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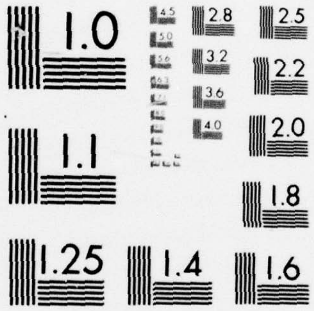
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METHODOLOGIES FOR EVALUATING THE IMPACT OF TIME-VARIABLE NUCLEAR EFFECTS ON SMALL UNIT COMBAT OPERATIONS

②

The BDM Corporation
7915 Jones Branch Drive
McLean, Virginia 22101

4 April 1977

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

Two methods of assessing the impact of time-variable nuclear effects (TNE) on small-unit combat operations are examined. TNE is postirradiation performance degradation, short of death, and radiation-caused fatalities that occur a substantial time after irradiation. The first method examined is the modeling of human performance degradation from nuclear radiation, and the resulting impact on combat operations. The principal difficulties with this method stem from the fact that man's performance response to nuclear radiation is unknown. →

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20. ABSTRACT (Continued)

The second method examined is the use of degraded-performance units in troop training exercises, wherein commanders and their personnel can observe the impact of performance degradation on their capabilities.

SUMMARY

1. TNE

Time-variable nuclear effects (TNE) refers to human performance degradation, short of death, and to fatalities occurring hours to weeks after exposure to initial nuclear radiation. It is hypothesized that after a nuclear burst in combat, there will be irradiated military personnel who will have escaped casualty-producing injury from thermal radiation and from blast effects, but who exhibit TNE. This study is concerned with the development of a methodology to evaluate the impact of TNE on combat operations.

2. IMPACT OF TNE

The relative magnitude of the impact of TNE on combat effectiveness will depend not only on the distribution of initial nuclear radiation doses among combatants, but also on nuclear blast and thermal radiation effects, the yields of weapons used, and the effects of conventional weapons. The distance from ground zero at which casualty-producing nuclear thermal radiation and blast effects occur increases faster with weapon yield than does the distance at which a given level of initial nuclear radiation occurs. Above a certain weapon yield, a person will suffer sufficient prompt injury from blast effects that he would be declared a casualty, independent of the initial nuclear radiation dose received. This yield depends upon weapon type and on a person's vulnerability to nuclear weapon effects. At such weapon yields or greater, only prompt casualties will be produced.

3. DISTRIBUTION OF INITIAL NUCLEAR RADIATION DOSES

For airburst weapons of 100 kt or less and a target comprising tanks uniformly distributed on a flat plain, the distribution of doses among tank crews surviving the blast effects is as follows:

Dose (Rad)	Percent of Irradiated* Personnel Receiving Dose	Performance Degradation
1-200	77-86	Minimal
200-1000	9-15	Moderate-Severe
1000+	1-11	Complete

*Personnel receiving at least one rad

4. PERFORMANCE RESPONSE TO NUCLEAR RADIATION DOSES

Though there are data on the clinical symptomatology of man's response to nuclear radiation, there are virtually none on his will and ability to perform while suffering radiation sickness. The tasks performed in combat vary with the situation and the individual. Though the basic elements of combat tasks may be known (e.g., observe for targets, load gun), the possible sets and sequences of tasks that could be associated with a given group of combatants in a particular combat situation have not been established; nor have standards or measures of performance been established for most tasks. The relationships between the performance levels of individuals, or groups of individuals, and the actions or combat capabilities of aggregated combat units such as a tank crew, platoon, company, or battalion are unknown.

Data from radiation experiments on monkeys appear to be applicable to man only in the most elemental instances. Even then there are such significant differences between man and monkey, and between laboratory and combat environments, that an extrapolation of the data from monkey to man would have serious uncertainties.

5. MODELING THE IMPACT OF TNE

The framework of a model of land combat that reflects the impact of TNE can be readily constructed. A model treating the actions of individual combatants is the most direct approach, in that it reflects the basic mechanism of the impact of TNE. This type of model would be very large and complex. Aggregative models treating groups of combatants would be smaller and more manageable. Both types of models are defeated, however, by the lack of data about man's performance response to nuclear radiation.

6. SYNTHETIC NUCLEAR EXPERIENCE

An alternative approach to modeling is to synthesize nuclear experience in training exercises via performance-degraded trainees, and to observe the impact on force capabilities. Performance degradation is effected either by using low-achieving trainees, or by modifying equipment or procedures so that tasks are more difficult to perform. Alternatively, a trainee is made to experience some symptoms similar to those that would result from irradiation, and the resulting impact on his performance is observed, together with its effect on simulated combat operations. The production of a radiation-like syndrome for a lower range of radiation doses could be safely and reversibly accomplished pharmacologically. The synthetic nuclear experience approach appears to offer more potential for producing useful results than does the modeling approach.

PREFACE

This work was performed for the Director, Defense Nuclear Agency, under contract DNA 001-75-C-0281, Program Element NWED 3250--V99QAXNG042, Work Code 07. The work was performed at BDM's Monterey office. Major contributions were made by BDM staff members Arthur F. Mitchell in the area of tank crew member activities, and Dr. Wm. Bruce Weaver in the use of the TETAM Land Combat Model.

Nuclear weapon effects produce time variable degradations of personnel capabilities and overall combat force performance that are difficult to quantify and evaluate. The US Army Combat Development Experimentation Command (CDEC) has developed an extensive, detailed experimental data base of individual and small unit actions under various simulated battlefield conditions. This data, on two-sided, free play engagements that document positions, times, casualties, communications, etc., may contribute substantially to understanding this issue. As a result, DNA sponsored this effort by BDM commencing in May 1975 to apply existing time-dependent nuclear weapons effects and personnel incapacitation data to a series of field trials performed by CDEC and to develop methods for assessing the impact of time-variable nuclear effects on small-unit combat operations. The emphasis of this report is on discussing and evaluating various methods and techniques for examining this problem. For a more complete treatment of time-variable nuclear effects, one should refer to the results of a concurrent effort published by DNA in September 1976 as DNA 4143D, "Report of the Defense Nuclear Agency Working Group on Nuclear Radiation Effects on Ground Combat Units (U)".

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1. INTRODUCTION

1.1 Time-Variable Nuclear Effects

Time-variable nuclear effects (TNE) refers to human performance degradation, short of death, and to fatalities occurring hours to weeks after exposure to initial nuclear radiation. It is hypothesized that after a nuclear burst in combat, there would be irradiated military personnel who will have escaped casualty-producing injury from thermal radiation and from blast effects, but who exhibit TNE. This study is concerned with the development of a methodology to evaluate the impact of TNE on combat operations.

Figure 1 schematically illustrates the basis for the supposed performance degradation. It is observed that the monkey, trained to perform a certain task, suffers a degradation in ability to perform that task after irradiation. Performance is measured relative to preirradiation performance level. The duration of each of the three phases illustrated and the level of performance is a function of the absorbed radiation dose, time after irradiation, the type of task being performed (cognitive or physical), and other variables. No data exist that permit direct quantification of this effect on man's performance of combat tasks, but the radiation syndrome observed in man indicates that such effects would occur.

1.2 Impact of TNE on Combat Operations

The impact of TNE on combat operations would be seen at different levels. An individual may tire easily; he may show less initiative and judgement; the time required to perform a task may increase; the precision with which the task is accomplished may decrease. Tank and weapon crews may show similar degradations in team performance. The knowledge that irradiation will, for certain doses, result in death some days to weeks later may have a profound psychological effect on an affected person. The same knowledge may impact on a commander's deployment of personnel and his plans for replacement or reinforcement.

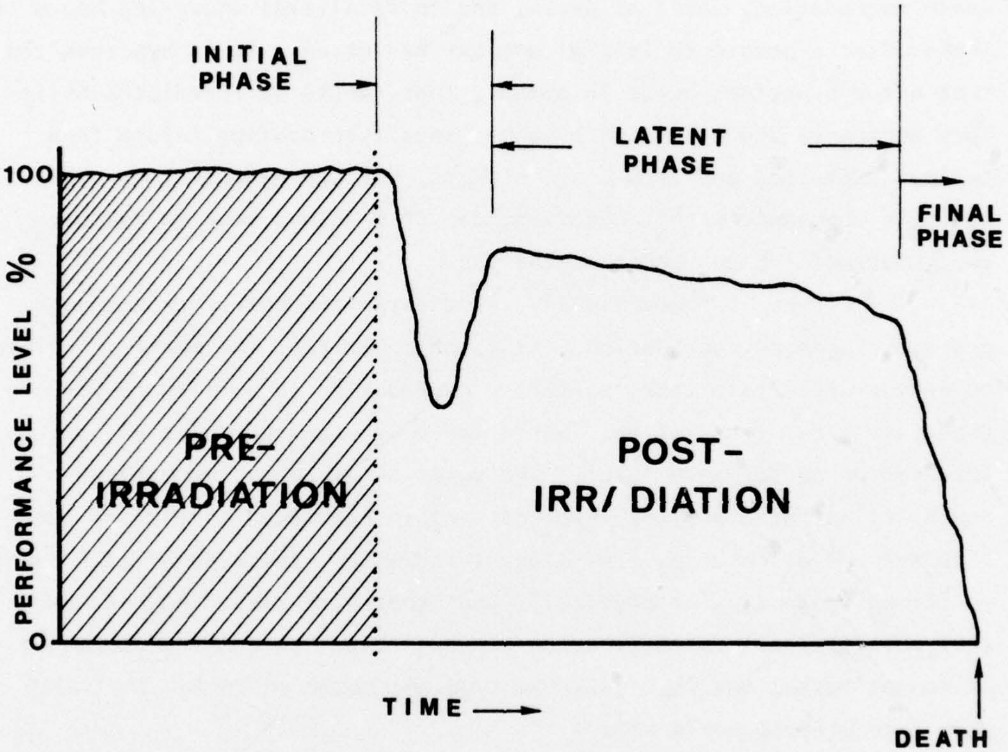

FIGURE 1. RESPONSE OF MACACA MULATTA MONKEY TO WHOLE-BODY NUCLEAR RADIATION (SCHEMATIC)

1.3 Methodological Problems

Several unknowns must be resolved before a methodology for evaluating the impact of TNE on combat operations can be developed. Though there are data on the clinical symptomatology of man's response to nuclear radiation, there are virtually none on his will and ability to perform while suffering radiation sickness. The tasks performed in combat vary with the situation and the individual. Though the basic elements of combat tasks may be known (e.g., observe for targets, load gun), the possible sets and sequences of tasks that could be associated with a given group of combatants in a particular combat situation have not been established; nor have standards or measures of performance been established for most tasks.

The analytical tools commonly used to study combat operations do not, in general, treat the performance of individual soldiers; instead, the actions of a tank or group of tanks may be treated. The relationships between the performance levels of individuals, or groups of individuals, and the actions or combat capabilities of aggregated combat units such as a tank crew, platoon, company, or battalion are unknowns and are usually not explicitly treated.

2. THE IRRADIATED TANK CREW IN THE ATTACK

2.1 Purpose

In this section, the effects of TNE on the actions of one tank crew in nuclear combat are hypothesized. This is done to gain insight into possible impacts of TNE on combat operations, and to help develop the principal characteristics of a model of land combat that could facilitate an evaluation of such impacts.

2.2 TETAM

In 1971 - 1973, a series of two-sided, real-time, casualty-assessed field trials were conducted at Fort Hunter Liggett, California.

This series was designated Experiment 11.8, Tactical Effectiveness Testing of Anti-Tank Missiles (TETAM). A description of TETAM is given in Appendix A. In TETAM a number of tanks engaged defensively-deployed anti-tank missile systems in simulated combat. The actions of one of these tanks in a single trial of TETAM were selected as the basis for the hypothetical nuclear scenario described below. The events of the TETAM trial are given in Table 1, and engagement ranges and simulated ammunition expenditure are given in Table 2. Figures 2 and 3 show the geometry of the trial and the nuclear scenario respectively.

2.3 Nuclear Radiation Syndrome

In this scenario the hypothetical responses of the crewmembers to nuclear radiation are based on experience gained in various nuclear accidents. In particular, they are based on a nuclear accident in which the subject received a dose of about 1350 rad. For the first 12 hours after exposure the subject experienced nausea, vomiting, and some diarrhea; after about 12 hours these symptoms disappeared. On the sixth day they reappeared and persisted until death on the ninth day. Fatigue was experienced throughout the nine days, subsiding to a low level after the first 12 hours and gradually increasing thereafter. The effect of such a syndrome on the performance of combat tasks is a central issue in this study.

The symptoms occurring in the scenario are those that were experienced by the accident subject in the first few hours after irradiation. For a different subject, or a larger dose, temporary incapacitation could have occurred. This would have had a much different effect than the nausea, vomiting and fatigue. Similarly, the battle action in the scenario could have occurred one or two days after irradiation, in which case the only evident symptom would have been fatigue.

2.4 The Nuclear Scenario

2.4.1. General Situation

Tank 7 is the lead tank of the 1st platoon, Team B, 3rd Tank Battalion, 8th Armored Division. Team B is a battle-experienced

TABLE 1. RECORD OF EVENTS FOR TRIAL NO. 111-E79 - TANK NO. 7

Event Number	Time	Grid Coordinate* X	Grid Coordinate* Y	Event
1	10:55:00	53050	80968	Moves out of attack position
2	10:58:00	53400	80400	Crosses line of departure
3	11:05:05	54055	79430	Fired on by DRAGON ATGM (24)
4	11:05:19	54068	79420	Halts - fires on DRAGON
5	11:07:45	54055	79468	Fires 2nd round on DRAGON
6	11:09:09	54134	79369	Occupies defiladed firing position
7	11:12:10	54134	79367	Detects SHILLELAGH ATGM
8	11:12:12			Fires on SHILLELAGH
9	11:12:53			Detects TOW ATGM (18)
10	11:12:58			Fires at TOW ATGM (18)
11	11:13:30			Fires at SHILLELAGH
12	11:13:55	occupying same position		Fires 3rd round at SHILLELAGH
13	11:14:20			Fires 4th round at SHILLELAGH
14	11:14:45			Fires 5th round at SHILLELAGH
15	11:15:08			Fires 6th round at SHILLELAGH
16	11:15:36			Fires 2nd round at TOW ATGM (18)
17	11:16:10			Fires 7th round at SHILLELAGH
18	11:16:50			Fires 8th round at SHILLELAGH
19	11:17:05			Fires 9th round at SHILLELAGH
20	11:17:35			Fires 10th round at SHILLELAGH
21	11:17:55			Fires 3rd round at TOW ATGM (18)
22	11:18:35			Fires 11th round at SHILLELAGH
23	11:20:15			Fires 12th round at & kills SHILLELAGH
24	11:20:48			Fires 13th round at SHILLELAGH
25	11:21:05	54134	79367	Moves out of firing position
26	11:22:01	54286	79167	Killed by TOW ATGM (18)

END OF EXERCISE

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* AMS Map Sheet Series V-795, Sheets 1755 I and II.

TABLE 2. ENGAGEMENT RANGES AND AMMUNITION EXPENDITURE

ENGAGEMENT RANGES

Weapon Firing	Target	Range (meters)
DRAGON (24)	Tank 7	831
Tank 7	DRAGON	858
Tank 7	TOW ATGM (18)	2763
Tank 7	SHILLELAGH	2907
TOW ATGM (18)	Tank 7	2549

AMMUNITION EXPENDED BY TANK 7

Target	Number Rounds
DRAGON	2
TOW ATGM (18)	3
SHILLELAGH	13
TOTAL	18

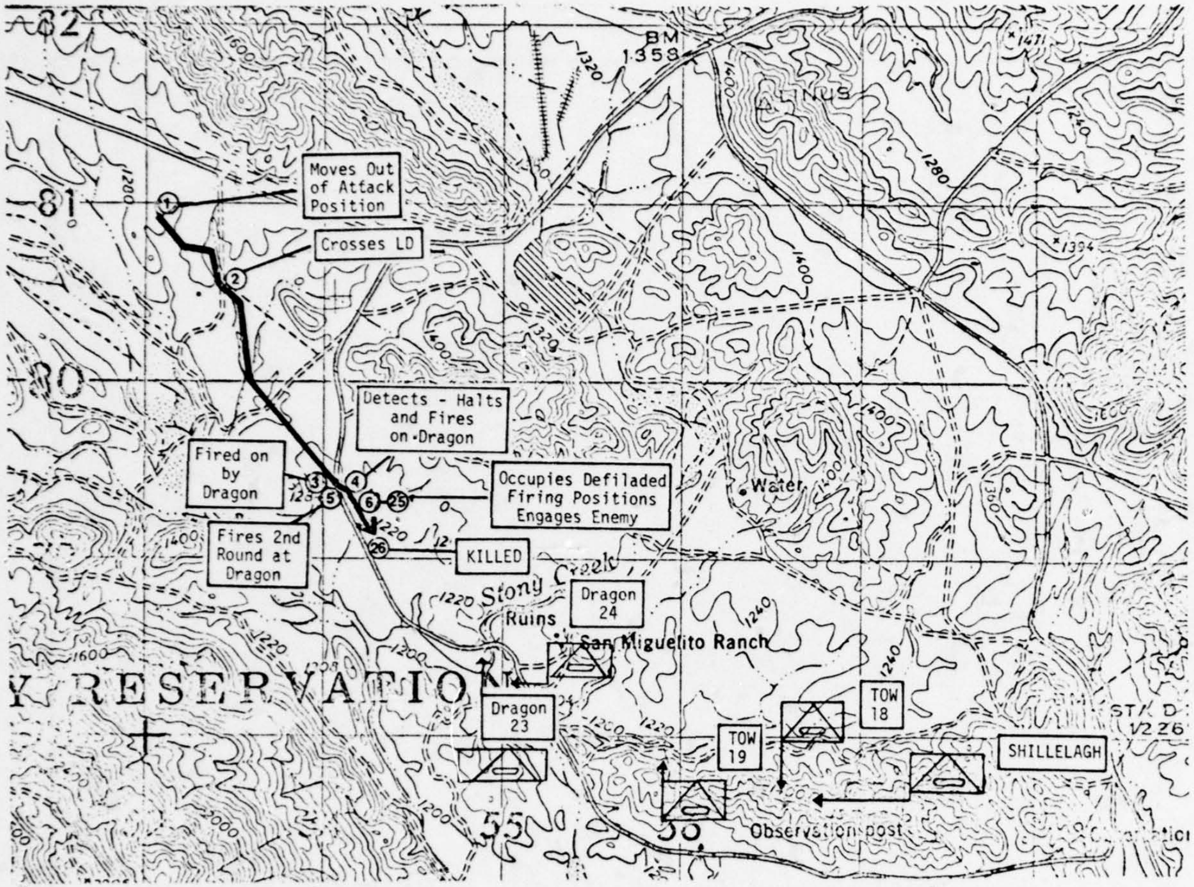

Figure 2. TANK 7 PATH AND EVENTS

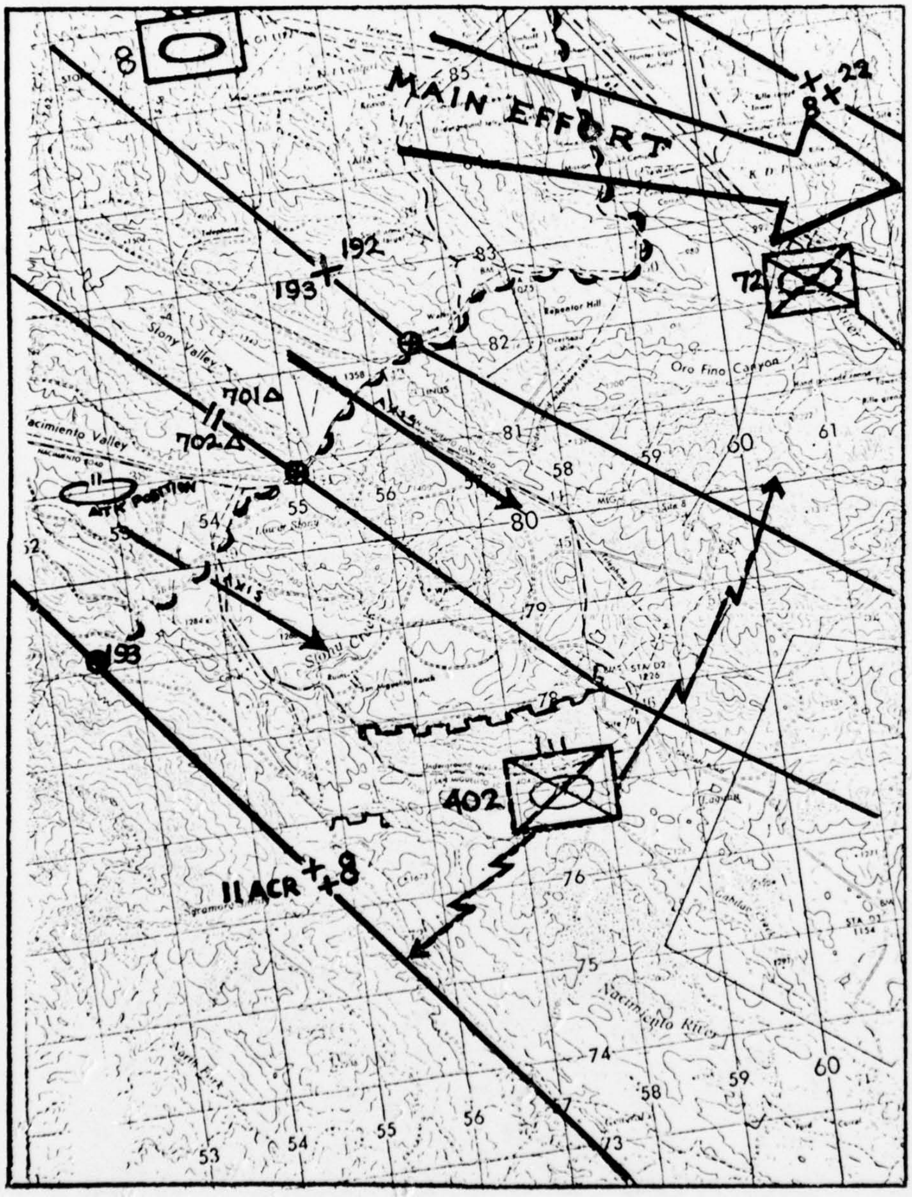

Figure 3. AREA OF OPERATIONS

unit and, along with the 8th Armored Division, has just arrived on-line from having been in Corps Reserve.

On the evening of 10 December, Team B moved from the Battalion Assembly area into a forward assembly position preparatory to jumping off at first light in an attack against what is believed to be light enemy covering forces. These forces are protecting the withdrawal of the enemy main force into previously prepared defensive positions. The mission of the 8th Armored Division is to destroy the enemy covering screen and disrupt and destroy the enemy's main force prior to its occupation of its defensive positions.

The plan of execution calls for the simultaneous attack of two brigades abreast, as shown in Figure 3. The 192nd Armored Brigade attacks south through the San Antonio Valley and the 193rd attacks south through the Stony Valley and Nacimiento Valley. The objective is to seize the high ground in the vicinity of Camp Roberts and to destroy the enemy 402nd Mechanized Rifle Regiment and elements of the 72nd Guards Mechanized Rifle Division. Brigades will attack in a column of reinforced tank battalions. Priority of supporting fires is to the 192nd Brigade.

While Team B was closing into the assembly area, the enemy launched a tactical nuclear strike along the front of the Corps. One nuclear weapon was detonated in the vicinity of the assembly area of the 3rd Tank Battalion. This round caused little or no blast damage, but it was thought that some tank crews received initial nuclear radiation. At the time of the nuclear strike (0400 hrs.) Tank 7 was moving into its leadoff position. All crew members were inside the tank, which was traveling buttoned-up. Darkness and a low overcast had prevented observation of the stabilized nuclear cloud, so that yield could not be estimated. This also precluded triangulation to establish the location of ground zero.

Some of the Team B members reported feeling sick about an hour after the burst, but there was no way to tell if this had been caused by the burst, or if the sickness would persist into the attack. All Team B members expressed confidence that they could carry out the attack.

Coordination was effected with 40th Mechanized Infantry Battalion, through whose area the 3rd Tank Battalion (reinforced) would pass on its way into the attack. At 05:30 the 1st Platoon, Team B, arrived at the attack position and, following a momentary halt, moved out to cross the designated line of departure.

2.4.2 Events for Tank 7, 1st Platoon, Team B (Reinforced)

Event 1 - Arrival and Departure from Attack Position

Driver: Experienced great fatigue and found closing of cockpit hatch unduly time consuming.

Loader: Just prior to closing his hatch became sick and vomited over the outside of turret. Like driver he found closing and locking hatch tiring and difficult. When responding to TC's order to load first round of APDS, noticed how unusually heavy 42 lb. round felt. Charging of M73 coaxial machine gun was also accomplished with great effort. Assumed position for viewing through his periscope. Nausea increasingly evident accompanied by some griping in bowels.

Gunner: Noticed increasing wooziness in stomach, aggravated by pitching motions of tank. Checked battle sight setting (1500 mm), all systems on.

Tank Commander (TC): Welcomed fresh air with hatch open. Nausea most pronounced, and thought probability of vomiting high. Checked M85 cupola machine gun, charging of weapon noticeably difficult. Radio inducing unusual headache. Turning to check on column formation aggravated nausea and brought on vomiting. Order to move out received. Vomited over side of turret before giving driver command to move forward.

Summary

The first effects of radiation are being observed following the exposure to nuclear strike (one and one-half hours previous). Fatigue and nausea have been evidenced with some vomiting and a hint of diarrhea present. All actions were conducted without significant impairment up to now, and task times compare favorably with those of unaffected crew members.

Event 2 - Crossing Line of Departure

Driver: Nausea becoming more acute. Distracted and failed to slow down for drainage ditch, tank bounced and rocked violently, resulting in vomiting spasm, covering lap and legs. Vehicle halted, vomiting stopped, driver stepped down on accelerator and continued to move.

Loader: Violence of vehicle bounce causes recurrence of vomiting (this time inside of tank). Vomit spewed over turret floor and ready round racks. Impossible to hold eyes to periscope. Vomiting subsides. Disinterested in scanning left sector of vehicle.

Gunner: Becoming increasingly sick. Difficult to scan through sights. Very warm, feverish and noticeably tired.

TC: Violence of impact of tank hitting ditch caused severe bruise to right elbow, and induced spasm of vomiting which, fortunately, was again delivered outside of vehicle. Distracted from observing to front and right side of tank.

Summary

During this period some, and at times, all personnel were distracted from observing over their assigned sectors. Security was thus reduced and the vehicle vulnerable to unobserved enemy attack and faults in the terrain. The driver's failure to adequately respond to terrain conditions could have caused serious bodily injury to a crew member. Halting the tank to vomit increased its vulnerability to enemy fire. A reluctance to employ frequent evasive maneuvers, relative to those which would have been employed by an unaffected crew, appears evident. Nausea was increased by the quick motions of the tank.

Event 3 - Fired on by DRAGON ATGM (24)

Driver: Halted vehicle because of nausea and possible further vomiting and with great effort opened hatch and raised seat. Did not see or hear DRAGON missile hit in vicinity of vehicle. Heard TC urge movement to left front and to halt in swayback hollow in ground. Noticed feeling of increased fatigue. Vomited over front glacis before moving into indicated position.

Loader: Was vomiting at time of attack and did not see or hear missile. Was attempting to open hatch when driver abruptly stopped, then started, resulting in his once more covering turret floor and self with vomit. Finally succeeded in unlatching and, with extreme difficulty, opening hatch; feeling of exhaustion follows.

Gunner: Having difficulty in keeping mind off vomiting. Becoming more and more distracted from scanning sector of observation. Failed to observe flash of ATGM or see burst at left front of tank.

TC: Observed flash denoting launch of enemy missile to right front. Saw burst of missile to left front of tank. Unable to pinpoint exact location of ATGM. Ordered driver to turn left into defilade position and to halt. Driver slow in responding. Directed driver to ease tank forward for observation of suspected site. Halted vehicle and observed terrain through binoculars. Binoculars noticeably heavy and tiring to hold in observing position. Traversed turret to suspected ATGM location and at same time issued fire command to crew.

Summary

Vomiting has resulted in the opening of all hatches and heightened inattention to observation over assigned sectors, thus increasing the crew's vulnerability to unobserved attack and possible injury from artillery. Periodic halting of the tank by the driver to vomit has likewise increased the tank's vulnerability and slowed the attack. Because of the vomit inside of the turret in the loader's position, a hazardous, slippery condition has developed, making it difficult to handle the ammunition and load the machine gun. An unaffected crew would have remained buttoned-up (possibly with the exception of the TC) and would have moved with more facility into position. The unaffected crew would have been less vulnerable with higher probability of detecting enemy fire.

Event 4 - Tank 7 Engages DRAGON ATGM (24)

Driver: Lowers seat and positions head inside cockpit, hatch open, holding vehicle at point TC directed him to halt. As gun fires there is a blinding flash and he is covered with dirt and debris. Lurch of tank increases feeling of nausea.

Loader: Now inside turret, head pressed to brow pad of periscope, observing action. Conscious of whine of turret servos as TC traverses to lay on target. Gun fires - blinding flash - lurch rearward - deafening noise. 105mm gun returns to battery - violent pitch forward - breech opens - smoking brass case ejected - slams against turret rear plate - bounces on turret floor beneath loader's feet. Driver responds to TC's command - tank lurches in reverse. Acrid smell of fumes from spent shell case are choking as he bends down to pick up and toss 20 lb. case through open hatch. Vomiting continues, partially discharged outside of turret. TC issues fire command for next round. Weakness and trembling increase as he lifts HEP round from ready rack, shoves it into breech, crying "Up" as he completes chore. Loading action is now much slower, taking about 15 to 20 seconds to accomplish.

