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ANALYSIS OF RADIATION EXPOSURE, TASK FORCE RAZOR

Exercise Desert Rock VI, Operation Teapot

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Technical Report

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The radiation dose to Task Force RAZOR personnel participating in Shot Apple II of Operation Teapot, Exercise Desert Rock VI, is reconstructed. Task force personnel were exposed to initial radiation while in their vehicles or in trenches at the time of Apple II detonation. They were also exposed to residual radiation during their subsequent manuever and during an inspection of the equipment display area. The calculated total gamma doses to fully-participating Task Force RAZOR personnel range from about 0.8 rem to 1.8 rem. The highest dose was received by personnel of the armored infantry platoon on

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right flank nearest ground zero. Internal radiation dose commitments to maximally exposed personnel inside vehicles are estimated to be about 0.4 rem to the thyroid, 0.003 rem to the whole body, and 0.002 rem to the bone.

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Section 1
INTRODUCTION AND SUMMARY

This report presents an analysis of the nuclear radiation exposure for the personnel of the Task Force RAZOR during their participation in Operation Teapot. This troop test was known as Project 41.2 of Exercise Desert Rock VI. The armored task force maneuvered in conjunction with Shot Apple II, 5 May 1955, at the Nevada Test Site.

The troop test took place over a period of slightly more than two weeks, during which time the personnel trained, rehearsed, and conducted the assault maneuver after the shot. The maneuver consisted of an attack on an objective by a reinforced tank battalion and a provisional aviation company. The attack began 8 minutes after the shot.

The task force activities are traced from arrival at Camp Desert Rock on 21 April 1955 until departure on 7 May 1955. The shot was originally scheduled for April 26, but was postponed twice due to weather conditions. The detonation finally took place the following week on 5 May 1955. Time-dependent position information is determined from records, reports, interviews, and photographs. External (and internal as appropriate) doses are reconstructed, and the uncertainties associated therewith are calculated.

The analysis uses an automated procedure for determining dose due to residual radiation. All available radiological survey data are fit, in a statistical regression model, 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 any inconsistencies of the operational histories. It was only after this automated procedure was developed and thoroughly tested that there now exists the confidence to analyze an operation for which no film badge data exists.

Major findings of this report are:

- The troops of Task Force RAZOR were exposed to initial radiation from Shot Apple II. The initial dose was less than 0.2 rem (gamma), and less than 0.4 rem (neutron) for the shot.

- Task Force personnel who participated in the maneuver and viewed the equipment display thereafter received estimated total mean gamma doses that ranged from $0.8^{+0.5}_{-0.4}$ rem to $1.8^{+0.9}_{-0.8}$ rem.

- The 50-year whole body dose commitment due to possible inhalation of tank-lofted and helicopter-lofted contamination was no more than 0.003 rem. The corresponding bone-dose commitment was approximately 0.002 rem, while that of the thyroid was 0.4 rem.

Section 2
OPERATIONS

Task Force RAZOR, a reinforced tank battalion, completed its movement to the Nevada Test Site on 21 April 1955. Plans called for participation in maneuvers in conjunction with Shot Apple II, scheduled for 26 April 1955 (see Figure 2-1 for relative location of Shot Apple II). The shot was postponed twice due to weather conditions and was detonated on 5 May 1955.

2.1 SHOT DATA

Date: 5 May 1955, 0510 hours (PDT)
Location: Area T-1, UTM Coordinates 798009
Yield: 29 KT
Height of Burst: 500' (steel tower)

2.2 PARTICIPANTS

Task Force RAZOR had a troop strength of about 1000 (Reference 3) and was comprised of the following units:

From Camp Irwin, California
- 723rd Tank Battalion (minus one company)

From Fort Hood, Texas
- Company C, 510th Armored Infantry Battalion
- First Platoon, Company B, 510th Armored Infantry Battalion
- Battery A, 22nd Armored Field Artillery Battalion
- First Platoon, Company C, 24th Armored Engineer Battalion
- First Combat Aviation Company (Provisional), First Armored Division

2.3 CONCEPT OF OPERATIONS

The purpose of the exercise was to determine the capability of a reinforced tank battalion, in immediate exploitation of a nuclear attack, to seize an objective by capitalizing on the combined shock action and casualty effects of attacking armor in conjunction with the nuclear detonation. An additional purpose was to determine the

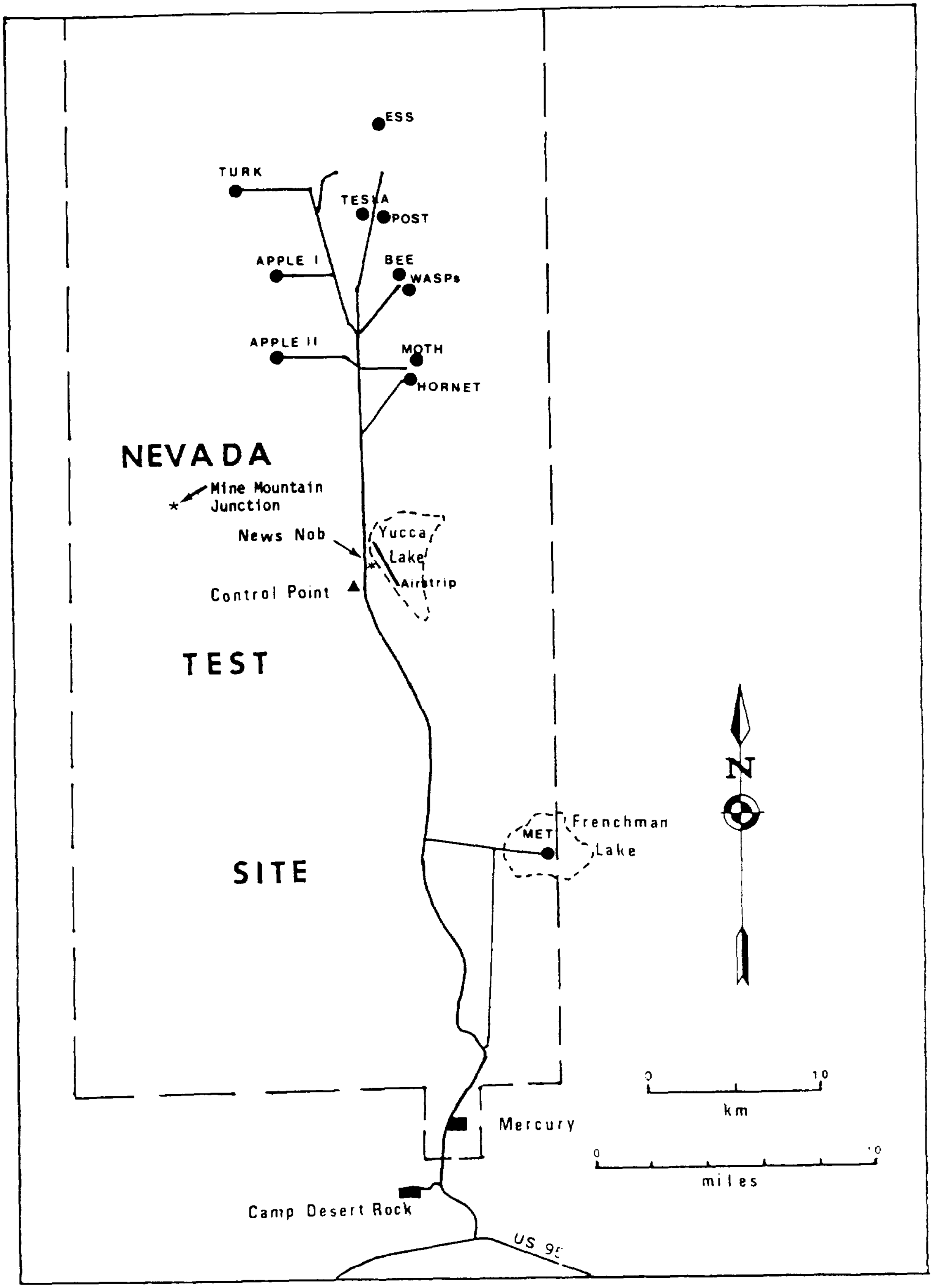


Figure 2-1. Operation Teapot Shot Locations

capability of a combat aviation company to support a reinforced tank battalion. The original objectives of the test were to determine:

(1) The feasibility of having a reinforced tank battalion in motion and its motion so timed that no delay will result in advance of the task force into a blast area.

(2) The capability of a reinforced tank battalion to pass through or near ground zero in a rapid follow-through of a nuclear detonation without endangering personnel inside the vehicles.

(3) The maximum time delay following a nuclear detonation before an armored unit can enter the affected area in exploitation of the weapon effects.

(4) The possibility of refining personnel safety precautions (taken during this exercise) by elements of a reinforced tank battalion in exploitation of a nuclear attack.

(5) Field expedients that should be developed or employed to facilitate passage through a blast area.

(6) The effect of the detonation on the formation, speed, and direction of attack in moving through a target area of a nuclear attack.

(7) The most effective organization for combat of a reinforced tank battalion in exploitation of a nuclear attack.

(8) The most effective use of artillery and tactical aircraft in conjunction with a nuclear attack and armored exploitation of such an attack.

Some of these objectives could not be tested as originally envisaged because the Atomic Energy Commission placed several restrictions on the exercise. Large segments of the area around ground zero were assigned to other test participants. Some of the restrictions were:

(1) No task force movement was permitted in the test area after 2200 hours the day before the shot. This restriction prevented the normal tactical movement from the assembly area to the attack position just before the shot. Therefore, a static position was adopted for the detonation.

(2) The task force was required to maintain radio silence from 30 minutes before until after the detonation. This restriction necessitated the use of telephone (wire) communications between elements of the task force.

(3) Vehicle engines were not permitted to operate within 30 minutes prior to the shot. This restriction necessitated restarting the engines after the shot.

(4) The task force was not permitted to pass through the ground zero area. Test instrumentation and the possibility of exceeding stringent safety limits for vehicle contamination were the reasons for this restriction.

(5) The task force was not permitted to continue the attack in a single direction. Instruments and cameras located northwest of ground zero forced the task force to attack an objective located to the west of ground zero.

The final plan was for the task force to be in attack formation at the time of the shot, with troops in their armored vehicles (a few troops were in trenches), and to attack an objective immediately thereafter. Upon completion of the maneuver, the troops were to be transported, by truck, back to the trench area. After viewing the equipment and fortifications in the display area, the task force troops would be returned to the objective area, where they would remount their vehicles for the non-tactical movement back to the Mine Mountain Junction assembly area.

An overview of the Task Force RAZOR operations area is provided in Figure 2-2. The task force was to be prepositioned facing north, with the leading tanks about 3200 yards (2930 meters) south of the shot tower. The task force used a line of tank companies in a wedge formation with the right flank just west of the 185 degree radial and with the front extending to the west (see Figure 2-3). Other elements of the task force were behind the tanks as shown.

