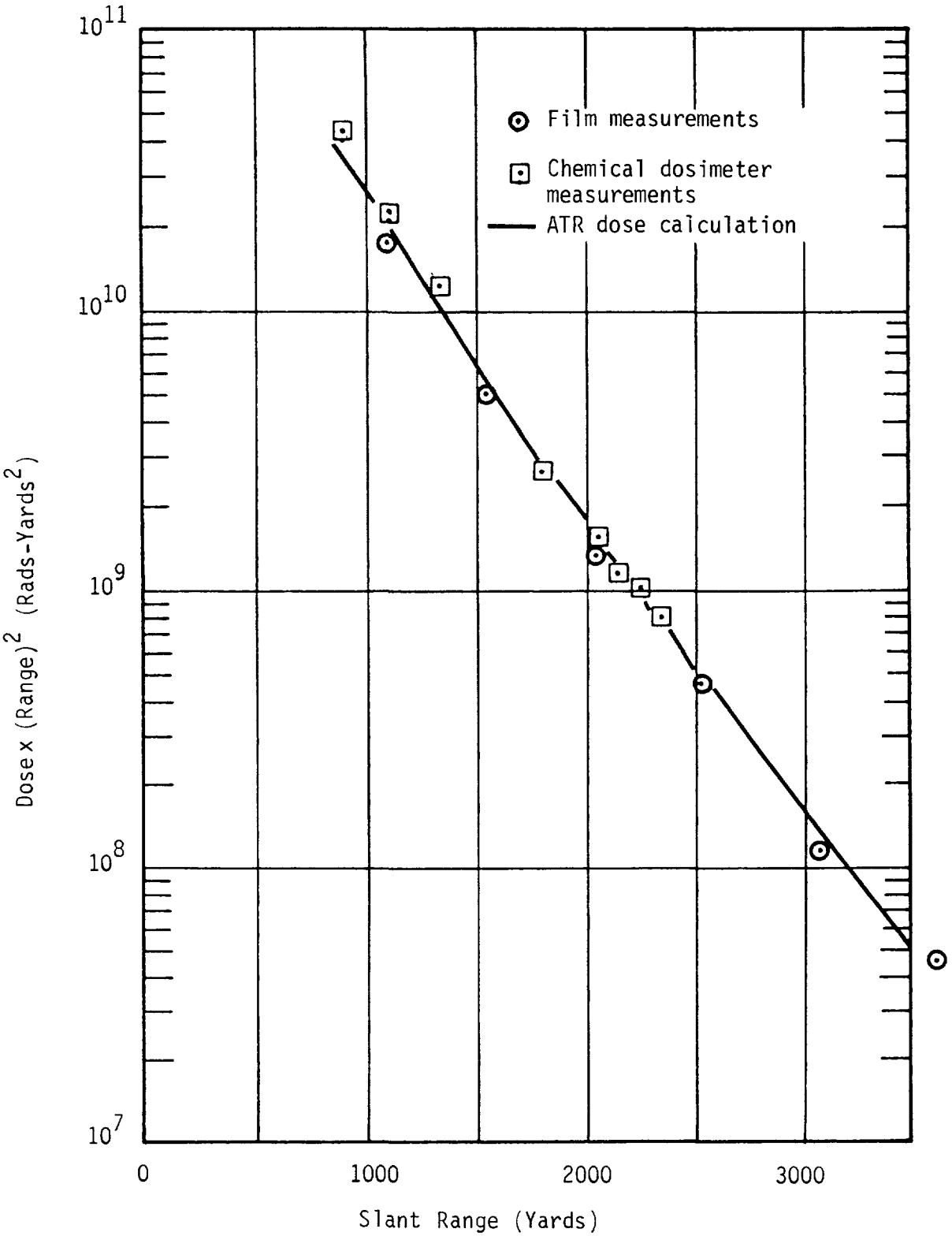


Figure 3-4. Shot Hood Gamma Dose.

SECTION 4
RESIDUAL RADIATION

4.1 RESIDUAL GAMMA EXPOSURE

Gamma doses are reconstructed for brigade personnel based on their activities in the fallout and neutron-induced activity fields of various shots of Operation Plumbbob. A computerized methodology, described in Reference 20, determines the radiological environment for each shot of interest. From this, doses are calculated based on the scenario of troop activities. Isointensity contours with superimposed troop tracks are displayed for Shots WILSON, PRISCILLA, and HOOD.

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 18: 1 r/hr → 0.7 rem/hr. This conversion is strictly applicable to an erect individual wearing a film badge on his chest and standing in a uniform, plane fallout field. However, the conversion is also approximately correct for the intensity gradients and induced activity fields also encountered by the marines.

Because of limited data concerning the details of display inspection and the timing involved, estimates are required for various parameters. Rates of movement are estimated from planned times or the few reported times, the number of displays viewed, the calculated 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. The stay time at each display line allows for some lateral spread of the observer group to see a variety of equipment. For PRISCILLA, the military effects shot in Frenchman Flat, the greater number of displays would have warranted walking the length of each display line. For these, a slow walking rate of 50 yds/min is assumed along display lines, without stops, and a faster pace of 70 yds/min is assumed between lines.

The radiation surveys from which the gamma intensity field is calculated were performed by the Reynolds Electrical & Engineering Company (REECo) for the AEC (References 11 through 14), and thus had no connection with the Desert Rock rad-safe effort. Few data reflecting specific radiation measurements by Desert Rock personnel are available, but they do supplement and are generally consistent with the REECo data at specific locations.

Several shots of Operation Plumbbob were potential contributors to the residual radiation dose of the 4th MCPAEB. Table 4-1 displays data for all Plumbbob shots through the time of the brigade activities. Shots FRANKLIN and LASSEN were of no consequence to the brigade (see Reference 18); other shots are analyzed as applicable.

4.1.1 Shot PRISCILLA Fallout

Observers of PRISCILLA from the troop trenches accrued a small dose from fallout within the first two hours. Almost all fallout blew directly away from the troops, to the northeast. Even near-surface wind data fail to indicate that any fallout would have drifted westward. However, both REECo survey data (Reference 13) and intensity readings taken by a participant indicate low-level fallout west of GZ. The REECo isointensity contours do not depict this fallout because it was generally less than the 10 mr/hr indicated by the lowest-level contour. Isolated readings from the initial survey and shortly thereafter show widespread fallout in the range of 1 to 10 mr/hr as far west as Mercury Highway. The reconstructed personnel dose from PRISCILLA fallout is based on the following participant data:

Table 4-1. Operation Plumbbob Shot Locations for Fallout Determination
28 May - 5 July 1957

SHOT NAME	DATE (1957)	TIME (PDT)	LOCATION* (UTM)	BURST HEIGHT (FT)	YIELD (KT)
BOLTZMANN	28 May	0455	T7c 867056	500 T**	12
FRANKLIN	2 June	0455	T3 870004	300 T	0.14
LASSEN	5 June	0455	B9a 852100	500 B	0.0005
WILSON	18 June	0455	B9a 852100	500 B	10
PRISCILLA	24 June	0630	FF 956728	700 B	37
DIABLO (Misfire)	28 June	0430	T-2b 792117	500 T	-
HOOD	5 July	0440	B9a 852100	1500 B	74

*Location is shown by AEC test area as well as in Universal Transverse Mercator (UTM) grid coordinates.
**T-Tower B-Balloon

Minutes after Shot	Intensity (mr/hr)
32	4
33	8
44	10
90	11
120	1.5

All but the last reading were taken at the trench area to the southwest of GZ; the last entry was taken while observers were en route to the display area. Linear interpolation for both time and intensity results in a film badge dose of about 9 mrem. Fallout apparently commenced just prior to the first reading.