Gunner: Head pressed to M31 periscope he observes prominent pile of rocks that is suspected enemy position, makes final lay, places sight reticle cross-hairs on center of mass. Gun fires - blinding bright flash - wall of dust totally obscures vision - acrid smell of powder and sudden recoil of tank causes further vomiting - all interest in task at hand is momentarily lost.

TC: Ducks down inside of cupola - presses eyes to M28 periscope - traverses turret in over-ride to target. (The gunner, following his command, makes final lay on suspected target location.) Like gunner, he is temporarily blinded by flash and dust. A feeling of exhaustion comes over him as tank moves in reverse and halts.

Summary

The interior environment of the tank, as it fires, causes increased distress to the already sickened crew, further degrading their performance. The acrid fumes of the spent round and the violence of the gun reaction in particular are most objectionable.

Fatigue and physical weakness are most apparent in the Loader. The 42 lb. shell and its spent 20 lb. casing now require a major physical effort to move. Increased loading times are now evident, thus increasing overall time of engagement.

A significant difference in reaction time between the affected vs. an unaffected crew is now evident. The loader in particular, because of the physical effort involved in his duties, becomes increasingly fatigued and weakened, resulting in longer times to accomplish required actions.

The TC, concerned about decreasing performance and wondering if other tank crews are similarly affected, considers a holding tactic until he can get artillery to deliver suppressive fire.

Event 5 - Fires Second Round on DRAGON (24)

Fires second round at ATGM position, although this target was destroyed by Tank 6 from a flanking position (unknown to Tank 7). Actions are a repeat of those described in Event 4.

Event 6 - Tank Moves Forward into a Better Defiladed Firing Position

Driver: Head down inside cockpit, hatch open, observes through M27 periscope as he moves tank on TC's command. As vehicle lurches forward a spasm of dry retching causes him to halt and raise head out of cockpit. Recovers and moves into position designated.

Loader: Has disposed of empty casing through hatch and as he lifts APDS round from ready rack, slips and injures knee. Immense effort is required to raise 42 lb. round and shove it into breech. Desire for fresh air drives him to raise his head out of hatch, removes helmet.

Gunner: Extremely nauseous and feeling weak. It is even an effort to crank ammunition selector handle of ballistic computer to input the correct round to be fired.

TC: Stands on platform as he directs driver into position, fresh air refreshing. Legs feel weak and griping of bowels becoming more acute. Notices that (apparently) two of platoon's tanks have been knocked out. Observing over crest of position through binoculars - detects enemy armored vehicle in position on distant crest of dominating ridgeline. Slides down into position to operate rangefinder - traverses turret to bring target into line - overcome by spasm of dry retching - interrupts ranging actions. Eyes watering and stomach aching he returns to rangefinder eyepiece. After several rangings issues fire command to crew; realizes that his action took far too long.

Summary

The sensitivity of the crew to the pitching movement of the tank and the stench emanating from within all contribute to the frequent retching and disruption of duty performances required at each station. Increasingly the crew members are forcing themselves to expose their heads outside of the turret, thus increasing the probability of becoming a casualty. Times required to perform a specific function have lengthened for each crewman.

Events 7 through 24 - Engagement of the Enemy Tank (SHILLELAGH) and an ATGM (TOW 18)

SHILLELAGH and ATGM were positioned on the same ridgeline at a range of 2900 and 2750 meters, respectively. A total of 16 rounds was expended, 13 against the enemy tank, all fired from the same defiladed position.

Summary

The actions of the crewmen are similar to those described in Event 4. However, as the engagement progressed all crewmen became increasingly fatigued. All tasks required an increased time to perform. The loader, having depleted the 13 rounds in the turret ready rack, was forced to replenish same with ammunition from the turret bustle racks. At the conclusion of the engagement the loader was near physical collapse. The remaining crewmen, although still feeling nauseous, were retching less frequently, but were tired. The gunner was finding it more difficult to lay precisely on the target, thus increasing the time of engagement. The noise of the turret blower and the high-pitched whine of the turret traversing servos were becoming more and more oppressive. Failure to be responsive in delivering covering fire for accompanying tanks of the team at the moment required may have resulted in their being knocked out when in an exposed position. The momentum of the attack was diminished, resulting in a successful delay by the enemy and possible escape of the enemy main force elements.

Events 25 and 26 - Movement Forward out of Defiladed Firing Position and Attack by Enemy ATGM (TOW 18)

Having destroyed the enemy tank and believing its accompanying ATGM to have been destroyed, Tank 7 moved toward the next defiladed position some 850 meters to its direct front.

Driver: Responds to TC's command to head toward rock pile where DRAGON ATGM has been destroyed earlier, and moves tank forward. Gnawing stomach ache distracts his full attention from driving. Desire to reach shelter of rock pile where safety and possible respite from physical distress might be possible causes him to drive faster than terrain dictates. Some 260 meters from its last position, tank crashes violently into steep-sided dry wash, causing tank to abruptly halt. At that moment the driver dies.

Loader: Seated on ring seat, observing through M37 periscope, very conscious of exhausted condition and "don't-give-a-damn" attitude. Track noise, turret vibration, and engine roar increased his grogginess. Violent impact of tank hitting ditch sent him sprawling on turret floor - at that instant the loader dies.

Gunner: Dry retching over but painfully aware of ache in his stomach, finds it difficult to keep his forehead pressed against periscope. Depressed and distracted by pitching, noise, and stench of tank. Now minus helmet (which was removed for comfort), a violent pitch of tank causes a severe head injury. Tank comes to an abrupt halt; a brilliant flash, and the gunner dies.

TC: As tank moves forward raises his seat, plants feet on pedestal platform standing in his station. Peering through left cupola vision block notices flash and puff of smoke from distant ridgeline. Abrupt halt of tank throws him against turret; stunned and shaken, he dies as TOW missile strikes tank. Tank 7 has been destroyed.

Summary

As a result of exhaustive efforts in the previous engagement, the effects of the prolonged nausea, and the strain and weakness induced by the frequent vomiting, the crew was in seriously degraded physical condition. This resulted in a disregard for caution and safety and in a significantly lowered level of responsiveness. The

Driver's increasing carelessness and weakened state caused the final event of the action to occur; the halt had clinched Tank 7's doom.

An unaffected crew could conceivably have succeeded in making it to the next defiladed position if it is assumed that the accompanying tanks were still in action and capable of rendering covering fires at the moment Tank 7 broke from cover to move into its next position.

2.5 Alternative Actions

The events described above were those of an actual TETAM trial, with hypothetical sickness from nuclear radiation superimposed. Many alternatives to the events of the TETAM trial can be imagined, given the presence of the radiation syndrome in the crew. For example, in Event 3 in which DRAGON (24) fires on Tank 7, the tank is not hit. In the TETAM field trial, this tank was exposed to the DRAGON only briefly. In the nuclear scenario, the driver may have stopped long enough at that point, because of sickness, that the DRAGON crew would have had more time to aim at and to track Tank 7, possibly hitting it with the first round. They may even have had time to fire a second round.

The TC, after observing several driving errors, may have decided to replace the driver with the loader, who perhaps may have seemed not as sick as the driver. In this case, perhaps the tank would not have crashed into the dry wash. The time taken in switching loader and driver may have permitted other tanks of the platoon to move to better covering positions, and Tank 7 would not have been killed. On the other hand, this delay may also have permitted the enemy to improve its positions, and Tank 7 would have been killed. The number of possible alternative events is large, each potentially resulting in a different combat outcome.

Looking at alternatives at a higher level, the TC of Tank 7, who was also the platoon leader, could have:

(1) Fired smoke rounds on suspected enemy sites from own basic load.

(2) Augmented own fires with supporting fires from other surviving tanks of platoon.

(3) Requested air and/or artillery supporting fires on enemy positions.

(4) Reported casualties sustained and requested assistance, noting inability to continue attack due to sickness.

(5) Directed surviving tanks to hold in place and occupy optimum firing positions, and be prepared to support friendly reinforcing or relieving unit.

The team commander (B Company Commanding Officer) could have:

(1) Directed attached mortar platoon to deliver coordinated fires on suspected enemy positions.

(2) Requested tactical air strike and/or artillery fires on enemy positions.

(3) Directed reserve reinforced platoon to advance, making sweeping turn wide of right flank of Tank 7 along covered approach of stream bed. This would be coordinated with Tank 7's platoon, which would deliver covering fire if capable. This action would be dependent on combat effectiveness of this unit at time of commitment.

(4) Reported situation to Task Force Commander (3rd Tank Battalion) if entire team has been incapacitated and determined incapable of sustaining the attack.

The Task Force Commander (3rd Battalion, Reinforced) could have:

(1) Directed Team Bravo to hold in place, taking supporting firing positions, and prepare to deliver covering fire in

support of reserve team, which will attack through Team Bravo position.

(2) Relieved Team B.

(3) Reported the situation to the Brigade Commander, who could replace TF 3 with whatever unaffected brigade reserve he had available.

3. MODELING THE IMPACT OF TNE ON COMBAT OPERATIONS

The style of the description of events in the nuclear scenario above derives from what is known about the effects of nuclear radiation; i.e., in this particular case, the individual human response in terms of the more apparent, immediate syndrome of nausea, fatigue, and diarrhea. There are other symptoms, such as loss of hair, bleeding, or infections that run unchecked because of white blood cell depression. Each would have a psychological as well as physical impact. Infections in the mouth, for example, could result in reduced food intake and amplification of fatigue.

In considering models or simulations of combat that would reflect the impact of the radiation syndrome, one is first led to consider an elemental approach in which the actions of individual combatants are treated. This approach and others are discussed below.

3.1 Elemental Model

In this approach, shown schematically in Figure 4, a combatant's physical condition is continuously updated as a function of time and his time history of absorbed nuclear radiation. His perception of combat events, his decision processes, and his physical activity are all affected by his changing physical condition. His actions are summed with those of all other combatants, irradiated and nonirradiated, to produce combat events. For example, the actions of the crewmembers of a tank sum to, or result in, the combat event of a tank moving from A to B, or firing at target E. Another combat event could be the death of a combatant, or his removal from action by his commander, who perceives his

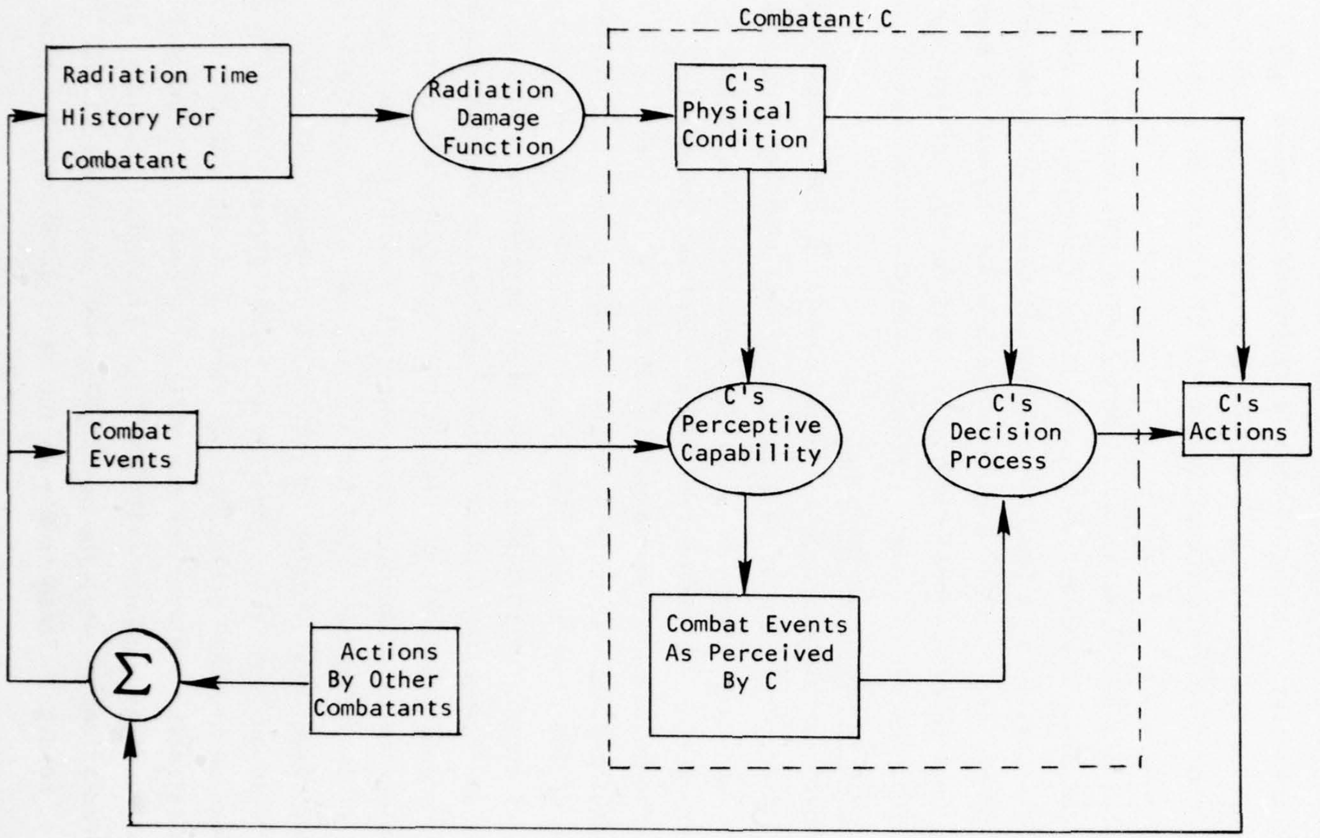

Figure 4. Elemental Model of Impact of TNE

deteriorating physical capabilities as being detrimental to his unit's operation. The merit of this approach is that combat events are a direct function of TNE. In particular, if an objective could not be achieved by a combatant or group of combatants in the "standard" way because of degraded capability, an alternative course of action would be chosen. The innovative process that is the key of all combat would therefore be reflected.

To build a useful mathematical model using this approach is currently infeasible. The model would be enormously complex, and modeling human decision processes as a function of physical condition is not within the state of the art. Added to this is the unknown of physical capability as a function of absorbed radiation. Consideration of this approach is useful, however, in constructing alternative approaches.

3.2 Computer-aided Elemental Model

A more feasible approach is to use players to decide what each combatant would do, given a particular physical condition and perceivable combat events, and have a computer assist by calculating the combat events and interactions resulting from player-specified actions (e.g., time to move from A to B, hit on target E, mobility kill of E). A simulated engagement, played in this fashion, would reflect the imagination of each of the players regarding the will, motivation, and physical capabilities of irradiated combatants. A set of descriptors would be required that would specify "typical" human responses to various absorbed doses as a function of time after irradiation. A player would consult these descriptors to help decide what a combatant does in a given situation. For example, if the response listed for a given time after irradiation is "fatigue", the player must imagine how active his combatant has been, his motivation to perform (e.g., does the combatant perceive his life as being dependent on his next action?), what tasks he decides to do, etc.

Substituting a player for the model of a combatant's perception and decision processes does not solve the basic problem of how these are affected by radiation, or what the combatant's will and physical capabilities are, however. These remain as the basic unknowns. The game could be played, however the results would be player-dependent and it would be difficult to compare them in any meaningful way to a control case in which no radiation was assumed.

3.3 Aggregative Models

If modeling or playing individual combatants is infeasible, an alternative is to model or play groups of combatants. This is what is normally done in models of ground combat in order to reduce the model to a manageable size. However, existing models of this type usually explicitly treat the physical characteristics of weapon systems that are being operated, rather than the actions of the operators. For example, a tank will move over a certain terrain type at a particular speed; the probability of hitting a target of given size at some range is specified; the probability of detecting a target under given conditions is specified. These specifications assume some level of performance by a crew or an individual, but this is not an explicit function and it does not vary with the combat history (and therefore, the physical condition) of the combatants.

To reflect the impact of TNE in such a model, weapon/equipment performance as a function of crew or operator physical condition would have to be known, as well as crew physical condition as a function of absorbed nuclear radiation and time. These functions are unknown, but in their absence a parametric analysis of the effect of changes in weapon/equipment performance on combat outcome could be made. This was done in this study using the TETAM Land Combat Model and a prototype reliability model.

3.3.1 TETAM Land Combat Model - Parametric Analysis

This is a simple model based on the results of the TETAM field trials (see Appendix A). It was designed to post-play the field trials for the purpose of conducting a sensitivity analysis of the effects of changes in anti-tank missile performance parameters. If the model is run using values of performance and operational parameters corresponding to those actually used in the field trials, the model results closely approximate field trial results. Varying the values of weapon system and operational performance parameters would be expected to produce valid results also, provided that such variation is within some small interval about the model design values.

In the analysis performed in this study with the TETAM model, four model inputs related to combatant performance were parametrically varied. These were tank speed, tank main gun reload time, engagement rate, and offensive and defensive weapon kill probability. The assumption was made that if a tank crew had been irradiated, the values of these parameters would change. The results of this parametric analysis are given in Appendix A. They show that relatively little change in engagement outcome occurs when parameters are varied one at a time, and that the greatest sensitivity occurs when tank speed, engagement rate, and kill probability are varied simultaneously.

Whether these sensitivities are realistic for the TETAM scenario over the entire range of variation of the parameters is moot. What is important is that, though such an analysis can be performed, it fails to illuminate the critical relationship between the dose a combatant receives, the resulting performance degradation, and the corresponding value of a related parameter such as tank speed or engagement rate. Without such relationships it is impossible to know what sets of weapon performance parameters or other variables treated by a model are internally consistent, or which sets match specific times (and, therefore, physical conditions of combatants) in a given nuclear scenario. For example, if a tank's speed is assumed to be only 70% of its normal speed, (i.e., the assumption being that an irradiated tank crew would operate the tank at a reduced speed), there is no way to know what the corresponding values of kill probability and engagement rate should be.

Another consideration in the use of the parametric approach is that like TETAM, most models of land combat employ fixed tactics within a given simulated engagement. In reality, as a nuclear engagement progresses and the impact of TNE begins to be felt, tactics would be expected to change. In particular, as the combat effectiveness of a unit begins to decrease as a result of TNE, the unit may be withdrawn and replaced, or its role may be changed so that the success of the combat operation is less sensitive to changes in the unit's performance level.

The TETAM Land Combat Model was used in this analysis because of its availability and recent use by the BDM Corporation. It is probably too highly aggregated and specific in its application to be very useful in investigating the effects of TNE. This analysis shows that a more appropriate land combat model would treat the effects of crew performance level more explicitly, and would treat tactics for individual crews as a variable.

3.3.2 Reliability Model - Parametric Analysis

Because of cross-training, and the ability to operate a 4-crewmember tank with only three crewmembers, a tank crew can be treated as a system with series and parallel elements. This suggests a modeling approach using classical reliability analysis. If all the various tasks performed by an individual crewmember in a given time period, or mission, are aggregated into just one "task", a simple reliability equation can be derived that expresses tank crew "reliability" as a function of crewmember "reliabilities".

A prototype model using this approach was developed and is described in Appendix B. A parametric analysis was performed, using a range of values of reliability for each crewmember. These values correspond to the postirradiation performance level of a crewmember for all tasks he performs during a mission. The result, for each such set of performance values, is a crew reliability. This could be construed to mean the probability that the crew would perform as if undegraded. Alternatively, if applied to a large number of tank crews, crew reliability could be interpreted as the effective force level; i.e., 10 tanks each with a crew reliability of 0.9, would be equivalent to 9 or fewer tanks with undegraded crews, depending upon the tactical situation and the tanks' roles.

This approach was an attempt to bypass the data gaps of the human performance response to nuclear radiation, and weapon system performance as a function of operator physical condition. In effect, it replaces these two gaps with a single, equivalent gap labeled "reliability". Though this does not really change the problem, it might simplify the collection of data and validation of the concept via the type of test described below in section E, "Synthetic Human Nuclear Experience".

3.4 Other Factors

The preceding has dealt mainly with the effects of initial nuclear radiation on man's combat performance. His performance will be a function of other factors as well.

3.4.1 Fallout and Rainout

Fallout and rainout can result in high levels of radiation. A unit may find itself in an area of fallout, or may have to pass through such an area, and its mobility may be constrained by enemy forces. In such cases, the time spent in the area may be enough to cause the absorption of doses large enough to produce TNE. Such doses could be additive to those already experienced, depending on the times of exposure.

3.4.2 Maintenance Tasks

There is a considerable amount of maintenance to be performed on military equipment. If the maintenance personnel are suffering TNE, the work they perform may be of less than normal quality. Equipment so maintained may exhibit degraded reliability, and this will impact on the combat effectiveness of a unit. Appendix D, which lists tasks required of the M60A1E3 crewmembers, shows that about 15 percent of the crew's time is spent in maintenance tasks.

3.4.3 Synergistic Effects

A combatant suffering injuries from nuclear weapon blast effects, thermal radiation, or conventional weapons sufficient to be declared a casualty* will be removed from action, regardless of TNE, and should be so treated in a model of land combat. If lesser injuries occur, they may, in combination with TNE, be sufficient to cause a casualty. Alternatively, they may cause degradation of performance in addition to that caused by TNE.

3.5 Relative Magnitude of TNE Impact on Combat

The relative magnitude of the impact of TNE on combat effectiveness will depend not only on the distribution of initial nuclear radiation doses among combatants, but also on nuclear blast and thermal radiation effects, the yields of weapons used, and the effects of conventional weapons. Appendix C treats the distribution of initial nuclear radiation doses and blast and thermal effects. A discussion of some of the data from that Appendix follows.

The distance from ground zero at which casualty-producing nuclear thermal radiation and blast effects occur increases faster with weapon yield than does the distance at which a given level of initial nuclear radiation occurs. Above a certain weapon yield, a person will suffer sufficient prompt injury from blast effects that he would be declared a casualty, independent of the initial nuclear radiation dose received. This yield depends upon weapon type and on a person's vulnerability to nuclear weapon effects. At such weapon yields or greater, only prompt casualties will be produced.

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* The definition given in AR 310-25 "Dictionary of United States Army Terms", dated June 1972, is taken: "Any person who is lost to his organization by reason of having been declared dead, wounded, injured, diseased, interned, captured, missing; or a person whose whereabouts or status has not been determined."
The relevant part of this definition is "...who is lost to his organization...", which implies that a casualty contributes <u>nothing</u> in the performance of a task or mission by his organization.

Below these yields, time-variable nuclear effects (TNE) will be produced in thermal radiation and blast effect survivors in varying degrees. Table 3 shows the distribution of initial nuclear radiation doses greater than 1 rad in tank crews surviving the blast effects.

For the weapon yields treated in Table 3 up to and including 100 kt, from 76.7 percent to 86.2 percent of tank crews not becoming casualties from blast effects (i.e., blast effect survivors) will receive less than 200 rad. This dose is the threshold of fatality production from initial nuclear radiation. Few or no deaths would result. The radiation syndrome would be of relatively low intensity, and the mean performance degradation would be correspondingly low.

From 9.4 percent to 15 percent of the tank crew blast effect survivors would receive doses of from 200 to 1000 rad. According to Reference 1, fatalities among these combatants due to initial nuclear radiation would be as follows:

Dose (Rad)	% Fatalities	Time to Death
200-400	0-30	4-12 weeks
400-600	30-90	2-10 weeks
600-1000	90-100	1-6 weeks

From 0.6 percent to 11.2 percent would receive a dose greater than 1000 rad. According to Reference 1, all such personnel would die from the dose received. Reference 2 states that for a dose of 2500 to 3500 rad,

> "Personnel will become incapacitated within 5 minutes of exposure and will remain so for 30-45 minutes. Personnel will then recover but will be functionally impaired until death. Death will occur in 4-6 days."

For a dose of 7000 to 9000 rad,

> "Personnel will become incapacitated within 5 minutes of exposure and for physically demanding tasks will remain incapacitated until death. Death will occur in 1-2 days."

TABLE 3. PERCENT OF TANK CREW BLAST SURVIVORS RECEIVING INDICATED DOSE

	.01	0.1	0.3	1.0	3	10	30	100	300
1 - 100	80.2	78.2	75.5	74.7	71.9	70.1	70.8	76.6	100
100 - 200	6.2	6.1	6.1	6.2	6.4	6.6	7.0	7.8	-
200 - 1,000	9.4	9.5	10.0	10.5	11.2	12.1	13.0	15.0	-
1,000 - 3,000	3.0	3.4	4.1	4.4	5.1	5.8	6.7	0.6	-
3,000 - 8,000	0.9	1.6	2.2	2.5	3.2	3.9	2.5	-	-
8,000 - 18,000	0.2	0.7	1.1	1.3	1.8	1.5	-	-	-
18,000+	0.1	0.5	1.0	0.4	0.4	-*	-	-	-

Target: Tanks uniformly distributed over flat plain

Weapon: Single low airburst

Crews of tanks moderately damaged by blast effects are assumed to be prompt casualties.

Protection factors assumed: 0.6 for neutrons, 0.4 for fission and secondary gamma.

*Maximum dose for blast survivors is less than lower bound of interval.

For a dose of 17000 to 19000 rad,

"Personnel will become incapacitated within 5 minutes of exposure and for any task will remain incapacitated until death. Death will occur within 1 day."

The severity of response for the higher doses, coupled with the relatively low percentage of personnel receiving such doses and the probable incidence of accompanying blast and thermal radiation effects, suggests the following classification:

Dose (Rad)	Percent of Irradiated* Personnel Receiving Dose	Performance Degradation
1-200	77-86	Minimal
200-1000	9-15	Moderate-Severe
1000+	1-11	Complete

*Personnel receiving at least one rad

For purposes of modeling or of estimating the impact of TNE, the gross assumptions could be made that personnel receiving more than 1000 rad are prompt and permanent casualties; those receiving less than 200 rad perform as if they had not been irradiated (this still admits of considerable variation of performance among personnel); and those receiving between 200 and 1000 rad exhibit marked performance degradation prior to death from one to 12 weeks postirradiation. In effect, this reduces the problem to one of estimating or calculating the impact of prompt casualties (from blast effects, thermal radiation, and initial nuclear radiation for blast effect and thermal radiation survivors receiving more than 1000 rad) and, for a relatively small group, performance degradation plus delayed fatalities. This does not solve the problem of finding the impact of performance degradation, but does confine it to a small percentage of the combatants.

Recall that in the above, the results are based on the detonation of a single, airburst nuclear weapon. The overlapping effects of multiple weapons are not treated (this would tend to increase the incidence of higher doses), nor is fallout or rainout treated. Neither is a non-uniform distribution of combatants treated. Clearly, this would affect the distribution of doses among personnel and it would differentiate among classes of personnel (e.g., if only command personnel suffered all of the prompt casualties and fatalities, or if only a particular element of a force, say the artillery, were to suffer prompt casualties, the impact would be different than if such casualties were distributed among the entire force).

4. THE IMPACT OF NUCLEAR RADIATION ON PERFORMANCE

Each of the modeling approaches discussed above requires data on the performance response of man to nuclear radiation. These data do not exist, nor is it likely that they will ever be collected in a timely manner. A summary of the effects of nuclear radiation on man and on other mammals is given here. In Section E, following, considerations on the use of such data in predicting man's performance response are presented.

4.1 Effects of Ionizing Radiation

Physiologically, ionizing radiation principally affects the ability of immature cells to mature to functional cells of organ systems. Normally, as older cells wear out or die, they are replaced by maturing cells which continue the physiological and biochemical functions of body maintenance. For example, the bone marrow supplies mature functional blood cells continuously. Immature cells of an organ system are radiosensitive and are easily killed or damaged by radiation, whereas mature functional cells are more radioresistant.

Organ systems composed primarily of mature functional cells with a very low or zero turnover rate are quite radioresistant. Radiosensitive organ systems contain a large proportion of immature cells and have a high turnover rate of mature functional cells. The level of radiosensitivity of an organ system is to a large extent proportional to the replacement rate of mature functional cells.

4.1.1 Time to Death

Whole body radiation may result in death due to three significantly different mechanisms depending on the dose level and the organ system most affected. Figure 5 schematically shows mean survival time for essentially all tested mammalian animal species (denoted by the letter "A") as a function of dose.

The dashed lines labeled "C" represent rough limits for mammalian species. The three segments of curve A correspond to three different fatality mechanisms. Mean survival time for the first portion of the curve (about 350 to 1300 rad) is dose dependent and corresponds to fatalities resulting from radiation damage to the hematopoietic organ system. The symptoms of this type of damage are called the hematopoietic syndrome. The second portion (from about 1300 to 10,000 rad) corresponds to fatalities resulting from radiation damage to the gastrointestinal (GI) organ system. The symptoms of this type of damage are called the GI syndrome. Man's response to GI damage is shown by the curve segment labeled "B". The third segment of curve A corresponds to fatalities caused by damage to the central nervous system (CNS), the symptoms of such damage being called the CNS syndrome.

Depending on the absorbed dose, the frequency distribution of survival times of the decedent occurs about one or two modes, corresponding to whether an individual is dying from damage to one or two organ systems. The frequency distribution of survival times is characteristically a Poisson distribution.

Figure 6 diagramatically presents the frequency of death as a function of time for different doses.