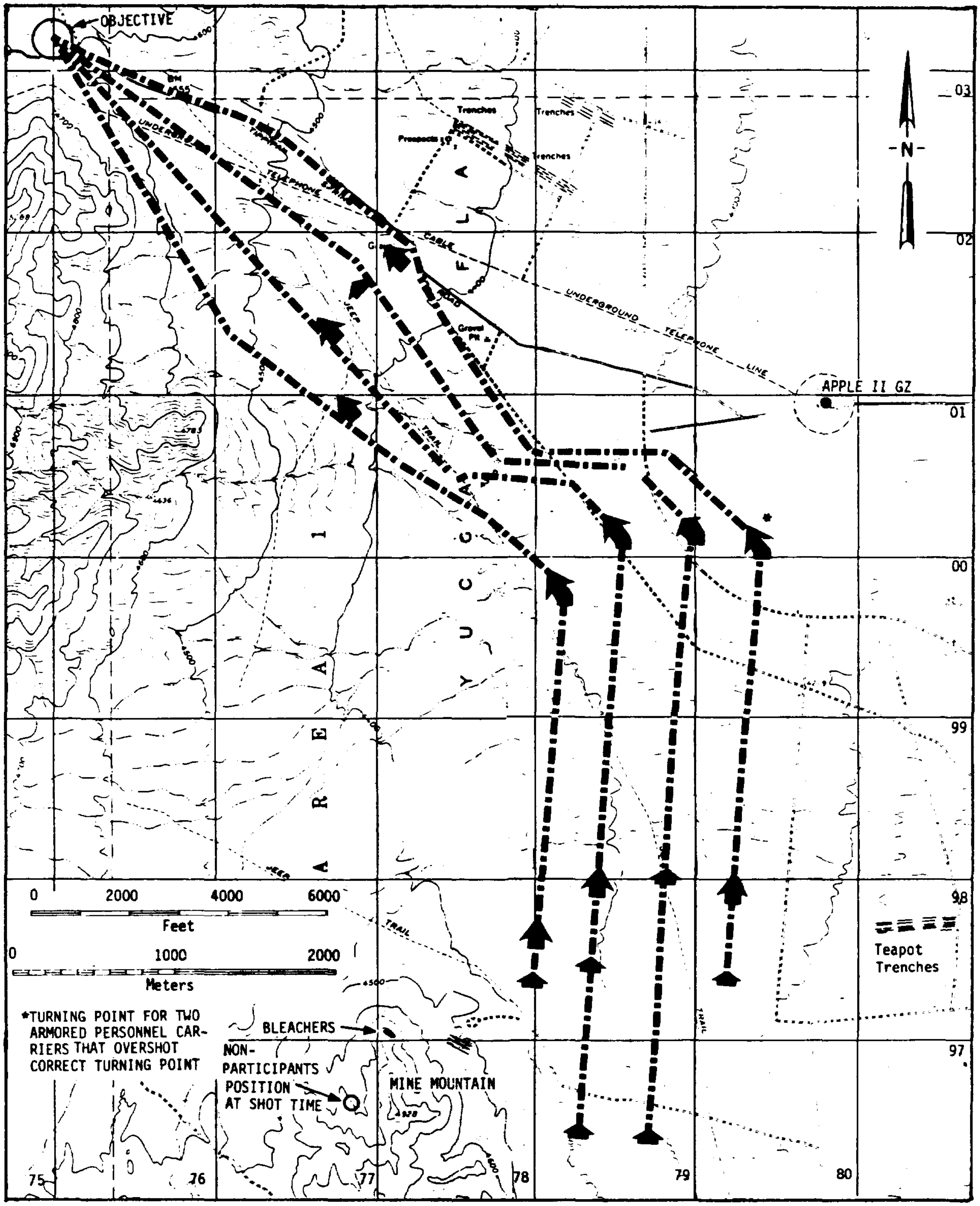
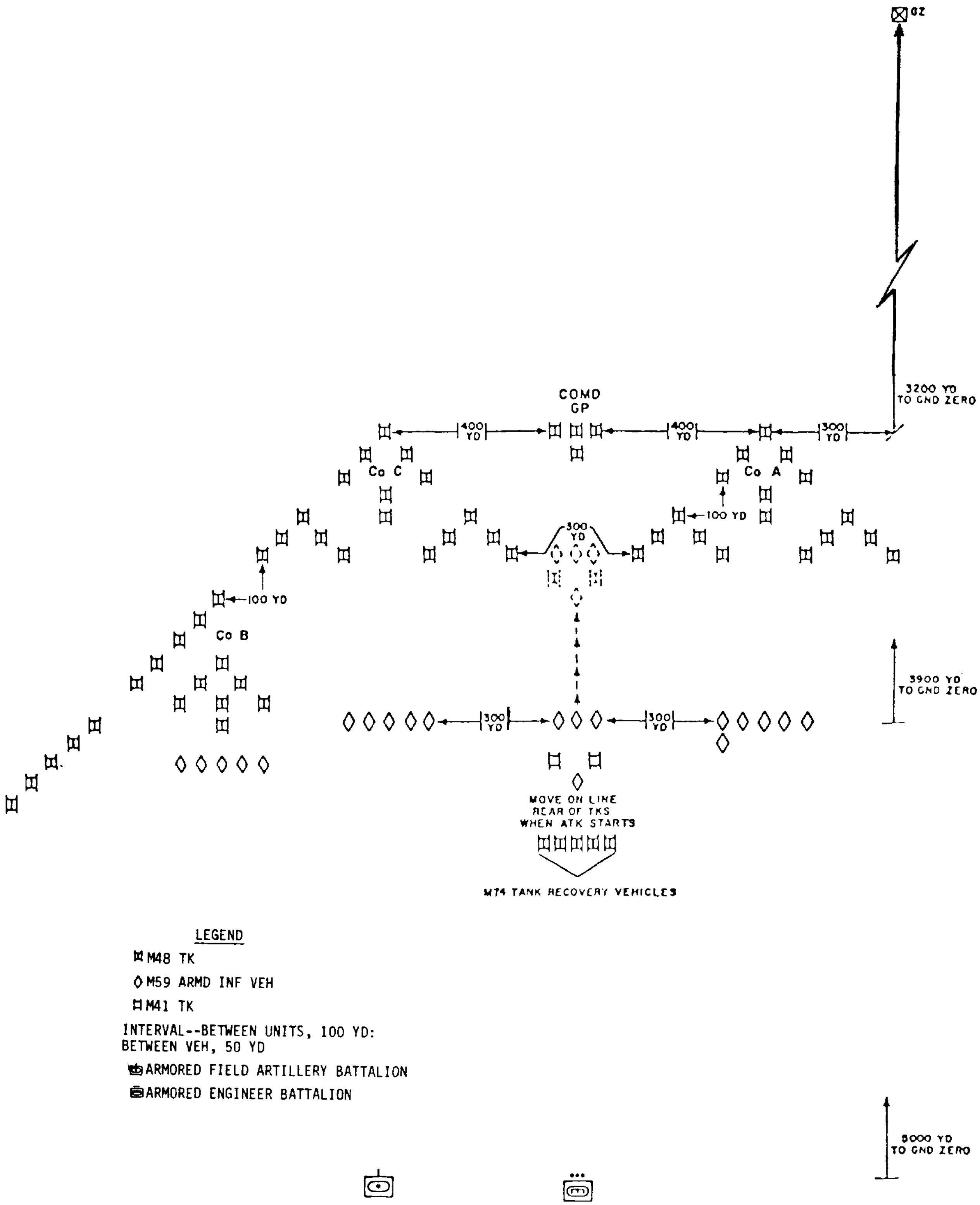


Figure 2-2. Task Force RAZOR Maneuver Area



Source: References 1,2

Figure 2-3. Task Force RAZOR Attack Formation

The tank personnel were to be located in 55 M-48 and 2 M-41 tanks (Figure 2-3) at the time of the shot with all turrets rotated to the rear to prevent damage to the optical systems. Additionally, drivers' and commanders' sight prisms were to be taped to prevent damage during the blast. Reference 4 states the following: "Twenty (20) monitors will be provided for the Armored Force Test for continuous area and vehicle monitoring during the advance of the armored force and after the objective is reached. The monitors will be positioned mainly in the lead and right flank armored vehicles, with the remaining monitors dispersed throughout the formation. The lead tank will proceed toward ground zero from the IP until a radiation intensity reading inside the tank of one roentgen is reached (this will indicate approximately eight roentgens on the outside of the tank) and then veer to the left toward the objective."

Company C, 510th Armored Infantry, was to be in line behind the tank companies, about 3900 yards (3570 meters) from ground zero, with personnel mounted in M-59 armored personnel carriers. Sight prisms were to be taped as with the tanks. The company consisted of three platoons. The one on the right would trail behind Company A of the tank battalion. The center platoon was to guide on the right platoon and trail behind Company C of the tank battalion. The platoon on the left would trail behind Company B of the tank battalion.

The First Platoon of Company C, 24th Armored Engineer Battalion, was to be located directly behind the command group tanks but far to the rear, at about 5000 yards (4570 meters) from ground zero, with personnel in their M-59 armored personnel carriers at the time of the shot. After the shot, the platoon would trail the command group of the task force by 1800 yards. Battery A, 22nd Armored Field Artillery Battalion, was to be located behind the center armored infantry platoon and directly left of the armored engineer platoon, about 5000 yards (4570 meters) from ground zero. The lack of overhead cover on the M-7 self-propelled howitzers precluded positioning the artillery in a more advanced position. The artillery personnel were to be in trenches to the rear of the vehicles at the time of the shot (Reference 36). After the shot, the personnel were to mount their four vehicles, guide on the engineer platoon to the right, and trail about 1800 yards behind Company C of the tank battalion.

The battalion reconnaissance platoon and the simulated battalion martar platoon were not planned to be in the forward position because the wheeled vehicles organic to these units were unarmored. Their vehicles were parked in the assembly area to the rear and were not used during the attack.

It should also be noted that the M-74 tank recovery vehicles, shown on Figure 2-3, are not addressed as a separate element in this report. These vehicles are similar to the tanks themselves in shielding characteristics, and they trailed to the rear of all tank elements during the attack. Their conditions of exposure were similar to those of Company B of the tank battalion.

The First Combat Aviation Company and the First Platoon of Company B, 510th Armored Infantry, were to be positioned at the Yucca Lake Airstrip where, after the shot, the H-19 helicopters would airlift the infantrymen to an area 6000 yards southwest of the attack objective.

2.4 PRE-SHOT OPERATIONS

The elements of Task Force RAZOR assembled at Camp Irwin, California, from 9 March to 13 March 1955. The task force conducted training until 17 April in preparation for the exercise. On 18 April, Task Force RAZOR departed Camp Irwin for the 160-mile overland march to Nevada Test Site. It arrived at its assembly area near Mine Mountain Junction (See Figure 2-1) on 21 April 1955. The schedule of operations while at the test site is shown in Table 2-1.

From 21 April to 4 May the task force engaged in rehearsals for the exercise, training for the atomic test, and maintenance of equipment. The Apple II shot was originally scheduled for 26 April but was postponed twice due to weather conditions. Consequently, the task force moved to the shot area for the night on three occasions during the period from 25 April to 4 May 1955.

2.5 SHOT SCENARIO

The following synopsis of events is based on the plan for the operation (Reference 1), the after action reports (References 2 and 3), and interviews of Dr. John J. Saalberg (Reference 36).

Table 2-1. Task Force RAZOR Schedule of Operations

DAY	TIME	EVENT
21 April 55	1200	Arrive Nevada Test Site assembly area (Mine Mountain Junction)
22 April 55	1000-1800	Dry-run. Move from the assembly area to the attack position. The attack is carried out and the objective occupied. Return to vicinity of the observer trenches (about 3500 yds. south of GZ).
23 April 55	0430-1030	Final rehearsal--movements essentially as in the dry-run.
25 April 55	1300	Move into position--personnel remain with vehicles. Personnel tour equipment display area in the afternoon.
26 April 55	H-hour (0510)	Shot APPLE II
	H+0:06 (0516)	Task Force RAZOR move to attack.
		H-23 helicopters depart Yucca Lake airstrip to provide aerial observation and furnish aerial evacuation of simulated casualties. Aircraft fly below 300 feet. Simulated casualties evacuated directly to Media Hill (located in proximity to News Nob) for "first impression interviews."
		L-19 observers and recon planes depart airstrip and fly column cover for task force. Maintain altitude 500 to 1000 feet above terrain.
	H+0:18 (0528)	H-19s take off from Yucca Lake airstrip to transport infantry platoon to an area southwest of the attack objective. Altitude 300 feet.
		L-20 aircraft depart airstrip. Cover H-19 movement of infantry platoon then cover forward movement of task force to attack objective. Fly at altitude of 500 to 1000 feet.
	H+0:45 (0555)	Task Force RAZOR to reach and secure objective. L-19s, L-20s, and H-19s depart airstrip for objective to resupply task force, H-19s fly under 300 feet. Fixed wing aircraft fly at 500-1000 feet.
	H+2:00 (0710)	Return to trench area--personnel dismount and walk through display area.
	H+4:00 (0910)	Return to objective area. Decontaminate vehicles and move to assembly area.
28 April 55		Depart assembly area for Camp Irwin.