4.1.2 Shot PRISCILLA Induced Activity

Viewers of the PRISCILLA equipment display (see Figure 4-1) were exposed almost entirely to neutron-induced activity from the shot. The observers left the trench area late in the second hour after burst. Most likely, the heavy dust from PRISCILLA was responsible for the late departure. The initial time for display inspection is taken as 125 minutes after burst, shortly after the time of the last data point shown above. A speed of 70 yd/min throughout the display proves consistent with a reading of 2 r/hr taken three hours after the burst at 700 yards from GZ. The prescribed walking pattern through the area then matches that time and distance very well, and the intensity is in agreement with that calculated from the REECo survey data (Reference 13). According to calculated intensities, the entire 600-yard display line was available to the observers within the 5 r/hr rad-safe limit. Within the calculated uncertainty in the gamma field, at least part of the 600-yard display would have in most cases been available to the observers. The one item of the 450-yard display line, actually at 515 yards, would in most cases not have been available to the observers. For the walk-through as described, the calculated film badge dose is 450 mrem.

4.1.3 Shot WILSON Fallout

Most of the time the 4th MCPAEB was in Yucca Flat, it operated in low-level fallout from Shot WILSON. Radiation exposure occurred at both the DIABLO and HOOD trenches, the helicopter loading zone (HLZ#2), and the

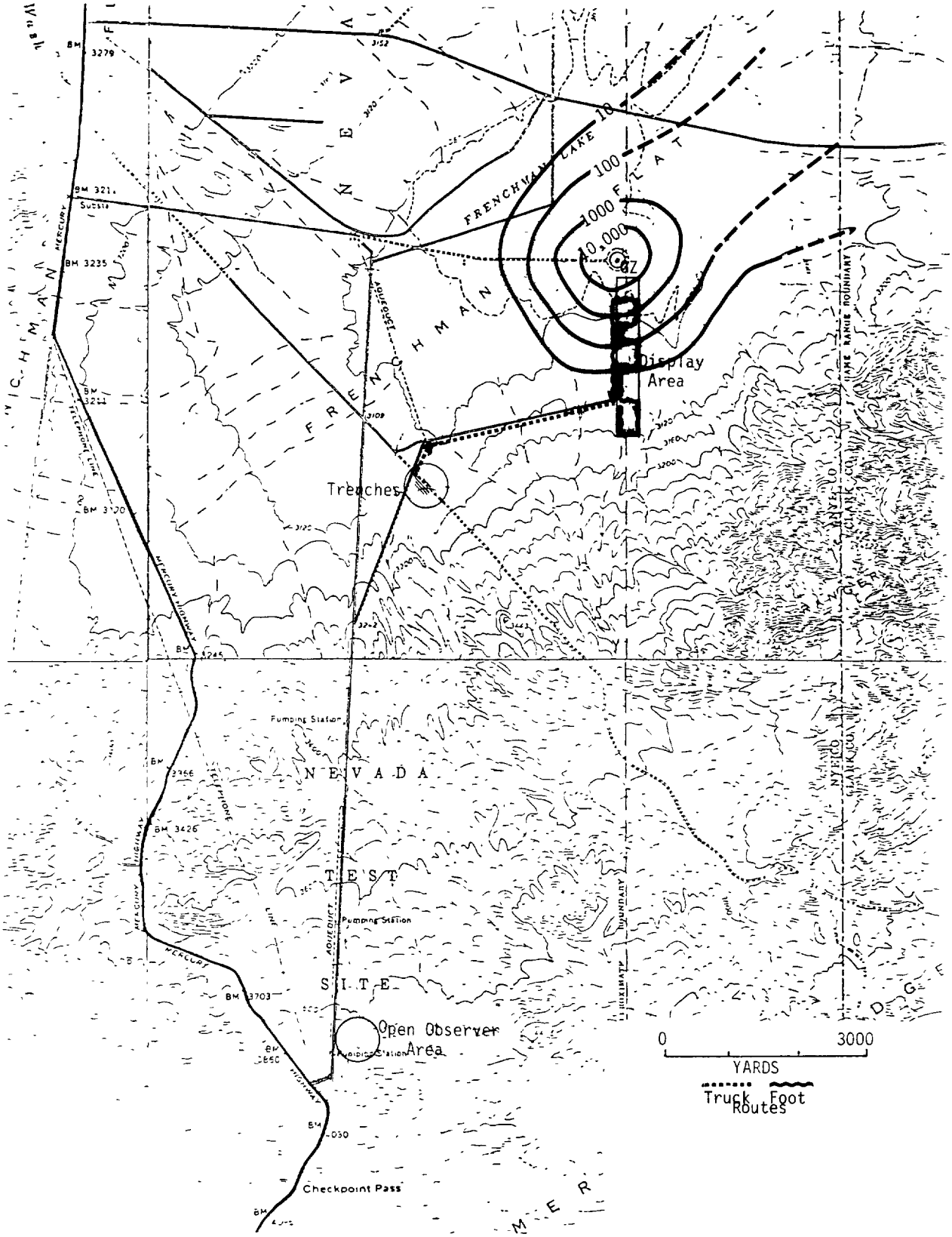


Figure 4-1. Shot Priscilla Residual Radiation (mr/hr @ H+3) and Observer Movements

Command Post. When E Company walked toward the HOOD GZ, it was also walking toward the WILSON GZ; however, the dose accrued from HOOD during that excursion so completely dominates that from WILSON that the latter is not calculated.

The WILSON fallout field shown in Figure 4-2 is basically that depicted in Reference 18, as derived from radiation survey plots in Reference 11. In these, however, isointensity contours did not extend to the areas of interest. The revision and extension of these contours has been made possible by the discovery of the original rad-safe survey data (Reference 12). Data at and near the GZs to the west of Mercury Highway (in Areas 1, 2, and 4) and extensive surveys along the west leg of Mercury Highway fairly well bracket the areas of interest except for the Command Post. The intensities along the west leg required adjustment because the initial survey plot did not account for radioactive decay during the period of that survey. Because the CP was well beyond the area of radiation surveys for Shot WILSON, the intensity cannot be well estimated. The closer-in hotline intensity of about 50 mr/hr (I_{12}) represents an upper limit.

H+12 intensities, I_{12}, for each position of interest are decayed to intensities on rehearsal and shot dates through the factors, f, obtained from Reference 18. The gamma film badge doses, D, accrued during exercise activities are reconstructed as follows:

Location	I_{12} (mr/hr)	Date	f	I (mr/hr)	$\dot{D}$ (mrem/hr)	Time (hr)	D (mrem)
DIABLO Trenches	~10	21 June	0.20	2.0	1.4	~6	8
		28 June	0.05	0.5	0.4	~5	2
HOOD Trenches	~45	5 July	0.022	1.0	0.7	~5	4
Command Post	~50	20-21 June	0.23	11.5	8.0	13-15	100-120
		27-28 June	0.05	2.5	1.8	13-15	24-27
		5 July	0.022	1.1	0.8	6-11	5-9
Helicopter Loading Zone (HLZ#2)	~20	21 June	0.20	4.0	2.8	~1	3
		28 June	0.05	1.0	0.7	~1	1
		5 July	0.022	0.4	0.3	~1	