There is a characteristic correspondence between mean survival time and the particular organ system whose damage produces death. The central nervous system (CNS) is composed primarily of mature functional cells with a zero turnover rate, and consequently the CNS is highly radioresistant. However, a dose of 10,000 rads or greater will kill or injure CNS cells and result in death within two days or less. The gastrointestinal (GI) tract has a nonzero turnover rate of mature functional cells. Death due to radiation damage of the gastrointestinal

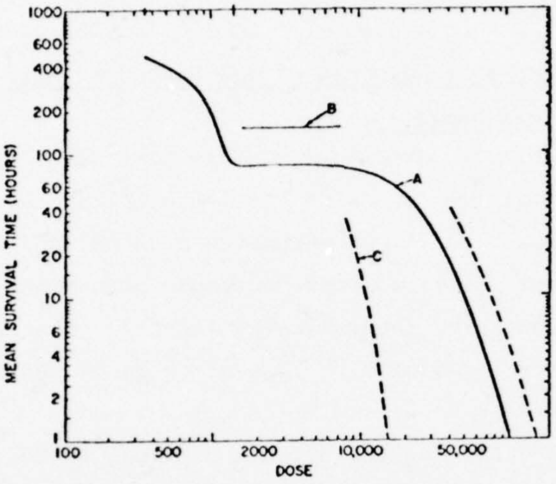

Figure 5. Mean Survival Times as a Function of Dose Following Exposure of a Mammal to Whole-Body Irradiation

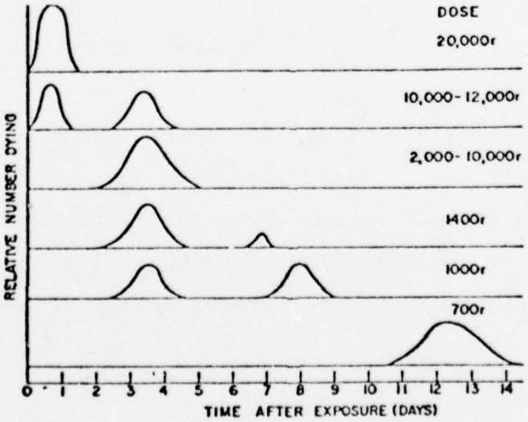

Figure 6. Distribution of Deaths as a Function of Time Following Whole-Body Irradiation (Diagrammatic)

tract occurs approximately six days after a 1000 to 5000 rad dose. Bone marrow has a high turnover rate of mature functional cells (blood cells). Death due to hematopoietic damage occurs approximately 20 days after irradiation and results from a dose of from 200 to 500 rads.*

4.1.2 Performance Response of the Macaca Mulatta Monkey to Nuclear Radiation

Performance decrement studies have been conducted at the Armed Forces Radiobiology Research Institute (AFRRI) and the USAF School of Aerospace Medicine (SAM). Research at AFRRI and SAM indicate that the performance of the irradiated Macaca Mulatta monkey as a function of time is influenced by the following factors: absorbed dose[3], dose rate, part of body irradiated[4,5,6], neutron-gamma ratio[7,3], type of task[7,8], and motivation.

Before examining the effects of these factors, it is relevant to define what is meant by "performance", especially if the response data for monkeys are to be used to indicate what man's performance response to nuclear radiation might be. The meaning of the word "performance" for the monkey is given by the following, abstracted from Reference 3 .

The monkeys "...were maintained in primate restraint chairs designed for behavioral studies and housed in idividual isolation booths. Each animal was placed in the restraint chair at the beginning of training and was maintained in the chair until postirradiation testing was completed, approximately 25 days."

"The animals were trained to do a discrimination task consisting of a circle and a square simultaneously projected onto the backs of two transparent pressplates. An additional cue was also available to the animal; at the beginning of each trial a 15-watt house light was illuminated in the cubicle. An interval of 10 seconds elapsed

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* Bond, Mammalian Radiation Lethality

"between the onset of successive trials. After the onset of the visual stimuli, an animal was allowed 5 seconds to complete the problem by pressing the pressplate illuminated with a square. If he performed correctly, the house light extinguished and the subject remained in darkness for the remainder of the 10-second interval. If the subject performed incorrectly by pressing the circle or failed to respond within 5 seconds, a tone was sounded, the cubicle light remained on, and an electrical shock was delivered to the subject. The animals were trained to an accuracy criterion of 90 percent correct or better. On completion of training, each animal was subjected to a base-line test. The data from this test allowed each animal to serve as its own control."

Postirradiation, the fraction of responses that were correct, normalized to the base-line test score, constituted the monkey's level of performance. In this case the task performed by the monkey was primarily cognitive in nature (i.e., an act of knowing, including both awareness and judgement); the only physical activity was to press the pressplate. In tests in which the monkey performed a physical task, namely running or walking in a squirrel cage type of apparatus called a "primate physical activity wheel", level of performance was measured by the number of revolutions of the wheel achieved during a given time period. The wheel had to be turned at a rate corresponding to a pace of between one and five miles per hour. Below one mph, an electrical shock was administered; above five mph the wheel was slowed by a brake, but no shock was given. Postirradiation performance was normalized to baseline, preirradiation performance.

The test data indicate that with increasing absorbed dose, dose rate, and/or gamma-neutron ratio, the initial performance decrement increases or is longer in duration. The level of performance degradation for a cognitive task requiring little physical activity (e.g., differentiating between two different visual cues) is not as pronounced as for a more physical task (e.g., running on a treadmill). The factor of motivation would seem to be critical, but unfortunately is difficult to quantify. Generally, the degradation in the performance of a task by a lightly motivated irradiated monkey appears to be greater than that by a highly motivated monkey.

The effect of increased dose on the performance of a simple cued avoidance task is displayed in Figure 7. The time of onset of the initial decrement in performance is independent of the dose level or the type of task; however, the rate of recovery is dependent upon dose.

The performance level of irradiated monkeys is dependent upon the type of task being performed. Figure 8 presents the performance of the Macaca Mulatta as a function of time after receiving 2000 rads. Performance is shown for a cued avoidance task (cognitive task) and for a physical activity task (running on a treadmill). The initial decrement in performance is much more pronounced for the physical task, and the time to recovery from this decrement is prolonged compared to the less physical task. In addition, when physical activity is an essential component of a task, the performance level of the whole task is degraded. In a test combining both physical and cognitive tasks, separating the physical task from the cognitive task improves the performance of the cognitive task.

In a collaborative study between AFRRI and SAM , the performance of irradiated animals that had been trained to operate a primate equilibrium platform (PEP)*, a physical task (see Figure 9), was compared to the performance of animals with similar radiation exposure but required to perform only a simple discrimination (cognitive) task (see Figure 10). No significant differences were observed in the incidence and severity of the initial performance decrement. However, the level of recovery observed in the discrimination-trained animals 30 minutes post-irradiation was not reached by the PEP-trained animals until 150 minutes after exposure.

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* The primate equilibrium platform was designed to determine the effect of radiation on the equilibrium function. The task for the primate was to pilot the platform by manipulating a "joy stick" in order to maintain the platform in a relatively horizontal position.

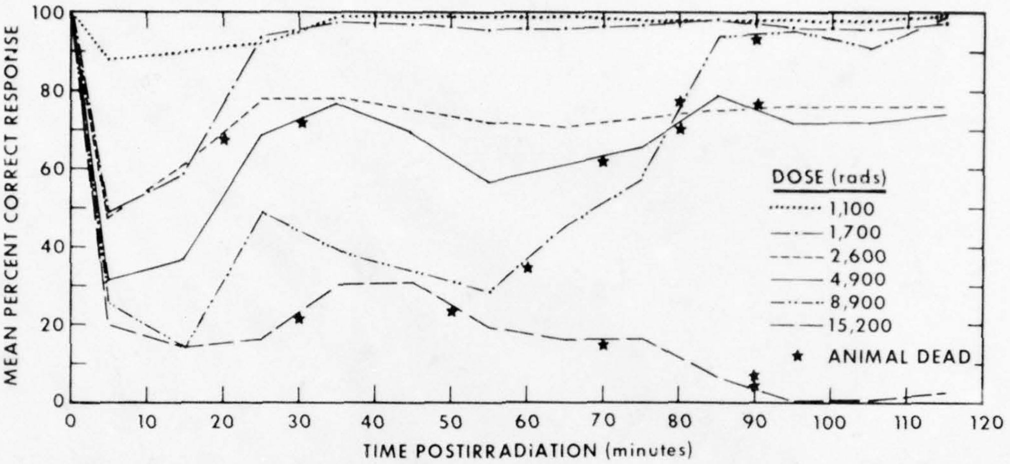

Figure 7. The Effect of Dose on the Level of Performance of the Macaca Mulatta Monkey for a Simple Cued Avoidance Task (AFRRI SR73-1).

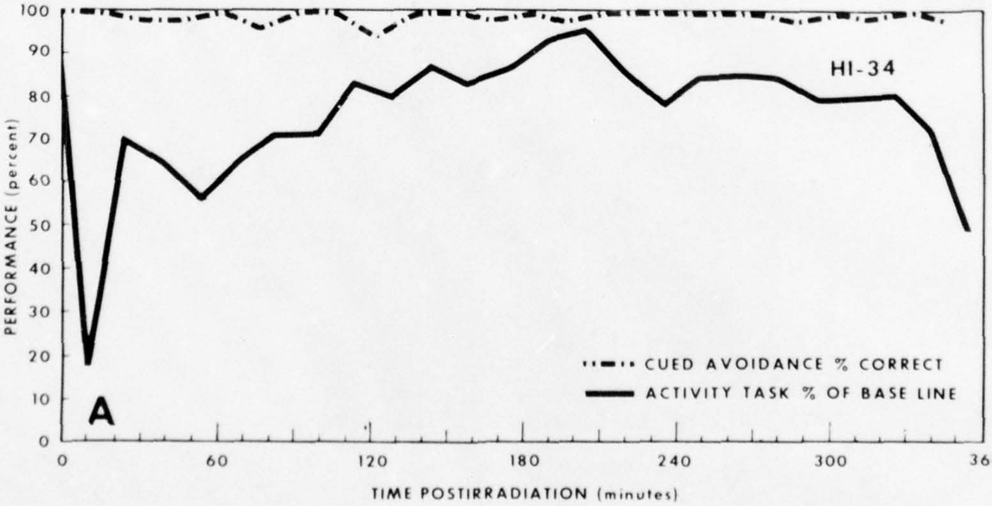

Figure 8. Postirradiation Performance of the Macaca Mulatta Monkey as a Function of Time for a Cued Avoidance (Cognitive) Task and an Activity (Physical) Task for a 2000 Rad Dose (n/g - 0.4) (SR74-29).

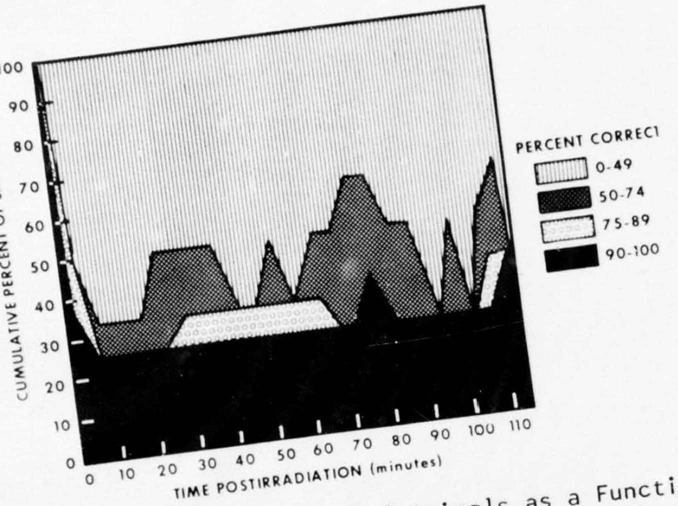

Figure 9. Cumulative Percent of 8 Animals as a Function of Time Falling Within Four Performance Ranges for the PEP (Physical) Task. (Mean Dose = 2700 Rads, n/g - 0.5:1) (SR72-14).

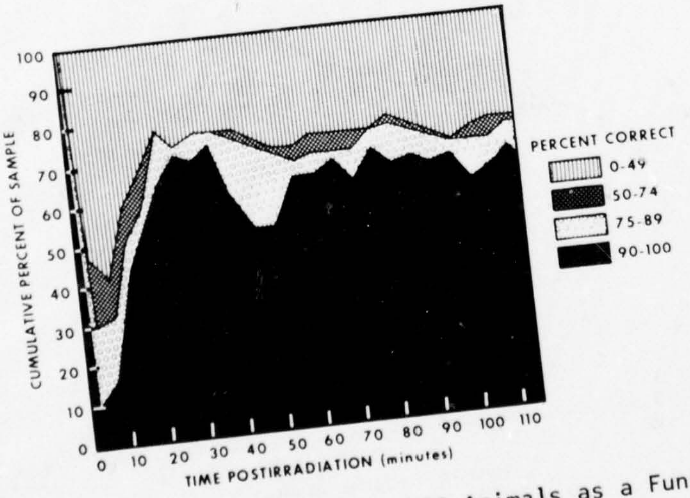

Figure 10. Cumulative Percent of 39 Animals as a Function of Time Falling Within Four Performance Ranges for a Discrete Avoidance (Cognitive) Task (Mean Dose = 2800 Rads, n/g - 0.5:1) (SR72-14).

The neutron-gamma ratio (ng) has a potentially significant effect on postirradiation performance . Calculations by Thorp and Young suggest that the ability of neutrons to incapacitate, relative to gamma radiation, is only 0.68. Animals receiving a higher proportion of gamma in their total dose exhibit a more severe performance decrement. Figures 9 and 10 indicate that animals which receive a pulsed dose with a neutron-gamma ratio of 0.5:1 exhibited a more severe early transient performance decrement than animals irradiated with a neutron-gamma ratio of 9:1. (See Figure 11).

The biological response to ionizing radiation is dependent upon the particular monkey being irradiated. Under the same conditions, some monkeys may exhibit no performance degradation, some may exhibit an intermediate level of performance degradation, while others are virtually incapacitated. The variance in the performance of two irradiated monkeys is graphically displayed in Figure 12 for a cognitive task. The variation in performance of a physical task for two other animals is shown in Figure 13.

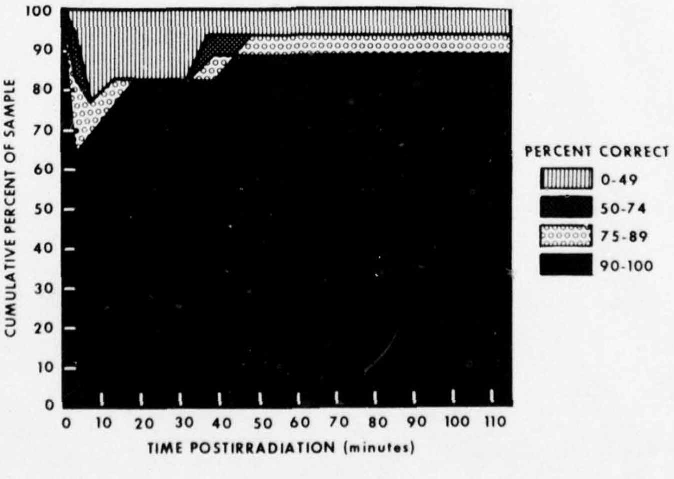

Figure 11. Cumulative Percent of the 16 PEP-Trained Animals That Fall Within Four Performance Ranges (Mean Dose = 2500 Rads, n/g - 9:1) (SR72-14).

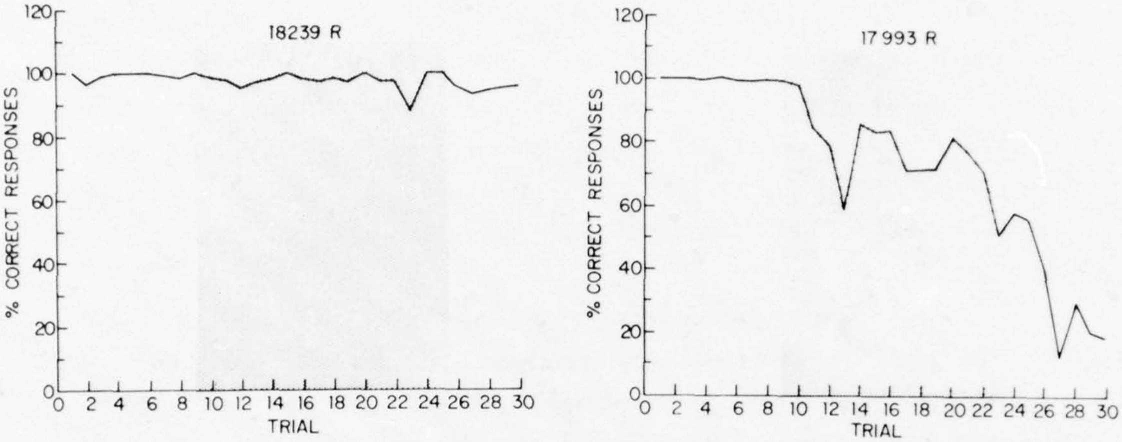

Figure 12. Individual Performance Curves for Trunk-Irradiated Animals For a Simple Cued Avoidance Task, Showing Percent Correct Responses for Individual 4-Minute Trials. The Shaded Area Represents the Period of Radiation Exposure. Subjects Received 280 Rads Per Minute. (SAM-TR-68-37).

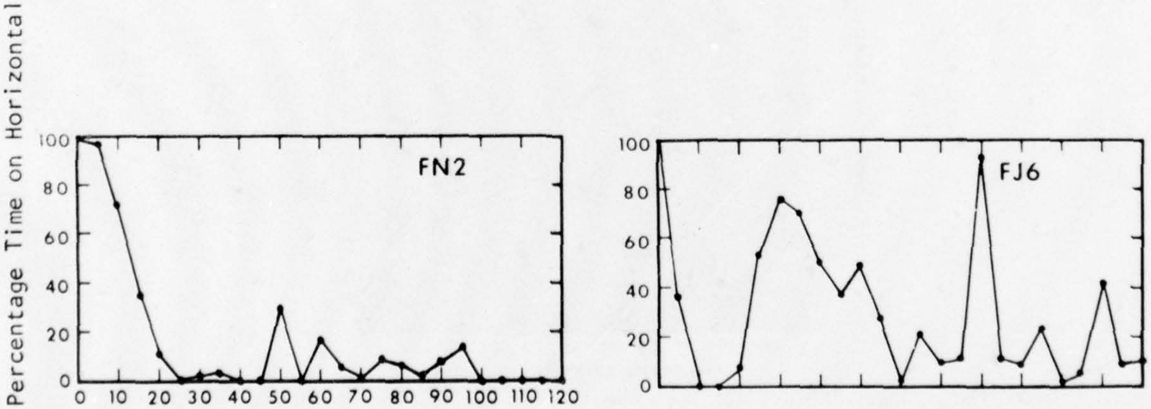

Figure 13. Individual Performance Curves (Percent Time on Horizontal Vs. Time Postirradiation) for Animals Operating the PEP Receiving a Whole-Body 2700 Rad (n/g - 0.5:1) Dose. (AFRRI) (SR72-14).

5. PERFORMANCE RESPONSE OF MAN TO NUCLEAR RADIATION

In the virtual absence of data on man's performance response to nuclear radiation, the test data on irradiated monkeys are perhaps the best available indicator. It would appear that, like the monkey, there would be an initial performance decrement for man after absorbing a dose of nuclear radiation. For doses less than those causing permanent incapacitation, the initial response would be followed by the latent phase, or a period of remission during which performance would improve, relative to the initial degraded level. Following this, and depending on the dose received, there would be either a continued recovery and performance improvement, or a terminal phase in which performance again degrades, followed by death.

For some lower range of doses, the duration and level of the initial performance decrement and performance during remission would be such that a combatant would not be declared a casualty, but would remain in action. This would depend not only on the absorbed dose, but also on other injuries suffered (e.g., from thermal radiation, blast effects, or conventional munitions) and the severity of the combat situation.

The validity of an extrapolation from the results of monkey tests to the performance of such a person in combat would appear to rest, in part, on the similarity of task complexity. The monkey's tasks in the laboratory were relatively simple. Combat tasks can be broken down into simple elements, however. Appendix D presents a task breakout for M60A1E3 crew members, based on a study made for the M551 tank. One task for the gunner, "Firing in Power Mode", is analyzed below to explore the feasibility of extrapolation from monkey to man.

Assuming that the gunner has detected, identified, and acquired the target, this task requires the gunner to track the target (assume a moving target), placing the cross hairs of the sight on the desired impact point on the target, and to fire the gun when he feels he has established the correct tracking rate and aim point. Though none of the monkey's tasks were like this one, assume that the task of keeping the Primate Equilibrium Platform (PEP) level is sufficiently close to be equivalent.

If a gunner's preirradiation performance of the firing task were known, one could then hypothesize that, since the monkey's performance on the PEP at time T after absorbing a dose of R rads was 0.5, the gunner's performance under the same conditions would be 0.5. But how is the gunner's performance measured? For this task it could be some function of the means and standard deviations of aim and tracking rate errors in azimuth and elevation in a short time interval before firing. A performance of 0.5 could mean that the standard deviations are increased by a factor of two, with a corresponding change in the value of the function.

Some of the assumptions that are implicit in the hypothetical process described above include:

(1) The task of keeping the PEP level is as difficult for the irradiated monkey to perform as the task of "firing in the power mode" is for the irradiated tank gunner.

(2) Man and monkey are similarly affected by radiation despite interspecies, weight, and size differences.

(3) Man in combat is motivated to the same (unknown) degree as the monkey in the laboratory, even though environments, recent experience, knowledge of radiation effects, and knowledge of the consequences of action are different.

(4) Firing is either the only task the gunner has to do, or else his firing performance is unaffected by other tasks that he has performed or expects to perform.

(5) Aside from radiation effects, physical conditions of man and monkey are either similar, e.g., recent nourishment, sleep, fatigue and injuries, or else differences have no effect on task performance.

(6) Interactions with other combatants (e.g., the gunner's tank commander, who issues commands to him) have no effect on performance. Recall that the monkey was isolated, and did not work cooperatively with others.

(7) The unchanging environment of the monkey is equivalent, in terms of effect on performance, to the constantly changing environment of the man in combat.

This is not a trivial group of assumptions. Without some empirical data to support the assertion of equivalence in monkey-man performance, one is left only with a qualitative sense of similarity.

Quantification of performance is not necessarily straightforward for the tasks listed in Appendix D. For example, the Tank Commanders task 10.0, "Communications (Command and Control)", would not be easy to quantify, and there is no apparent corresponding task in the radiation experiments with monkeys. Given that the tasks that principally drive the outcome of a simulated engagement could be defined and "performance" established for each, however, their multiplicity and the necessity for treatment at individual combatant level produces an intractable modeling problem. Unfortunately, the radiation experiments with monkeys appear not to have produced data that could reasonably form the basis for estimates of group or aggregative performance of irradiated combatants.

6. SYNTHETIC HUMAN NUCLEAR EXPERIENCE

The data from experiments with irradiated monkeys have only a limited usefulness in predicting man's performance response to nuclear radiation. Of the data collected on the effect of whole body irradiation on man (combat, therapeutic, and accidental), practically none relates to man's ability to perform tasks, postirradiation. Reference 9 contains some information on postirradiation susceptability to easy fatiguability. It also contains data on certain physiological responses during exercise of a healthy, nonirradiated male volunteer who underwent pharmacologically-incuced gastrointestinal distress (ipecac was administered). These responses were similar to those of irradiated patients during exercise.

This suggests a different approach to the problem of finding the impact of performance degradation on combat operations; namely, to observe the operations of performance-degraded personnel in troop training exercises, and their impact on force capabilities. The virtue of this approach is that nothing is left out; all tasks and combatant interactions relevant to the "tactical situation" of the training exercise actually occur.

Two methods of performance degradation could be used. In the first, the physical condition of the trainees is not affected, and performance degradation is simulated either by using low-achieving trainees, or by modifying equipment or procedures so that tasks are more difficult to perform. Performance is a controlled variable in this case, and the effects of performance level on simulated combat operations are observed.

In the second method, the trainee is made to experience some symptoms similar to those that would result from irradiation, and the resulting impact on his performance is observed, together with its effect on simulated combat operations. *In this second method, it is possible* to correlate specific exposures to nuclear radiation with impact on combat operations, since the symptomatology of human response to nuclear radiation is relatively well known. This cannot be done in the first method since the relationship between dose and performance is unknown for man.

The production of a radiation-like syndrome for a lower range of radiation doses could be safely and reversibly accomplished by the use of emetics and cathartics. These would produce vomiting, stomach cramps and diarrhea. Fatigue could be induced by a combination of diet, exercise, sleep deprivation, and temporary blood level reduction (i.e., some of a subject's blood is removed and later returned). More realism would be achieved if patients undergoing whole-body radiation treatment could be used as trainees. The level of radiation used in treatments is relatively low, however, and performance degradation may be slight. Patients undergoing chemotherapy also exhibit symptoms similar to those produced by irradiation. The drugs used (e.g., cytoxin, vincristine, actinomycin) attack high turn-over rate cells and produce blood cell depression and some gastrointestinal tract denudation.

7. CONCLUSIONS

All of the modeling approaches require data on the performance response of man to nuclear radiation. Such data do not exist. Data from radiation experiments on monkeys appear to be applicable only in the most elemental instances. Even then there are such significant differences between man and monkey, and between laboratory and combat environments, that an extrapolation from monkey to man would have serious uncertainties. Approaches to bypassing the data gap, such as parametric analyses or the use of players to specify human response, are arbitrary and produce no new information about the impact of TNE.

The approach of synthesizing human nuclear experience in training exercises via performance-degraded trainees would do much to close the data gap. This approach may be controversial, however, depending on the manner in which performance degradation is achieved. A significant shortcoming of this approach would be the failure to achieve motivation in trainees of the level that might be seen in combat.

Of the two approaches, the latter appears to have the greatest potential for producing useful results.

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APPENDIX A

TETAM

I. GENERAL

From 1971 to 1973 the Combat Developments Experimentation Command conducted a series of field trials to evaluate antitank missile systems. This series of trials was designated Experiment 11.8, Tactical Effectiveness Testing of Antitank Missiles (TETAM). The field trials were designed to:

(1) Contribute to the assessment of the effectiveness of U. S. TOW, SHILLELAGH, and DRAGON, the British SWINGFIRE, and the German/French MILAN Anti-Tank Missile (ATM) systems under simulated combat conditions.

(2) Provide data for use as input to and verification of certain U. S. Army high resolution predictive combat models.

The field trials were conducted in four distinctive phases: IE, I, II, and III. Each phase investigated a particular aspect of ATM system effectiveness.

The primary objective of Phase III was to obtain performance data on defensively-employed ATM systems and attacking armor elements when engaging each other in simulated combat.

Phase III consisted of two-sided, real-time casualty assessed field trials. Trials were run over varying terrain with varying threat and defensive tactics, and some trials were run under artificial illumination conditions. Data was collected on all significant events (e.g., each missile firing and its subsequent effect on a target). Positional data on each player element was also collected throughout the duration of each trial.

The defensive force was deployed in a deliberate defense while the threat force attacked using either a Rapid Approach* (RA) or Fire and

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* Rapid Approach is the tactic which permits an attacking force to close on its objective in the shortest possible time, relying on speed to minimize casualties.

Movement* (FM) tactic. The positions of defensive Anti-Tank Missile Systems (ATMS) were selected to provide adequate coverage of the defensive front. The platoon leader was given latitude for position selection for each trial. The threat force route of advance was selected by the threat force commander, constrained only by the boundaries of the experimentation site and influenced by the approach tactic. The maximum threat force was nine simulated T-62 tanks, three BTR-40P with SAGGER ATGMs (Anti-Tank Guided Missile) and three unarmed BMP (Infantry Combat Vehicles). The maximum defensive force was two TOWs, two DRAGONs, and one SHILLELAGH ATM system.

2. CONDUCT OF TRIALS

The threat force's objective was to seize and destroy the defensive force by fire and reach the Trial Termination Line (TTL)**. The defensive force's objective was to destroy the threat force forward of the TTL. Prior to the commencement of each trial, the defensive systems were emplaced within the defensive area. Simultaneously, the threat force was assembled approximately 5 kilometers downrange out of sight of the defensive area. Both the defensive platoon leader and threat company commander were briefed on the tactical situation and were allowed free play in planning their defense or attack.

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* Fire and Movement tactic is a technique employed by and within a maneuvering force, wherein one element of the maneuvering force covers by fire the advance of the remainder of the force; the firing and movement phases are alternated as required.

** Threat vehicles were halted and administratively removed from play when they reached the Trial Termination Line. This line was established approximately 200 meters forward of the ATM positions and designed to keep the threat force from actually overrunning the defensive positions, possibly causing damage to vehicles or instrumentation or injuring personnel. The full effect of close combat and armor shock action were therefore not played during the trials.

A trial consisted of the free play between the two forces, as each attempted to destroy the other's force by simulated fire. A computerized casualty assessment model was used in near real-time to decide the result of each simulated fire (mobility kill, firepower kill, total kill, miss). Referees called these results to the players, who then simulated a corresponding action. The design of the experiment required that the battle be forced in order to obtain engagement data over the entire range of the battlefield. The threat force was therefore denied the options of calling in artillery support, or obtaining assistance from second echelon forces, and was compelled to continue the attack. If all of one force received total kills and/or depleted their ammunition stock, the trial was terminated. If this event did not occur, the trial was terminated when all surviving threat vehicles reached the TTL.

3. TETAM LAND COMBAT MODEL

The TETAM Land Combat model is a simple empirical model based on the results of the analysis of Phase III trials. It was designed to post-play the Phase III trials for the purpose of conducting a sensitivity analysis of the effect of changes in the missile performance parameters of flight times, reload times, hit probabilities, and kill probabilities.

The model can be divided into four logical components: trial preparation, offense, defense, and utility programs.