On 5 May 1955, the task force conducted its maneuver in conjunction with the nuclear detonation. The total manning of Task Force RAZOR was approximately 1000 personnel, but only an estimated 500 were in the vehicles that participated in the attack. Because of the excess personnel, maneuver participation was on a voluntary basis (except for essential personnel). The others observed the shot from Mine Mountain (see Figure 2-2), to the west of the task force (Reference 36). They were in a protected location about 5750 yards (5260 meters) from ground zero at the time of the shot. After the shot, the observers moved forward about 500 yards to bleachers to observe the armored task force test.

The shot was detonated at 0510 hours, just before sunrise. There was no damage to tanks of the task force from the shot. However, most of the engine and fan access panels on the armored personnel carriers were dislodged. This damage was minor and required straightening and replacement of the panels. Tank turrets were then rotated to the forward positions. The tape was removed from sight prisms and from other optics. Permission was received from the Atomic Energy Commission to turn on engines and radios, and radio communication was established three minutes after the shot (References 2,3).

There was some initial movement within the task force at about 4½ minutes; this was probably the staff element vehicles moving into attack formation. The task force as a whole did not get underway until about eight minutes after the shot (Reference 7). The dust conditions reduced visibility for the first 10-15 minutes to about 500 to 800 yards. Driving lights were turned on by some tanks to enable those vehicles in the rear to establish their relative positions. Radios functioned perfectly. Moving at an average speed of 2-6 miles per hour (Reference 2), the task force experienced no major difficulty until about 975 yards (890 meters) from ground zero, where the radiation monitoring equipment in the lead tank of Company A registered the maximum permissible reading of one Roentgen per hour.* At this time, all tanks made a left wheel turn away from ground zero so as not to receive higher readings.

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*Note: Reference 3 indicates that the tank received 12 R (sic) inside, estimated 130 - 160 R outside, at the turning point. This is refuted in all other references, and even later in the same reference. The limit of 1 R/hr inside the tank was rigidly adhered to. Captain Saalberg, who was commander of the lead tank of Company A, supports this contention (Reference 36).

All lead elements of the Task Force slowed or stopped to guide on Company A after making the turn and heading northwest. However, when the armored infantry reached the turning line, two armored personnel carriers missed the turn and moved to within 900 yards (820 meters) of ground zero before they could be turned toward the attack objective behind Company A of the tank battalion. Radiation readings were continued as the task force moved northwest, and the direction of travel was adjusted to the left (more westerly) as the readings approached one Roentgen per hour. The task force headed northwest to Tippipah Spring Road and then through the defile to the objective (see Figure 2-2). The earliest task force element reached the objective at 54 minutes after the shot, and the last element reached there at 1 hour and 5 minutes after the shot (Reference 2).

See Appendix I for times and routes for each platoon and company during the maneuver.

The task force personnel at Yucca Lake were able to watch the shot in the open, merely protecting their eyes from the initial flash by turning away. As a safety measure, aircraft doors and sliding windows were opened before the shot. There was no damage to the aircraft, except that windows in the cargo compartments of the H-19s were dislodged by the blast wave. These windows were easily pushed back into position.

All aircraft remained on the ground until three minutes after the shot. At this time, one L-19 took off to provide observation and radio relay for the task force (Reference 2), and two H-23s took off to evacuate simulated casualties from the task force. One H-19 was used to mark the task force objectives as a control measure. At nine minutes after the shot, six H-19s, each carrying six combat troops, airlifted the armored infantry platoon of Company B, 510th Armored Infantry Battalion, to an area located 6000 yards southwest of the attack objective. At 40 minutes after the shot, five H-19, two L-20s, and one L-19 commenced the aerial resupply operation from Yucca Lake to the task force objective. (Note that some of the events described above did not occur at the planned times indicated on the schedule shown in Table 2-1).

2.6 POST-ATTACK ACTIVITIES

After the tactical maneuver ended at the objective, the vehicles were parked and the task force initiated radiological decontamination procedures. All personnel were swept off with brooms, and then surveyed for radiation contamination. Rad-Safe personnel conducted the survey, augmented by a 20-man monitoring team with AN/PDR-27A radiac instruments. The maximum permissible intensity level was 20 mR/hr. Although it was not required, there was a contingency plan to take personnel to a decontamination station near Yucca Lake if field decontamination failed to lower the intensity below 20 mR/hr. Vehicle decontamination was postponed until after the personnel returned from the equipment display area (Reference 36).

The decontamination was completed by approximately two hours after the shot. Personnel then loaded aboard trucks for transport to the display area. The drive took about twenty-five minutes, and the walk-through started about 0740 hours, 2½ hours after the shot (Reference 36). The Desert Rock equipment display area was located to the south of ground zero starting at 500 yards (460 meters) and extending to 2000 yards (1830 meters) (see Appendix I, Figure I-1). The task force personnel who had participated in the maneuver were joined here by the other members of the task force who had observed the shot and the task force maneuver from Mine Mountain. The personnel detrucked at the trench area, walked forward to the display area, observed the displays, and returned to the trucks. The route of their progress is described in Appendix I. Calculations show that all the displays could have been visited without exceeding the 5 R/hr intensity restriction imposed (Reference 4). After the walk-through, personnel were swept off with brooms and surveyed before entrucking. Again, the maximum tolerance for personnel contamination was 20 mR/hr. In no instance after being swept off was further decontamination required (Reference 3).

Under the assumptions discussed in Appendix I, it would have taken about one hour and forty minutes to walk through the entire display area. Thus, the walk-through ended about 0910, four hours after the shot. After loading of the trucks and the twenty-five minute drive back to the parked vehicles, the time was about 0945. The task force vehicles were then decontaminated using the same procedures that had been used for personnel. The vehicles were brushed off to remove any possible contamination, even though rad-safe surveys of vehicles and personnel showed that this was unnecessary (Reference 36). The task force then returned to the assembly area by the most direct route, through Tippipah Spring.

On the afternoon of 5 May (the day of the shot), the aviation company was released from task force control and began preparation for the return to Fort Hood, Texas. Three L-19s remained to support the task force during its return march to Camp Irwin, California. Task force departure from the Nevada Test Site was on 7 May.

Section 3
INITIAL RADIATION

Shot Apple II is investigated to determine the possible exposure of Task Force RAZOR to initial neutron and gamma radiation. This section discusses the method used to compute the initial radiation dose to personnel and summarizes the doses to all distinct elements of the task force.

3.1 COMPUTATIONAL METHOD

At the time of the Apple II detonation, various elements of Task Force RAZOR were positioned in M-48 tanks, M-59 armored personnel carriers (APCs), and trenches. Initial radiation doses for these personnel are determined from the free-field neutron and gamma environments at relevant ranges, the shielding afforded by the appropriate vehicle or trench, and the associated gamma film badge dose and neutron dose equivalent for personnel.

In the first step, the free-field neutron and gamma radiation environments for Apple II are determined with computer codes ATR4 (Reference 12) and ATR4.1 (Reference 13), as described in References 15, 33, and 44. The resulting neutron and gamma free-field doses as functions of range are displayed in Figures 3-1 and 3-2, respectively. No neutron dose or fluence measurements at Shot Apple II are available (Reference 10) for comparison with the calculated neutron dose curve. The effect of this on the neutron doses determined from Reference 15 is discussed in Section 5. Gamma dose measurements taken at the shot agree with the calculated gamma dose curve out to approximately 2700 yards, as shown in Figure 3-2. Beyond that range, the measured data show systematically larger doses than the calculated values. A conservative (i.e., high-sided) dose is determined by extrapolating from data at ranges greater than 2700 yards. The extrapolation used in these calculations is indicated in the figure.

The radiation environments inside the M-48 tanks and M-59 APCs are calculated from the free-field environment by means of transmission factors synthesized from analytical calculations and past field experiments. This determination is described in Appendix II. A summary of the values used is given below.