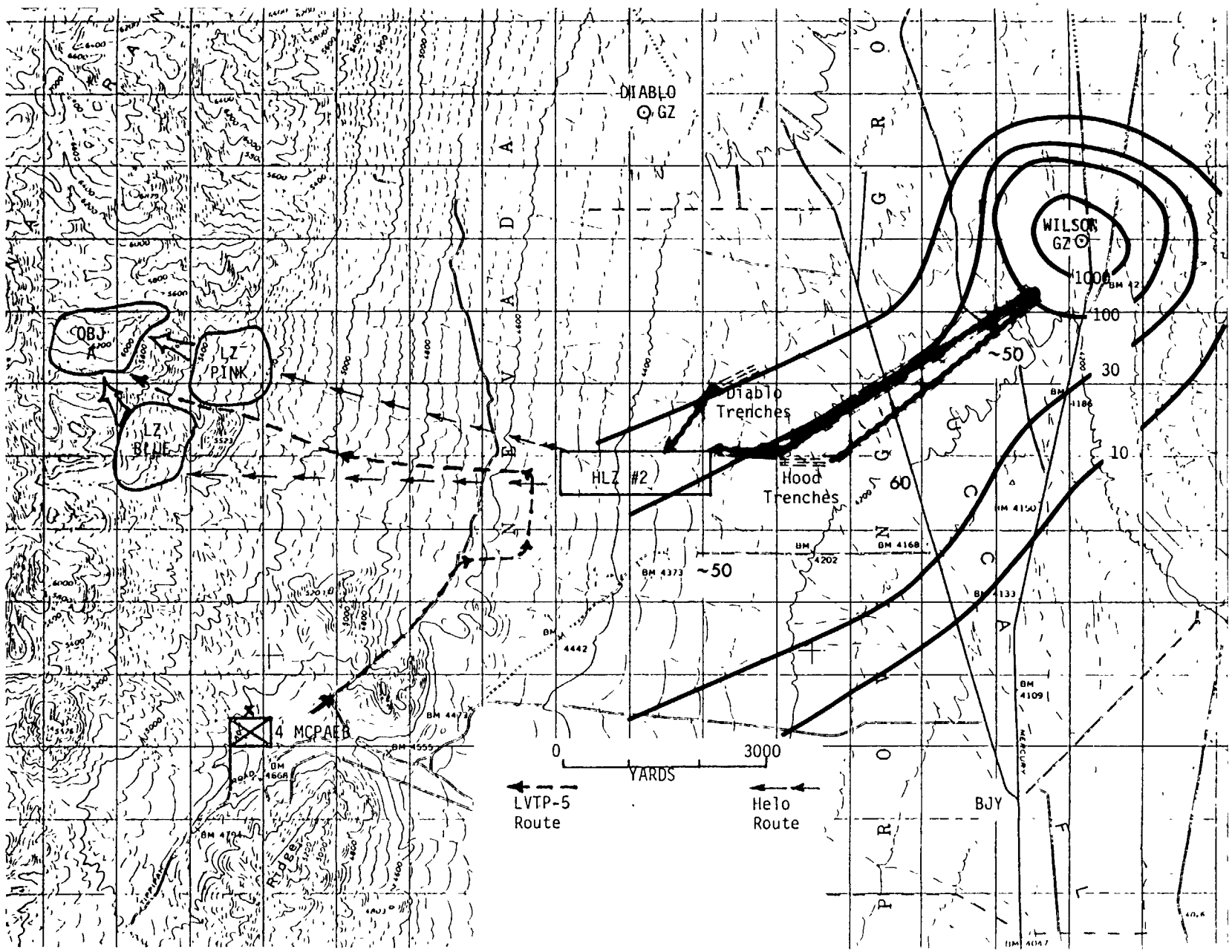


Figure 4-2. Shot Wilson Residual Radiation (mr/hr @ H+12) and Marine Brigade Movements

4.1.4 Shot HOOD Induced Activity

The only occasions upon which personnel were exposed to residual radiation from Shot HOOD were during E Company's march toward GZ and the viewing of the equipment display (see Figure 4-3). Essentially all contamination was in the form of the neutron activation products Mn^{56} and Na^{24}. During these excursions only, personnel were also exposed to month-old fallout from Shot BOLTZMANN (see Reference 18) and induced activity from Shot WILSON. The other early shots, FRANKLIN and LASSEN, contributed no residual in the exercise area. The contamination from HOOD was so dominant that the small contribution to external dose from all previous shots need not be computed.

Company E is assumed to have moved out from the trench area (southwest of GZ) 15 minutes after the shot. Walking at an average of 3 mph, they would have reached the calculated position of the 5 r/hr rad-safe limit 49 minutes later (if they remained on-line with GZ). A five-minute stay at the rad-safe limit, 1070 yards from GZ, followed by a return to the trench area at 3 mph results in a total calculated film badge dose of 530 mrem. Just over half of this dose results from the stay at the 5 r/hr line, the location of which is assumed to have been updated for the arriving troops.

Viewers of the equipment display are assumed to have examined all displays outside the rad-safe limit. Because repeated surveys by Desert Rock and later Marine personnel located the display closest to the 5 r/hr line, the viewers would not have gone closer to GZ than this display. The distances at which the HOOD displays were positioned are not precisely known; only the documentation for the intended DIABLO display (Reference 8) has been located. Those distances were scaled for the intended yield of Shot HOOD to provide the same planned damage effects (Reference 4). Rescaled distances for the HOOD display are calculated based on the mean predicted yields and heights of burst of DIABLO and HOOD. The scaling information available in 1957 was very close to that currently used. Blast scaling is applied to the equipment at (DIABLO) distances of 230 through 1350 yards from GZ. Thermal radiation scaling is applied to the mannequin displays at 1835 through 2485 yards. Distances scaled to HOOD range from 260 to 2530 yards for equipment and about 4200 to 5400 yards for mannequins.