3.1 Trial Preparation

The following TETAM input parameters can be varied: offensive tactic; number of tanks, ATGMs, TOWs, SHILLELAGHs, SWINGFIREs, and DRAGONs - nominal mix is 9-3-2-1-0-2; basic missile loads; defensive and offensive P_k and P_E; tank speed; and reload time.

Tank and ATGM paths are selected randomly from those that were used in Phase III trials, weighted by their frequency of use during field trials. Likewise, the ATM sites are chosen randomly from those used in the field trials, weighted by their frequency of use during trials.

Intervisibility descriptions for each path-ATM pair, based on line-of-sight measurements of the actual terrain are used.

3.2 Offense

A time step of 10 seconds was chosen. If, at the beginning of each 10 second interval, the tanks and ATGMs are alive and have not experienced mobility kills, they are allowed to move forward at the average speed appropriate for the offensive tactic being played. ATGMs move at tank speeds for the first 5 minutes of the trial, then slow to a speed such that their average trial speed is equal to that observed during Phase III field trials.

Then for each of the tanks, a random number is compared to the probability that a tank will have an engagement at its range from the defensive positions in a 10-second period. If the random number selected is less than this probability, the tank may have an engagement. The target is selected from the intervisible ATMs, weighted proportional to the length of time they have been intervisible. If an ATM has recently fired, it is twice as likely to be engaged. Because the tank engagement rate is so low, the selection of targets for tanks is not crucial to the results of the trial. The result of this engagement is then decided by essentially the same casualty assessment routine as was used during the Phase III trials.

Following the determination of engagements by tanks, fire engagements by ATGMs are determined. ATGMs fire if a minimum time since its last engagement (normally 20 seconds for flight time and reloading) is exceeded and if a randomly selected number is less than the number of intervisible ATMs times the ATGM engagement rate per 10 seconds. If the ATGM fires, it fires at the last target engaged, if that target is still alive. This reflects the behavior of the ATGMs during the field experiments. If a new target is to be selected, the target is selected as it was with tanks. ATGMs are not allowed to fire after their basic load has been exhausted. Out-of-range aborts can occur.

The above procedure is performed in sequential order on the offensive vehicles. After all of them have been considered, each of the defensive systems is examined according to the following rules.

3.3 Defense

3.3.1 DRAGONS

If the reload and flight time for the last engagement is exceeded, and the live DRAGON has not exhausted its basic load, a random number is compared to the probability that a DRAGON fires at intervisible targets within range in a 10-second period. If the random number is less than this probability, it is ascertained whether a target is within 1100 meters. The additional 100 meters permits the appropriate number of out-of-range aborts as observed in the Phase III field experiment to occur. The first offensive vehicle satisfying these conditions is engaged. After casualty assessment, whether the DRAGON survives to fire again is determined by selecting a random number and comparing it to the probability (as observed in the field trials) that the DRAGON survives for the offensive tactic being played. If the DRAGON is to die, the nearest intervisible offensive vehicle is credited with the kill, since who actually does kill it is not a significant trial performance indicator.

3.3.2 TOWs

If a TOW is alive, has exceeded its flight and reload times since its last engagement, has not exhausted its basic load, and a random number selected is less than the probability of a TOW engaging a target in a 10-second period, a target is selected. The combined TOW and SHILLELAGH preference for tanks over ATGMs was not considered large enough to significantly affect the trial outcomes, so all intervisible targets are given equal weights. These weights are increased if the offensive vehicle has just become intervisible or if it was the last target at which the TOW fired. A random number is then used to select the target, and casualty assessment occurs.

3.3.3 SHILLELAGHs and SWINGFIREs

They behave like the TOW, with appropriately different values of the input parameters. Flight and reload times are shorter, but the probability of engaging during a 10-second period is the same as the TOW.

3.4 Utility Programs

The threat vehicles are moved on straight line segments approximating the paths used in the Phase III trials.

The result of a casualty assessment is held until the average flight time of the missile has expired. If intervisibility still holds between the firer and target, the actual casualty assessment is made (total kill, firepower kill, mobility kill); otherwise it is recorded as a loss-of-acquisition abort.

Intervisibility is updated in the following fashion:

(1) If a threat vehicle is intervisible with an ATM, its cumulative intervisibility* is incremented every 10 seconds.

(2) If a vehicle is partially obscured by vegetation, its cumulative intervisibility is incremented 50 percent of the time depending upon the selection of a random number.

(3) If a vehicle is not intervisible, its cumulative intervisibility is set equal to zero.

(4) If a vehicle has died, its cumulative intervisibility decays to zero over about a minute.

The results of each engagement are recorded, including firer type, target number, range, results of the engagement, and trial time at time of missile impact. Possible engagement results are total kill, firepower kill, mobility kill, out-of-range abort, loss of acquisition abort, previous kill, and survive.

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* Length of time that intervisibility has been in effect.

4. RESULTS

Sensitivities of measures of battle outcome to changes in values of TETAM land combat model inputs are based on the analysis of 6620 simulated trials. Table 4 describes the four general types of trials run, the offensive and defensive parameters varied, and the sample size. For each set of trials, values of input parameters were degraded in ten equal steps to approximately one percent of their initial values. Twenty trials were run at each level of degradation. Baseline trials (i.e., those with no degradation in the values of the input parameters) were run for each of the four sets. In the first, second, and fourth set of trials, the capabilities of the offense and defense were based on the results of TETAM Field Trials conducted at Fort Hunter Liggett. The term "normal trials" will refer to these trials, as values of offensive and defensive parameters were derived from the actual field data. In these trials the defense was very strong and virtually destroyed the offense, with only 23 percent of the threat force reaching TTL for the FM tactic. In the third set of trials, in order to more evenly balance the forces, the offense was strengthened 80 percent and the defense was weakened 28 percent. These trials will be referred to as "adjusted trials." Under these conditions more than half of the threat force reached the TTL.

The offensive parameters varied in the first set of normal trials were tank speed (TS), kill probability (P_k), engagement probability (P_E), and tank gun reload time. Battle outcome showed little sensitivity to changes in any of the offensive parameters. This can be attributed to the low initial value for offensive P_E and the high initial value for defensive P_E and defensive P_k. The low tank engagement probability resulted in very few tank engagements (.5 engagements per tank per trial, FM), a very low percentage of the offense reaching TTL, and very few casualties being sustained by the defense. Only 23 percent of the offense reached TTL in these trials. Since the offense was already virtually destroyed in the baseline trials, any further decrease in offensive P_E and/or offensive P_k had little impact on trial outcome.

TABLE 4. TRIAL DESCRIPTION, PARAMETERS VARIED, AND SAMPLE SIZE FOR TETAM LAND COMBAT MODEL SENSITIVITY ANALYSIS

Trial Description	Parameters Varied	Sample Size
Offense Normal Defense Normal Offensive Parameters Varied Defensive Parameters Fixed	Tank Speed Offensive Kill probability Offensive Engagement Probability Tank Reload Time	1540* 80 Baseline
Offense Normal Defense Normal Offensive Parameters Fixed Defensive Parameters Varied	Defensive Engagement Probability Defensive Kill probability	600 20 Baseline
Offense Strengthened (80%) Defense Weakened (28%) Offensive Parameters Varied Defensive Parameters Fixed	Tank Speed Offensive Engagement Probability Offensive Kill Probability	880 70 Baseline
Offensive Force Varied Defense Normal Offensive Parameters Fixed Defensive Parameters Fixed	Number of Tanks Number of ATGMs	80 40 Baseline

*This is the sample size for each tactic FM or RA.

In order to find sensitivities of combat outcome to variations in values of offensive parameters, the defense was weakened in the second set of trials so that more of the offense would survive and reach TTL. In this set of trials the values of the defensive parameters of engagement probability and kill probability were degraded. Table 5 presents a partial summary of these trials for two measures of battle outcome - percent of offense reaching TTL (% OFF) and the ratio of kills inflicted/sustained by the defense (I/S)* (see ANNEX for complete results). Since the threat is detection limited, the percentage of the threat force able to reach the TTL is a more relevant measure of balanced forces than the I/S ratio. Table 5 indicates that the offensive and defensive capabilities are more balanced when the defense is weakened by approximately 40 percent**. At this level of degradation about half of the threat force reaches TTL. In this set of trials sensitivities of measures of battle outcome to degradation in values of defensive P_k and P_E appear. Measures of battle outcome were found to be only slightly more sensitive to changes in defensive P_k than to changes in defensive P_E.

In the first two sets of trials, the threat force was much weaker than the defense. Most of the offense was killed and most of the ATMs survived. This is not unexpected, and it is verified by the field data. However, the sensitivities of battle outcome to changes in the offensive parameters of P_E, P_k, and TS are masked to some degree by the unequal capabilities of the offense and defense. In the second set of trials sensitivities begin to appear as the defense is weakened.

In the third set of trials the offensive and defensive capabilities were more evenly balanced. The offense was strengthened by increasing the tank engagement rate by 80 percent. The defense was weakened by reducing the ATMs engagement rate and P_k by 28 percent. For the FM tactic

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* Defensive casualty exchange ratio I/S is the number of casualties inflicted by defense divided by number of casualties sustained by defense.

**i.e., 40 percent reduction in the values of defensive P_k and P_E.

TABLE 5. SENSITIVITY OF INDICATED MEASURES OF COMBAT OUTCOME TO COMBINED DEGRADATION OF THE DEFENSIVE ENGAGEMENT PROBABILITY AND KILL PROBABILITY (NORMAL TRIALS)

Percent Degradation in Defensive P_E and P_k	Measure			
	Percent of Offense Reaching TTL		Defensive Casualty Exchange ratio (I/S)	
	FM	RA	FM	RA
0	23	21	4.21	12.13
10	30	31	3.46	6.18
20	37	34	3.39	6.14
30	54	41	1.56	5.85
40	59	53	1.40	3.61
50	65	54	1.55	4.11
60	72	62	1.16	2.14
70	82	73	0.63	3.00
80	87	79	0.33	1.00
90	91	84	0.02	0.18
99	94	85	0.00	0.00

this resulted in 57 percent of the offense reaching TTL and 64 percent of the defense being killed (see Table 6). Table 7 displays baseline values for several measures of battle outcome for these adjusted trials.

In this set of trials, values of three offensive parameters were varied. They were engagement probability, probability of kill, and tank speed. The values of these parameters were degraded individually and together in ten equal steps to approximately one percent of their initial values except for tank speed, which was degraded to approximately 30 percent of its initial value. Twenty trials were run at each level of degradation. The sensitivity of measures of battle outcome to changes in values of the offensive input parameters PE, Pk, and TS were approximated by fitting a straight line to the data points (see Appendix) using the technique of linear regression. Measures of battle outcome considered include:

(1) Number of tanks coming within 200 meters of defense;

(2) Number of ATMs alive when trial ends;

(3) Number of tanks killed;

(4) Percent of offensive vehicles coming within 200 meters of defense;

(5) Defensive casualty exchange ratio.

Figures 14 through 29 graphically display the straight line fit for the number of tanks alive and the number of ATMs alive when the center of mass of the tanks is 2000 meters, 1000 meters, and 200 meters from the defense for each of the offensive input parameters varied and for both the FM and RA tactics. Table 8 and 9 show relative sensitivities of five measures of combat outcome to changes in the values of the indicated offensive input parameters for the FM and RA tactics, respectively. The table entries are not absolute values, but are proporational to the slope of the underlying regression line (the actual intercepts and slopes of all

TABLE 6. COMPARISON OF MEASURES OF BATTLE OUTCOME FOR NORMAL VS. ADJUSTED TRIALS

Trial Type	Measure of Combat Outcome			
	Percent of Offense Reaching TTL		Percent of Defense Killed	
	FM	RA	FM	RA
Normal Offense Normal Defense	23	21	38	12
Offense Strengthened (80%) Defense Suppressed (28%)	57	38	64	20

TABLE 7. BASELINE VALUES OF MEASURES OF COMBAT OUTCOME (ADJUSTED TRIALS)

Tactic	Measure						
	No. of Tanks Reaching 200M From Defense	Number of ATMs Alive at Trial Termination	% of TOWS killed	% of Offensive Vehicles Reaching 200M From Defense	Defensive Exchange Ratio	Rounds Fired Per Tank	Trial Time (Sec)
FM	5.30	1.80	68.5	56.5	1.28	1.02	1130
RA	4.04	4.00	25.7	38.2	5.07	0.24	830

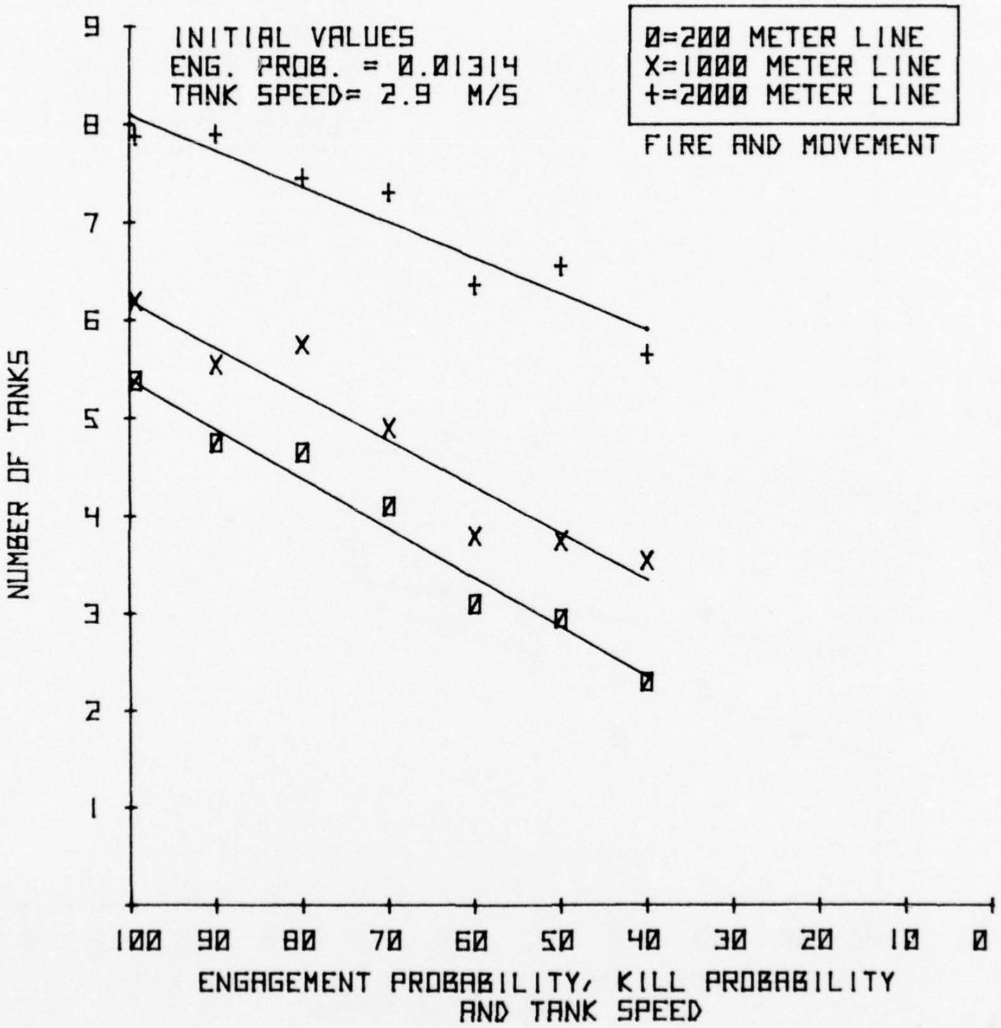

FIGURE 14. NUMBER OF TANKS ALIVE AT INDICATED RANGE FROM DEFENSIVE POSITION VS PERCENT DECREASE IN ENGAGEMENT PROBABILITY, KILL PROBABILITY AND TANK SPEED

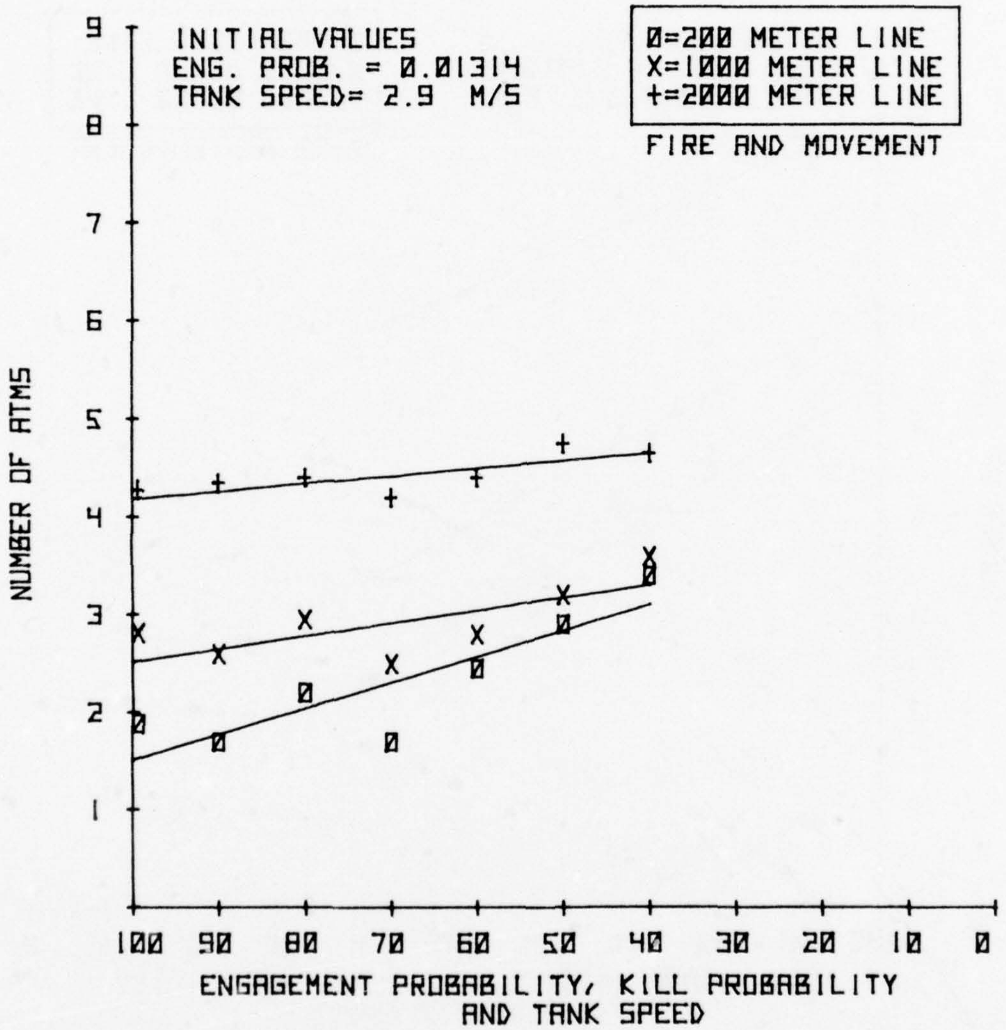

FIGURE 15. NUMBER OF ATMS ALIVE WHEN TANKS REACH INDICATED RANGE FROM DEFENSIVE POSITION VS PERCENT DECREASE IN ENGAGEMENT PROBABILITY, KILL PROBABILITY AND TANK SPEED

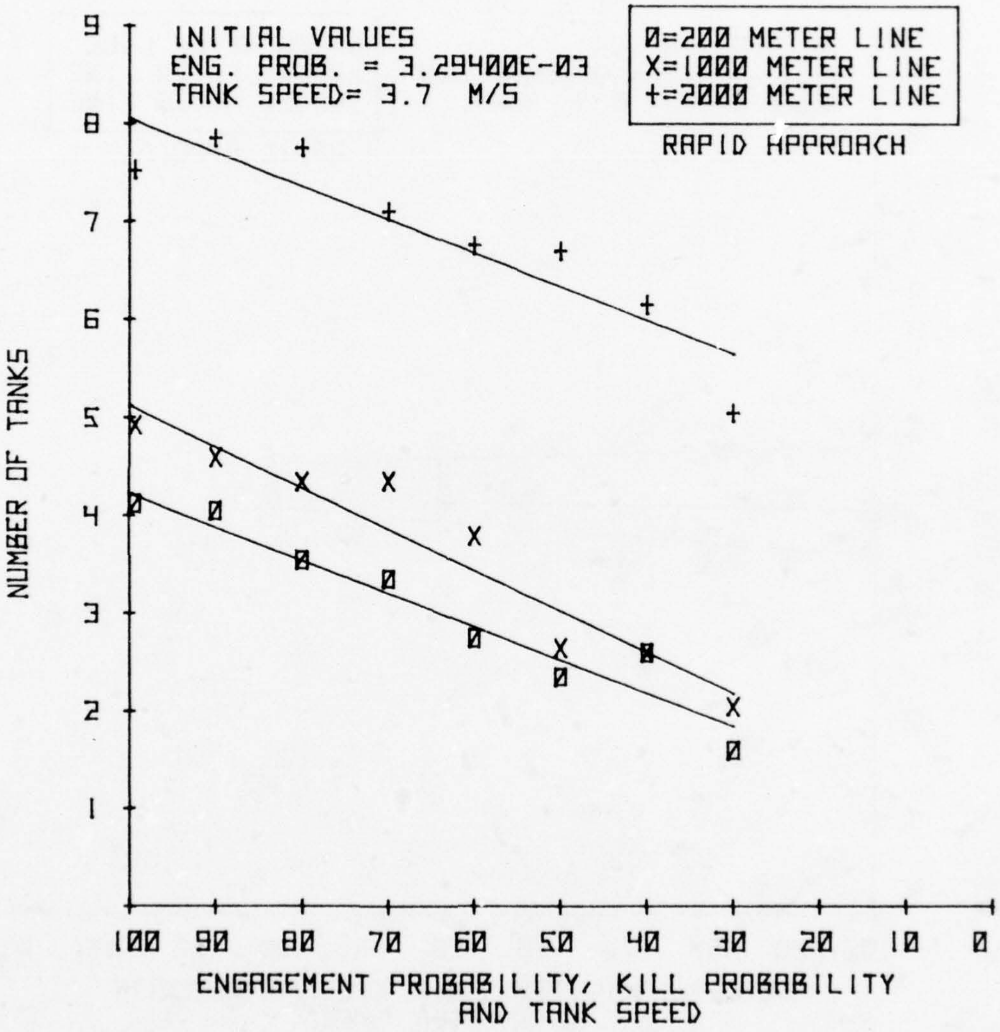

FIGURE 16. NUMBER OF TANKS ALIVE AT INDICATED RANGE FROM DEFENSIVE POSITION VS PERCENT DECREASE IN ENGAGEMENT PROBABILITY, KILL PROBABILITY AND TANK SPEED

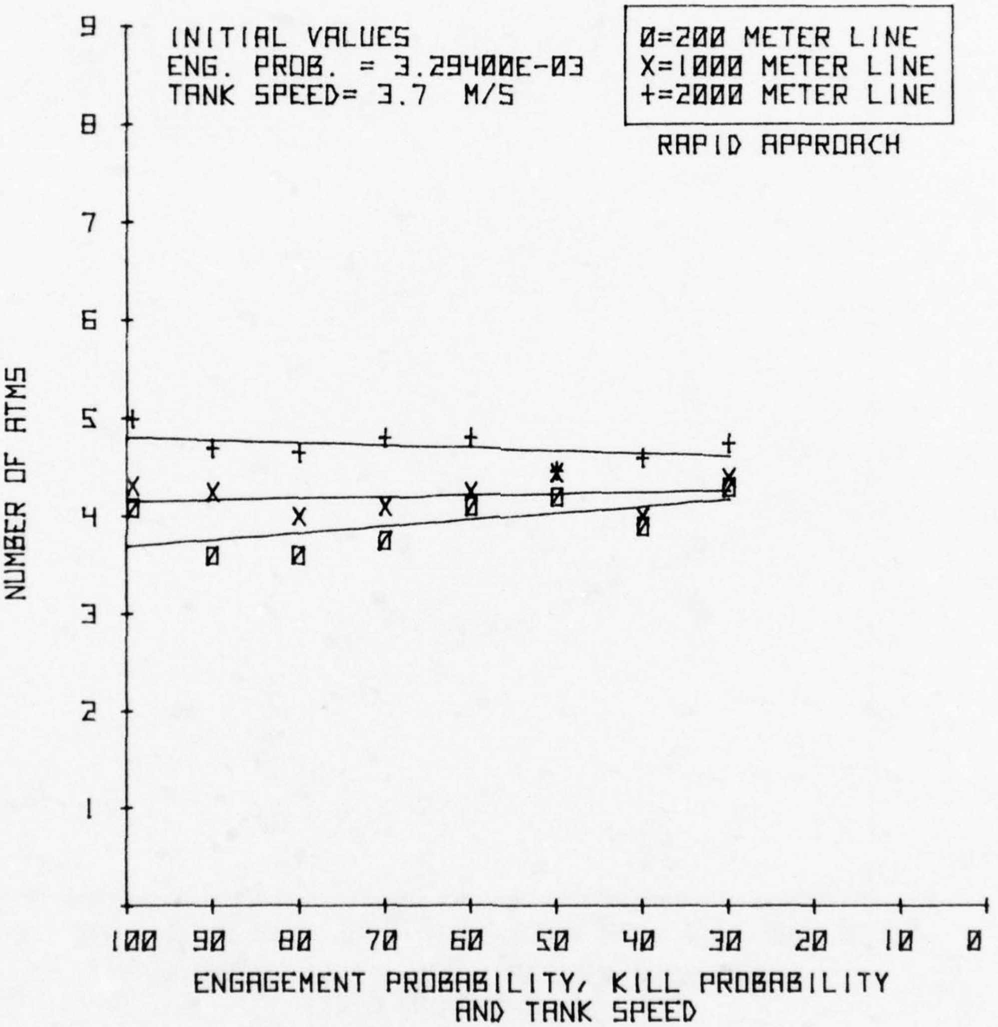

FIGURE 17. NUMBER OF ATMS ALIVE WHEN TANKS REACH INDICATED RANGE FROM DEFENSIVE POSITION VS PERCENT DECREASE IN ENGAGEMENT PROBABILITY, KILL PROBABILITY AND TANK SPEED

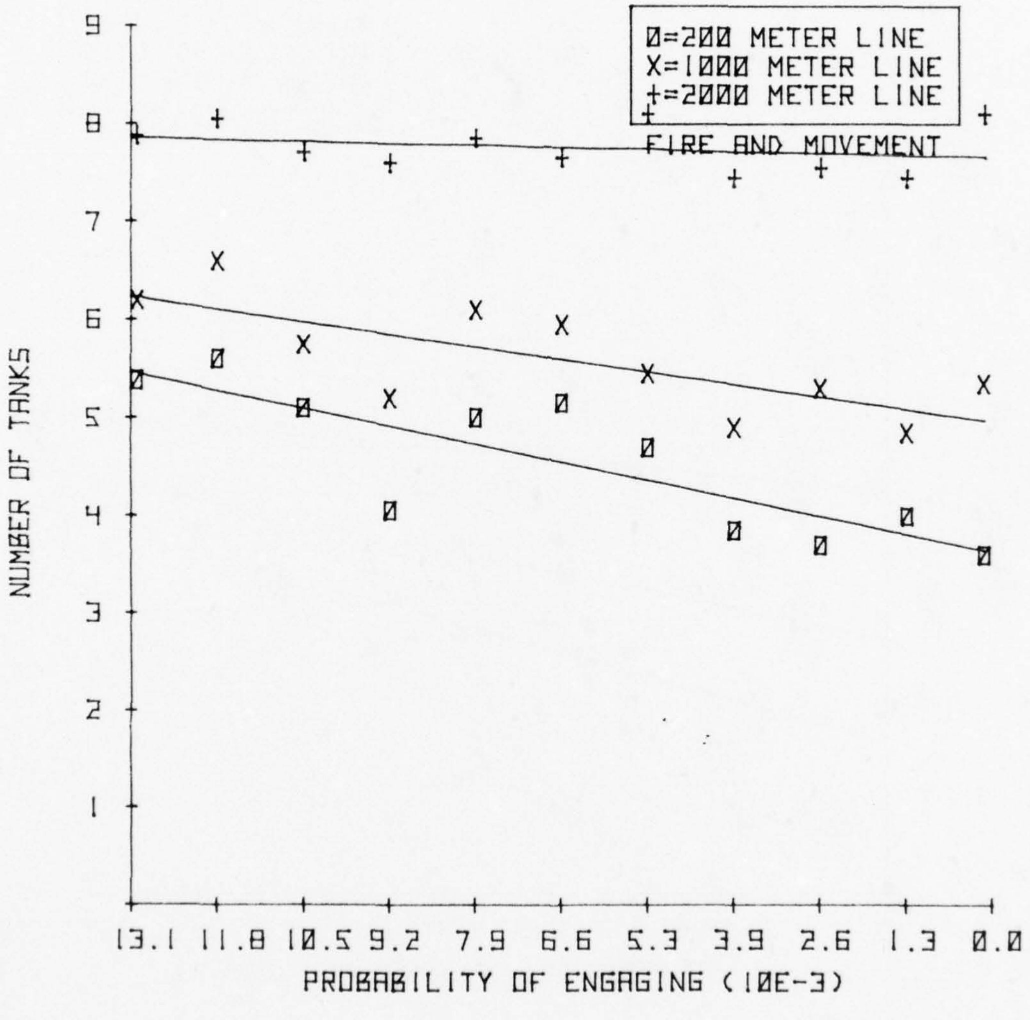

FIGURE 18. NUMBER OF TANKS ALIVE AT INDICATED RANGE FROM DEFENSIVE POSITION VS PROBABILITY OF ENGAGING IN 10 SECONDS

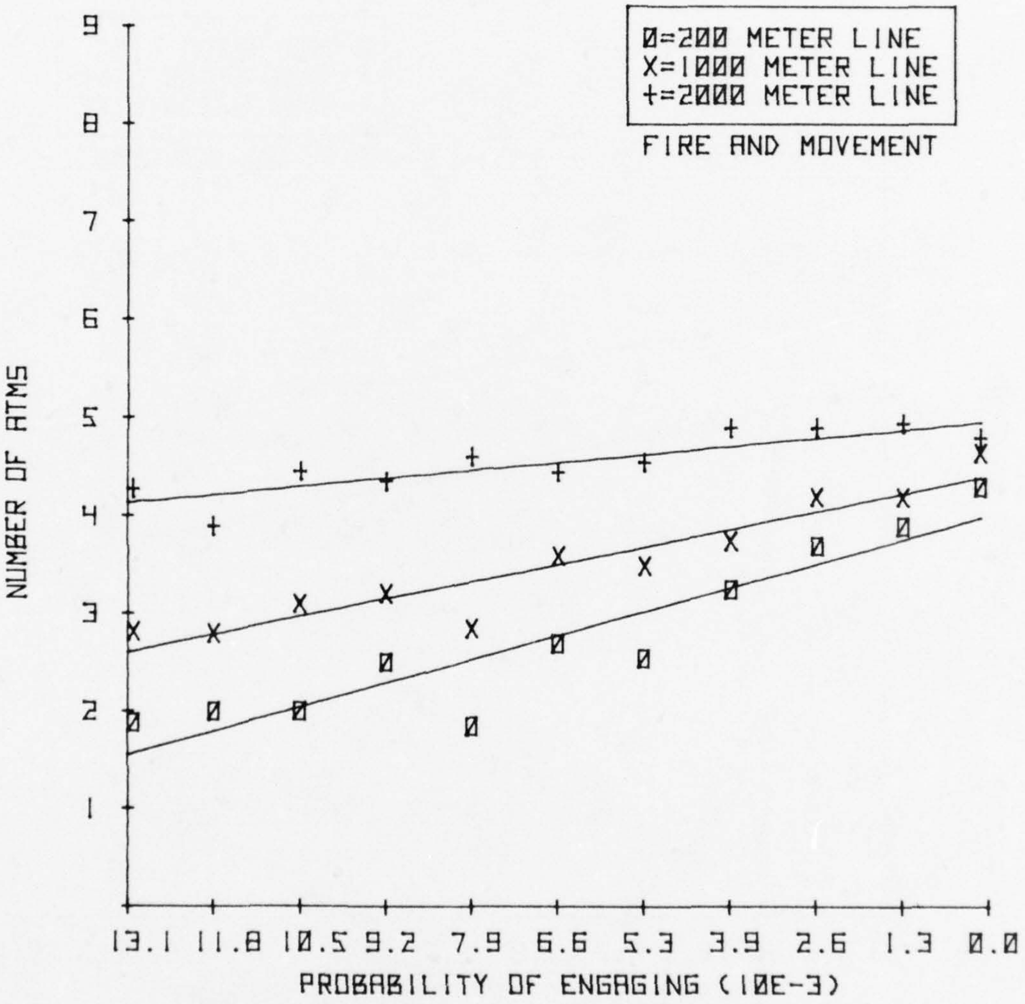

FIGURE 19. NUMBER OF ATMS ALIVE WHEN TANKS REACH INDICATED RANGE FROM DEFENSIVE POSITION VS PROBABILITY OF ENGAGING IN 10 SECONDS