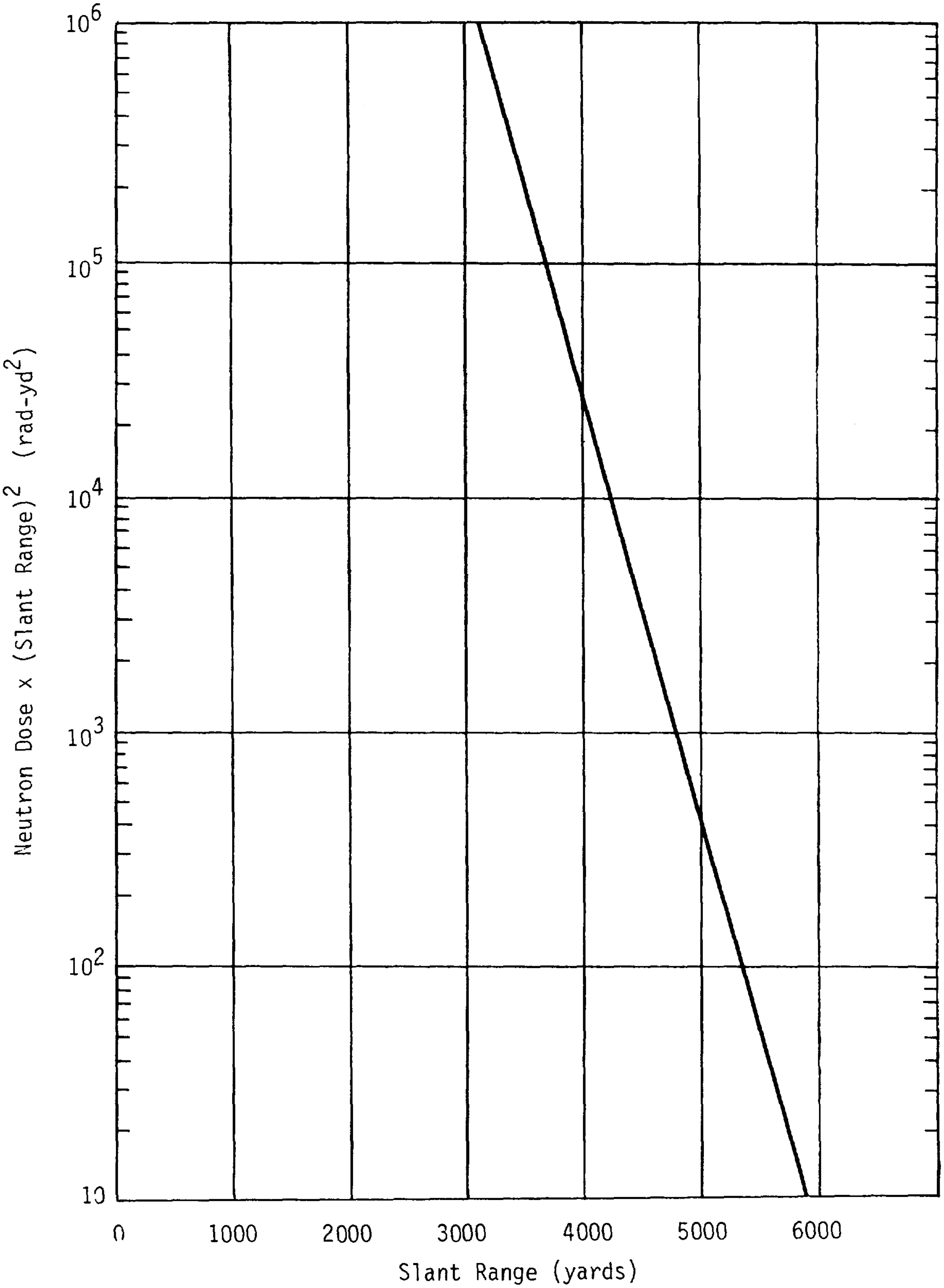

Figure 3-1. Calculated Neutron Free-Field Dose, Shot Apple II

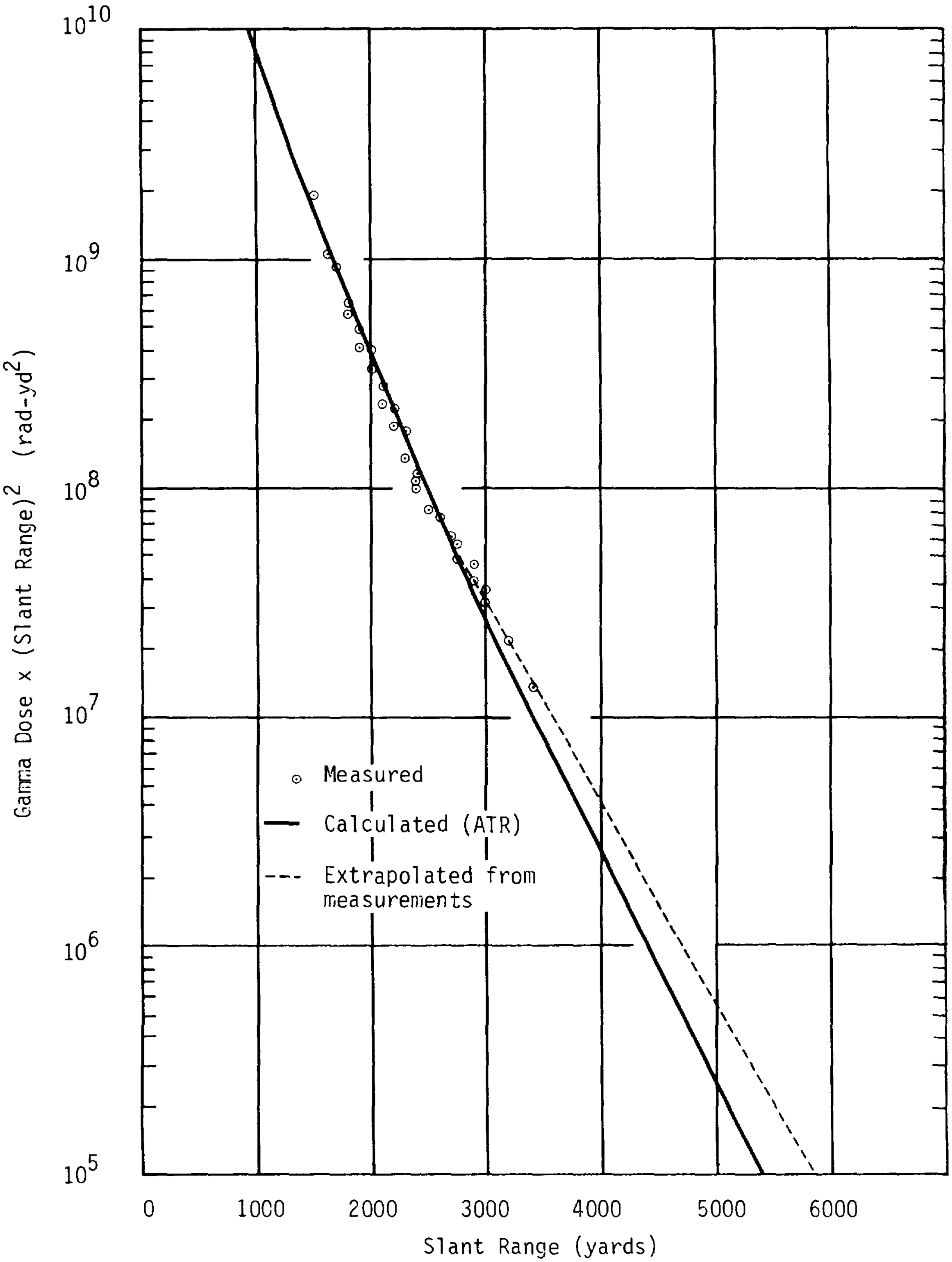

Figure 3-2. Gamma Free-Field Dose, Shot Apple II

Transmission Factors

	Initial Gamma	Neutron
M-48 (crew average)	.10	.5
M-59	.6	.8
Trenches	.04	.25

The trench shielding factors utilized to calculate the in-trench radiation environment from a free-field environment (for the artillery personnel) are identical with those used for other Shot Apple II personnel in trenches at 4900 yards, as reported in Reference 15. The trench factors are defined as the ratio of dose (neutron or gamma) in the trench to the dose (neutron or gamma) above the trench; their derivation is discussed in Appendix I of Reference 33. In developing these factors, it is assumed that personnel remained crouched in the trenches until approximately three seconds after passage of the blast wave, at which time they stood upright in the trench. In so doing, they would have exposed themselves to the the debris gamma radiation emitted from the rising fireball.

A film badge conversion factor must be applied to all gamma dose calculations. This conversion factor converts the free-field gamma dose to the dose that would have been recorded by a film badge worn on the chest. In Reference 45, a discussion is presented of the use of the MORSE code (see also References 34 and 46) to calculate the conversion factor for a film badge worn on the chest of a man-phantom model located in an infinite, uniform fallout field. It is found that, for any realistic fission debris gamma spectrum, a conversion factor of 0.7 is accurate to within 10 percent, which is approximately the accuracy of the film badge itself. Inside a tank, this factor is also applicable because of the retained azimuthal symmetry; the increased scattering into the vertical plane has only a minor effect. The question remains, however, as to the appropriateness of 0.7 as a conversion factor for initial radiation.

Calculations have been made (Reference 48) to obtain film badge conversion factors for initial gamma radiation for a man standing with various azimuthal orientations with respect to GZ. These calculations were done for the free-air case with a gamma spectrum similar to that incident on Task Force

RAZOR personnel. The range of values obtained was 0.6 (facing away from GZ) to 1.0 (facing toward GZ). For a person inside a tank or APC, the scattering of the gamma radiation by the vehicle armor makes the radiation more nearly isotropic than in the free-air case. Thus, one would expect a conversion factor of less than 1.0 for a man in the vehicle facing GZ, and greater than 0.6 for a man in the vehicle facing away from GZ. In either case, 0.8 is the appropriate value for the average orientation (e.g., for men in APCs facing sideways) and likely good to within 0.1 for those in tanks facing toward or away from GZ. The use of 0.8 is approximately correct as an overall factor for personnel in the trenches, as based on the specific scenario of crouching and then standing.

The rad-to-rem conversion factor has been discussed extensively in the literature (References 25, 35, 37, 38, 41, 43). The neutron dose (in rads) is converted to an equivalent tissue dose (in rem) using the quality factors and methods prescribed in Reference 41. The rad-to-rem conversion factor for neutrons, derived from calculations utilizing computer codes DOT (Reference 42) and MORSE (Reference 34), is an almost constant value of 13 for the weapon type and ranges of interest. The rad-to-rem conversion factor for gamma radiation of all energies is taken to be unity.

3.2 INITIAL DOSE SUMMARY

The results of these initial dose calculations for the elements of Task Force RAZOR are shown in Table 3-1. The free-field doses are interpolated/extrapolated from Shot Apple II observer calculations as presented in Reference 15. The transmission factors are as discussed above and in Appendix II. The uncertainties associated with these values are discussed in Section 5. The film badge and rad-to-rem conversion factors are as discussed above. Air support personnel were too distant to accrue an initial radiation dose.

Table 3-1. Intial Dose for Elements of Task Force RAZOR

Task Force Element	GZ Distance (yds)	Shielding[1] At H-Hour	Free-Field Dose (mrad)		Transmission Factor		Dose[2] Equivalent (mrem)	
			γ	n	γ	n	γ	n
Company A	3220	M-48	2100	60	0.1	0.5	170	390
Command Group	3300	M-48	1700	41	0.1	0.5	140	270
Company C	3430	M-48	1200	22	0.1	0.5	100	140
Company B	3960	M-48	320	2	0.1	0.5	26	13
Armored Inf. Plt. (Rt)[3]	3920	M-59	350	3	0.6	0.8	170	31
Staff Element	3960	M-59/M-41[4]	320	2	0.6	0.8	150	21
Armored Inf. Plt. (Ctr)	4100	M-59	230	1	0.6	0.8	110	10
Armored Inf. Plt. (Left)	4330	M-59	120	0.4	0.6	0.8	58	4
Engineer Plt.	5060	M-59	21	0.013	0.6	0.8	10	<1
Artillery Bty.	5160	Trenches	17	0.008	0.04	0.25	<1	<1
Observers[5]	5750	Trenches	4	0.001	0.04	0.25	<1	<1

NOTES:

(1) M-48 and M-41 Tanks, M-59 Armored Personnel Carriers

(2) Rad-to-rem conversion factor used: 13 for neutrons, 1 for gamma; film badge conversion factor used: 0.8

(3) A subdivision of this element occurs in the analysis of residual radiation exposure.

(4) Shielding calculated only for the thinner-walled M-59; this overestimates the dose for personnel in the M-41s

(5) Task Force personnel who observed the attack phase from Mine Mountain.

Section 4
RESIDUAL RADIATION

4.1 RESIDUAL GAMMA EXPOSURE

In the appendix to Reference 15, a computerized methodology for the estimation of residual gamma radiation from nuclear detonations is described. The computer program combines the gamma intensity data from all radiation surveys of a particular shot to construct the gamma environment within confidence limits. Doses are then determined for any specified position and time scenario.

Gamma doses are reconstructed for each of the elements of Task Force RAZOR. The detailed time/position information shown in Appendix I is combined with the residual fallout field of Shot Apple II. Consideration is given to the possibility of some residual radiation from other shots affecting the results. From inspection of the residual radiation plots from previous Teapot shots (Reference 15), it can be seen that the fallout from all of these, except Shot Turk, blew away from the area of operations. The Shot Turk residual radiation plot does not indicate the radiation levels in the area of task force operations; however, data from Reference 5 do so indicate. Readings taken about 3 hours after Shot Turk were 100 mR/hr in and overlooking the defile near the objective; lesser intensities were encountered to the east. Based on these data and the overall Turk fallout pattern, it is estimated that the intensity at the objective (at the same time) could have been a few hundred mR/hr. Shot Turk was detonated on 7 March, 59 days before the Task Force RAZOR operation. The decrease in activity over this period is by a factor of approximately 1600 (using $t^{-1.2}$). Thus, the residual activity in the objective area was less than 1 mR/hr (and still less elsewhere) on 5 May. Since the task force personnel remained in the area only slightly more than one hour, their dose was less than 1 mrem, and can be neglected.

Figure 4-1 shows the Shot Apple II residual radiation field at H + 21 minutes after the shot and the task force route to the objective. The 21-minute time is chosen because that was the approximate time that the task force turned, following the 1 R/hr reading inside the lead tank of Company A. The approximate turning point of this vehicle is shown (rightmost "turning" arrow) in Figure 4-1, and the residual radiation at that point is reasonably consistent with a reading of 1 R/hr inside the tank. The residual field was derived by the computer program from radiation survey