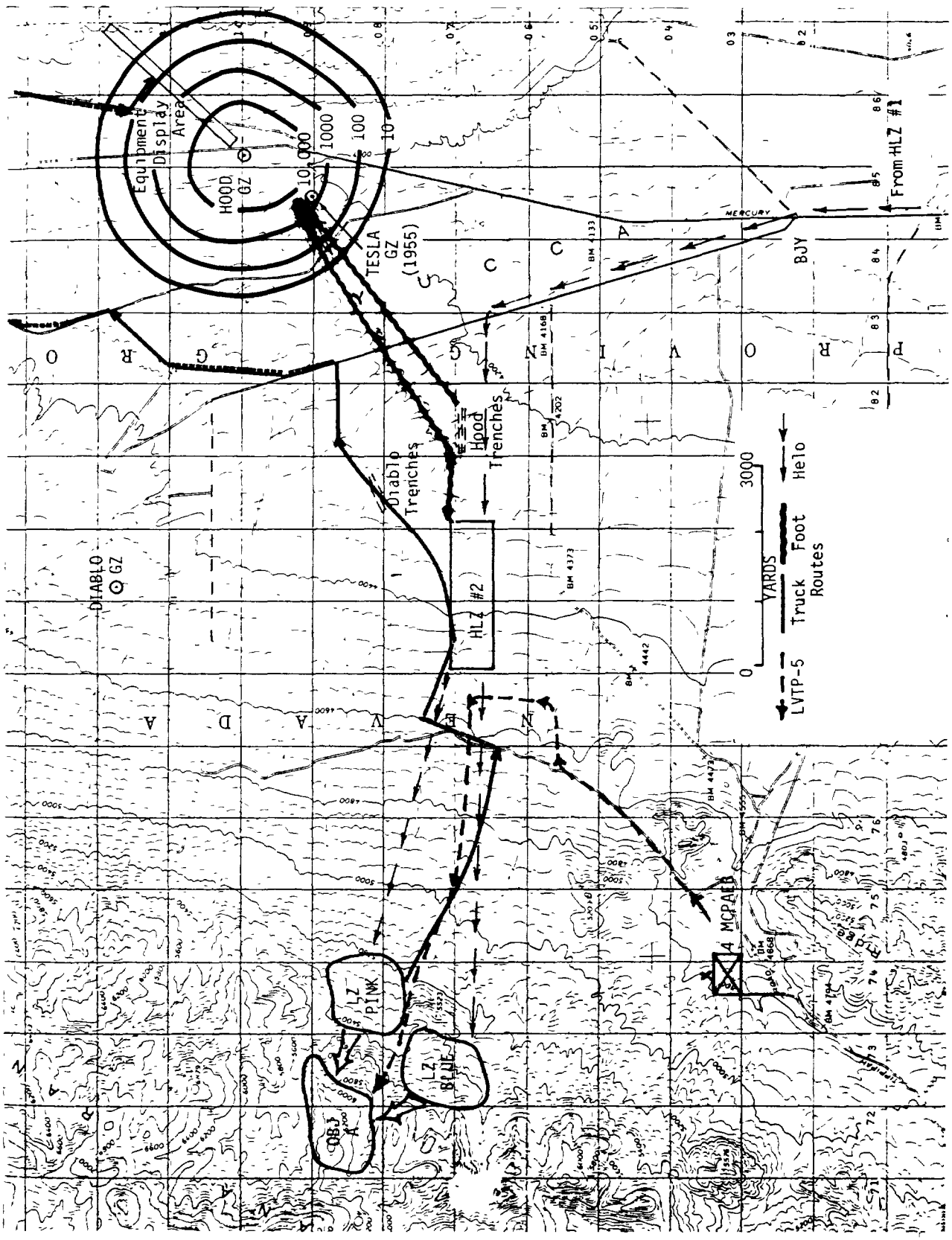


Figure 4-3. Shot Hood Residual Radiation (mr/hr @ H+1) and Marine Brigade Movements

Both the DIABLO and HOOD displays were planned to be northeast of GZ (Reference 6 and 7). For HOOD, the great distances for mannequins would have put them high in the hills to the east of Yucca Flat. The most likely scenario is that the equipment was placed to the northeast, but the mannequins, at much greater distances, were placed in line with the trenches. A burning mannequin at the trench area was noted after the shot; the trench distance from GZ matches the farthest scaled mannequin distance. The other mannequins would have been at least several hundred yards distant, and may not have been noticed in the midst of other burning vegetation.

Equipment viewed at HOOD is calculated to have been at approximately 2530, 1310, 1160, 1070, and 840 yards from GZ. At the latter, the gamma intensity upon troop arrival is calculated to have been 3.2 r/hr. The calculated film badge dose for viewing displays at these distances after the conclusion of the battalion exercise is 610 mrem.

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. Situations of possible significant inhalation exposure to Marine elements are analyzed. 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 19, 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 the marines; thus, the calculated dose commitments are high-sided.

4.2.1 Personnel in an Induced Field

As indicated in Reference 21, the internal dose commitment resulting from activities in neutron-activated soil is small compared to the corresponding acute external dose unless there is extreme soil suspension. For Shot HOOD, what dust was lofted by the shock wave had either settled or blown out of the shot area, away from the troops, before the HOOD radiation field was entered. Any internal dose commitment from suspension of dust by walking would have been far less than 1 mrem. At Shot PRISCILLA, dust did linger in the shot area for the duration of the observers' tour. Helicopters were unable to complete a survey of the area until midday, when visibility had sufficiently improved for their purposes. What dust there was did not impede the observation of the display area, but apparently delayed the start of observer activities. The suspension factor must have been considerably less than for the dust storm at Shot Grable (1953), for which 10^{-2} m^{-1} was used (Reference 21). A high-sided value of 10^{-3} m^{-1} is assumed for the PRISCILLA dust at the time of the display observation. Following the analysis of Reference 21, the whole body commitment for exposure at three hours after burst (the approximate mid-time for the observers' tour) is 2.3 mrem per mr of time-integrated intensity from Na^{24} for unit resuspension factor (m^{-1}) of activity in the top centimeter of soil and unit breathing rate (m^3/hr). For the calculated film badge dose of 450 mrem, the time-integrated intensity was 650 mr, of which about 350 mr would have been from Na^{24}. At time zero, the Na^{24} contribution would have been about 400 mr. The 50-year whole body dose commitment, with a 1.3 m^3/hr breathing rate, is then given as

$$D = (2.3)(400)(1.3)(10^{-3}) = 1.2 \text{ mrem}$$

There is no evidence that dust within the area was significantly redistributed; neither the rad-safe survey conducted just before the observers' arrival in the display area nor intensity readings taken during the tour indicate a level of airborne activity that could cause transient irregularities in the radiation field.

4.2.2 Personnel Exposed to Helicopter-Lofted Fallout

Personnel waiting to board helicopters at HLZ#2 may have been subjected to helicopter-resuspended WILSON fallout for as long as an hour at both the DIABLO rehearsal and the maneuver at HOOD. Particularly at the former, only three days after WILSON, the fresh fallout might have remained loose on top of the ambient soil. The worst case is considered by assuming the fallout to be of respirable size, and thus sufficiently small to afford the possibility of complete resuspension by the helicopter-induced winds. Because of the spacing of the helicopters, only a small portion of the loading zone fallout is resuspended. Each landed helicopter would occupy an area of approximately 50x100 yards. If each helicopter lofts the fallout directly under the sweep of the main rotor (about 300 yd^2 for a 60-foot diameter sweep), then only six percent of the fallout in the area of landed helicopters is resuspended. If the suspended dust attains a depth of about 10 meters, assumed to be of uniform concentration, then the effective resuspension factor for the area of landed helicopters is $6 \times 10^{-3} m^{-1}$. It is assumed that the lofted dust diffuses to fill the volume corresponding to each helicopter, but does not diffuse out of the area of landed helicopters; thus, a uniform concentration of dust over that area is achieved.

For marines waiting to board for up to an hour just outside of the loading area, the dust patch could drift over to them and remain over them if the winds were sufficiently light. At the time of the DIABLO rehearsal, the whole body 50-year dose commitment (Reference 22) is 250 mrem per mr of time-integrated intensity for unit resuspension factor (m^{-1}) and unit breathing rate.* From Section 4.1, the intensity at the time of rehearsal is 4 mr/hr. For the exercise after HOOD, the conversion is about 1400 mrem per mr, but the intensity at that

*This calculation incorporates both fission product and actinide (e.g., plutonium) contamination.

time is only 0.4 mr/hr. The total 50-year whole body commitment from WILSON fallout at the helicopter landing zone is then

$$D = (250x4+1400x0.4)(1.3)(6x10^{-3}) = 12 \text{ mrem}$$

If the dust described above, which would be visibly dense, were endured without protective masks (as assumed), it follows that the masks worn at the trench area during the HOOD detonation probably were not removed until the dust level was comparable to that experienced during the rehearsal at HLZ#2. For similar intensities (0.4 vs. 1.0) of fallout from the same source (WILSON), a briefer exposure to still-dissipating dust at the HOOD trenches would have resulted in a clearly lower dose commitment than from proximity to landing helicopters.

4.2.3 Personnel Walking in Fallout Fields

For personnel walking in fallout fields, a resuspension factor of $10^{-5}m^{-1}$ (as in References 19 and 21) is chosen. It is assumed that the activities of Command Post personnel subjected them to a resuspension factor less than $10^{-5}m^{-1}$. Because of the time spent at the CP, these personnel had the greatest internal dose potential (except helicopter-related) from WILSON fallout. The other Plumbbob fallout field that personnel entered was the BOLTZMANN field (see Reference 18), in which the HOOD equipment display lay. Rad-safe monitors may have been in the area for as long as six hours. The doses for each situation are obtained in the following table (with a 1.3 m^3/hr breathing rate in all cases):

Location	Date	Intensity (mr/hr)	Maximum Time (hr)	Normalized mrem/mr	Fifty-year Dose Commitment (mrem)
Command Post	20-21 June	11.5	15	230	0.52
	27-28 June	2.5	15	800	0.39
	5 July	1.1	11	1400	0.22
Equipment Display	5 July	<8*	6	2280	<1.42

*Based on entire area being <1000 mr/hr at H+12 hours, and decay from Reference 18

Thus, no individual in the 4th MCPAEB accrued as much as 2 mrem to the whole body from these other activities in fallout fields.