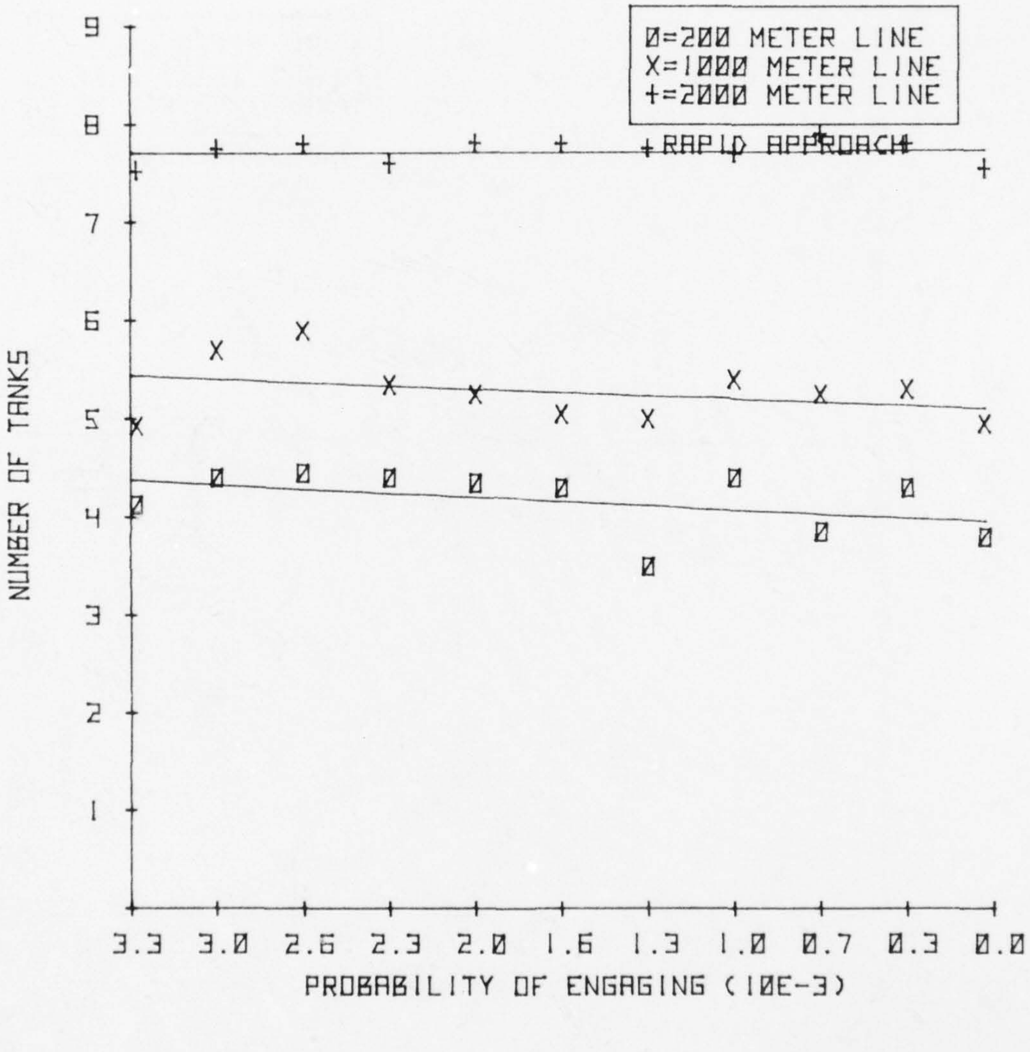

FIGURE 20. NUMBER OF TANKS ALIVE AT INDICATED RANGE FROM DEFENSIVE POSITION VS PROBABILITY OF ENGAGING IN 10 SECONDS

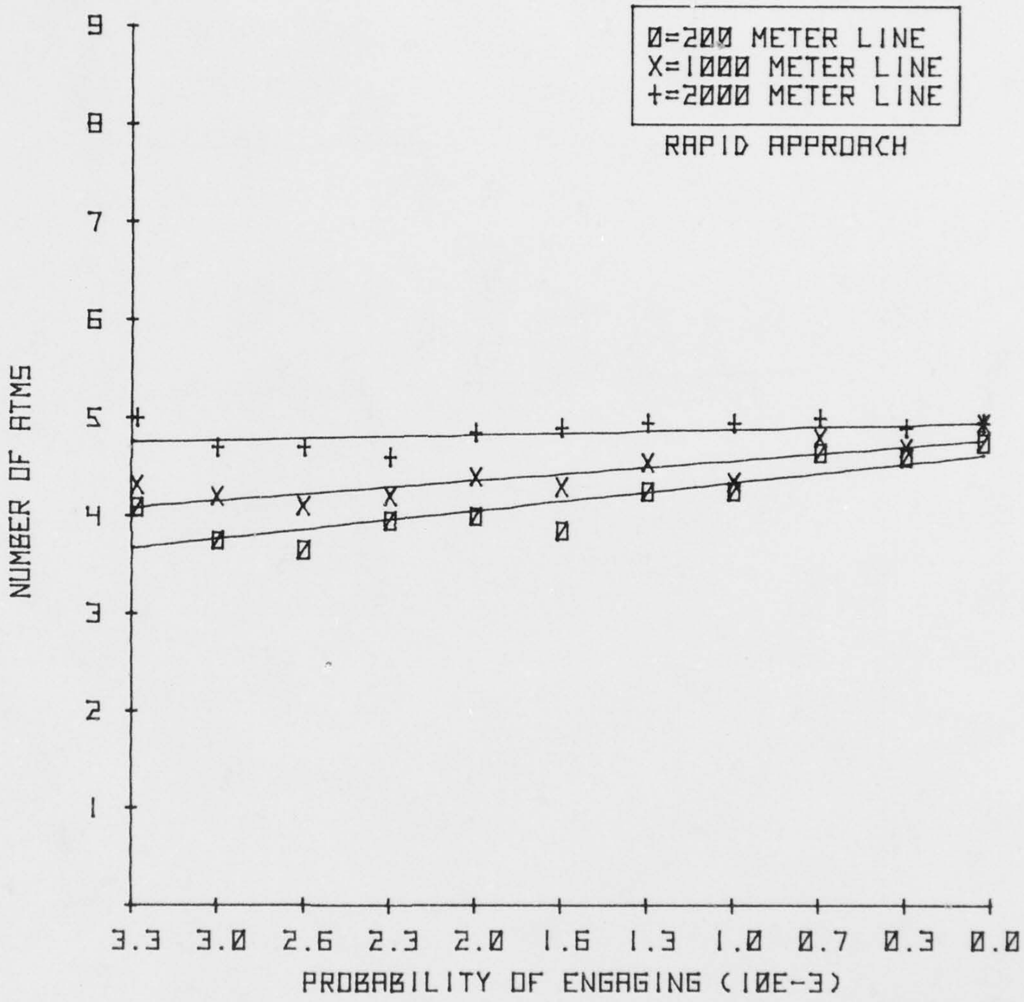

FIGURE 21. NUMBER OF ATMS ALIVE WHEN TANKS REACH INDICATED RANGE FROM DEFENSIVE POSITION VS PROBABILITY OF ENGAGING IN 10 SECONDS

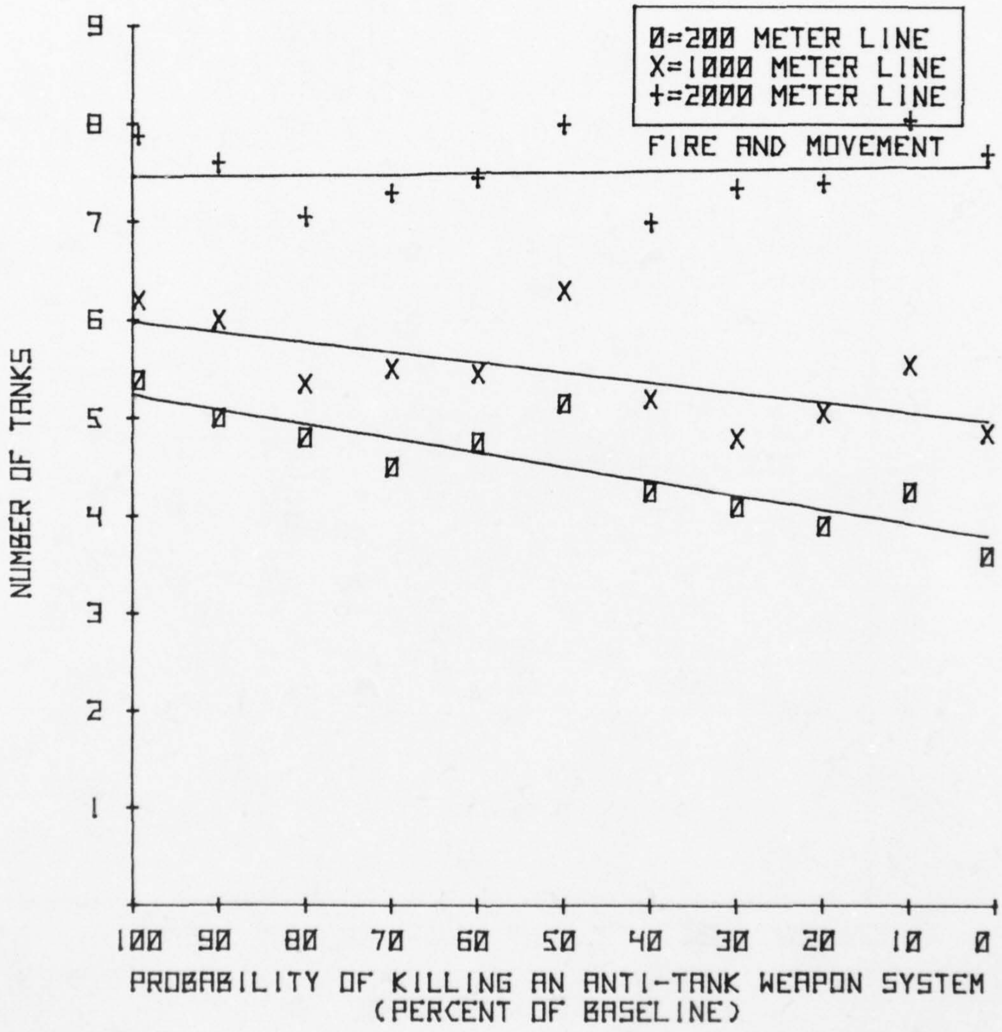

FIGURE 22. NUMBER OF TANKS ALIVE AT INDICATED RANGE FROM DEFENSIVE POSITION VS PROBABILITY OF KILLING AN ANTI-TANK WEAPON SYSTEM

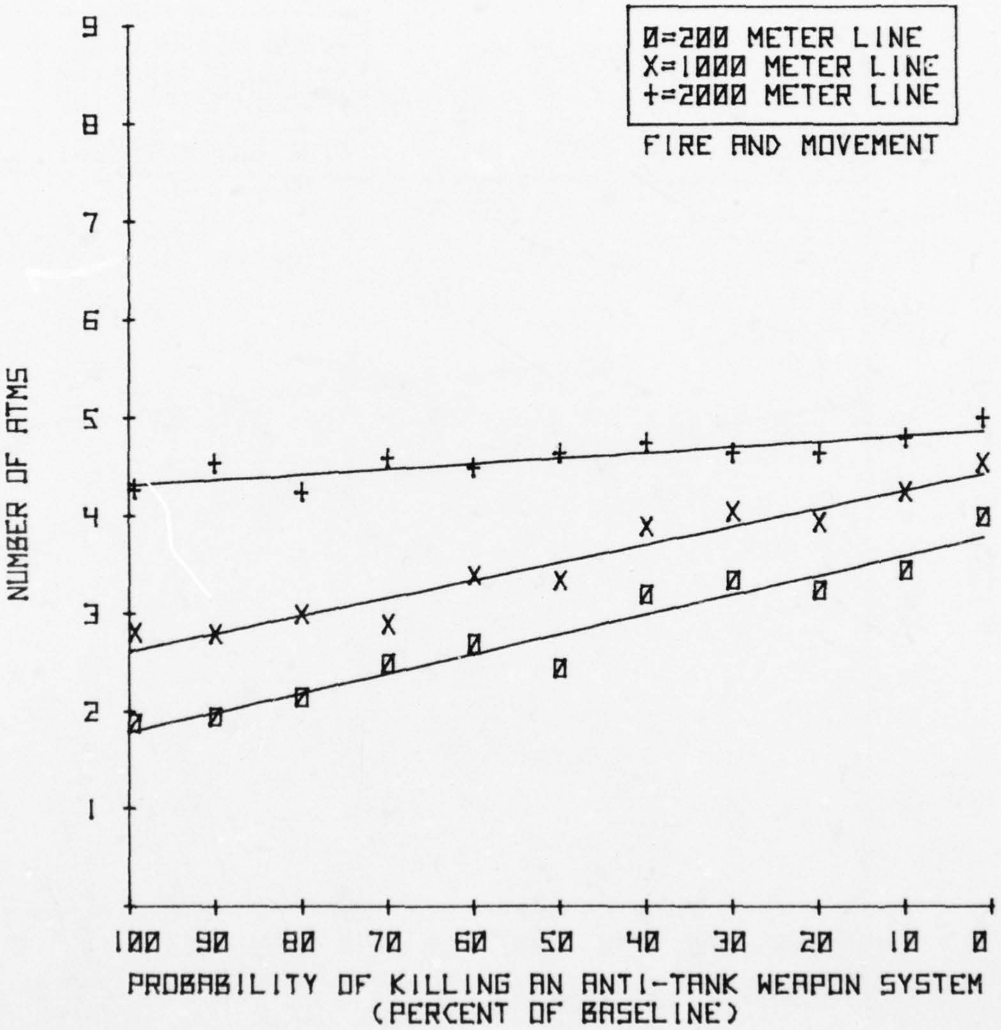

FIGURE 23. NUMBER OF ATMS ALIVE WHEN TANKS REACH INDICATED RANGE FROM DEFENSIVE POSITION VS PROBABILITY OF KILLING AN ANTI-TANK WEAPON SYSTEM

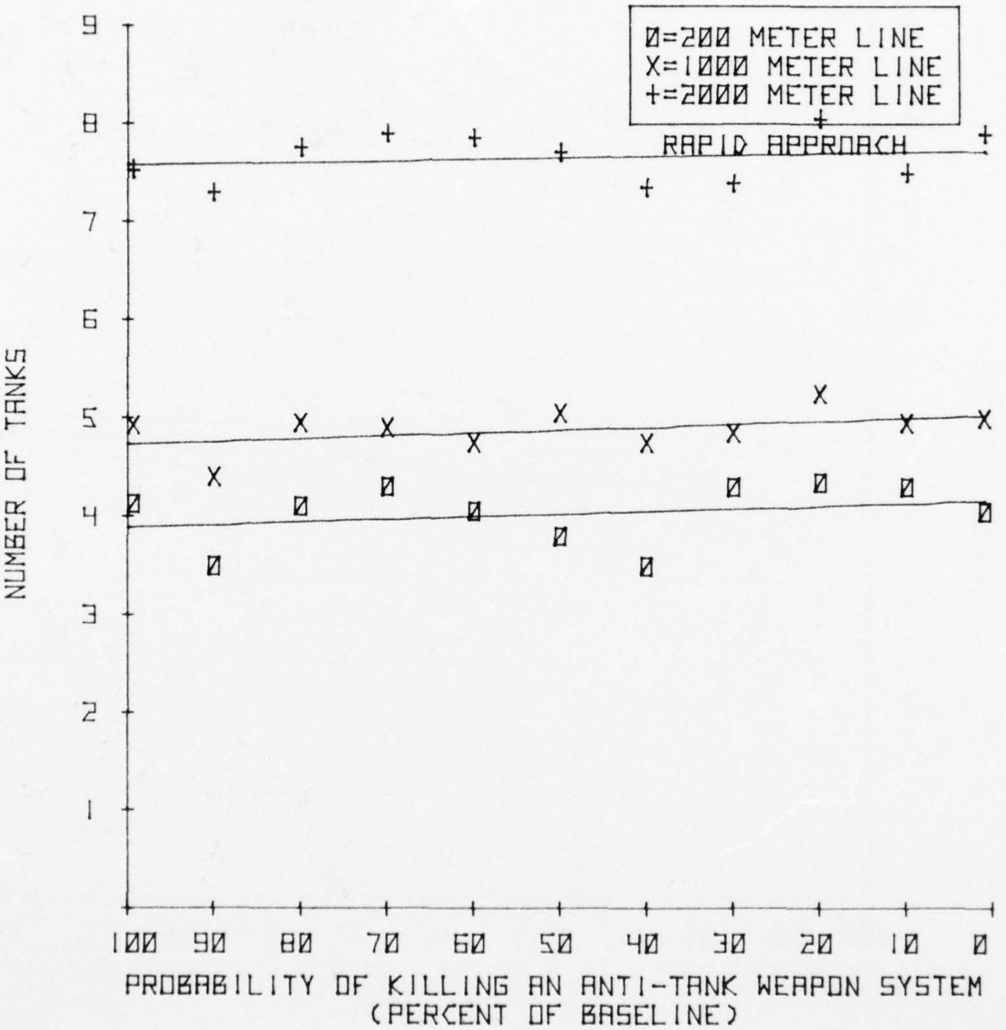

FIGURE 24. NUMBER OF TANKS ALIVE AT INDICATED RANGE FROM DEFENSIVE POSITION VS PROBABILITY OF KILLING AN ANTI-TANK WEAPON SYSTEM

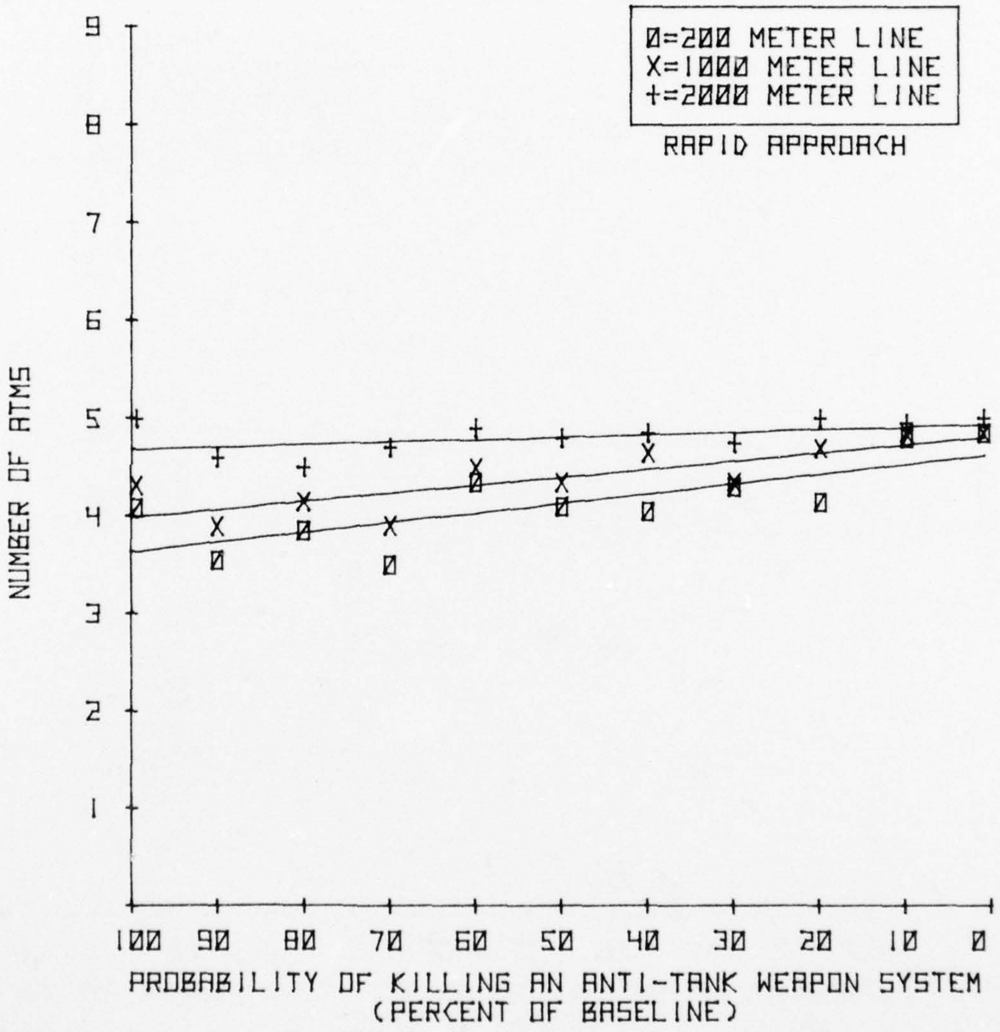

FIGURE 25. NUMBER OF ATMS ALIVE WHEN TANKS REACH INDICATED RANGE FROM DEFENSIVE POSITION VS PROBABILITY OF KILLING AN ANTI-TANK WEAPON SYSTEM