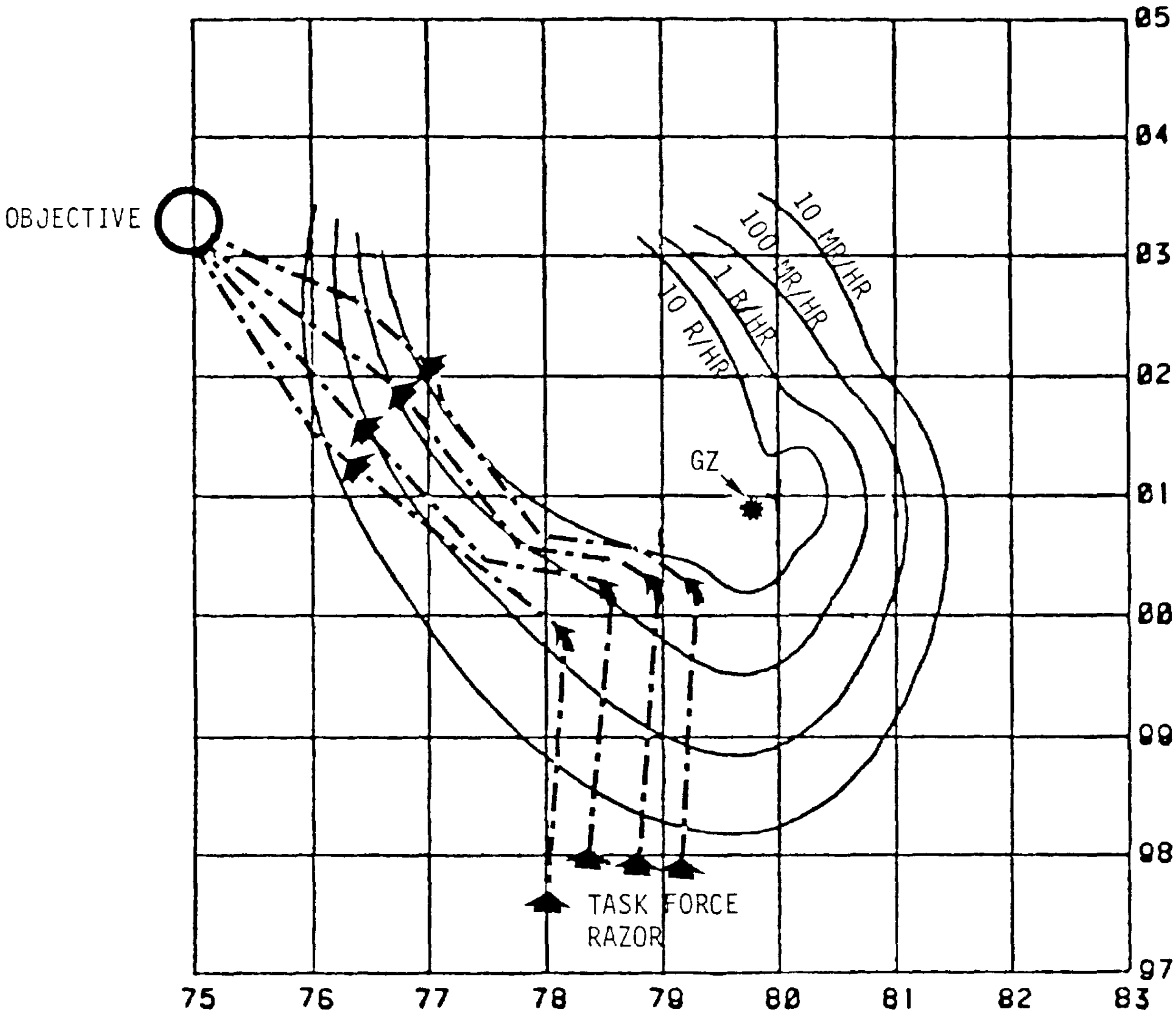

Figure 4-1. Apple II Residual Radiation at H+ 0.35 Hours

plots in Reference 5. That the track of the "A" company tanks on the right flank crosses the 10 R/hr contour in Figure 4-1 near coordinate 770020 does not necessarily indicate that this intensity was exceeded. Not only are there uncertainties involved in the residual field activity calculations and in the times and positions of the task force movements, but also the contours drawn in Figure 4-1 represent a "snapshot" in time, at H+21 minutes. The task force did not reach the 770020 location until about H+41 minutes, by which time the fallout intensity had decayed to less than half of its value at H+21 minutes.

The results for the residual gamma exposure are shown in Table 4-1. The residual dose is seen to range from about 0.4 to 1.5 rem, larger than the initial gamma dose for all elements of the task force. A discussion of the transmission factors associated with vehicle shielding is presented in Appendix II. The film badge conversion factor of 0.7 is used, as discussed in Section 3.1.

Air support personnel received essentially no radiation dose. Landing sites were uncontaminated, and transport and observation operations did not require overflight of the Shot Apple II fallout field.

4.2 INTERNAL DOSE TO TANK OCCUPANTS

Resuspension of radioactive fallout may lead to contamination within a tank. While no data are available for activity levels in a tank while driving into a contaminated area, related studies of dust infiltration into tanks provide a means for bounding the airborne activity levels.

It has been observed that dust levels in a closed tank, in an open tank, and outside the tank are all similar (Reference 49). Engine operation causes dust to infiltrate a closed tank through leaks in the hull. Therefore, a resuspension factor (the ratio of airborne to surface activity) relevant outside a tank should also be appropriate for tank occupants. The suggested value in the reference, for dust raised by vehicles traversing a fresh fallout field, is 10^{-3} Ci/m^3 per Ci/m^2, or 10^{-3}m^{-1}.

Another approach involves the amount of activity that could possibly be associated with dust levels measured inside a tank. Of the measurements reported in Reference 49, the following, made under desert conditions, is very pertinent to the TF

Table 4-1. Residual Gamma Dose for Elements of Task Force RAZOR

		Integrated Intensity (mR)		Integrated Intensity (mR)					
Task Force Element	Shielding(1)	Free-Field During Attack	Transmission Factor(2)	Inside Vehicle during Attack	Post-attack TR1	Post-attack WT	Post-attack TR2(3)(4)	Film Badge Conversion Factor	Residual Gamma Dose (mrem)
Company A	M-48	2250	.06	135	270	590	140	.7	790
Command Group	M-48	570	.06	34	270	590	140	.7	720
Company C	M-48	230	.06	14	270	590	140	.7	710
Company B	M-48	47	.06	3	270	590	140	.7	700
Armored Inf. Plt. (Rt)	M-59	2160	.55	1190	270	590	140	.7	1530
Two APCs off course	M-59	2190	.55	1200	270	590	140	.7	1540
Staff Element	M-59/M-41(5)	730	.55	400	270	590	140	.7	980
Armored Inf. Plt. (Ctr)	M-59	200	.55	110	270	590	140	.7	780
Armored Inf. Plt. (Left)	M-59	44	.55	24	270	590	140	.7	720
Engineer Plt.	M-59	420	.55	230	270	590	140	.7	860
Artillery Bty.	M-7	170	.55	94	270	590	140	.7	770
Observers(6)	N/A	N/A	N/A	N/A	N/A	590	N/A	.7	410

NOTES:
(1) M-48 and M-41 Tanks, M-59 Armored Infantry Vehicles, M-7 Self-Propelled Howitzer
(2) See Appendix II
(3) TR1: Truck ride from objective to trench area (See Appendix I, Table I-2)
WT: Walk-Through of equipment display area (Table I-3)
TR2: Truck ride from display area to parked vehicles (Table I-4)
(4) Transmission factor of 1.0 assumed for these activities
(5) Shielding calculated only for the thinner-walled M-59; this overestimates the dose for personnel in the M-41s
(6) Task Force personnel who observed the attack phase from Mine Mountain.

RAZOR exposure; five tanks in a wedge resulted in 18 mg of dust per ft^3, or about 0.6 g/m^3, inside a sixth center tank. Because the fallout particles, despite fields as high as 10 R/hr, are sparsely distributed on the ground, a great amount of soil must accompany the resuspension of fallout. For particles to remain airborne long enough to be inhaled, the diameter must be less than about 100 m. While most close-in fallout particles are considerably larger, they may have been fragmented by lead tanks. The relative resuspension of fallout particles is greatest if the top 100 μm of soil is lofted (Actually, tanks loft particles from far deeper, but the treads do not cover the entire surface area; thus, the activity/mass ratio is lower than calculated). For a soil density of 1.5 g/cm^3, the mass of lofted soil from the top 100 μm is 150 g/m^2. If the lofted soil is distributed vertically over 3m, then the airborne dust concentration is 50 g/m^3, or about two orders of magnitude in excess of that actually measured in the tank. For these conditions, the activity would follow proportionally, so that instead of about 0.3 m^{-1} for the presumed complete lofting of fallout particles, the resuspension factor would be about $4 \times 10^{-3} m^{-1}$. At any lesser depth of scouring, both mass and activity would be left unlofted to comparable degrees; therefore, the implied resuspension factor would be about the same. For any greater depth of scouring, the implied resuspension factor would decrease in inverse proportion to that depth. Because tank treads can fragment soil and scour rather deeply, the latter situation must be the case and, therefore, a resuspension factor of $10^{-3} m^{-1}$ is definitely high-sided.

For an exposure at about H + .5 hr, a total free-field integrated intensity of 2250 mR (for Company A), and a breathing rate of 1.3 m^3/hr, Reference 51 (using inhalation dose factors) gives a whole body dose of (.001 rem/m^2 per mR/hr)(2250 mR) ($1.3 m^3/hr$)(10^{-3} m^{-1}) = 3 mrem. The bone dose is about 2 mrem, and the thyroid dose is about 400 mrem. Thus, the internal and external thyroid doses are similar, but the external dose dominates otherwise.

The following order-of-magnitude estimate is sufficient to demonstrate that the contamination within the tank contributes negligibly to the gamma intensity read inside the tank; thus, radiation survey readings require adjustment by the tank transmission factor only to obtain the intensity within the tank.

There is about 0.1 Ci/m^2 per R/hr, free-field, at the early time of exposure (Reference 51). For the intended maximum intensity to be encountered by the tanks, 10 R/hr, this implies 1 Ci/m^2. At a resuspension of $10^{-3}m^{-1}$ (approximate for inside and outside the tank), the concentration in air is 1 mCi/m^3. The internal volume of a tank is on the order of 10 m^3; therefore, the activity inside the tank is about 10 mCi. The intensity at a point within the tank is readily obtained from an estimate of a single effective distance from the source to that point. For activity from fallout at a distance of 0.5 m, Reference 37 indicates an intensity on the order of 1 mR/hr per 1 mCi. Thus, the intensity in a tank from this source could have been as much as about 10 mR/hr, but no more than a few percent of the intensity transmitted through the armor from the fallout field.

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 element of Task Force RAZOR. In the following discussion, error factors are expressed in terms of 90-percent confidence limits.

5.1 UNCERTAINTIES IN INITIAL RADIATION DOSE

5.1.1 Neutron Dose

The sources of error in the calculation of neutron dose for cases where neutron data exist include: uncertainties in doses derived from foil measurements, uncertainty in neutron output spectrum of the device, errors associated with the use of ATR4 to extrapolate beyond the range of measured data, and errors in relating doses outside vehicles or above trenches to the doses inside the vehicles or trenches.

For Shot Apple II, there are not sufficient neutron data to determine dose versus range experimentally. Without the capability to normalize to measured data, the uncertainties in neutron output spectra and environmental factors dominate. These uncertainties were estimated in Reference 15 by examining the distribution of dose versus range curves for six Teapot shots for which full neutron foil data were taken, after normalization to common yield and air density. The error factors determined in this manner were 2.8-3.7 for ground ranges of 3200-5000 yards. The ATR4 extrapolation error factor was 1.15. The uncertainties in vehicular shielding and trench factors are discussed in Section 5.1.3.

5.1.2 Initial Gamma Dose

Sources of error in the calculation of initial gamma dose include: uncertainty in experimental film badge readings, extrapolation/interpolation techniques to determine dose at vehicle and trench locations, errors in relating doses outside vehicles or above trenches to the doses inside the vehicles or trenches, uncertainty in converting in-trench dose to film badge reading for the artillery personnel in trenches in a fixed position, and uncertainty in the artillery personnel reorientation (i.e., standing up) in the trench.

The error factor associated with experimental film badge readings is determined to be approximately 1.4, based on estimates made in Reference 9. The error in interpolation/extrapolation techniques used to determine gamma doses is range-dependent, with estimated values from 1.2 at 3200 yards to 1.7 at 5000 yards. The remaining sources of error are discussed in the following section.

5.1.3 Vehicular and Trench Shielding Factors for Initial Radiation

Appendix II discusses the subject of shielding of initial and residual radiation by vehicles. For neutrons, the values reported in the references for the transmission factors for the M-48 are reasonably consistent, and show a spread equivalent to an error factor of about 1.3. There were no values reported for the M-59, but an error factor of around 1.2 is consistent with the value estimated as described in Appendix II. The neutron trench factor used for the artillery personnel in trenches at just beyond 5000 yards is the value 0.25 calculated in Reference 15. The error factor associated with that calculation is 1.25.

For initial gamma radiation, the analysis for the M-48 is described in Appendix II. The error factor in the transmission value is estimated by assuming a reasonable level of accuracy in the effective M-48 shielding thickness that emerged from the analysis. It is determined that a 4-inch effective shielding thickness is in rough agreement with the transmission factor analysis. A reasonable level of accuracy in this thickness is estimated at about ±½ inch, which leads to an approximate error factor of 1.3. An analogous approach to the M-59 shielding leads to an effective shielding thickness of 1±½ inch and an error factor of about 1.3.