4.3 RESIDUAL RADIATION DOSE SUMMARY

The calculated film badge doses to personnel of the 4th MCPAEB from residual gamma radiation are summarized chronologically as follows:

Event	Radiation Source	Dose (rem)
CPX Rehearsal	WILSON Fallout	0.10
DIABLO Rehearsal	WILSON Fallout	0.011
Shot PRISCILLA:		
Trench Area	PRISCILLA Fallout	0.009
Display Area	PRISCILLA Induced Activity	0.45
CPX	WILSON Fallout	0.024
Shot DIABLO (misfire)	WILSON Fallout	0.002
Shot HOOD:		
Command Post/ Trench Area	WILSON Fallout	0.009
Walk Toward GZ	HOOD Induced Activity	0.53
Display Area	HOOD Induced Activity	0.61

For most brigade activities, the 50-year dose commitment to the whole body from inhaled radionuclides is calculated to be less than 0.002 rem. A greater dose commitment, up to 0.012 rem, could have occurred only for personnel having a substantial wait to board helicopters in HLZ#2. The calculated dose commitments to bone are approximately double these values.

SECTION 5
UNCERTAINTY ANALYSIS AND TOTAL DOSE DETERMINATION

The sources of error in the calculation of the more significant doses are examined in order to estimate the uncertainty in personnel dose resulting from 4th MCPAEB activities. Doses from all activities are summed as applicable to determine the total dose to the various units within the brigade.

5.1 UNCERTAINTY ANALYSIS

The group activities resulting in the most significant doses were the CPX rehearsal, the tours of the PRISCILLA and HOOD equipment display areas, and the march toward HOOD GZ. For the CPX, the only uncertain parameter of importance is the gamma intensity at the Command Post. The uncertainty for the other activities arises from both the gamma radiation environment and the space-time scenarios of troop movements. For these, for which ample local radiation data were available, 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 20. Parametric studies are made using the automated procedure to determine the influence of scenario variations on personnel dose.

Errors in position, time, and gamma intensity are not independent because of the rad-safe constraint limiting troops to intensities of less than 5 r/hr. For both maneuver and observer elements, this limit was enforced by rad-safe and control elements who supervised these group activities (Reference 4). Troop positions are well known except with regard to limits of advance. Because reference material does not adequately report the actual limits of advance, the limit is assumed to be the 5 r/hr line or the display line just outside it. Consequently, the upper limit on dose is not necessarily obtained by considering the upper confidence limits 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.

The various sources of error are combined approximately; they cannot be combined rigorously due to the 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 for each activity. 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 limits are considered separately.

5.1.1 CPX Rehearsal

The intensity used in the dose calculation for the Command Post was based on the high-sided assumptions that the CP was on the hotline of the WILSON fallout pattern and that the intensity along the hotline did not diminish with distance from GZ. Reference 15 depicts a fallout pattern that continues straight and narrow offsite to the west-southwest. Thus, it is likely that the CP was indeed on or near the hotline, as Figure 4-2 suggests. The decrease in hotline intensity with distance from GZ, certain in the absence of precipitation, is not known for this shot. Reference 15 shows no isopleth greater than 1 mr/hr (H+12), almost certainly not the maximum, even offsite.

The decay rate used from H+12 hours to the time of the CPX rehearsal also contributes to a high-sided dose estimate. Although on-site fallout survey data are available for about one day after WILSON (Reference 12), there are too few data after that to extrapolate a decay rate. For the average time of the rehearsal, the H+12 intensity is multiplied by a decay factor of 0.23, as obtained from the Plumbbob composite decay from Reference 15. That decay is weighted heavily by tower shots and thus is probably not reliable for WILSON. By way of

contrast, the traditional $t^{-1.2}$ decay (Reference 17) would give a decay factor of 0.13. If these two decays are regarded as extremes, the film badge dose for the CPX rehearsal is between 60 and 100 mrem.

5.1.2 PRISCILLA Equipment Display

The calculated film badge dose of 450 mrem for observers of the PRISCILLA equipment display has an associated error factor (based on the 90-percent confidence limits for the calculated value) of 1.9 based on the gamma radiation field. Because the maximum intensity calculated on the 600-yard display line was 4.8 r/hr, just below the rad-safe limit, the dose could be scarcely any higher from this source of error. It could be the full factor of 1.9 lower because the observers would not have approached closer to GZ than this display. The assumed walk-through had no halt. If the observers had waited five minutes on the 600-yard display line near the point of maximum intensity, there would have been a 60-percent increase in dose. This might have occurred to allow stragglers to catch up before all began the return walk. Alternatively, if display lines were walked through at the slower pace of 50 yd/min, the additional dose would have been 85 mrem. Overall, the observers' film badge dose could have been $450\ ^{+270}_{-210}$ mrem. Because it is difficult to quantify this distribution, no mean dose is calculated; however, the 450 mrem is likely on the high side for most participants.

5.1.3 HOOD Equipment Display

The most significant uncertainty with regard to the dose accrued at the HOOD display area is the time spent at the displays. Because the three innermost displays viewed were not far apart, a different stay time at each has an impact on the total dose. If an error factor of 2 is assumed for the stay time at each, not taken independently, the calculated film badge dose is $610\ ^{+280}_{-140}$ mrem. The HOOD gamma field was unusually well defined through frequent surveys; for the tour through the display area, the overall error factor from gamma field uncertainty is only 1.2. Thus, the display at 840 yards was

definitely available, but no display closer to GZ could have been viewed. With the uncertainties from gamma field and stay time combined, the dose is 610^{+300}_{-150} mrem. Other uncertainties play a much less significant role. If the DIABLO display was correctly scaled to HOOD, the calculated display line distances must be very close to the actual ones. The exact time of entry into the display has little influence on the dose because it was so many hours after burst. The precise walking speed also has a minor effect.

5.1.4 March Toward HOOD GZ

The dominant uncertainty with regard to the dose from the march toward GZ is the time spent at the rad-safe limit. For an error factor of 2 in the stay time, the calculated film badge dose is 530^{+290}_{-140} mrem. Uncertainty in the gamma field has a very minor effect. The position of the 5 r/hr line slightly affects the timing of the march, which in turn has a minor effect on dose in an induced field. Error in the gradient of the intensity would have some effect on the total dose, but this error is very small.

The calculated closest approach to GZ, 1070 yards, is at odds with some statements in reference material. This in turn makes it worth considering the possibility that E Company advanced beyond the 5 r/hr rad-safe limit. Reference 4 states that marines moved to 400 yards from GZ, but qualifies this as a safe distance. Some maneuver participants believe that the approach was nearly this close. Reference 3 states only that the advance was limited by safety restrictions.

The calculated error factor for intensity at 1070 yards at the time of the troops' arrival is 1.7. The gradient of the intensity field was such that an error of this magnitude would displace the 5 r/hr location by only 100 yards. Therefore, the 400-yard distance is definitely inconsistent with a 5 r/hr intensity. In fact, the calculated intensity at 400 yards, had the marines continued their march, is 120 r/hr. The total dose for their march, even with an instantaneous turnaround assumed, would have been no less than 7.3 rem.

However, no film badges or other indications of doses approaching this value have been located for this unit.

It is most probable that the alleged approach to 400 yards from GZ never occurred. This distance would have been difficult for a participant to establish. After a balloon shot, such as HOOD, there would have been no clear indication where GZ was. The desert would have been denuded of vegetation at 1070 yards; there would have been little additional effect at GZ short of cratering, for which the burst was too high. Because the marines advanced cross-country, they would not have benefited from any marked stakes for other shot activities. No landscape features were close enough to permit an accurate sighting. A possible source of confusion may have been the tower debris of Shot TESLA (fired in 1955), which was only a few hundred yards from the line of advance toward GZ and, at about 1370 yards from the HOOD GZ, near the calculated limit of advance for F Company (see Figure 4-3).