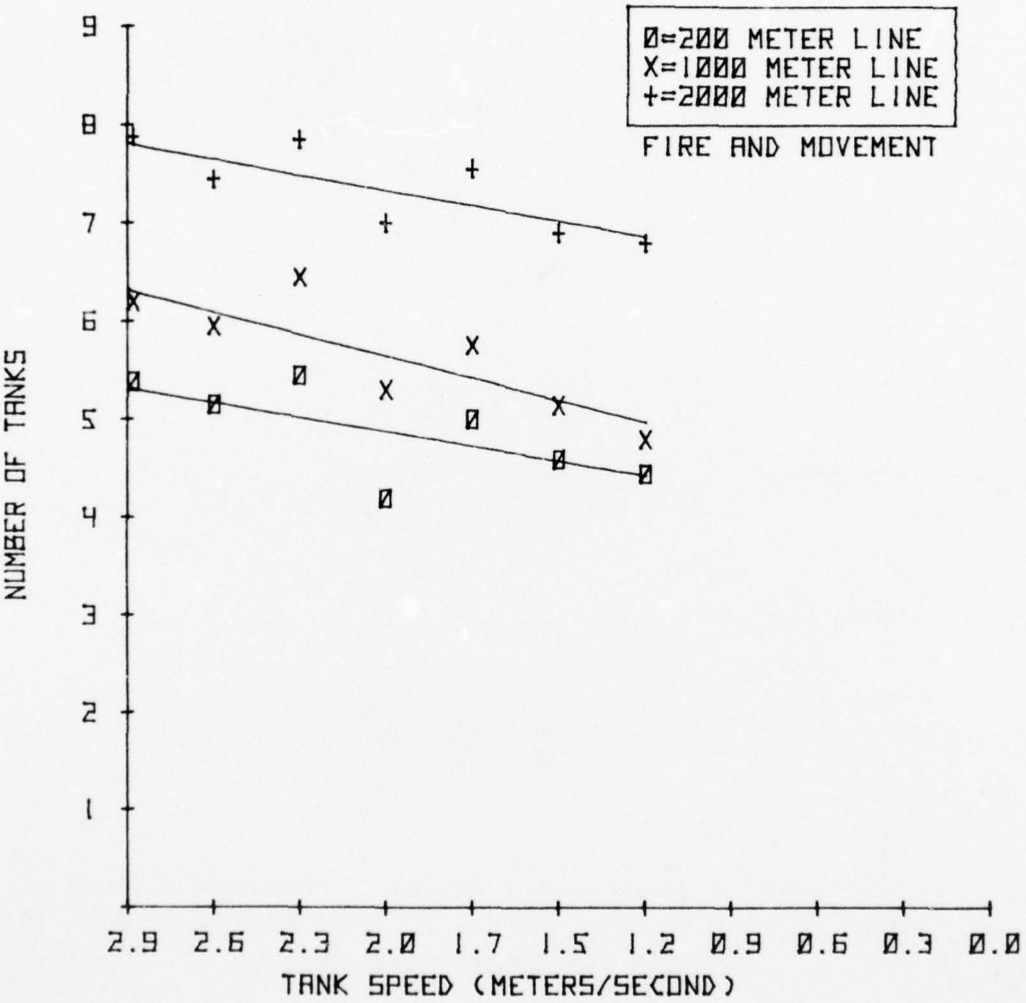

FIGURE 26. NUMBER OF TANKS ALIVE AT INDICATED RANGE FROM DEFENSIVE POSITION VS TANK SPEED

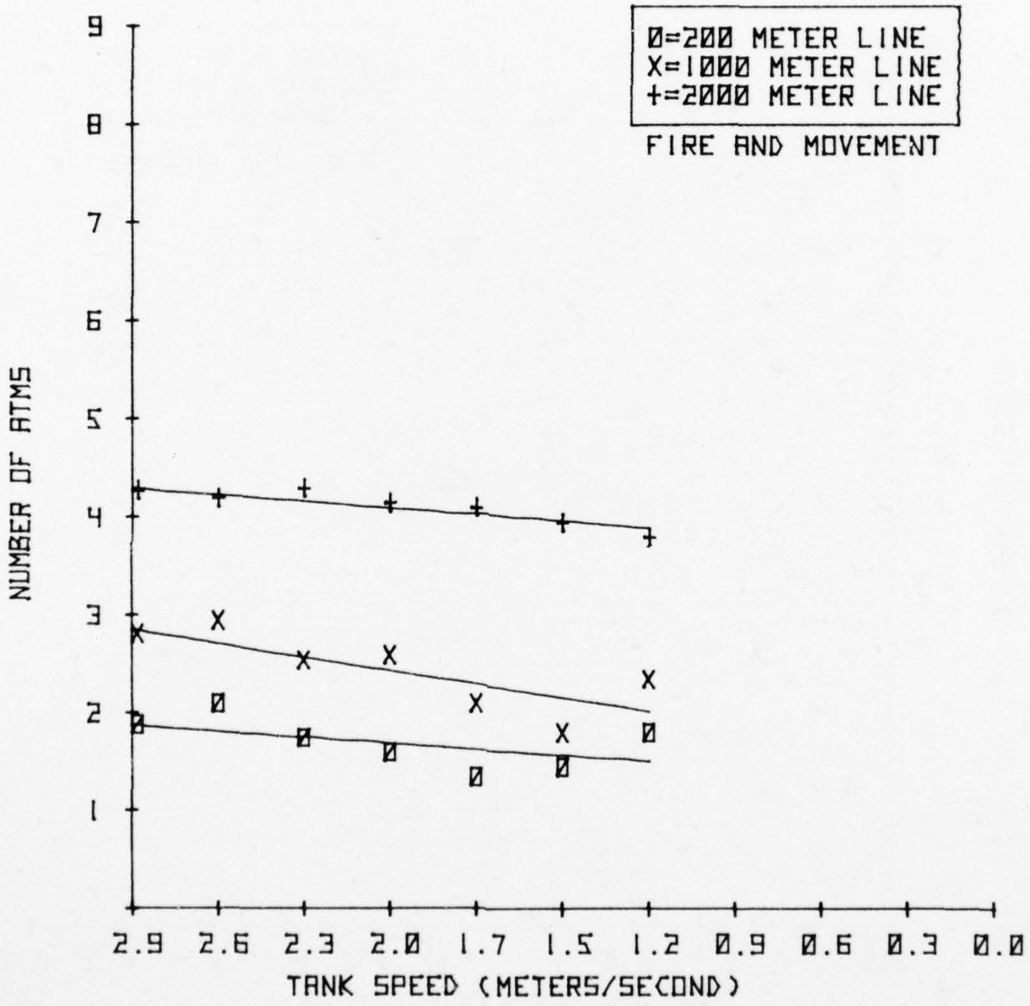

FIGURE 27. NUMBER OF ATMS ALIVE WHEN TANKS REACH INDICATED RANGE FROM DEFENSIVE POSITION VS TANK SPEED

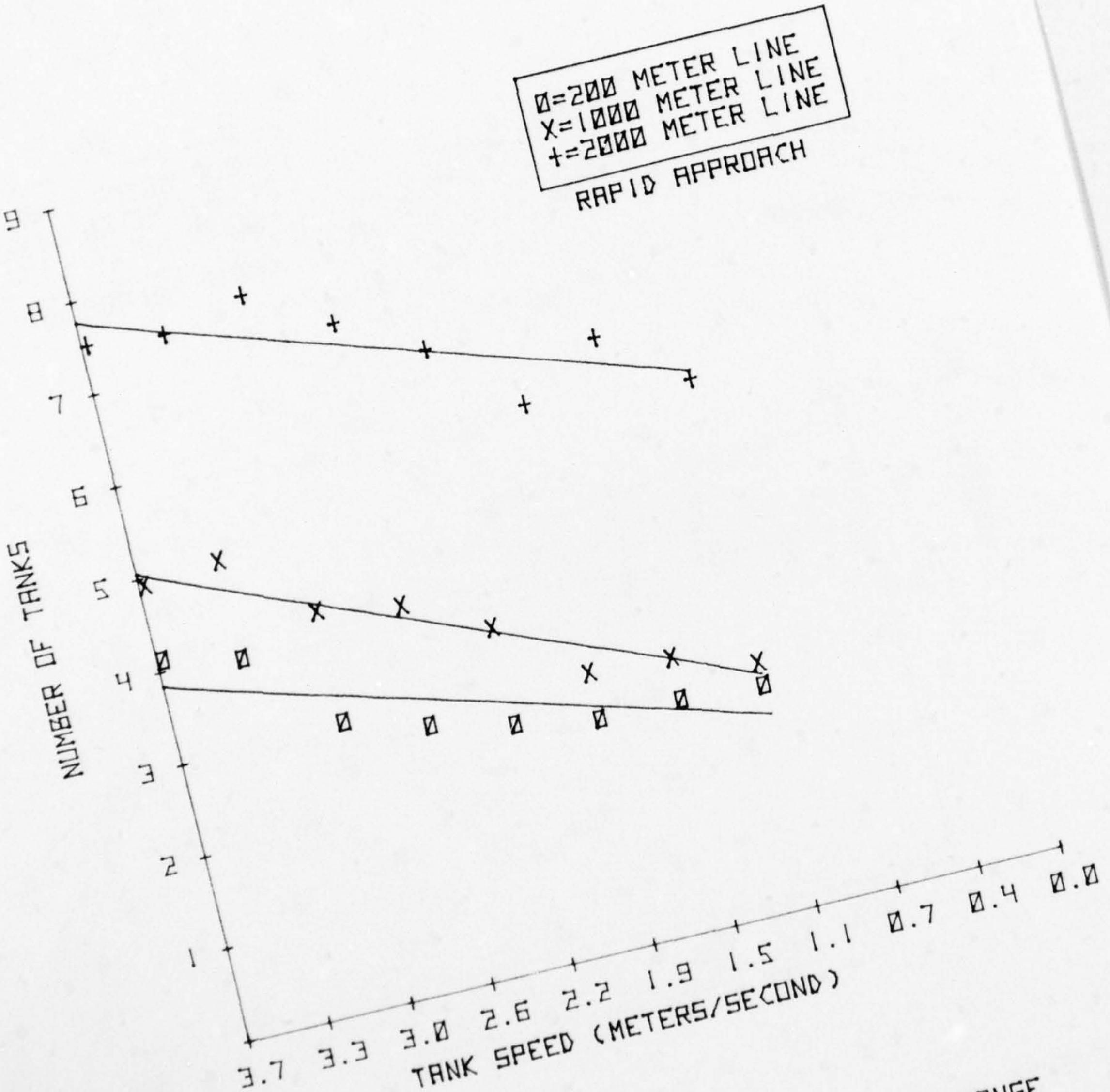

FIGURE 28. NUMBER OF TANKS ALIVE AT INDICATED RANGE FROM DEFENSIVE POSITION VS TANK SPEED

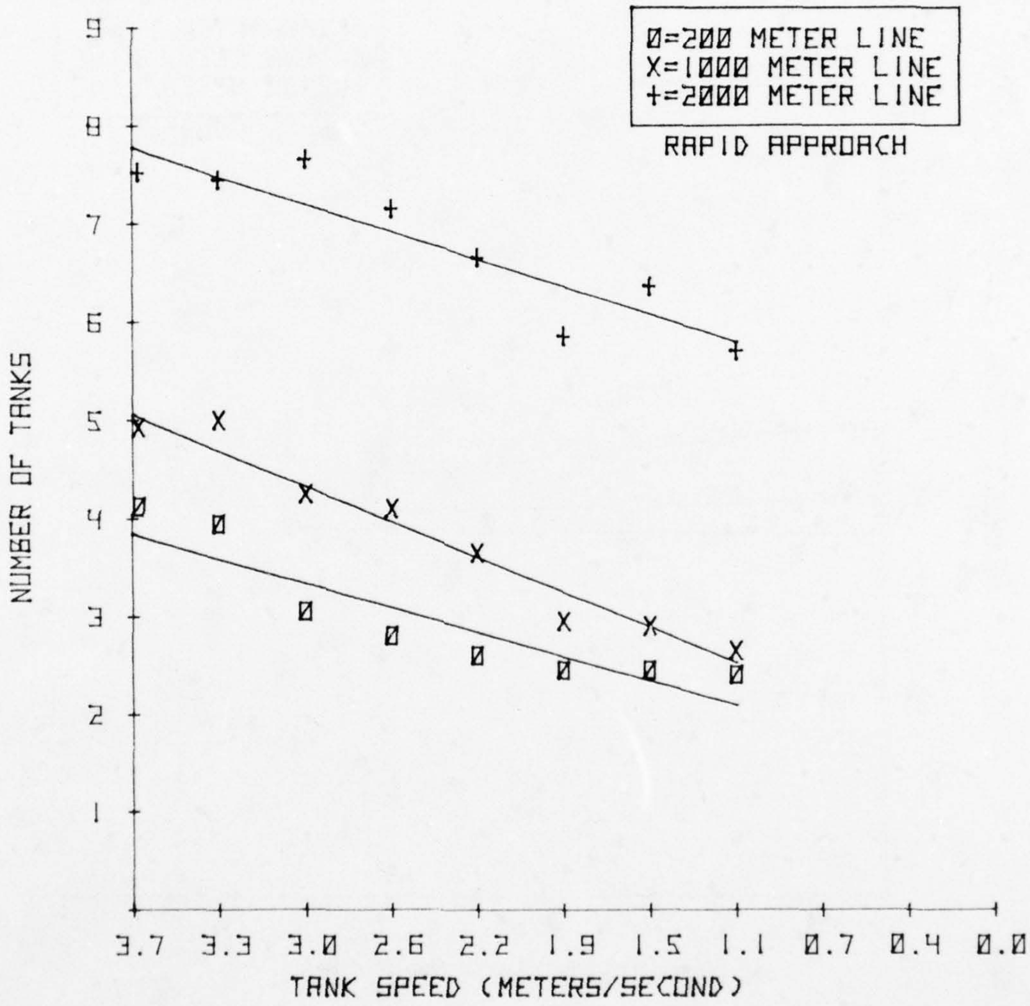

FIGURE 28. NUMBER OF TANKS ALIVE AT INDICATED RANGE FROM DEFENSIVE POSITION VS TANK SPEED

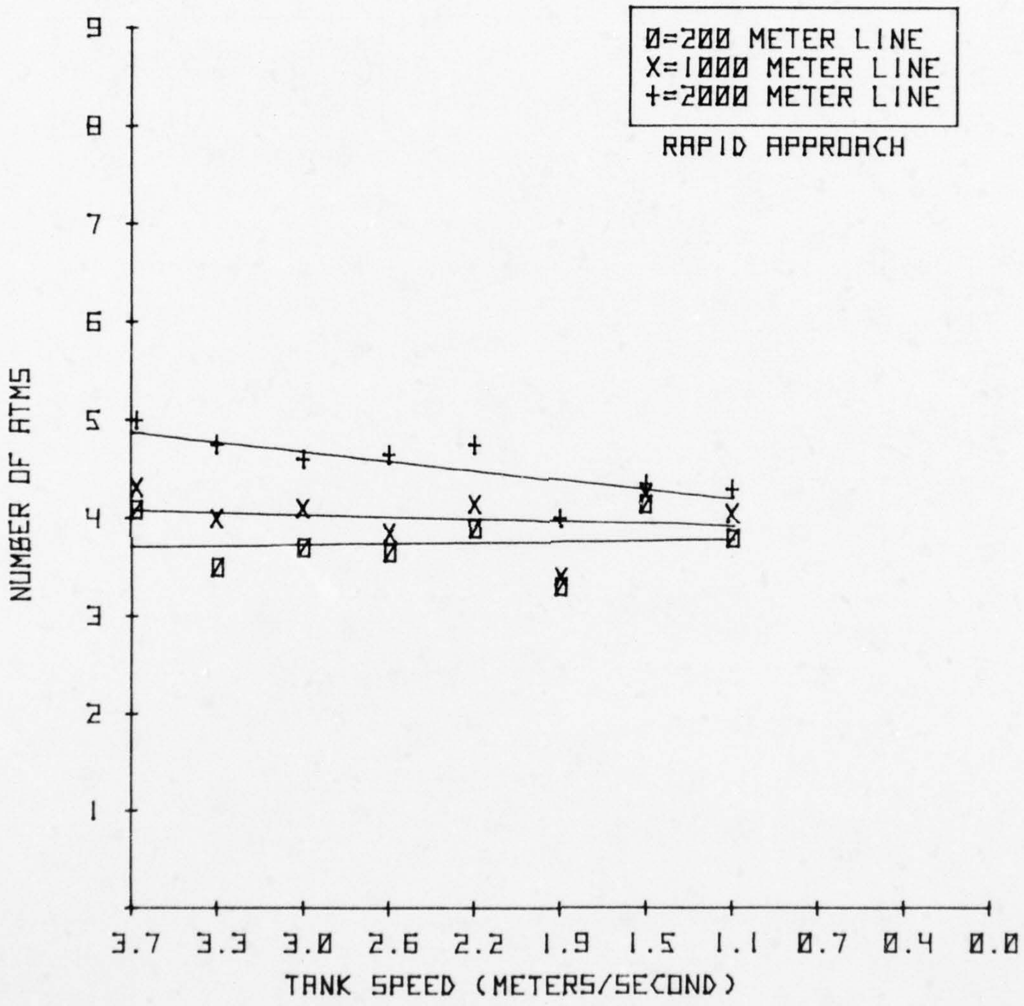

FIGURE 29. NUMBER OF ATMS ALIVE WHEN TANKS REACH INDICATED RANGE FROM DEFENSIVE POSITION VS TANK SPEED

TABLE 8. RELATIVE SENSITIVITY OF MEASURES OF BATTLE OUTCOME TO CHANGES IN VALUES OF OFFENSIVE INPUT PARAMETERS FOR THE FM TACTIC (ADJUSTED TRIALS)

Input Parameter(s) Varied	Measure				
	No. Tanks Reaching TTL	No. ATMs Alive When Trial Ends	Percent of TOWs killed	Percent of Offensive Vehicles Reaching Defense	Defensive Casualty Exchange Ratio
Tank Speed, Engagement Probability, & Kill Probability	-5.1	2.7	-65	-50	5.5
Engagement Probability	-1.8	2.5	-69	-22	6.3
Kill Probability	-1.4	2.1	-71	-18	3.9
Tank Speed	-1.5	-0.6 $\alpha = 10$	25 $\alpha = 5$	-4.5 $\alpha > 20$	-0.0 $\alpha > 20$

Note: The α-risk that an entry is incorrect is $\leq 1\%$ unless otherwise noted.

TABLE 9. RELATIVE SENSITIVITY OF MEASURES OF BATTLE OUTCOME TO CHANGES IN VALUES OF OFFENSIVE INPUT PARAMETERS FOR THE RA TACTIC (ADJUSTED TRIALS)

Input Parameter(s) Varied	Measure				
	No. Tanks Reaching TTL	No. ATMs Alive When Trial Ends	Percent of TOWs killed	Percent of Offensive Vehicles Reaching Defense	Defensive Casualty Exchange Ratio
Tank Speed, Engagement Probability, & Kill Probability	-3.4	0.7 $\alpha = 10$	-46	-24	9.0
Engagement Probability	-0.4 $\alpha > 20$	1.0	-28	-4.0 $\alpha > 20$	16.7
Kill Probability	0.3 $\alpha > 20$	1.0	-29	1.3 $\alpha > 20$	16.2
Tank Speed	-2.5	0.1 $\alpha > 20$	2.1 $\alpha > 20$	-13 $\alpha = 20$	2.1 > 20

Note: The α-risk that an entry is incorrect is $\leq 1\%$ unless otherwise noted.

regression lines are presented in ANNEX. Table 8 indicates that the majority of measures of combat outcome are more sensitive to changes in P_E, P_k, and TS. For the FM tactic the number of tanks reaching TTL is almost three times as sensitive to the simultaneous degradation of all parameters as it is to a degradation in P_E. For the FM tactic a given change in P_E results in approximately a 25 percent larger change in the number of tanks reaching TTL and in the number of ATMs alive at trial termination than for a similar change in P_k. Very little can be concluded about the impact of the changes in tank speed on measures of battle outcome other than the fact that measures of battle outcome are generally not sensitive to a degradation in tank speed. In all but one measure of battle outcome for both tactics, the α-risk* that the sensitivities associated with TS in Tables 8 and 9 are incorrect is greater than 5 percent and in most cases greater than 20 percent.

In the preceding trials, the changes in offensive and defensive parameters reflected decreases in crew member performance. When the decrement in performance is so severe that a crew cannot operate at all, or when death occurs, the effect is the same as reducing the number of offensive or defensive forces (assuming no replacements are available). In the fourth set of trials, this effect was explored.

In these trials the offensive and defensive values of input parameters were held fixed at baseline levels while the threat force was reduced in number. Table 10 presents a summary of these trials for three measures of battle outcome (% OFF, I/S, and number of ATMs killed per threat vehicle).

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* α is a function of the correlation of measures of battle outcome to level of degradation of TETAM input parameters and the number of degrees of freedom. α is statistically equivalent to the risk of being incorrect in making a statement "The slope of the regression is different from zero."

TABLE 10. SENSITIVITY OF MEASURE OF COMBAT OUTCOME TO REDUCTION IN NUMBER OF THREAT VEHICLES (NORMAL TRIALS)

No. of Threat Vehicles	Measure					
	% Offensive Vehicles Reaching TTL		Defense Exchange Ratio		Number ATMs killed Per Threat Vehicle	
	FM	RA	FM	RA	FM	RA
9 Tanks 3 ATGMs	31	28	4.21	12.13	.158	.052
7 Tanks 2 ATGMs	11	16	9.47	43.67	.094	.017
5 Tanks 1 ATGM	8	8	11.94	66.67	.067	.013

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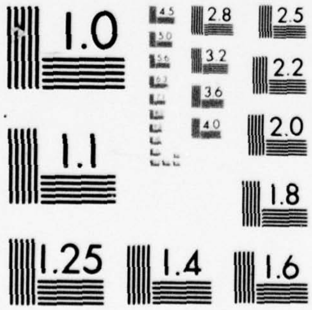

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Figures 30 and 31 show the percentage of tanks alive and the percentage of ATMs alive as a function of the initial size of the threat force when the center of mass of the tanks is 2000 meters, 1000 meters, and 200 meters from the defense for the FM tactic. Figures 32 and 33 display similar curves for the RA tactic. Figures 14 and 16 indicate that more of the tanks are killed in the 1000 to 2000 meter range than in the 200 to 1000 meter range. Table 10 presents the sensitivities of battle outcome to changes in the number of threat vehicles. As the threat force decreases by 50 percent the percentage of threat vehicles reaching TTL decreases by 70 percent and the defensive casualty exchange ratio increases 200 percent for the FM tactic and 450 percent for the RA tactic. Forty percent more ATMs are killed per threat vehicle when the threat force increases from 6 to 9 as compared to 68 percent more ATMs killed per threat vehicle when the threat increases from 9 to 12. This set of trials indicates that the threat is strongest in proportion to the number of threat vehicles when 12 threat vehicles are played, and the indication is that 15 threat vehicles would more nearly equalize the capabilities of the offense and defense. Sensitivities found in this set of trials indicate that the removal of tanks due to postirradiation performance degradation of tank crews would impact negatively on battle outcome. The indication is that the impact of the initial loss of three tanks on battle outcome is greater than the impact due to the subsequent loss of three additional tanks.

The analysis performed with the TETAM land combat model illustrates the sensitivity of measures of combat outcome to changes in offensive and defensive force parameters. However, the relation between the performance of tank crews or crew members and force parameters must be developed. Probability of kill, probability of engagement, tank speed, and tank gun reload time are the four parameters of the TETAM model most closely related to human performance. The following is a discussion of these relationships.

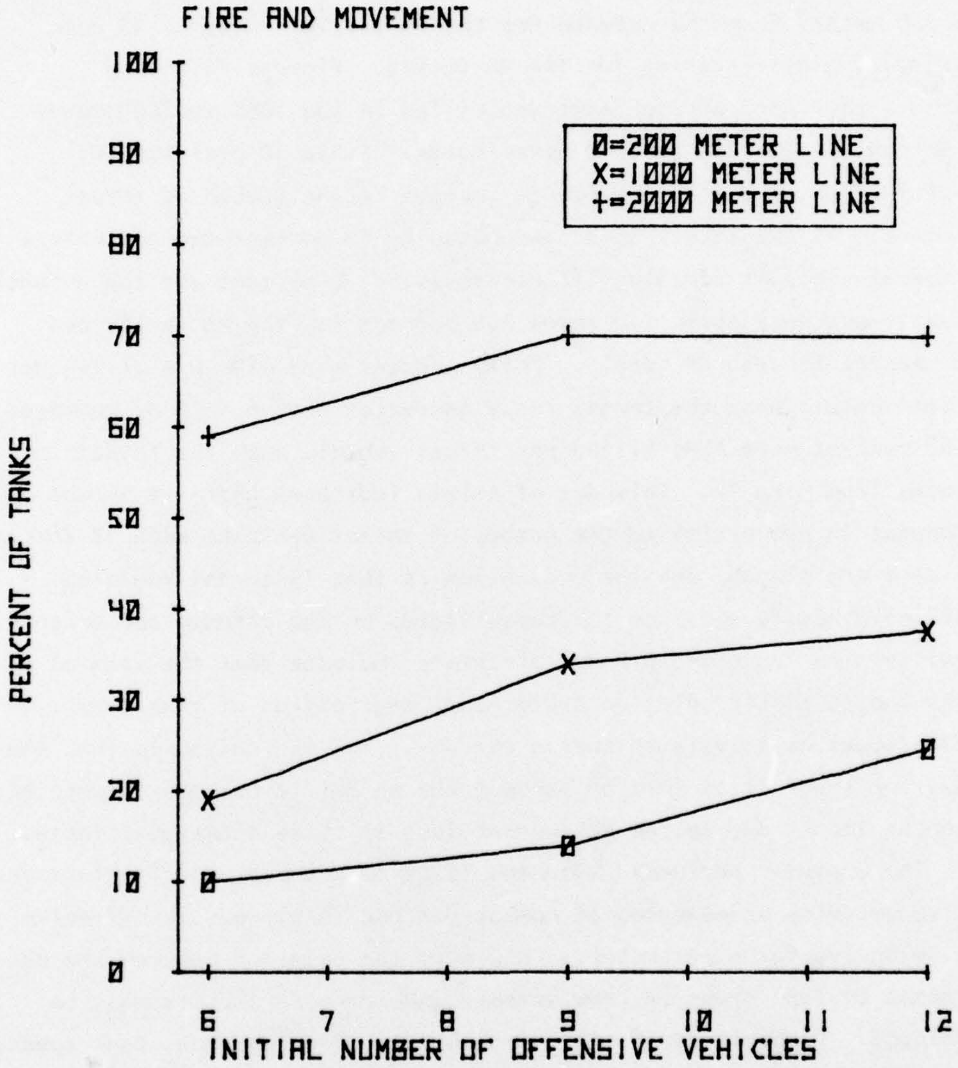

FIGURE 30. PERCENT OF TANKS ALIVE AT INDICATED RANGE FROM DEFENSIVE POSITION VS INITIAL NUMBER OF OFFENSIVE VEHICLES

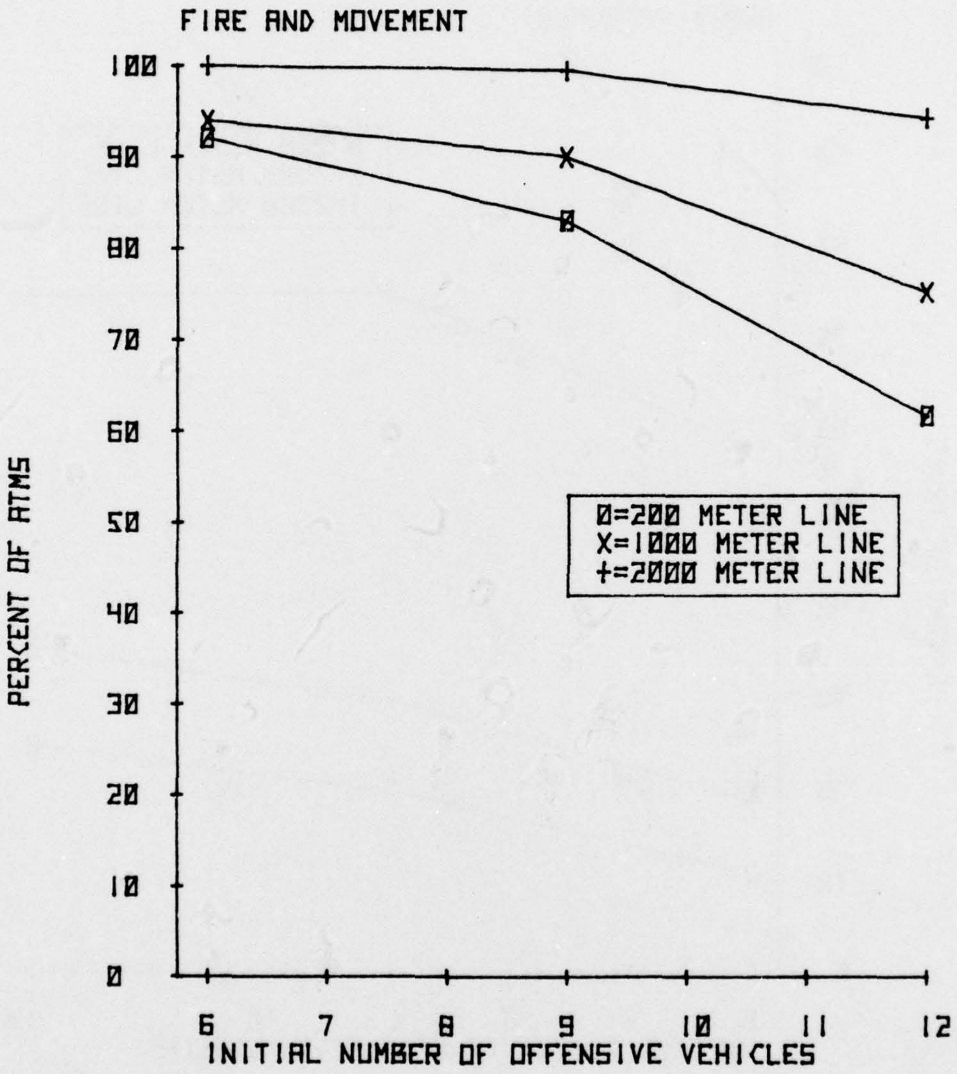

FIGURE 31. PERCENT OF ATMS ALIVE WHEN TANKS REACH INDICATED RANGE FROM DEFENSIVE POSITION VS INITIAL NUMBER OF OFFENSIVE VEHICLES

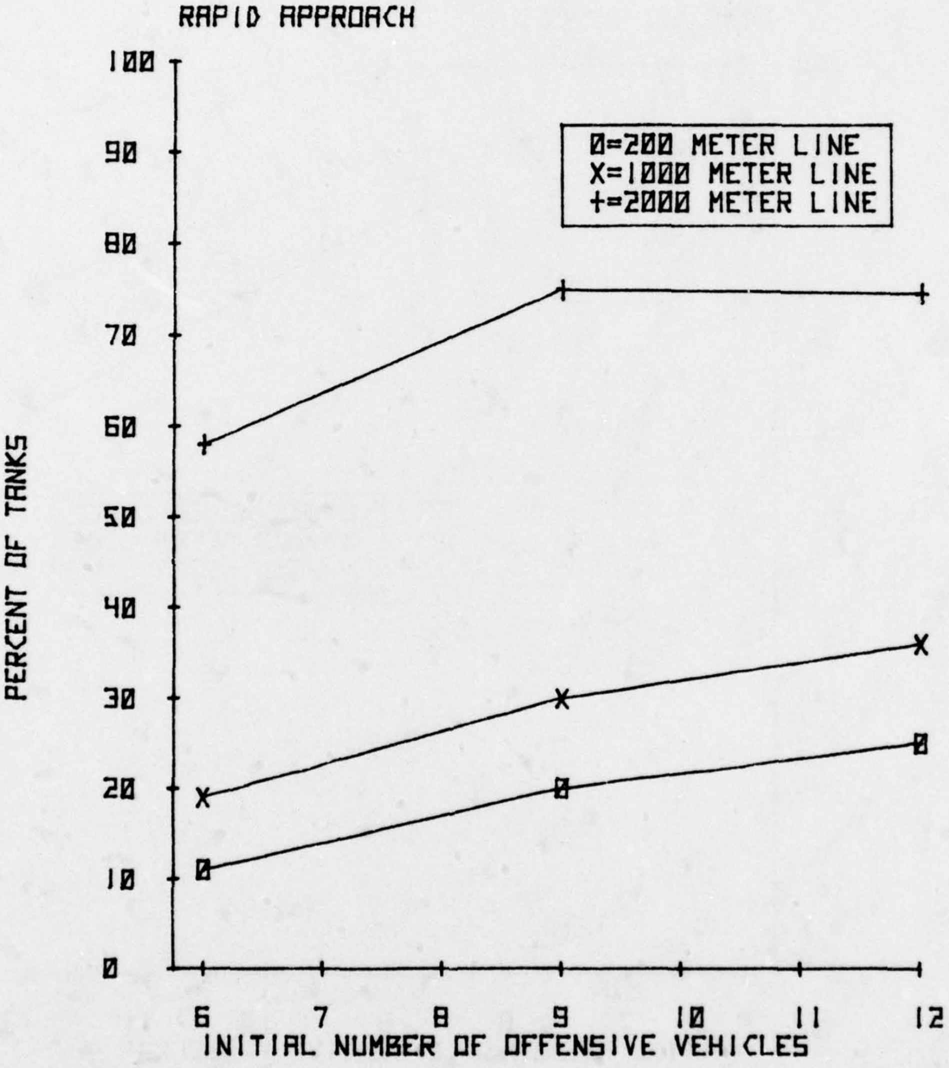

FIGURE 32. PERCENT OF TANKS ALIVE AT INDICATED RANGE FROM DEFENSIVE POSITION VS INITIAL NUMBER OF OFFENSIVE VEHICLES

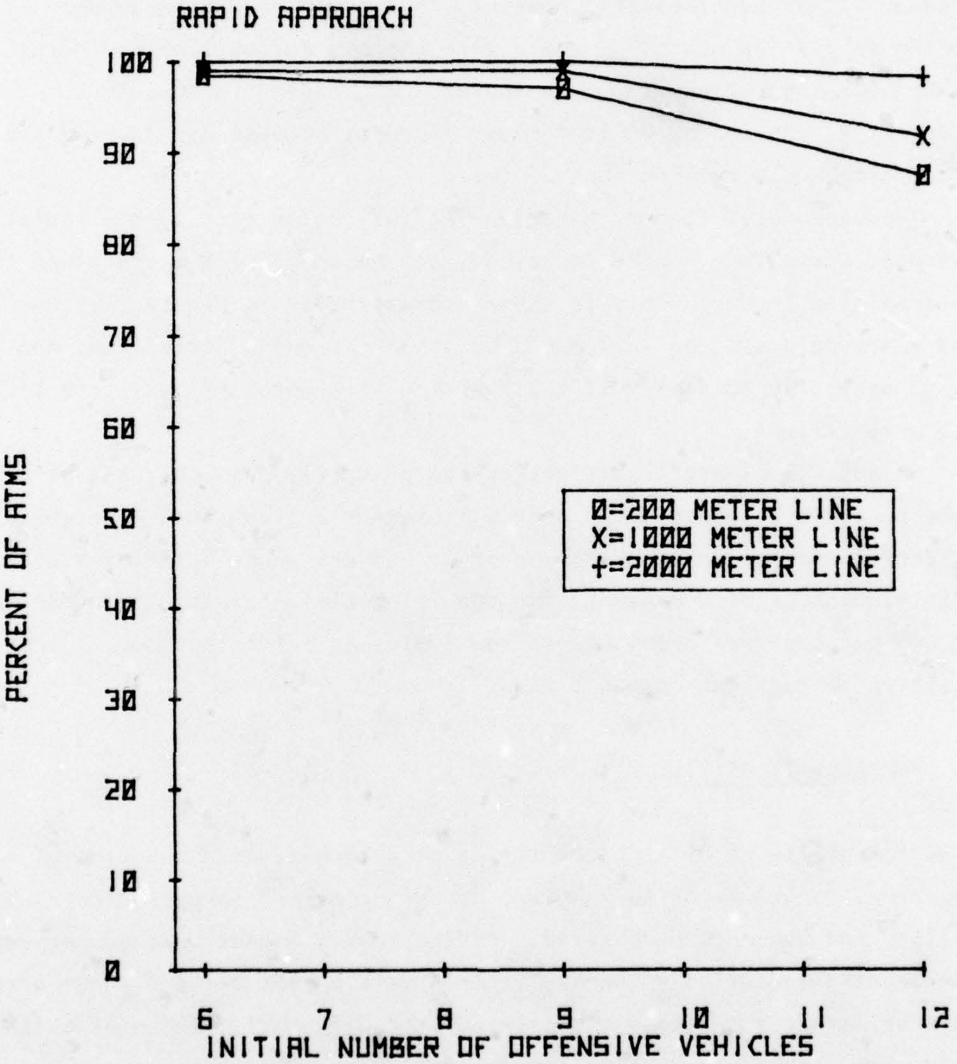

FIGURE 33. PERCENT OF ATMS ALIVE WHEN TANKS REACH INDICATED RANGE FROM DEFENSIVE POSITION VS INITIAL NUMBER OF OFFENSIVE VEHICLES

5. TANK GUN RELOAD TIME

The form of the relationship between dose and reload time is uncertain. It is hypothesized, however, that a nonirradiated loader, loading as fast as he could, would tire and his reload time would increase with the number of rounds loaded. If loading is done at a slower rate, the loader would recover somewhat between rounds, and the reload time would not increase as fast.