It is estimated that the uncertainty in the gamma trench factors, which relate the above-trench dose to in-trench dose, introduce an error factor of 1.2 for 2-foot wide trenches. In addition, there is an uncertainty in relating the in-trench gamma dose to film badge reading, 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 the artillery personnel in the trenches is estimated to be 1.5. There is another uncertainty in initial gamma dose due to the probability that the artillery troops stood up in the trenches to observe the rising cloud soon after the blast effects of the weapon had subsided. As discussed in Reference 15, the error factor due to the uncertainty in time of stand-up is about 1.2.

5.1.4 Summary of Initial Radiation Dose Uncertainties

The error factors discussed above are combined by summing the squares of the logs of the component error factors, and then computing the antilog of the square root of that sum. The combined error factor for neutron radiation ranges from 3.0 to 3.8 for ground distances of 3200-5000 yards. The overall factors for initial gamma radiation range from 1.6 for the tanks at 3200 yards to 2.0 for the elements at 5000 yards.

5.2 UNCERTAINTIES IN RESIDUAL RADIATION DOSE

The uncertainty in calculated residual radiation doses arises from three basic sources: the gamma radiation environment, the space-time scenario of troop movements, and uncertainties in vehicle shielding. The 90-percent confidence limits in the gamma intensity, including the uncertainty in the decay parameter, are provided by the automated procedure described in the appendix to Reference 15. For clarity, the following discussion is organized into subsections on vehicular shielding, the attack phase, and the post-attack phase.

5.2.1 Vehicular Shielding for Residual Radiation

Essentially no radiation protection was provided by the trucks during the rides to and from the display area. Because of the minimal shielding by this type of vehicle, it has not warranted the study afforded to armored vehicles. Consequently, the high-sided transmission factor of unity is assumed for the trucks. For the attack phase, the values determined for transmission factors for the M-48 and M-59 are as discussed in Appendix II. The uncertainty considerations for these vehicles discussed in Section 5.1.3 apply here, and result in error factors of 1.3 for these transmission factors as well.

5.2.2 Attack Phase

The three attack-phase scenarios discussed in Appendix I were all processed by the automated procedure. The results each have an uncertainty associated with the computerized fallout field calculation (gamma radiation environment). These uncertainties are combined with the uncertainties in troop movements embodied in the three scenarios. The latter results in an effective error factor that is in the 1.2-1.6

range for each of the task force elements. The radiation environment error factors are less consistent, ranging from 1.7 to 3.3 for integrated intensity. Moreover, the upper confidence levels of the right-most elements of the task force are truncated in view of the fact that rad-safe personnel were in the right-most tanks of A Company with instruments to ensure that 1 R/hr inside the tanks was not exceeded. These truncations result in a reduction of the error factors associated with the upper confidence levels of integrated intensity to approximately 1.8. For personnel in APCs, who had the most significant attack-phase exposure, the overall attack-phase error factors are about 1.9 (upper) and 3.4 (lower).

5.2.3 Post-Attack Phase

As described in Appendix I, this portion of the task force operation is divided into the truck ride to the display area, the walk through the display area, and the truck ride back to the objective area. The routes assumed for each segment are given in the appendix. The resulting dose calculations each include 90-percent confidence limits from gamma environment uncertainties. The upper confidence limit for the walk-through is truncated because of the presence of rad-safe personnel to ensure compliance with the 5 R/hr limit. The error factors for the truck ride to display, walk-through, and truck ride back are approximately 3.0, 2.7, and 2.4, respectively (except that the error factor associated with the truncated upper confidence level for the walk-through is around 2.2). These error factors include uncertainties in the times and speeds, as well as the uncertainties in the radiation field. The uncertainties in time and speed are estimated by assuming a maximum possible error of 30 minutes in the times reconstructed for the post-attack events. For instance, the truck ride to the equipment display area (TR1 in Table 4-1) is estimated as traversing the most intense portion of the fallout field at 2.3 hours after the detonation. If a maximum error of ± 30 minutes is assumed, the earliest (worst case) that the traversal could have occurred would have been 1.8 hours. Using a $t^{-1.2}$ decay factor, the dose received would have been 1.34 times the most probable dose computed. The gamma field error factor for the upper limit of TR1 is 2.89. The combined error factor is thus 3.0.

Because the estimated doses for the post-attack phase dominate those of the attack phase (except for APC personnel), while the error factors are of the same magnitude, uncertainties in residual radiation dose primarily reflect those from the post-attack phase. The multiple contributions to dose within that phase result in error factors (as opposed to magnitudes of error) on the total dose that are less than on each separate contribution.

5.3 TOTAL MEAN DOSE SUMMARY

The reconstructed neutron and gamma doses for the elements of Task Force RAZOR are presented in Table 5-1. These are totals of the best-estimate doses of Sections 3 and 4 and are presented in the table with estimated 90-percent confidence limits. The doses are not added further because the neutron dose would not have been recorded by film badges. Values of mean dose are additionally determined from the error distributions of this section. Only for the larger error factors and untruncated distributions is the mean much different from the best estimate. This is the case for the neutron dose and the post-attack contributions to the residual gamma dose. Upper and lower limits are unaffected.

Not discussed in the foregoing analysis is the possibility of variation in dose among personnel occupying the various crew positions of an armored vehicle. There have been some measurements and calculations of these variations, but none for the conditions (range, particular shot) of Task Force RAZOR. The reported variations have been as much as 20 percent from the mean for a given vehicle exposure, but there is little consistency among experiments. Only APC drivers and vehicle commanders could be inferred to accrue doses higher than the mean, and then for initial gamma radiation only. If the magnitude of the variation with position is similar for the conditions of Task Force RAZOR, the uncertainties in total dose introduced for personnel in specific positions are much less than those analyzed in this section.

Table 5-1
Task Force RAZOR Dose Summary

Task Force Element	Neutron Dose (mrem)(1)	Initial Gamma Dose (mrem)	Residual Gamma Dose (mrem)(2)	Total Gamma Dose (mrem)(2)
"A" Company	390^{+780}_{-260}	170^{+100}_{-60}	790^{+620}_{-300}	960^{+630}_{-310}
Command Group	270^{+530}_{-180}	140^{+80}_{-50}	720^{+620}_{-290}	860^{+620}_{-300}
"C" Company	140^{+290}_{-90}	100^{+60}_{-40}	710^{+620}_{-290}	810^{+620}_{-290}
"B" Company	13^{+31}_{-9}	26^{+17}_{-10}	700^{+620}_{-290}	730^{+620}_{-290}
Armored Infantry Platoon (Right)	31^{+71}_{-22}	170^{+120}_{-70}	1530^{+970}_{-670}	1700^{+980}_{-670}
Two APCs off course	31^{+71}_{-22}	170^{+120}_{-70}	1540^{+990}_{-660}	1710^{+1000}_{-660}
Staff Element	21^{+48}_{-15}	150^{+110}_{-60}	980^{+790}_{-340}	1130^{+800}_{-350}
Armored Infantry Platoon (Center)	10^{+23}_{-7}	110^{+80}_{-50}	780^{+630}_{-300}	890^{+640}_{-300}
Armored Infantry Platoon (Left)	4^{+9}_{-3}	58^{+42}_{-24}	720^{+620}_{-290}	780^{+620}_{-290}
Engineer Platoon	< 1	10^{+10}_{-4}	860^{+670}_{-310}	870^{+670}_{-310}
Artillery Battery	< 1	< 1	770^{+620}_{-300}	770^{+620}_{-300}
Observers	< 1	< 1	410^{+490}_{-260}	410^{+490}_{-260}

(1) Mean dose is 30 percent greater than the best estimate for the first three entries; 25 percent greater for the remainder.

(2) Values shown are best estimate doses. The mean dose is approximately 100 mrem greater than the best estimate for each entry except for the observers, for whom it is about 50 mrem greater. It should be noted that the 90 percent confidence limit numbers relate to the best estimate values, and must be adjusted accordingly if used with mean values. For example, the total gamma mean dose for the two APCs off course would be expressed as 1810^{+900}_{-760} mrem.

Section 6
CONCLUSIONS

Personnel of the Armored Task Force RAZOR participated in an exercise in conjunction with Shot Apple II on May 5, 1955, and were exposed to radiation as a result. The main body of the task force maneuvered through the Apple II fallout field enroute to an objective in an uncontaminated area. Some elements of the task force participated in airborne support of the maneuver, while some personnel observed the attack from Mine Mountain before joining the main body in a walk-through of the equipment display area. These personnel received lower doses than those who participated in the task force maneuver.

For most of the elements of the task force, the post-attack phase (including the truck rides to and from the equipment display area and the walk-through of the display area) of the exercise contributed the predominant share of the total gamma dose received. However, personnel in the armored personnel carriers on the right flank also received a comparable amount of gamma dose from residual radiation during the attack. These personnel received the highest dose of all the elements of the task force--a total mean gamma dose of approximately 1.8 rem, with 90 percent confidence limits of 1.0 and 2.7 rem. Only one-tenth of their total dose was from initial gamma radiation. The prime reasons that the personnel of the armored infantry platoon on the right flank received a higher radiation dose than the other Task Force RAZOR personnel are that task force elements on the right flank went through a more intense portion of the radiation field during the attack than did the elements of the center and left, and that M-59 armored personnel vehicles provide less effective radiation shielding than do M-48 tanks.

The remaining elements of Task Force RAZOR that participated in the attack received total mean gamma radiation doses that range from about 0.8 rem to about 1.2 rem. These elements received initial neutron mean doses that range from less than 0.001 rem to about 0.5 rem. The inhalation dose due to resuspension of radioactive fallout and the resulting contamination within the M-48 tanks is based on related studies of dust infiltration into tanks. The estimated inhalation dose is about 0.4 rem to the thyroid, 0.003 rem to the whole body, and 0.002 rem to bone.

The uncertainties in the calculated doses originate from uncertainties in the times and positions of the task force elements, the intensity of the radiation field, and the shielding values of the armored vehicles. This latter uncertainty includes variations in the locations of the various crew members within the vehicles.

Section 7
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Appendix I
MOVEMENTS OF TASK FORCE RAZOR

This appendix describes the movement of Task Force RAZOR in time and space. Spatial parameters that define the locations for each platoon and company are given in UTM coordinates. Times are based on the various delay times and speeds of the task force given in the after-action reports (References 2 and 3) and telephone interviews of Dr. John J. Saalberg (Reference 36).

A. THE TASK FORCE MANEUVER

Based on the above references, there are three options the task force could have taken during the attack on the objective. The first option is based on the most likely course of action, which would have the task force starting the attack at 0518 hours, eight minutes after the shot, and moving at an average speed of six miles per hour until reaching the objective. This value follows from the distance traveled by the rear elements and from the statement in Reference 2 that the entire task force reached the objective 57 minutes after departure. Table I-1 presents the times and locations for 10 sub-units of the task force. In addition, two APCs from the armored infantry platoon on the right side of the formation missed the turning point and moved to within 900 yards (820 meters) of ground zero (Reference 2); the data for these two vehicles are shown separately.

The second option assumes that the task force conducted the attack at the slower rate of four mph until it reached the turn, at which time it increased its rate to more than six mph to arrive at the objective in 57 minutes. The start of the attack remains the same as the first option, eight minutes after the shot. This option provides lower residual radiation levels because of the increased speed after the turn, resulting in a shorter time required to cross the contaminated area.

The third option assumes that the attack began at 4½ minutes after the shot* at an initial rate of eight mph to the turning point and a commensurate decrease in speed

*Reference 2 states that "movement occurred" after 4½ minutes. It is not stated, however, that this was the departure of the task force as a whole; it was probably an adjustment in the formation prior to departure, such as the movement of the staff element vehicles to their forward position (See Figure 2-3).