5.2 TOTAL DOSE SUMMARY

The reconstructed gamma film badge doses for 4th MCPAEB participants are presented in Table 5-1. From the best-estimate doses of Section 4 and the error distributions of Section 5, the mean dose is calculated for elements of the brigade. These are presented along with estimated 90-percent confidence limits.

Table 5-1. Dose Summary, 4th MCPAEB

Brigade Element	Shot WILSON Dose (rem)	Shot PRISCILLA Dose (rem)	Shot HOOD Dose (rem)	Total Gamma Dose (rem)
Brigade Staff	0.08-0.16	$0.46^{+0.27}_{-0.21}$*	$0.64^{+0.25}_{-0.17}$*	0.12 ± 0.04, $0.58^{+0.27}_{-0.21}$, $0.76^{+0.25}_{-0.17}$
2nd Battalion				
E Co.	0.02	$0.46^{+0.27}_{-0.21}$*	$0.56^{+0.26}_{-0.17}$	$0.58^{+0.26}_{-0.17}$, $1.04^{+0.37}_{-0.27}$
G Co. (-)	0.00	$0.46^{+0.27}_{-0.21}$*	$0.64^{+0.25}_{-0.17}$	$0.64^{+0.25}_{-0.17}$, $1.10^{+0.37}_{-0.27}$
All Others	0.02	$0.46^{+0.27}_{-0.21}$*	$0.64^{+0.25}_{-0.17}$	$0.66^{+0.25}_{-0.17}$, $1.12^{+0.37}_{-0.27}$
Observers	< 0.01	--	0.00	< 0.01
Helicopter Crews	0.01	$0.46^{+0.27}_{-0.21}$*	0	0.01, $0.47^{+0.27}_{-0.21}$**
Rad-Safe Monitors	0.02	$0.46^{+0.27}_{-0.21}$*	0, > 0.5	0.02, $0.48^{+0.27}_{-0.21}$, > 0.5**

*Accrued by some members of group; others accrued zero dose

**Does not include additional undocumented activities

NOTE: Initial radiation dose was less than 0.01 rem from all sources.

SECTION 6
FILM BADGE DOSIMETRY

6.1 FILM BADGE DATA

Personnel of the 4th MCPAEB were issued individual film badges for their stay at Camp Desert Rock. Film badges were of the type described in Reference 18. Most brigade personnel had one film badge for the duration of the exercise; the rad-safe monitors had two or three. Dosimetry survives for about one-third of the brigade. Film badge records appear to be essentially complete for the brigade staff, rad-safe monitors, helicopter crews, and observers. For the 2nd Battalion, 5th Marines, dosimetry is available for only senior personnel. In general, very few low-ranking enlisted men are represented in the existing dosimetry records.

It is evident from film badge readings within a unit that personnel did not always operate together. In Section 4, it is determined that the major sources of radiation exposure to the brigade were the viewing of the PRISCILLA and HOOD displays and E Company's march toward the HOOD GZ. Members of the brigade staff likely had the opportunity to view the PRISCILLA display, in addition to their HOOD activities. The rad-safe monitors, divided into sixteen teams performing seven different functions, encountered various levels of radiation in the performance of their duties. Also, some of the monitors observed the PRISCILLA display.

The film badge readings for the brigade staff fall into three groups: less than 100 mrem (41 personnel), about 300 to 500 mrem (11 personnel, mean of 370 mrem), and about 900 to 1200 mrem (13 personnel, mean of 1020 mrem). Most readings for the 2nd Battalion are in the vicinity of 500 mrem. A few have much lower readings. Personnel with higher readings correlate very well with individuals appearing on a list of PRISCILLA participants from the 2nd Battalion. Company E, despite its walk toward GZ, has readings typical of the rest of the battalion. The rad-safe monitors received doses of up to 400 mrem from rad-

safe training on 20 or 21 June. Half of the monitors received additional doses of up to 300 mrem on another badge in the same time frame, presumably for the same purpose. Readings covering the period of PRISCILLA and HOOD range from virtually 0 to 2400 mrem. Most of the planned rad-safe activities involved surveying in areas of significant radiation. Seventy percent of the monitors' doses exceeded 800 mrem, normally from HOOD alone. Marine observers with the 4th MCPAEB all received less than 50 mrem. The majority of the MAG-36 helicopter crewmen had readings below 100 mrem; most others were below 200 mrem. Twenty crewmen received 290 to 470 mrem on badges turned in on the day after PRISCILLA. Eight others accrued about 1000 mrem for their entire stay.

Because of the numerous subgroups involved, the 2nd Battalion and the monitor teams are analyzed in more detail. In the 2nd Battalion, there are minor differences in dose among the companies. With the listed PRISCILLA attendees excluded, the mean film readings for Companies E, F, G, H, and HμS are 520, 550, 570, 470, and 540 mrem, respectively. These results are obtained from a total of 86 readings. Others not included in the averaging are three below 100 mrem, four of about 200-300 mrem, and one of 1200 mrem. Companies E and H are the most tightly grouped, with standard deviations of about 30 mrem. The readings in all companies are clearly distinct from those for personnel who attended PRISCILLA in addition to HOOD. The PRISCILLA attendees from the battalion as a whole have film badge readings in two clusters, averaging 840 mrem (18 readings) and 340 mrem (7 readings). There is one outlier of 1220 mrem.

The identification and segregation of the PRISCILLA subgroup for the 2nd Battalion makes it possible to conclude that there was no statistically significant difference in dose between officers and enlisted men for the HOOD exercise. Although fewer than ten percent of the 2nd Battalion enlisted men are represented in the dosimetry, there is no indication that their film badge readings are atypical. A strong contraindication is provided by the readings of company-level rad-safe monitors. Four low-ranking enlisted men from each of

E, F, G, and H Companies were specially trained at Camp Desert Rock in the ten days prior to the arrival of the 4th MCPAEB to provide rad-safe support to their units. These men, for whom dosimetry records are complete, should have accrued as much dose as anyone by operating at the head of their units. Their doses are very near the average for each company, except that in G Company, they exceed the average by about 100 mrem.