The irradiated loader, experiencing fatigue as part of the radiation syndrome, would take longer to reload, and he would tire faster than the nonirradiated loader. This is shown schematically in Figure 34. Reload time would also be influenced by other fatiguing activities, and by the necessity to vomit, if that particular symptom of radiation sickness were present.

Because the loader's activities are primarily physical, his performance would be expected to degrade more for a given dose than would the performance of the tank commander or gunner, whose activities are largely nonphysical. However, for the TETAM field trials, the number of firings per tank per trial was so low (.5) that battle outcome is insensitive to tank gun reload time.

6. PROBABILITY OF KILL

Probability of kill, given firing at a target, is a function of aim error, range, error in ranging, boresight error, target vulnerability, and type of round fired. If the tank commander and gunner were experiencing radiation sickness, it is possible that aim and range errors would be larger than those of nonirradiated personnel. These effects would vary with the radiation symptom being experienced.

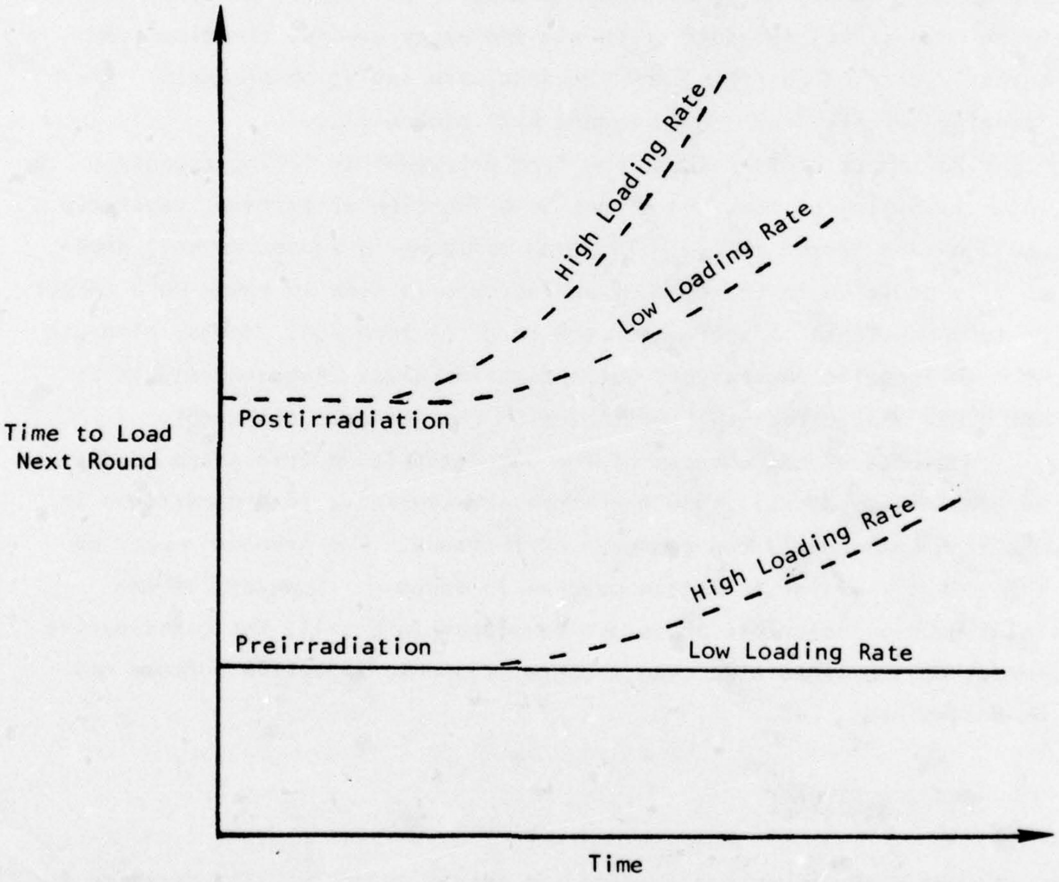

Figure 34. SCHEMATIC REPRESENTATION OF THE IMPACT OF NUCLEAR RADIATION ON TANK GUN RELOAD TIME

Aim error would be larger when the gunner is nauseous and/or vomiting than when these symptoms have subsided. Aim error as a function of time after irradiation may be as shown in Figure 35. The shape of the curve is based on the typical monkey response to nuclear radiation.

If the target is detected by the tank commander and handed off to the gunner, he may do so with less precision or clarity of communication if he were sick. In addition to aim and range errors, the time from target detection to firing may increase with radiation sickness. For fleeting targets, this could reduce kill probability.

The impact of increased time from detection to firing depends on the intervisibility of tank and target as a function of terrain, vegetation, and tank and target motion. The tank commander's impact on kill probability could be in the form of an increase in time to range on a target or to communicate to the gunner the target's location. He may also err more in locating the target, but except for gross inaccuracies, it is not clear what effect this will have on the gunner's aim error.

Measures of the outcome of the simulated TETAM trials are sensitive to probability of kill, and therefore are sensitive to degradations in the tank commander's and gunner's performance. The precise impact of these sensitivities on battle outcome is unknown. However, if the relationships described above are developed in detail, the quantitative impact of the irradiated crew members' response in battle outcome may be determined.

7. ENGAGEMENT RATE

Engagement rate is a function of target detection, the decision to fire at a detected target, the ability to lay the gun on the target and to fire, and the response of all crew members. Only live tanks can fire so engagement rate also depends upon the ability to detect and kill a defensive target before the tank itself is killed. Engagement rate is thus more like an outcome of combat, rather than a parameter whose value

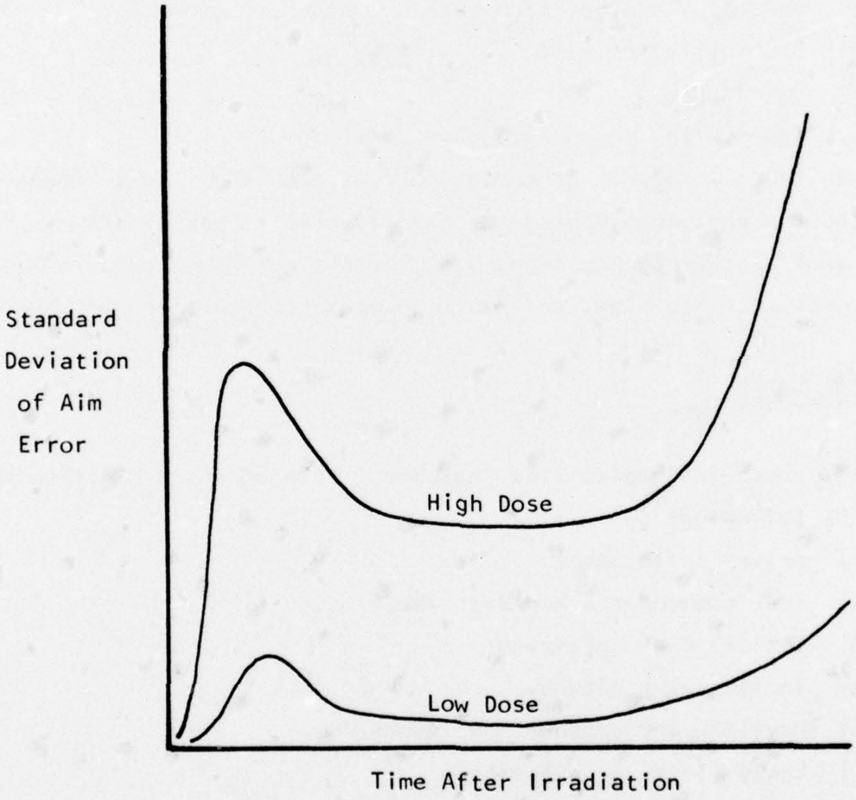

Figure 35. AIM ERROR VERSUS TIME POSTIRRADIATION

determines the outcome. The impact of crew member performance degradation on engagement rate requires a model of land combat in which the impact of crew member performance degradation on the following is represented:

(1) Target detection (by any crew member);

(2) Decision to engage a given target. (This would be a function of the number of other targets detected, supporting fires from other tanks of the unit, ranges to various targets, and the tactic being played);

(3) Handoff of target from tank commander to gunner;

(4) Probability of kill;

(5) Reload time;

(6) Maneuvering to advantageous positions.

Even though measures of combat outcome are sensitive to changes in the offensive engagement rate, the quantitative impact of crew member performance degradation on engagement rate is not known because the relationships are complex, and man's response to radiation is unknown.

8. TANK SPEED

Tank speed is complex like engagement rate and is a function of at least the following:

(1) Driver performance;

(2) Tank commander's maneuver decision;

(3) Terrain and vegetation;

(4) Tactic being played;

(5) Daylight and weather conditions;

(6) Enemy forces and tactics;

(7) Tank operational status.

It is not clear how driver performance, as affected by the radiation syndrome, interacts with other variables above except in very general terms. Figure 36 illustrates the relation in terms of a simplified feedback loop. The driver response function is the critical unknown in this figure.

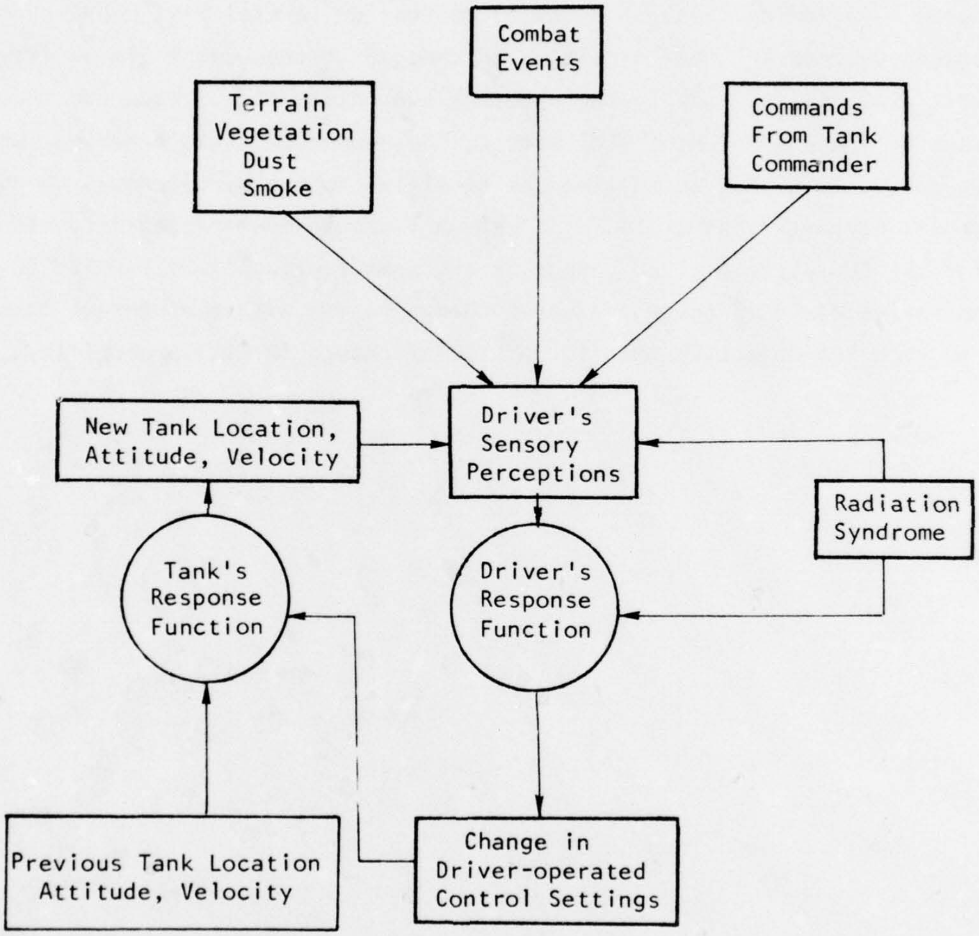

Figure 36. SIMPLIFIED SCHEMATIC REPRESENTATION OF DRIVER RESPONSE

9. CONCLUSIONS

Measures of combat outcome are most sensitive to the simultaneous change in values of engagement probability, kill probability, and tank speed. Following this, in order of decreasing sensitivity, measures of combat outcome are most sensitive to changes in engagement probability, kill probability, tank speed, and tank gun reload time. When the threat uses a fire and movement (FM) tactic, the number of tanks reaching the objective is almost three times as sensitive to the simultaneous changes of all parameters as it is for a change in engagement probability alone. For the FM tactic a given change in engagement probability results in approximately a 25 percent greater change in the number of threat tanks reaching the objective than for a similar change in kill probability.

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ANNEX TO APPENDIX A

DATA PACKAGE

TABLE 11. SENSITIVITY OF MEASURES OF COMBAT OUTCOME TO DEGRADATION OF VALUES OF DEFENSIVE P_k AND DEFENSIVE P_E FOR THE FM TACTIC (NORMAL TRIALS)

Measure of Battle Outcome / Percent degradation of defensive input parameter(s)	Number of Tanks Reaching Trial Termination Line			Percent of Defensive Vehicles Reaching Defense			Defensive Exchange Ratio			Percent of Tows Killed		
	Kill Prob.	Eng. Prob.	Kill & Eng. Prob.	Kill Prob.	Eng. Prob.	Kill & Eng. Prob.	Kill Prob.	Eng. Prob.	Kill & Eng. Prob.	Kill Prob.	Eng. Prob.	Kill & Eng. Prob.
0	2.21	2.21	2.21	23	23	23	4.21	4.21	4.21	32	32	32
10	3.7	2.8	3.2	34	28	30	2.6	3.1	3.5	38	40	30
20	3.8	3.0	3.5	36	29	37	3.1	4.2	3.4	38	33	30
30	4.4	3.7	5.4	45	36	54	2.2	2.8	1.6	43	55	53
40	4.6	3.6	5.9	46	35	59	2.0	3.5	1.4	45	33	53
50	5.6	3.6	6.1	59	38	65	1.3	3.0	1.6	63	45	53
60	6.5	5.1	6.5	66	52	72	1.0	1.7	1.2	70	65	53
70	6.3	6.5	7.6	67	66	82	1.2	1.2	0.6	53	70	68
80	7.4	7.0	8.4	76	74	87	0.7	0.7	0.3	50	68	63
90	6.9	7.8	9.0	86	80	91	0.3	0.6	0.0	53	50	70
99	8.9	8.9	9.0	91	94	94	0.0	0.0	0.0	58	63	60

TABLE 12. SENSITIVITY OF MEASURES OF COMBAT OUTCOME TO DEGRADATION OF VALUES OF DEFENSIVE P_k AND DEFENSIVE P_E FOR THE RA TACTIC (NORMAL TRIALS)

Measure of Battle Outcome / Percent Degradation of defensive input parameter(s)	Number of Tanks Reaching Trial Termination Line			Percent of Defensive Vehicles Reaching Defense			Defensive Exchange Ratio			Percent of Tows Killed		
	Kill Prob.	Eng. Prob.	Kill & Eng. Prob.	Kill Prob.	Eng. Prob.	Kill & Eng. Prob.	Kill Prob.	Eng. Prob.	Kill & Eng. Prob.	Kill Prob.	Eng. Prob.	Kill & Eng. Prob.
0	2.25	2.25	2.25	21	21	21	12.13	12.13	12.13	14.5	14.5	14.5
10	2.6	2.3	3.5	25	23	31	9.0	12.5	6.2	15	53	25
20	4.0	2.6	3.7	35	24	34	6.2	12.2	6.1	18	15	13
30	3.3	3.2	4.5	30	28	41	8.4	8.7	5.9	8	20	25
40	4.3	2.8	5.9	38	27	53	5.3	7.0	3.6	23	25	23
50	5.0	3.8	6.0	46	34	54	3.6	12.0	4.1	25	18	13
60	5.7	4.5	6.6	54	42	62	3.1	5.3	2.1	20	30	33
70	6.2	4.8	7.2	60	43	73	1.9	5.1	3.0	38	33	15
80	7.0	6.2	8.1	71	57	79	1.5	3.4	1.0	28	25	33
90	7.7	6.9	8.8	77	67	84	1.0	2.6	0.2	30	20	30
99	8.9	8.5	9.0	85	81	85	0.1	0.4	0.0	15	35	18

TABLE 13. PERCENTAGE CHANGE IN MEASURES OF COMBAT OUTCOME FOR A 99% DEGRADATION IN THE VALUES OF OFFENSIVE INPUT PARAMETERS FOR THE FM TACTIC (ADJUSTED TRIALS)

Measure of Battle Outcome Parameter(s) Varied	Engagement Probability	Kill Probability	Tank Speed	Tank Speed, Engagement Prob., & Kill Probatility
Number of Tanks Reaching 200 Meters From Defense†	-33	-27	-28	-94
Number of Tanks Reaching 1000 Meters From Defense	-20	-16*	-35	-76
Number of Tanks Reaching 2000 Meters From Defense	-2*	3*	-20*	-45
Number of ATMs Alive When Tanks Reach 200 Meters From Defense	163	115	-32*	176
Number of ATMs Alive When Tanks Reach 1000 Meters From Defense	71	72	-49*	52*
Number of ATMs Alive When Tanks Reach 2000 Meters From Defense	21	14	-16	19*
Percent of TOWs Killed	-90	-93	36*	-88
Percent of Offensive Vehicles Reaching 2000 Meters From Defense	-38	-32	-9*	-91
Defensive Exchange Ratio	630	508	-2*	760
Rounds Fired Per Tank	-89	17	179	-41*
Trial Times	-5*	-4*	172	140

† This is the Trial Termination Line

* Risk ≥ 2%

TABLE 14. PERCENTAGE CHANGE IN MEASURES OF COMBAT OUTCOME FOR A 99% DEGRADATION IN THE VALUES OF OFFENSIVE INPUT PARAMETERS FOR THE RA TACTIC (ADJUSTED TRIALS)

Measure of Battle Outcome Parameter(s) Varied	Engagement Probability	Kill Probability	Tank Speed	Tank Speed, Engagement Prob., & Kill Probability
Number of Tanks Reaching 200 Meters From Defense†	-9*	8*	-65	-80
Number of Tanks Reaching 1000 Meters From Defense	-5*	7*	-71	-82
Number of Tanks Reaching 2000 Meters From Defense	1*	3*	-36	-43
Number of ATMs Alive When Tanks Reach 200 Meters From Defense	27	29	3*	19*
Number of Tanks Reaching 1000 Meters From Defense	18	22	-5*	4*
Number of ATMs Alive When Tanks Reach 2000 Meters From Defense	5*	7*	-19*	-5*
Percent of TOWs Killed	-83	-86	6*	-118
Percent of Offensive Vehicles Reaching 2000 Meters From Defense	-10*	3*	-37*	-65
Defensive Exchange Ratio	550	475	47*	274
Rounds Fired Per Tank	-95	13*	127	-42*
Trial Times	-2	-3*	203	193

† This is the Trial Termination Line

* Risk ≥ 2%

TABLE 15. MEASURES OF COMBAT OUTCOME FOR 500% INCREASE IN VALUES OF OFFENSIVE PARAMETERS FOR THE FM TACTIC (ADJUSTED TRIALS)

Measure of Battle Outcome Parameter(s) Varied	Engagement Probability	Kill Probability	Tank Speed	Tank Speed, Engagement Prob., & Kill Probability
Number of Tanks Reaching 200 Meters From Defense† (5.30)*	6.85	6.70	7.75	8.50
Number of Tanks Reaching 1000 Meters From Defense (6.11)	7.30	7.45	8.20	8.65
Number of Tanks Reaching 2000 Meters From Defense (7.79)	7.80	7.95	8.65	8.80
Number of ATMs Alive When Tanks Reach 200 Meters From Defense (1.80)	1.20	1.05	3.60	1.65
Number of ATMs Alive When Tanks Reach 1000 Meters From Defense (2.73)	1.90	1.90	4.45	2.70
Number of ATMs Alive When Tanks Reach 2000 Meters From Defense (4.19)	3.60	3.55	4.80	4.05
Percent of TOWs Killed (69)	88	98	23	95
Percent of Offensive Vehicles Reaching 2000 Meters From Defense (56.5)	74	74	82	93
Defensive Exchange Ratio (1.28)	.59	.60	.93	.14
Rounds Fired Per Tank (1.02)	2.95	.62	.36	.83
Trial Times (1130)	1180	1210	290	300

† Trial Termination

* Numbers in parenthesis are baseline values.

TABLE 16. MEASURES OF COMBAT OUTCOME FOR 500% INCREASE IN VALUES OF OFFENSIVE PARAMETERS FOR THE RA TACTIC (ADJUSTED TRIALS)

Measure of Battle Outcome Parameter(s) Varied	Engagement Probability	Kill Probability	Tank Speed	Tank Speed, Engagement Prob., & Kill Probability
Number of Tanks Reaching 200 Meters From Defense† (4.04)*	5.15	5.75	7.70	8.10
Number of Tanks Reaching 1000 Meters From Defense (4.84)	5.70	6.10	7.85	8.90
Number of Tanks Reaching 2000 Meters From Defense (7.44)	7.50	7.95	8.90	8.95
Number of ATMs Alive When Tanks Reach 200 Meters From Defense (4.00)	2.75	2.25	4.55	2.30
Number of ATMs Alive When Tanks Reach 1000 Meters From Defense (4.23)	3.25	2.70	4.65	2.85
Number of ATMs Alive When Tanks Reach 2000 Meters From Defense (4.91)	4.30	4.25	4.80	3.85
Percent of TOWs killed (26)	65	80	5	83
Percent of Offensive Vehicles Reaching 2000 Meters From Defense (38.2)	50	53	82	84
Defensive Exchange Ratio (5.07)	1.80	1.20	2.64	.37
Rounds Fired Per Tank (.24)	.93	.29	.04	.31
Trial Times (830)	830	840	240	250

† Trial Termination

* Numbers in parenthesis are baseline values.

Table 17 presents measures of battle outcome and linear regression parameters for the TETAM trials with offense strengthened 80 percent and defense weakened 28 percent. The heading on each of the eight pages of Table 17 indicates which offensive parameter was degraded and which tactic was played. Measures of combat outcome and linear regression parameters are displayed in the first third of each page. The following list explains the abbreviations used for the linear regression parameters and measures of combat outcome.

Linear Regression Parameter

INT = Intercept of Regression Line

Slope = Slope of regression line (depends on scaling of axes).

Corr = Regression correlation coefficient.

% CHG = Percent change of ordinate of regression line from baseline value to maximum degradation.

T = Slope divided by standard error of slope.

80% Conf (Slope) = Confidence interval for slope.

Measures of Combat Outcome

% TOWs = Percent of TOWs killed.

% DEF = Percent of offense coming within 200 meters of defense.

Ratio = Defensive casualty exchange ratio (# casualties inflicted by defense # casualties sustained by offense).

Rounds = Number of rounds a tank fires per trial.

Mean Time = Mean trial duration in seconds.

Tanks = Number of tanks within 200 meters of defense.

1000m = Number of tanks coming within 1000 meters of defense.

2000m = Number of tanks coming within 2000 meters of defense.

ATMS = Number of ATMS alive when center of mass of tanks comes within 200 meters of defense.

1000m = Number of ATMS alive when center of mass of tanks comes within 1000 meters of defense.

2000m = Number of ATMS alive when center of mass of tanks comes within 2000 meters of defense.

The bottom two-thirds of each page presents the raw data for the indicated measures of battle outcomes. The first column indicates the level of degradation of the offensive parameters. Succeeding columns list values of the combat outcome measures. 100 percent of baseline means there is no degradation, 80 percent of baseline means there is 20 percent degradation of the values of the indicated offensive parameters, and 500 percent of baseline means that the value of the input parameter has been improved 500 percent.

The bottom third of each page shows the average number of tanks that have come within the indicated range from the defense and the number of ATMS alive when the center of mass of the live tanks come within the indicated range of the defense.