Table I-1

Task Force RAZOR Locations During Attack Phase

Task Force Element	Time* (PDT)	H + * (Minutes)	UTM Coordinates	Distance from GZ (Meters/Yards)
"A" Company Tanks	0510	0	792981	2940/3220
	0518	8	792981	2940/3220
	0531	21	794001	890/970
	0536	26	788006	1090/1190
	0540	30	780006	1820/1990
	0551	41	770021	3030/3310
	0604	54	750032	5290/5780
Command Group Tanks	0510	0	788981	3020/3300
	0518	8	788981	3020/3300
	0531	21	790002	1110/1210
	0536	26	785005	1320/1440
	0542	32	776006	2230/2430
	0551	41	768019	3110/3400
	0604	54	750032	5290/5780
"C" Company Tanks	0510	0	784981	3140/3430
	0518	8	784981	3140/3430
	0531	21	786002	1410/1540
	0537	27	783004	1570/1710
	0544	34	772006	2630/2880
	0551	41	766016	3230/3530
	0604	54	750032	5290/5780
"B" Company Tanks	0510	0	780978	3620/3960
	0518	8	780978	3620/3960
	0531	21	782999	1930/2110
	0541	31	778003	2090/2290
	0547	37	768006	3000/3280
	0552	42	764013	3360/3680
	0607	57	750032	5290/5780
Armored Infantry Platoon (Right)	0510	0	792974	3580/3920
	0518	8	792974	3580/3920
	0535	25	794001	890/970
	0540	30	788006	1090/1190
	0544	34	780006	1820/1990
	0555	45	770021	3030/3310
	0608	58	750032	5290/5780

Table I-1 (Continued)

Task Force Element	Time* (PDT)	H + * (Minutes)	UTM Coordinates	Distance from GZ (Meters/Yards)
Staff Element Vehicles	0510	0	788974	3660/4000
	0518	8	788977	3360/3680
	0533	23	790002	1110/1210
	0538	28	785005	1320/1440
	0544	34	776006	2120/2320
	0553	43	768019	3110/3400
	0606	56	750032	5290/5780
Armored Infantry Platoon (Center)	0510	0	784975	3740/4100
	0518	8	784975	3740/4100
	0535	25	786002	1410/1540
	0541	31	783004	1560/1710
	0548	38	772006	2630/2880
	0555	45	766016	3230/3530
	0608	58	750032	5290/5780
Armored Infantry Platoon (Left)	0510	0	780974	3960/4330
	0518	8	780974	3960/4330
	0533	23	782999	1930/2110
	0543	33	778003	2090/2290
	0550	40	768006	3000/3280
	0555	45	764013	3360/3680
	0609	59	750032	5290/5780
Engineer Platoon	0510	0	787965	4630/5060
	0518	8	787965	4630/5060
	0541	31	790002	1110/1210
	0547	37	785005	1320/1440
	0552	42	776006	2220/2430
	0601	51	768019	3110/3440
	0615	65	750032	5290/5780
Artillery Battery	0510	0	783965	4710/5160
	0518	8	783965	4710/5160
	0541	31	786002	1410/1550
	0547	37	783004	1570/1710
	0554	44	772006	2630/2880
	0601	51	766016	3230/3530
	0615	65	750032	5290/5780
Two APCs off-course	0510	0	792974	3580/3920
	0518	8	792974	3580/3920
	0535	25	794002	820/900
	0540	30	788006	1020/1120
	0544	34	780006	1820/1990
	0555	45	770021	3030/3310
	0608	58	750032	5290/5780

* Based on the most likely scenario (Option 1).

thereafter for consistency with the 57-minute maneuver duration. This option provides the highest residual readings in conjunction with the longer time required to cross the contaminated area.

The tracks presented for each tank company represent the lead tank of each unit. For Company A it is assumed that the vehicles to the right-rear of the lead tank turned in such a manner as to not come closer to GZ than did the lead tank. Each tank on the right flank carried rad-safe personnel (see Section 2.3 and Reference 2). For other types of units, the tracks represent the centroid of each unit.

B. POST-ATTACK MOVEMENT OF THE TASK FORCE

This section presents the movement of the task force personnel after the attack on the objective had been completed and the troops had boarded trucks to return to the equipment display area.

Table I-2 presents the route and time at each location along the route to the display area based on a truck speed of fifteen mph and the quickest route to the rear of the trenches, as stated by Dr. Saalberg (Reference 36). The trucks used Tippipah Spring Road and then turned south on the 185-degree radial road until they reached the rear of the trench area (See Figure 2-2). There, they were joined by the other members of the task force who had observed the shot and the attack phase from Mine Mountain. The twenty-five minute drive to reach the display area would have the troops arriving about 0740 hours, two hours and thirty minutes after the shot.

Table I-3 presents the data for the walk-through of the equipment display area. The itinerary shown is based on inspection of pre-shot aerial photographs of the display area, descriptions of the displays in Reference 2, interviews (Reference 36), and calculations of the residual radiation field (see Section 4). There is some uncertainty as to which displays were visited. The sole item specifically mentioned as having been viewed (Reference 36) is the tank turret discussed below. However, the calculations show that all displays could have been visited without exceeding the 5 R/hr restriction, so it is assumed that all displays were visited. Inspection of the pre-shot aerial photographs of the GZ looking south helped to determine the locations of the displays. A light tank was located at 1000 yards from GZ. The blast blew its turret 600 yards (Reference 3). The tank was identified in the photograph, and the position of the turret was thus determined to be along the same radial from GZ at 1600 yards. Part of the walking path of the troops was along roadways. The walking speed of the troops is assumed to have been 100 yards per minute along the roads and 50 yards per minute across the unprepared areas. Figure I-1 shows the assumed walk-through path and display equipment locations. The walk-through took about one hour and forty minutes and was completed about 0920 hours, four hours and ten minutes after the shot.

Table I-4 presents the time and space parameters used for the truck ride back to the parked vehicles, which required another twenty-five minutes. The personnel reached the parked vehicles at about 0945. This was their last exposure to any contamination from the shot. The return to the task force assembly area was by the most direct route, likely through Tippipah Spring, to avoid interference with other activities at the test site.

Table I-2. Truck Ride from Objective to Equipment Display Area

Location	UTM	Azimuth from GZ	Dist. from GZ (meters)	Dist. from GZ (yards)	Distance Traveled (meters)	Travel Time (hrs) at 15 mph	Total Travel Time (hrs)	Time After Shot (hrs)	PDT
Objective area	750032	295	5288	5783	-0-	-0-	-0-	2.083	0715
Bend in Road	763026	296	3870	4233	1420	.058	.058	2.141	0718
Bend in Road	772019	290	2760	3020	1110	.046	.104	2.187	0721
"Y" in Road	772017	287	2649	2897	170	.007	0.111	2.194	0722
Turn East	790995	208	1693	1852	2875	0.119	0.230	2.314	0729
Turn South (on 185° Road)	796992	185	1768	1933	694	0.029	0.259	2.343	0731
Turn East	795971	184	3844	4203	2078	0.086	0.345	2.429	0736
East End of Trenches	806972	168	3844	4203	1073	0.044	0.390	2.473	0738
Park Behind 3500 yd Trenches	806977	166	3383	3700	478	0.020	0.410	2.493	0740

Table I-3. Walk-Through of Equipment Display Area

Location	UTM	Azimuth From GZ	Dist. from GZ (meters)	Dist. from GZ (yards)	Distance Traveled (meters)	Walking Speed (m/min)	Travel Time (hrs)	Total Travel Time (hrs)	Time After Shot (hrs)	PDT
Unload	806977	166	3383	3700	-0-	-0-	-0-	-0-	2.50	0740
Turn in Road	806979	165	3182	3480	201	91	0.037	0.037	2.537	0742
Road Intersection	803989	165	2123	2322	1059	91	0.193	0.230	2.730	0754
2000 yds	800991	175	1829	2000	1353	91	0.085	0.315	2.815	0759
Observe Displays	800991	175	1829	2000	-0-	-0-	0.033	0.348	2.848	0801
1600 yds Turret of Light Tank	800995	173	1463	1600	366	46	0.134	0.482	2.982	0809
Observe Turret	800995	173	1463	1600	-0-	-0-	0.033	0.515	3.015	0811
1000 yd Displays	799000	176	914	1000	600	46	0.200	0.715	3.215	0823
Observe Displays	799000	176	914	1000	-0-	-0-	0.065	0.780	3.280	0827
500 yd Displays	798005	185	457	500	500	46	0.167	0.947	3.447	0837

Table I-3. Walk-Through of Equipment Display Area (Continued)

Location	UTM	Azimuth from GZ	Dist. from GZ (meters)	Dist. from GZ (yards)	Distance Traveled (meters)	Walking Speed (m/min)	Travel Time (hrs)	Total Travel Time (hrs)	Time After Shot (hrs)	PDT
Observe Display	798005	185	457	500	-0-	-0-	0.033	0.980	3.480	0839
Rejoin east perimeter road	802996	165	1372	1500	952	91	0.167	1.147	3.647	0849
Road Intersection	803989	165	2123	2322	1810	91	0.330	1.477	3.977	0909
Trucks	806977	166	3383	3700	201	91	0.037	1.514	4.014	0911
Load	806977	166	3383	3700	-0-	-0-	0.167	1.681	4.181	0921

Table I-4. Truck Ride From the Equipment Display Area Back to the Parked Vehicles

Location	UTM	Azimuth from GZ	Dist. from GZ (meters)	Dist. from GZ (yards)	Distance Traveled (meters)	Travel Time (hrs) at 15 mph	Total Travel Time (hrs)	Time After Shot (hrs)	PDT
Load Area	806977	166	3383	3700	-0-	-0-	-0-	4.183	0921
East End of Trenches	806972	168	3844	4203	478	0.020	0.020	4.203	0922
Turn North (Behind Trenches)	795971	184	3844	4203	1073	0.044	0.064	4.248	0925
Turn West (Off 185° Road)	796992	185	1768	1933	2078	0.086	0.150	4.334	0930
Turn Northwest	790995	208	1693	1852	694	0.029	0.179	4.362	0932
Join Tippipah Spring Road	773102	287	2649	2897	2875	0.119	0.298	4.483	0939
Bend in Road	772102	290	2760	3020	170	0.007	0.305	4.490	0940
Bend in Road	763103	296	3870	4233	1110	0.046	0.351	4.536	0943
Attack Objective	750103	295	5288	5783	2688	0.058	0.409	4.594	0946