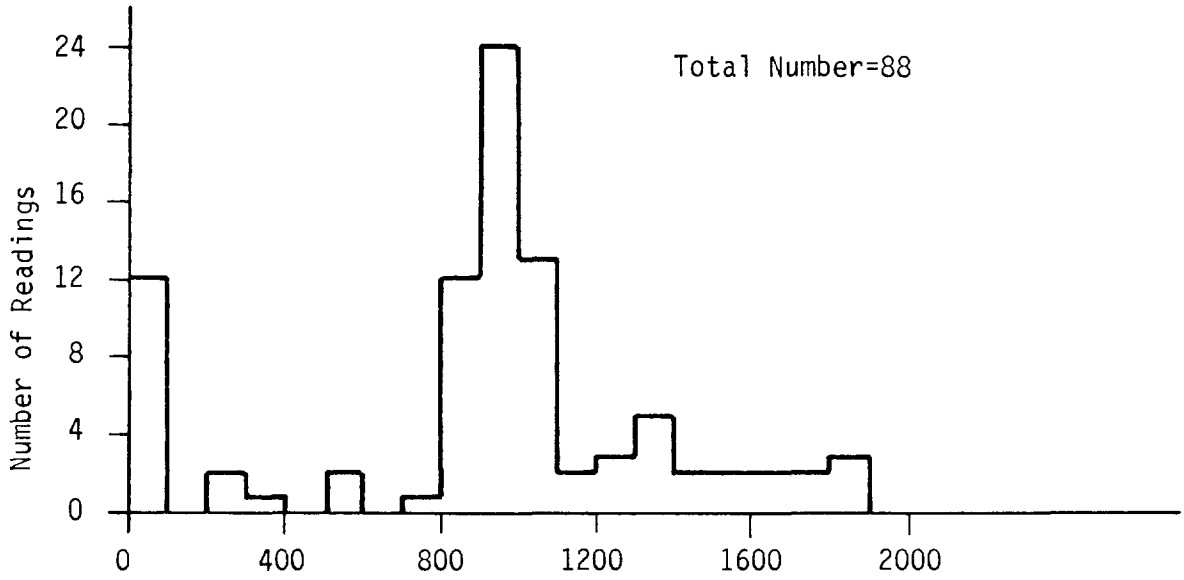
The multiple film badges of the 178-man Monitor Teams Group deserve special comment because of the overlap provided by their alleged dates of use: 20 June to 21 June, 20 June to 6 July, and 21 June to 6 July. Examination of all Desert Rock dosimetry shows that recording of film badge exchanges was not reliably precise as to the date. For example, the receipt of returned badges may not have been logged until the following day. Normally, a film badge log remained open until all badges were returned. Early turn-ins were usually not noted. The monitors' badge dates are then as follows: Everyone exchanged film badges after rad-safe training in Yucca Flat on 20 or 21 June (mean dose of 220 mrem). Half of the monitors kept their second badge for the duration of the exercise. The other half turned in badges on the 21st (mean dose of 130 mrem), presumably after additional training, and drew a third badge for the duration of the exercise. The turn-in of their second badge was not specially logged because the others were still outstanding. This interpretation is supported by the readings themselves. All readings on the first badge, except one, were 420 mrem or less. For personnel with three badges, if they had a subsequent reading greater than 320 mrem, it was always on the third badge. Personnel with only two badges typically had larger readings than 320 mrem on the second. This is consistent with the conclusion that the more significant exposures occurred during the PRISCILLA- HOOD time frame.

Only the film badge readings themselves are available to indicate the differences between the two- and three-badge monitors. That there are 50 percent in each category makes it likely that eight monitor teams were issued the third badge. It is possible that similar activities were performed by all on 20-21 June without uniform badge reissue, but not likely because the mean dose

on the final badge for both groups is identical (920 mrem). However, the doses in each group are widely distributed, so the significance of this fact is debatable. The dissimilar dose distributions, displayed in Figure 6-1, are not consistent with a hypothesis that half the teams for each planned shot-day activity fell into each group.

The planned activities of the monitor teams at HOOD would have involved twelve of the teams in areas of significant radiation while surveying the equipment display area, surveying around GZ, surveying the path to be followed toward GZ by E Company, and accompanying brigade personnel through the display area. All of these activities would have resulted in doses at least as great as those accrued by E Company and viewers of the equipment display, except for any teams that may have surveyed only the outer portion of the display area. The other four teams should not have operated any closer to HOOD GZ than the trenches, and should have accrued a negligible dose from HOOD. Their total film badge reading would have been less than 100 mrem, which was the case for two teams, as shown in Figure 6-1. How a third team at 300-plus mrem and a fourth team (not resolved in the figure) accrued higher levels of radiation is not known. The teams with higher dose levels are not readily distinguishable. Information regarding certain individuals provides some clues, however. A monitor who surveyed in advance of E Company accrued 890 mrem. The two teams planned for that activity were probably sufficiently cohesive to provide part of the peak in the 900 mrem range. Most of the highest readings, including the 2400 and 2300 mrem readings, apparently are for some of the display area monitors. Some of these individuals, both officers and enlisted men, are known to have participated in PRISCILLA as well. All monitor teams were to observe the HOOD equipment display at the conclusion of the exercise (Reference 10), but both film badge readings (the very low values) and personal accounts offer evidence to the contrary.

Some dosimetry not worn by 4th MCPAEB personnel is relevant to the determination of their dose. A film badge placed on a stake above the HOOD trenches read 66 mrem (the reading for a marine in a trench is known to have



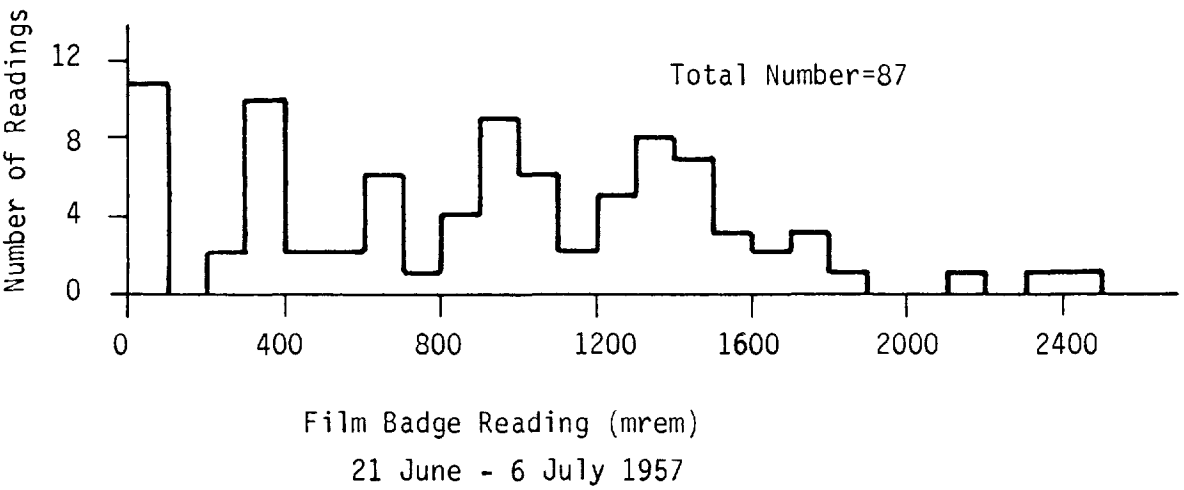


Figure 6-1 Distribution of Final Film Badge Readings for Monitor Teams Group

been 0). This provides a useful comparison with initial radiation calculations. Dosimetry is available for hundreds of observers from all services who walked through the PRISCILLA equipment display. Their doses, which should have been similar to those of participants from the brigade, were mostly between 300 and 500 mrem. The spread likely indicates that the walk-through was not tightly controlled; officers were probably permitted to linger at points of interest.

Of as much interest as the available film badge data is the missing data for the majority of marines. Film badge dosimetry is virtually complete for all other participants in Exercise Desert Rock VII-VIII. This has been determined by analysis of the issuance of film badge series. Film badges in each alphabetically-designated series were numbered from 1 to 299. The alphabetic progression of issued badge series correlates well with the time progression of badge issue dates. All badge series have been accounted for, as have almost all numbers within each series, except for one entire series that can be pinpointed to within one day of 20 June 1957. Marines are heavily represented in the series both immediately before and after.

Even more enigmatic than the selective disappearance of dosimetry records for the 4th MCPAEB is that one 299-badge series cannot account for about 1200 marines with missing individual film badges. Everyone else in Exercise Desert Rock VII-VIII had individual dosimetry; Marines would have been no exception. Statements by Marine participants overwhelmingly indicate that everyone did indeed have a film badge. The missing dosimetry, to whatever extent it existed, was probably lost in 1957. In an on-going search of medical records, Headquarters Marine Corps has found no entry of a 1957 dose that was not also in the presently available film badge records.

6.2 COMPARISON OF DOSE CALCULATIONS WITH FILM BADGE DATA

Film badge readings confirm that the initial radiation dose from HOOD was minimal. The above-ground reading of 66 mrem at the HOOD trench area agrees favorably with the calculated above-ground gamma dose of 29 mrem.

Because the film badge was probably at the command trench, slightly closer to GZ than the average troop trench (at which the dose was calculated), the badge reading would be expected to be somewhat greater. The calculated dose to personnel in the HOOD trenches of 1 mrem (gamma) is beneath the threshold of film badge sensitivity. Therefore, the reading of 0 mrem for an individual known to have been in a trench is in agreement with the calculated dose. No independent confirmation exists for the calculated initial radiation dose at PRISCILLA. Observers in the PRISCILLA trenches subsequently received larger residual radiation doses.

For observers of the PRISCILLA equipment display, the film badge data are in agreement with the calculated film badge dose of 460 mrem. Personnel from all services, known to have been observers of PRISCILLA only, have readings distributed around this value. Marine Brigade personnel known to have walked through the PRISCILLA display have readings that are either consistent with a PRISCILLA walk-through only (at a mean of 340 mrem, too low for a dose from HOOD), or are consistent with walk-throughs for both the PRISCILLA and HOOD displays (about 300 mrem greater than the mean HOOD-only dose).

The calculated mean film badge dose for E Company is 580 mrem, in good agreement with the mean film badge reading of 520 mrem. It is evident that the company did not also visit the equipment display area, as originally planned. Company E personnel have confirmed the elimination of this activity from their scenario. That the calculated dose, based on the rad-safe limit of 5 r/hr, agrees well with actual readings, is strongly suggestive that this constraint was not violated in the field. Company E apparently advanced only to a "safe" distance from GZ, regardless of what yardage has been subsequently associated with that distance.

For the remainder of the 2nd Battalion, the calculated mean film badge dose is 660 mrem, resulting almost entirely from the walk-through of the HOOD equipment display. This is in good agreement with the dosimetry data. The slight variation in company-averaged dose, especially for H Company, likely

indicates that each company viewed the equipment somewhat independently at a slightly different pace. That these companies accrued about the same dose as E Company is not highly coincidental: the scenarios for both included about the same walking speed in a radiation field of similar gradient at all azimuths, about the same gamma intensity at the point of closest approach to GZ, and about the same stay time at that point.

The calculated dose for members of the brigade staff participating in the CPX but not viewing a display area is 130 to 160 mrem. Exactly what that dose should be depends considerably upon different functions performed by the staff, particularly during the CPX. These likely account for the considerable variations in film badge reading observed within the 0 to 100 mrem range. Those film badge readings averaging 370 mrem are consistent with the calculated 450 mrem dose for observers of the PRISCILLA display. The highest group of doses for the brigade staff, averaging 1020 mrem, is not consistent with the rapid walk-through of the equipment display assumed for the 2nd Battalion. Perhaps all high-dose personnel viewed the PRISCILLA display as well, but the composition of the high-dose group, which included the Commanding General, 4th MCPAEB, provides another explanation for the dose level. The group also included low-ranking officers and most enlisted grades, who possibly acted as escorts and drivers for distinguished visitors. They probably toured the HOOD display area at a different time from the exercise troops and, at a more leisurely pace, would have accrued a greater dose.

The dose to personnel of MAG-36, while small, is greater than the estimate for the ground troop rehearsal dose. Undoubtedly, the helicopters touched down in areas that have not been recorded. Twenty of the crewmen evidently observed the PRISCILLA display. Doses in the vicinity of 1000 mrem for eight men cannot be explained in the context of the brigade exercise. One of these men claims to have piloted civilian scientists to an old shot area.

Outliers do not detract from the comparison of calculated doses and film badge readings. It is inevitable that certain individual or small-group missions were required that were not in the documented mainstream of troop activities.

That these missions may have resulted in higher than usual doses does not necessarily indicate any disregard for radiation safety procedure. Even the one anomalously high dose for a marine, 7200 mrem, can be logically explained in terms of a military mission. This dose was accrued by the equipment display officer, whose extended presence in the HOOD display area was required on shot day and on subsequent days.

Calculated and actual film badge doses for the major groups of the 4th MCPAEB (functionally and radiologically) are displayed in Table 6-1.

Table 6-1. Calculated and Actual Film Badge Doses

Brigade Element	Calculated Mean Film Badge Dose (rem)	Mean Film Badge Reading (rem)	Range of Film Badge Reading (rem)
Brigade Staff			
Viewed:			
PRISCILLA Display	0.59	0.37	~0.25-0.5
HOOD Display	0.75	1.02	~0.9-1.2
No Display	0.14		≤0.1
2nd Battalion			
E Co.	0.58	0.52	
F Co.	0.66	0.55	
G Co.	0.64	0.57	
H Co.	0.66	0.47	
H&S Co.	0.66	0.54	
F,G,H Co.			
+ PRISCILLA Display	1.12	0.84	
PRISCILLA Display only	0.46	0.34	
Observers	<0.01		0; <0.05
Helicopter Crews	0.01		<0.2
+PRISCILLA Display	0.46		0.29-0.46
Rad-Safe Monitors			
20-21 June	-	0.22	0-0.42,0.77
21 June	-	0.13	0-0.32
20 or 21 June-6 July	0.02, >0.5	0.92	0.018-2.4
Total Dose	-	1.2	0.253-3.02

SECTION 7
CONCLUSIONS

Elements of the 4th Marine Corps Provisional Atomic Exercise Brigade, Exercise Desert Rock VII, participated in two nuclear shots while at the Nevada Test Site during Operation Plumbbob. For Shot PRISCILLA, selected officers and enlisted personnel were in trenches 4250 yards (3890 meters) southwest of ground zero. They also toured the equipment display area after the shot.

The brigade staff conducted a command post exercise in the forward area before the first scheduled detonation of Shot DIABLO. The remainder of the brigade also moved to the forward area to witness this shot. Because the shot misfired, the only radiation exposure to these personnel was the residual from previous shots, the most significant of which was Shot WILSON, fired 10 days before.

Although the command post exercise was not repeated, most of the brigade participated in Shot HOOD, observing the shot from trenches 5360 yards (4900 meters) from ground zero. After the shot, the maneuver elements conducted the assault exercise originally planned for post-DIABLO. One company of marines also advanced toward ground zero before joining other maneuver elements in the assault on an objective over 12 kilometers from ground zero. The brigade, not including the helicopters or the company that marched toward ground zero immediately after the shot, then toured the display area before returning to Camp Desert Rock.

Initial radiation totaled less than 0.01 rem for participants in Shots PRISCILLA and HOOD. Therefore, external exposure was primarily due to residual radiation from these and previous shots. Although all four previous Plumbbob shots were examined, only Shot WILSON contributed significantly to the doses of exercise personnel, both during exercise rehearsals as well as before and during the DIABLO misfire, and during the Shot HOOD activities. The total contribution to the dose of any participant due to Shot WILSON was less than 0.16 rem.

The major radiation exposure of brigade personnel was due to Shots PRISCILLA and HOOD. However, few participants were exposed to both shots in the range of either's maximum contribution. Thus, the highest likely dose to a typical maneuver troop was 0.66 rem, almost all accrued during the post-shot inspection of the HOOD equipment display.

Due to the possible high levels of dust in the helicopter loading zone, where contaminants could have been lofted, a 50-year whole body dose commitment of 0.012 rem could have been received by personnel who may have had to wait for as long as an hour for their airlift during both the rehearsal and the actual maneuver. For others who were not exposed to these rather extreme conditions, the internal dose would be correspondingly less. The bone dose commitment is calculated to be about twice the whole body commitment.

Film badge dosimetry and other records of activities for Exercise Desert Rock VII are sufficient to identify the personnel who had the greatest potential for exposure and to determine their specific activities. Dosimetry data correlate well with calculated doses, thus providing the necessary confidence in the calculated doses, and group activities, for those personnel with no dosimetry records.

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