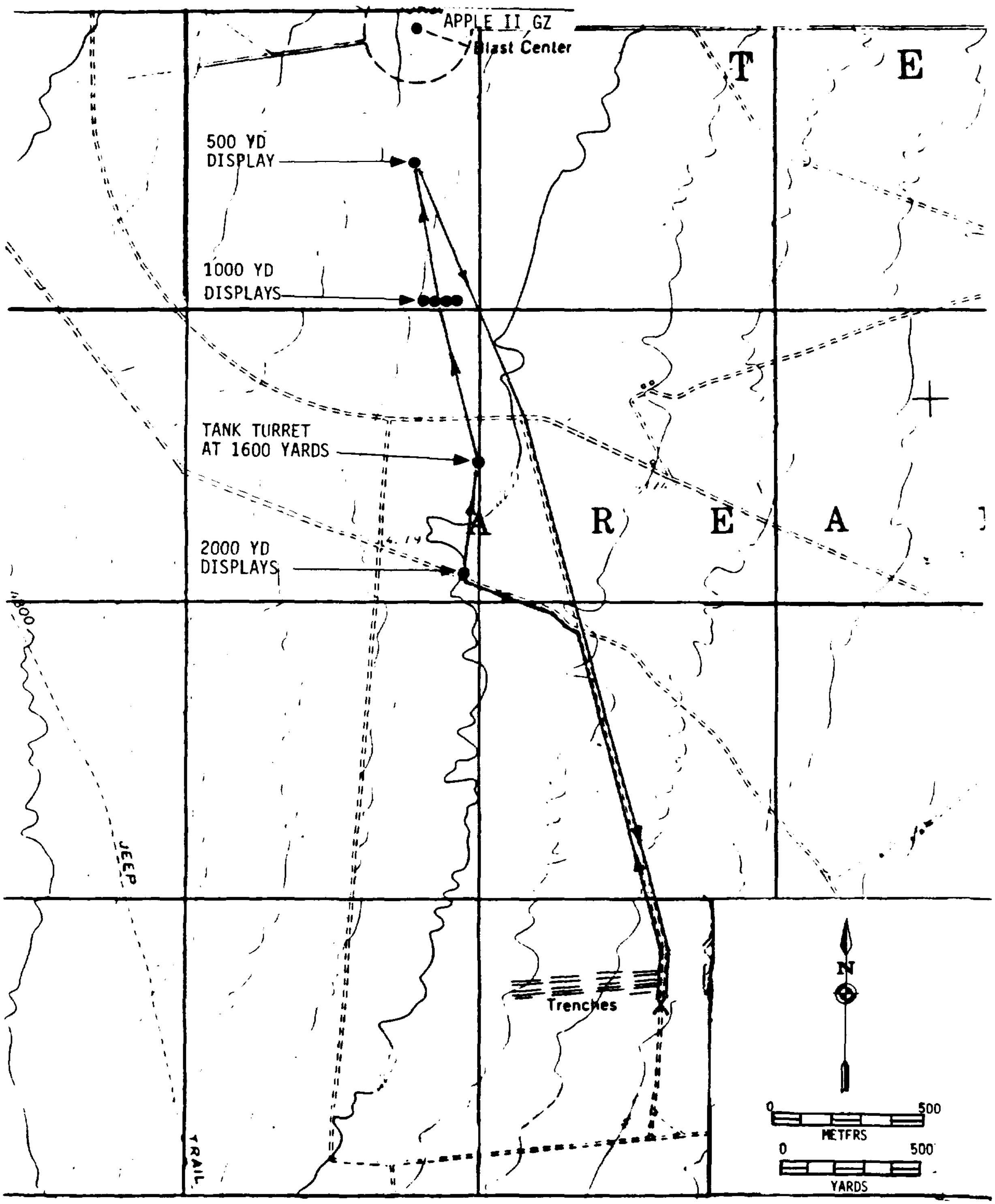


Figure I-1. Assumed Walk-Through Path

Appendix II
ARMORED VEHICLE SHIELDING

There has been a significant amount of work done to determine the shielding of nuclear radiation by tanks and armored personnel carriers (APCs). Work of potential relevance to the exposure of Task Force RAZOR is in References 16-32. However, most of the measurements and calculations are for other shots and different ranges than was the case for the task force. Summary documents inadequately synthesize the data. EM-1 (Reference 31) provides guidance for generic vehicle types only, often with a wide range of shielding factors. Therefore, the transmission factors chosen reflect careful interpretation of the literature. Physical bases are established that account for the considerable variations among data and permit extrapolation to the conditions relevant to Task Force RAZOR.

A. INITIAL RADIATION

Neutron. Transmission factors for neutrons were measured for the M-48 tank during Operation Plumbbob at Shots Wilson (632 yd slant range) and Hood (1120 yd slant range) (Reference 18). Values for the driver, gunner, and loader were around 0.4 and for the commander around 0.6 (Figure II-1 shows the relative positions of the M-48 tank crew members). For this analysis 0.5 is used. No values for the M-59 APC were obtained. Since the M-48, with a transmission factor of about 0.5, is certainly a better shield than the M-59, a value for the M-59 of about 0.8 with a suitably estimated uncertainity appears to be appropriate. For reference and comparison, one can consider the M-113 APC, for which Reference 22 instructs operations personnel to use 0.8, and Reference 39 calculations obtained 0.8 for the driver and 0.64 for the squad members.

Gamma. A wide range of values has been reported for transmission of gamma radiation into tanks. Few measurements were made under sufficiently similar circumstances to afford a just comparison, however. Reference 27 analyzed the available data for M-48 tanks in an attempt to separate the contributions to dose of transmitted (including scattered) gamma radiation from those of gamma radiation from neutron interactions with armor and other tank materials. Using measurements made during Operation Plumbbob, the authors obtained the equation $c = 0.05 + 0.15R$, where c is the apparent gamma transmission factor, and R is the shot- and range-

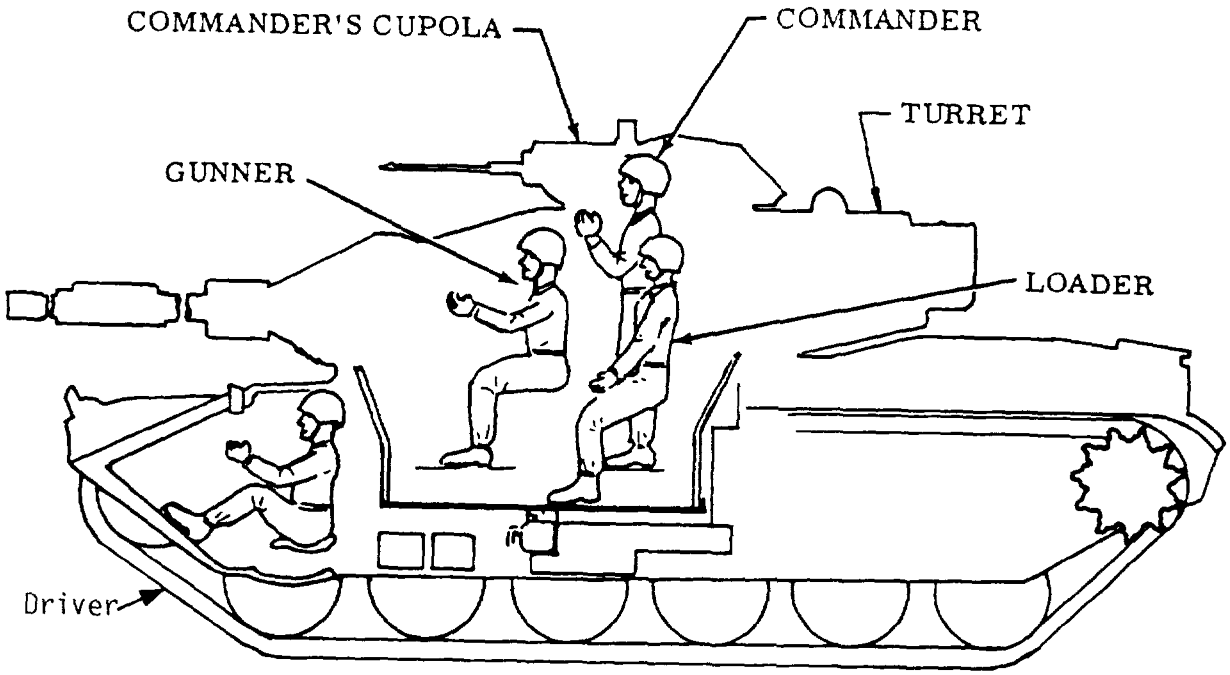
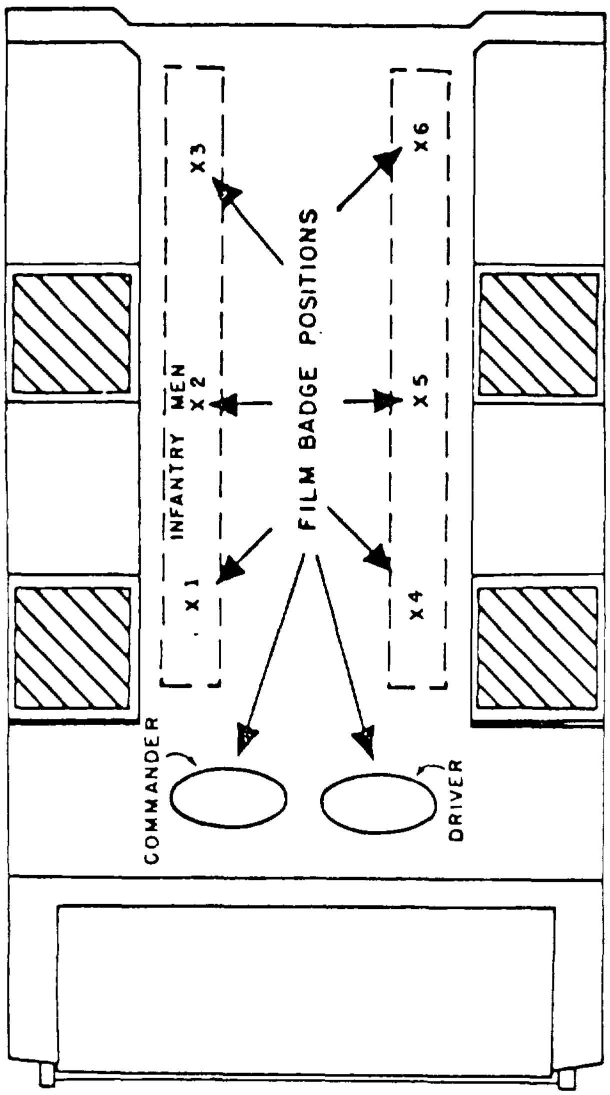


Figure II-1. Positions of Tank Crew Members dependent ratio of the free-field (outside the tank) neutron dose to the free-field gamma dose. Most of their data were obtained at ranges from GZ of roughly 1000 yards, where the neutron fluence from certain shots significantly augmented the apparent gamma transmission factor. However, the impact of neutrons on the factor decreases with distance from GZ. For a range of 3200 yards (closest Task Force RAZOR distance to GZ at shot-time), Reference 15 calculations for Apple II give R=0.03. Thus, neutrons at this range result in only a small perturbation to the gamma transmission factor.

The Reference 27 analysis did not consider the effect of the gamma spectrum on the transmission factor, which becomes the dominant effect beyond the range of neutron influence. ATR4 (Reference 12) calculations show that for Apple II at about 1000 yards, the contribution of fission product (debris) gamma radiation is about 70 percent of the total gamma free-field dose; at 3200 yards only about 40 percent is from debris gamma radiation. The remainder is almost entirely from secondary gamma radiation, for which the higher energy spectrum results in increased transmission. Calculations of transmission through a 4-inch-thick steel slab for debris and secondary gamma result in transmission factors of 0.05 and 0.13, respectively. These values are applied to the contributions of each gamma source to determine the overall transmission factor with range. For the Task Force RAZOR tanks, the factor is 0.10.

The only initial gamma data specific to the M-59 APC are those of Reference 30. These were obtained at Shots Wasp, Turk, and MET of Operation Teapot, at ranges from GZ of less than 1000 yards. Average transmission factors at the troop positions (see Figure II-2) were 0.84 for Wasp, 0.71 for Turk, and 0.53 for MET. The commander and driver positions had factors about 20 percent higher except at MET, where the APC was rear-on toward GZ. As indicated for the M-48 data, the variation among shots may result from a neutron contribution to the apparent transmission factor at close ranges; however, neutron fluence data and transport calculations are unavailable for confirmation. Consequently, a calculated value is adopted. For an estimated one-inch effective thickness of steel (half from the hull, half from internal materials), the transmission factor is about 0.6 for both secondary and debris gamma radiation. The neutron contribution at the range of the APCs from Apple II is too small to augment this value as the effective gamma transmission factor. Agreement with the data appears suitable for the different circumstances of exposure.

TOP VIEW



FRONT

Figure II-2. M-59 Armored Personnel Carrier

B. RESIDUAL RADIATION

Reference 50 reports residual radiation transmission factors of about 0.02 for the M-48 tank. The data were obtained through a simulation of a fallout field by moving Cobalt-60 sources. Film badges were placed on man-phantoms within the tank; consequently, the reported transmission factors include the film badge (as worn) conversion factor of 0.7. The free-field transmission factor would have been about 0.03. Reference 30 reports several values from measurements at Operation Teapot that display dependences on shot and time after burst. The values are scattered about 0.1, except at Apple II, where anomalously high readings within the tanks are ascribed in the reference to contaminated dust that had infiltrated the tanks. For M-59 APCs the following values are given: 0.3, compensated for effect of film badge conversion (Reference 50), and 0.6 (Reference 30). The differences between the field data and the simulations, as well as the non-ideal applicability of each to the task force traversal of the Apple II fallout area, motivated the calculation of transmission factors. Effective shielding thicknesses of 4" (M-48) and 1" (M-59), as for the initial radiation calculations, and a fallout gamma spectrum representative of the early fallout time frame, are used to arrive at transmission factors of 0.06 (M-48) and 0.55 (M-59). These values are reasonably consistent with the references and are used in this report.

No values for the M-7 self-propelled howitzer were found, but because those of other self-propelled artillery vehicles are roughly the same as for the M-59 APC, a value of 0.55 is assumed.

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