Table 17 MEASURES OF BATTLE OUTCOME AND LINEAR REGRESSION PARAMETERS FOR ADJUSTED TRIALS

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ENGAGEMENT PROBABILITY, KILL PROBABILITY AND TANK SPEED
FIRE AND MOVEMENT


           INT     SLOPE      CORR      %CHG        T        80%CONF(SLOPE)
%TOWS    74.39   -0.6536    -0.85     -87.9     -3.65     -0.8830 -0.4241
%DEF     54.88   -0.4982    -0.98     -90.8    -11.98     -0.5515 -0.4449
RATIO     0.73    0.0553     0.92     760.4      5.43      0.0423  0.0684
ROUNDS    1.18   -0.0048    -0.57     -40.6     -1.54     -0.0088 -0.0008
TIME      1097   15.3929     0.98     140.3     10.54     13.5208 17.2649
#TANKS    5.39   -0.0505    -0.98     -93.7    -12.37     -0.0558 -0.0453
1000 M    6.19   -0.0473    -0.96     -76.3     -7.22     -0.0556 -0.0389
2000 M    8.09   -0.0365    -0.95     -45.1     -6.48     -0.0437 -0.0293
#ATMS     1.51    0.0266     0.88     176.3      4.10      0.0183  0.0349
1000 M    2.52    0.0131     0.74      51.9      2.47      0.0063  0.0199
2000 M    4.19    0.0078     0.79      18.6      2.93      0.0044  0.0112


% OF       % OF         %DEFENSE     DEFENSIVE    TANK       MEAN
BASE-      TOWS         REACHING     EXCHANGE     ROUNDS     TIME
LINE       KILLED       200M         RATIO        FIRED      (SEC)

 500         95           93          0.14         0.83       300
 100         69           57          1.28         1.02      1130
  90         70           50          1.37         1.12      1200
  80         55           43          1.63         1.11      1320
  70         73           40          1.56         1.31      1670
  60         50           35          2.63         1.02      1770
  50         35           27          3.65         0.96      1810
  40         33           28          4.59         0.71      2010

% OF
BASE-     TANKS ALIVE(MEANS)                ATMS ALIVE(MEANS)
LINE   200 M    1000 M    2000 M        200 M    1000 M    2000 M

 500   8.50      8.65      8.80         1.65      2.70      4.05
 100   5.30      6.11      7.79         1.80      2.73      4.19
  90   4.75      5.55      7.90         1.70      2.60      4.35
  80   4.65      5.75      7.45         2.20      2.95      4.40
  70   4.10      4.90      7.30         1.70      2.50      4.20
  60   3.10      3.80      6.35         2.45      2.80      4.40
  50   2.95      3.75      6.55         2.90      3.20      4.75
  40   2.30      3.55      5.65         3.40      3.60      4.65
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Table 17 (Continued)

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PROBABILITY OF ENGAGING IN 10 SECONDS
FIRE AND MOVEMENT


           INT     SLOPE     CORR      %CHG       T          80%CONF(SLOPE)
%TOWS    77.14   -0.6909   -0.94     -89.6     -8.07      -0.8006 -0.5812
%DEF     57.43   -0.2205   -0.90     -38.4     -6.28      -0.2654 -0.1755
RATIO    -0.05*   0.0634    0.84     630.0      4.63       0.0458  0.0810
ROUNDS    1.12   -0.0100   -0.98     -89.0    -14.03      -0.0109 -0.0091
TIME     1160    -0.5545   -0.61      -4.8     -2.29      -0.8643 -0.2448
#TANKS    5.45   -0.0180   -0.83     -33.0     -4.40      -0.0232 -0.0128
1000 M    6.21   -0.0122   -0.73     -19.6     -3.23      -0.0170 -0.0073
2000 M    7.82   -0.0012   -0.17      -1.6     -0.50      -0.0043  0.0019
#ATMS     1.53    0.0249    0.93     162.6      7.89       0.0209  0.0290
1000 M    2.59    0.0184    0.95      71.2      9.14       0.0158  0.0210
2000 M    4.11    0.0088    0.88      21.3      5.69       0.0068  0.0108


% OF        % OF          %DEFENSE       DEFENSIVE     TANK          MEAN
BASE-       TOWS          REACHING       EXCHANGE      ROUNDS        TIME
LINE        KILLED        200M           RATIO         FIRED         (SEC)

 500          88            74            0.59          2.95          1180
 100          69            57            1.28          1.02          1130
  90          65            58            1.27          1.00          1190
  80          60            52            1.48          0.91          1160
  70          58            45            2.19          0.82          1150
  60          70            49            1.42          0.85          1150
  50          45            53            1.77          0.74          1130
  40          45            47            2.04          0.54          1080
  30          25            38            3.29          0.42          1100
  20          18            38            4.57          0.33          1110
  10          15            40            5.70          0.14          1130
   1           0            34            9.27          0.08          1120

% OF
BASE-      TANKS ALIVE(MEANS)                   ATMS ALIVE(MEANS)
LINE     200 M    1000 M     2000 M         200 M     1000 M     2000 M

 500     6.85      7.30        7.80          1.20       1.90        3.60
 100     5.30      6.11        7.79          1.80       2.73        4.19
  90     5.60      6.60        8.05          2.00       2.80        3.90
  80     5.10      5.75        7.70          2.00       3.10        4.45
  70     4.05      5.20        7.60          2.50       3.20        4.35
  60     5.00      6.10        7.85          1.85       2.85        4.60
  50     5.15      5.95        7.65          2.70       3.60        4.45
  40     4.70      5.45        8.10          2.55       3.50        4.55
  30     3.85      4.90        7.45          3.25       3.75        4.90
  20     3.70      5.30        7.55          3.70       4.20        4.90
  10     4.00      4.85        7.45          3.90       4.20        4.95
   1     3.60      5.35        8.10          4.30       4.65        4.80
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* The negative value results from using a straight line fit of the data. In this case, a polynomial fit would be appropriate.

Table 17 (Continued)

PROBABILITY OF KILLING AN ANTI-TANK SYSTEM
FIRE AND MOVEMENT

	INT	SLOPE	CORR	%CHG	T	80%CONF(SLOPE)	
%TOWS	76.68	-0.7091	-0.95	-92.5	-9.39	-0.8059	-0.6123
%DEF	55.20	-0.1759	-0.93	-31.9	-7.39	-0.2064	-0.1454
RATIO	0.76	0.0388	0.89	507.9	5.81	0.0302	0.0473
ROUNDS	1.06	0.0018	0.74	17.0	3.28	0.0011	0.0025
TIME	1145	-0.4727	-0.68	-4.1	-2.79	-0.6896	-0.2559
#TANKS	5.21	-0.0141	-0.86	-27.0	-5.17	-0.0176	-0.0106
1000 M	5.95	-0.0097	-0.64	-16.3	-2.53	-0.0146	-0.0048
2000 M	7.42	0.0019	0.18	2.5	0.54	-0.0025	0.0063
#ATMS	1.78	0.0205	0.97	115.1	11.90	0.0183	0.0227
1000 M	2.60	0.0187	0.97	71.8	13.04	0.0168	0.0205
2000 M	4.30	0.0060	0.86	14.0	5.10	0.0045	0.0075

% OF BASE-LINE	% OF TOWS KILLED	%DEFENSE REACHING 200M	DEFENSIVE EXCHANGE RATIO	TANK ROUNDS FIRED	MEAN TIME (SEC)
500	98	74	0.60	0.62	1210
100	69	57	1.28	1.02	1130
90	80	52	1.37	1.02	1160
80	53	52	1.71	1.09	1140
70	55	48	1.95	1.12	1120
60	48	47	2.08	1.19	1120
50	55	52	1.79	1.24	1140
40	33	44	2.88	1.14	1110
30	30	41	3.33	1.15	1090
20	25	39	3.49	1.27	1130
10	8	42	3.61	1.20	1080
1	0	37	6.24	1.16	1110

% OF BASE-LINE	TANKS ALIVE(MEANS) 200 M	1000 M	2000 M	ATMS ALIVE(MEANS) 200 M	1000 M	2000 M
500	6.70	7.45	7.95	1.05	1.90	3.55
100	5.30	6.11	7.79	1.80	2.73	4.19
90	5.00	6.00	7.60	1.95	2.80	4.55
80	4.80	5.35	7.05	2.15	3.00	4.25
70	4.50	5.50	7.30	2.50	2.90	4.60
60	4.75	5.45	7.45	2.70	3.40	4.50
50	5.15	6.30	8.00	2.45	3.35	4.65
40	4.25	5.20	7.00	3.20	3.90	4.75
30	4.10	4.80	7.35	3.35	4.05	4.65
20	3.90	5.05	7.40	3.25	3.95	4.65
10	4.25	5.55	8.05	3.45	4.25	4.80
1	3.60	4.85	7.70	4.00	4.55	5.00

Table 17 (Continued)

TANK SPEED
FIRE AND MOVEMENT

	INT	SLOPE	CORR	%CHG	T	80%CONF(SLOPE)	
%TOWS	69.48	0.2482	0.77	35.7	2.70	0.1302	0.3663
%DEF	51.13	-0.0446	-0.25	-8.7	-0.57	-0.1453	0.0560
RATIO	1.39	-0.0002	-0.03	-1.5	-0.07	-0.0040	0.0036
ROUNDS	0.98	0.0176	0.97	178.8	8.52	0.0149	0.0202
TIME	1063	18.2500	0.98	171.8	10.77	16.0769	20.4231
#TANKS	5.32	-0.0146	-0.68	-27.5	-2.05	-0.0238	-0.0055
1000 M	6.31	-0.0223	-0.82	-35.3	-3.24	-0.0311	-0.0134
2000 M	7.80	-0.0156	-0.78	-20.0	-2.79	-0.0228	-0.0084
#ATMS	1.88	-0.0061	-0.52	-32.4	-1.37	-0.0117	-0.0004
1000 M	2.86	-0.0139	-0.77	-48.6	-2.69	-0.0205	-0.0073
2000 M	4.30	-0.0067	-0.85	-15.5	-3.60	-0.0091	-0.0043

% OF BASE-LINE	% OF TOWS KILLED	%DEFENSE REACHING 200M	DEFENSIVE EXCHANGE RATIO	TANK ROUNDS FIRED	MEAN TIME (SEC)
500	23	82	0.93	0.36	290
100	69	57	1.28	1.02	1130
90	73	49	1.57	1.02	1170
80	80	47	1.28	1.37	1320
70	70	44	1.54	1.54	1680
60	78	52	1.23	1.85	1900
50	88	50	1.28	1.77	1950
40	83	50	1.47	2.00	2120

% OF BASE-	TANKS ALIVE(MEANS)			ATMS ALIVE(MEANS)		
LINE	200 M	1000 M	2000 M	200 M	1000 M	2000 M
500	7.75	8.20	8.65	3.60	4.45	4.80
100	5.30	6.11	7.79	1.80	2.73	4.19
90	5.15	5.95	7.45	2.10	2.95	4.20
80	5.45	6.45	7.85	1.75	2.55	4.30
70	4.20	5.30	7.00	1.60	2.60	4.15
60	5.00	5.75	7.55	1.35	2.10	4.10
50	4.60	5.15	6.90	1.45	1.80	3.95
40	4.45	4.80	6.80	1.80	2.35	3.80

Table 17 (Continued)

ENGAGEMENT PROBABILITY, KILL PROBABILITY AND TANK SPEED
RAPID APPROACH

	INT	SLOPE	CORR	%CHG	T	80%CONF(SLOPE)	
%TOWS	39.47	-0.4644	-0.82	-117.7	-3.55	-0.6322	-0.2966
%DEF	37.25	-0.2421	-0.95	-65.0	-7.69	-0.2825	-0.2018
RATIO	3.28	0.0899	0.81	274.2	3.34	0.0554	0.1244
ROUNDS	0.28	-0.0012	-0.54	-42.3	-1.58	-0.0022	-0.0002
TIME	772	14.8810	0.97	192.8	9.70	12.9145	16.8474
#TANKS	4.23	-0.0340	-0.96	-80.4	-9.00	-0.0388	-0.0291
1000 M	5.12	-0.0419	-0.96	-81.8	-8.47	-0.0482	-0.0355
2000 M	8.05	-0.0342	-0.91	-42.5	-5.25	-0.0426	-0.0258
#ATMS	3.69	0.0068	0.63	18.5	1.99	0.0024	0.0113
1000 M	4.15	0.0017	0.25	4.1	0.63	-0.0018	0.0052
2000 M	4.80	-0.0026	-0.46	-5.4	-1.27	-0.0052	0.0000

% OF BASE-LINE	% OF TOWS KILLED	%DEFENSE REACHING 200M	DEFENSIVE EXCHANGE RATIO	TANK ROUNDS FIRED	MEAN TIME (SEC)
500	83	84	0.37	0.31	250
100	26	38	5.07	0.24	830
90	45	37	3.84	0.24	930
80	38	30	4.42	0.28	1040
70	30	30	4.89	0.28	1130
60	18	25	6.65	0.29	1250
50	10	24	7.85	0.24	1690
40	15	25	6.33	0.23	1700
30	5	21	12.36	0.12	1770

% OF BASE-LINE	TANKS ALIVE(MEANS)			ATMS ALIVE(MEANS)		
	200 M	1000 M	2000 M	200 M	1000 M	2000 M
500	8.10	8.90	8.95	2.30	2.85	3.85
100	4.04	4.84	7.44	4.00	4.23	4.91
90	4.05	4.60	7.85	3.60	4.25	4.70
80	3.55	4.35	7.75	3.60	4.00	4.65
70	3.35	4.35	7.10	3.75	4.10	4.80
60	2.75	3.80	6.75	4.10	4.25	4.80
50	2.35	2.65	6.70	4.20	4.45	4.47
40	2.60	2.60	6.15	3.90	4.00	4.60
30	1.60	2.05	5.05	4.30	4.40	4.75

Table 17 (Continued)

PROBABILITY OF ENGAGING IN 10 SECONDS
RAPID APPROACH

	INT	SLOPE	CORR	%CHG	T	80%CONF(SLOPE)	
%TOWS	33.53	-0.2783	-0.83	-83.0	-4.50	-0.3576	-0.1990
%DEF	41.11	-0.0400	-0.37	-9.7	-1.20	-0.0829	0.0029
RATIO	0.57	0.1672	0.80	550.0	3.94	0.1128	0.2215
ROUNDS	0.25	-0.0024	-0.91	-94.9	-6.58	-0.0028	-0.0019
TIME	836	-0.1545	-0.39	-1.8	-1.26	-0.3124	0.0033
#TANKS	4.36	-0.0039	-0.40	-8.9	-1.32	-0.0076	-0.0001
1000 M	5.42	-0.0029	-0.30	-5.3	-0.94	-0.0068	0.0011
2000 M	7.66	0.0011	0.27	1.4	0.84	-0.0006	0.0028
#ATMS	3.65	0.0100	0.88	27.4	5.59	0.0077	0.0123
1000 M	4.06	0.0074	0.88	18.2	5.66	0.0057	0.0091
2000 M	4.73	0.0025	0.63	5.2	2.42	0.0012	0.0038

% OF BASE- LINE	% OF TOWS KILLED	%DEFENSE REACHING 200M	DEFENSIVE EXCHANGE RATIO	TANK ROUNDS FIRED	MEAN TIME (SEC)
500	65	50	1.80	0.93	830
100	26	38	5.07	0.24	830
90	25	41	4.15	0.29	840
80	30	40	3.80	0.24	840
70	30	40	4.72	0.13	830
60	23	44	5.29	0.09	840
50	33	44	4.62	0.12	820
40	23	33	7.94	0.11	810
30	15	40	7.67	0.09	840
20	8	34	17.29	0.06	800
10	5	40	11.70	0.06	830
1	0	36	26.00	0.02	830

% OF BASE-	TANKS ALIVE(MEANS)			ATMS ALIVE(MEANS)		
LINE	200 M	1000 M	2000 M	200 M	1000 M	2000 M
500	5.15	5.70	7.50	2.75	3.25	4.30
100	4.04	4.84	7.44	4.00	4.23	4.91
90	4.40	5.70	7.75	3.75	4.20	4.70
80	4.45	5.90	7.80	3.65	4.10	4.70
70	4.40	5.35	7.60	3.95	4.20	4.60
60	4.35	5.25	7.80	4.00	4.40	4.85
50	4.30	5.05	7.80	3.85	4.30	4.90
40	3.50	5.00	7.75	4.25	4.55	4.95
30	4.40	5.40	7.70	4.25	4.35	4.95
20	3.85	5.25	7.90	4.65	4.80	5.00
10	4.30	5.30	7.80	4.60	4.70	4.90
1	3.80	4.95	7.55	4.75	4.95	4.95

Table 17 (Continued)

```
PROBABILITY OF KILLING AN ANTI-TANK SYSTEM
RAPID APPROACH

           INT     SLOPE     CORR      %CHG       T       80%CONF(SLOPE)
%TOWS    33.64   -0.2897   -0.79     -86.1     -3.84    -0.3865 -0.1929
%DEF     37.29    0.0127    0.17       3.4      0.53    -0.0181  0.0435
RATIO     0.90    0.1616    0.73     475.0      3.25     0.0978  0.2254
ROUNDS    0.23    0.0003    0.26      12.6      0.81    -0.0002  0.0008
TIME       837   -0.2091   -0.51      -2.5     -1.78    -0.3601 -0.0581
#TANKS    3.87    0.0031    0.34       8.1      1.08    -0.0006  0.0069
1000 M    4.71    0.0035    0.54       7.3      1.90     0.0011  0.0058
2000 M    7.54    0.0023    0.29       3.0      0.91    -0.0009  0.0055
#ATMS     3.62    0.0104    0.80      28.8      3.95     0.0070  0.0138
1000 M    3.97    0.0087    0.85      22.0      4.81     0.0064  0.0111
2000 M    4.66    0.0031    0.63       6.6      2.41     0.0015  0.0047

% OF        % OF        %DEFENSE      DEFENSIVE     TANK        MEAN
BASE-       TOWS        REACHING      EXCHANGE      ROUNDS      TIME
LINE        KILLED      200M          RATIO         FIRED       (SEC)

 500         80           53            1.20         0.29        840
 100         26           38            5.07         0.24        830
  90         43           33            4.32         0.21        830
  80         20           40            4.76         0.19        830
  70         33           40            3.63         0.31        820
  60         10           38            9.07         0.20        840
  50         25           37            5.95         0.28        840
  40         20           35            4.81         0.27        850
  30         15           42            7.47         0.24        820
  20         15           38            6.88         0.28        810
  10          5           38           23.40         0.24        810
   1          0           38           23.40         0.24        810

% OF
BASE-      TANKS ALIVE(MEANS)                  ATMS ALIVE(MEANS)
LINE    200 M    1000 M     2000 M       200 M     1000 M      2000 M

 500    5.75     6.10        7.95        2.25       2.70        4.25
 100    4.04     4.84        7.44        4.00       4.23        4.91
  90    3.50     4.40        7.30        3.55       3.90        4.60
  80    4.10     4.95        7.75        3.85       4.15        4.50
  70    4.30     4.90        7.90        3.50       3.90        4.70
  60    4.05     4.75        7.85        4.35       4.50        4.90
  50    3.80     5.05        7.70        4.10       4.35        4.80
  40    3.50     4.75        7.35        4.05       4.65        4.85
  30    4.30     4.85        7.40        4.30       4.35        4.75
  20    4.35     5.25        8.05        4.15       4.70        5.00
  10    4.30     4.95        7.50        4.80       4.85        4.95
   1    4.05     5.00        7.90        4.85       4.85        5.00
```

Table 17 (Concluded)

TANK SPEED
RAPID APPROACH

	INT	SLOPE	CORR	%CHG	T	80%CONF(SLOPE)	
%TOWS	32.80	0.0207	0.10	6.3	0.24	-0.0893	0.1308
%DEF	33.83	-0.1267	-0.54	-37.4	-1.57	-0.2301	-0.0233
RATIO	4.52	0.0214	0.47	47.3	1.30	0.0003	0.0425
ROUNDS	0.23	0.0029	0.91	127.2	5.29	0.0022	0.0036
TIME	754	15.3095	0.98	203.0	12.50	13.7395	16.8796
#TANKS	3.84	-0.0250	-0.91	-65.0	-5.48	-0.0308	-0.0191
1000 M	5.05	-0.0359	-0.98	-71.1	-10.99	-0.0401	-0.0317
2000 M	7.76	-0.0281	-0.91	-36.2	-5.32	-0.0348	-0.0213
#ATMS	3.71	0.0011	0.10	2.9	0.24	-0.0048	0.0069
1000 M	4.08	-0.0022	-0.19	-5.3	-0.48	-0.0079	0.0036
2000 M	4.87	-0.0095	-0.78	-19.5	-3.02	-0.0135	-0.0055

% OF BASE-LINE	% OF TOWS KILLED	%DEFENSE REACHING 200M	DEFENSIVE EXCHANGE RATIO	TANK ROUNDS FIRED	MEAN TIME (SEC)
500	5	82	2.64	0.04	240
100	26	38	5.07	0.24	830
90	33	37	3.74	0.28	910
80	38	27	5.21	0.31	1070
70	40	27	4.90	0.25	1120
60	33	22	6.70	0.31	1240
50	40	26	4.05	0.37	1590
40	30	26	6.86	0.41	1690
30	30	32	5.65	0.46	1870

% OF BASE-LINE	TANKS ALIVE(MEANS) 200 M	1000 M	2000 M	ATMS ALIVE(MEANS) 200 M	1000 M	2000 M
500	7.70	7.85	8.90	4.55	4.65	4.80
100	4.04	4.84	7.44	4.00	4.23	4.91
90	3.95	5.00	7.45	3.50	4.00	4.75
80	3.05	4.25	7.65	3.70	4.10	4.60
70	2.80	4.10	7.15	3.65	3.85	4.65
60	2.60	3.65	6.65	3.90	4.15	4.75
50	2.45	2.95	5.85	3.30	3.40	4.00
40	2.45	2.90	6.35	4.15	4.25	4.35
30	2.40	2.65	5.70	3.80	4.05	4.30

APPENDIX B

CREW RELIABILITY MODEL

There are two ways in which the performance levels for individuals of a tank crew can serve as inputs to the TETAM land combat model. One way involves the systematic variation of the input parameters used in the model. The second is based on a model of crew reliability. This involves the removal of a number of tanks from the threat force while other TETAM input parameters are held fixed.

The tank crew reliability model is based on the assumption that the individual crew members of a tank crew either can or cannot work together as a crew to perform a "well defined tank operation". That is, either the crew is functioning at a prescribed level of performance, or it isn't. If the crew is functioning, then a "go" situation exists; otherwise a "no-go" situation exists.

When the crewmembers are operating at near 100% of baseline performance, it is more probable that a "go" situation exists than when one or more of them is operating at some lesser level of performance. The reliability of a tank crew is the probability that the crew will perform as if undegraded, and is a function of the performance levels of the individual crew members.

Because of crew cross-training, and the ability to operate a tank with only three crew members, the functional relationship between reliability and performance of crew members may be approximated by considering the four individual crew members as components of a system with redundancies as illustrated in Figure 37. In this system the tank commander and gunner are assumed to be in "parallel", i.e., each can perform both the gunner's and tank commander's tasks in the absence of the other. The loader and driver are assumed to be in "series", i.e., both are required to perform in order to maintain the tank weapon system performance. Another constraint is that either the loader or driver, but not both, may be replaced by either the tank commander or gunner.

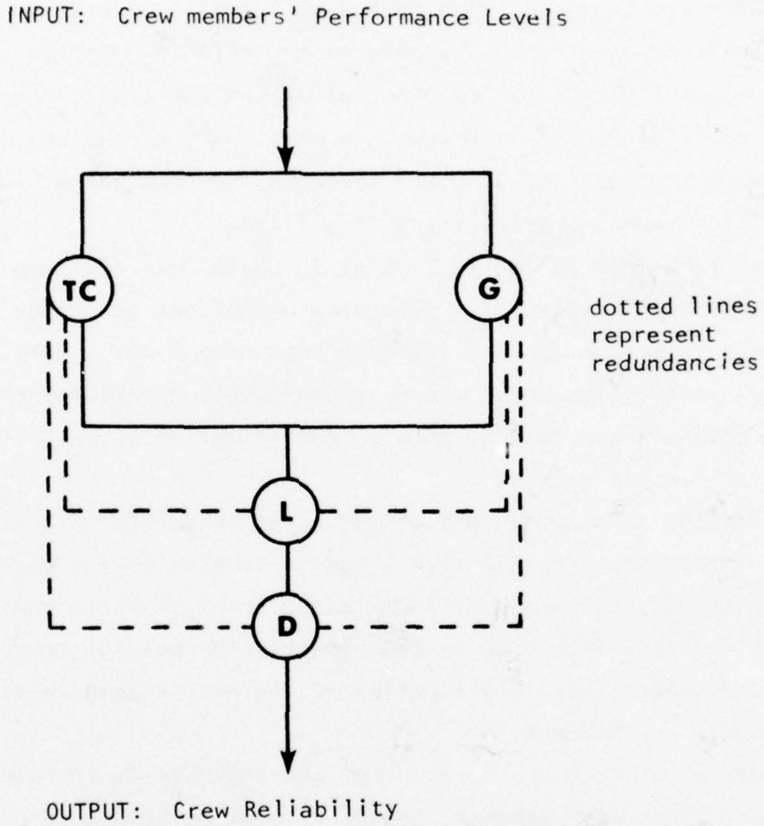

Figure 37. Schematic Representation of a Tank Crew as a System With Inherent Redundancies.

The reliability of this system is a function of individual crew member performance levels and is given by Equation 1. The reliability given by Equation 1 is the probability that the crew will perform as if undegraded, i.e., unaffected by nuclear radiation. When applied to a large number of tanks, the equation yields the effective percentage of undegraded tanks. This percentage, however, depends on the tactical situation, order of battle, and the task required of each group of tanks, which may vary in difficulty. Baseline values for the reliability of undegraded tank crews are needed to normalize the output of Equation 1 with respect to task difficulty. For example, a tank crew may be faced with such a difficult task that the probability of success is close to zero even though the tank crew may be at 100 percent of baseline performance. Therefore, the output of Equation 1, which indicates the percentage of undegraded tanks, is meaningful when compared to the number of undegraded tanks (i.e., tanks with undegraded crews) performing a mission at a given level of task difficulty.

$$\begin{aligned}\text{Reliability of crew} &= f(P_1, P_2, P_3, P_4)\\ &= P_1(1-P_2)\,P_3P_4 + P_2(1-P_1)\,P_3P_4 + P_1P_2P_3(1-P_4)\\ &\quad + P_1P_2P_4(1-P_3) + P_1P_2P_3P_4\end{aligned}$$

where P_1, P_2, P_3, P_4 are performance levels of Tank Commander, Gunner, Loader, and Driver, respectively.

Equation 1. Functional Relationship Between Crew Reliability and Crew Member Performance.

The following example of the reliability model is based on the sample data in Table 18. Performance levels of the individuals of five tank crews and the corresponding tank crew reliability levels determined by Equation 1 are shown in the table. The average of the reliabilities of the five tanks is the percentage of tanks in a "go" state. It is assumed that if a tank is in a "go" state or a "no-go" state it is operating at 100 percent or 0 percent of its preirradiation performance level, respectively.

Assuming that the level of task difficulty in this example is such that any nondegraded crew could perform the task, the average reliability from Table 18 indicates that 75 percent of the five tanks are in a "go" state and 25 percent in a "no-go" state. The number of tanks input into the TETAM Post Play model should therefore be reduced by 25 percent, while the other input parameters are held fixed. The impact of reduced threat on battle outcome may then be assessed through the use of the TETAM model. The output of TETAM has been found to be sensitive to changes in threat force.

Performance levels of individuals will vary depending upon the level of irradiation, dose rate, neutron-gamma ratio, motivation, stress, biological variation of individual sensitivity to ionizing radiation, and the task being performed (see ANNEX A). It is not known what the performance limits of irradiated crew members will be; however, 10 performance levels have been assumed. The 10 performance levels in Table 19 which have been chosen yield a broad range of results for crew reliabilities. For examble, performance level 1 corresponds to all of the individual crew members at 100 percent baseline performance with a resulting crew reliability of 1.0. Performance level 5 corresponds to the tank commander and gunner at 75 percent baseline performance and the loader and driver at 50 percent baseline performance. This level yields a crew reliability of .52 as determined by Equation 1. Performance level 10 results in a crew reliability of .05. If not otherwise noted, performance levels 1 through 10 in Table 19 are used throughout this Appendix.

TABLE 18. EXAMPLE OF TANK CREW RELIABILITY AS A FUNCTION OF CREW MEMBER PERFORMANCE

Tank #	Crew Member Performance				Reliability (from Eq. 1)
	Tank Commander	Gunner	Loader	Driver	
1	.75	.80	.80	.75	.78
2	.55	.95	.45	.85	.65
3	.95	.70	.70	.80	.80
4	.90	.45	.85	.85	.79
5	.80	.75	.45	.90	.71
1 - 5	Average Reliability				.75

TABLE 19. CREW RELIABILITY (FROM EQUATION 1) AS A FUNCTION OF CREW MEMBER PERFORMANCE

Level #	Crew Member Performance				Crew Reliability
	Tank Commander	Gunner	Loader	Driver	
1	1.0	1.0	1.0	1.0	1.00
2	1.0	1.0	.75	.75	.94
3	1.0	1.0	.50	.50	.75
4	.75	.75	.75	.75	.74
5	.75	.75	.50	.50	.52
6	1.0	1.0	.25	.25	.44
7	.50	.50	.50	.50	.31
8	.75	.75	.25	.25	.27
9	.50	.50	.25	.25	.14
10	.25	.25	.25	.25	.05

The assumption that the tank commander can substitute for the gunner (etc.) with no degradation in system performance is implicit in Equation 1. However, the effect of crew substitution on system reliability may be more than minimal.

The requirement to shift a crewman from his assigned position in the tank to another position could result in a performance decrement due to an initial unfamiliarity with that position. This could be minimal with a skilled crewman, but a more pronounced and sustained performance degradation could occur as a result of concentrating the functions of two stations into one.

This is best illustrated by the results of testing conducted by the 3rd Infantry Division, designed to evaluate the effectiveness of the three-man tank crew in the M60A1 tank. From these tests it was established that fewer first round hits, less success in adjusting fire after a first round miss, and a delay in getting off a first round resulted. However, scores on the Table VIII Crew Proficiency tests for the three-man crew were found to be much less affected than had been expected.[1]

Reduced levels of performance when crew members are required to substitute for others while performing all required functions may be accounted for by introducing replacement factors into Equation 1. The result is given by Equation 2.

Equation 2 gives the crew reliability as a function of individual crew member performance and degradation in crew member performance when a crew member substitutes for another crew member. Table 20 presents replacement factors as a function of the missing crew member, substitute crew members, and crew position which has been filled. The replacement factors are taken to be constants and not a function of radiation-degraded performance levels. In this table, for example, it is seen that when the gunner substitutes for the tank commander, the gunner's performance of his own tasks degrades by a factor of $1 - \alpha_4$ and by a factor of $1 - \alpha_3$ for the tank commander's tasks. If the tank commander were to substitute

$$
\begin{aligned}
\text{Crew Reliability} = {} & (1 - \alpha_2)\ (1 - \alpha_1)P_1(1 - P_2)\ P_3P_4 \\
& + (1 - \alpha_4)\ (1 - \alpha_3)P_2(1 - P_1)\ P_3P_4 \\
& + (1 - \alpha_2)\ (1 - \alpha_1)\ (1 - \beta_1)\ [P_1P_2P_3(1 - P_4) \\
& + P_1P_2P_4\ (1 - P_3)] + P_1P_2P_3P_4
\end{aligned}
$$

where P_1, P_2, P_3, P_4 are performance levels of tank commander, gunner, loader, and driver, respectively. α_1, α_2, α_3, α_4, β_1 are replacement parameters that degrade performance and $0 \leq \alpha_2 \leq \alpha_4 \leq \alpha_1 \leq \alpha_3 \leq 1$, $0 \leq \beta_1 \leq 1$ (See Table B-3).

Equation 2. Crew Reliability as a Function of Crew Member Performance and Degradation in Performance When a Crew Member Substitutes For Another Crew Member.

TABLE 20. PERFORMANCE REPLACEMENT FACTORS WHEN CREW MEMBERS ARE REQUIRED TO SUBSTITUTE FOR OTHER CREW MEMBERS WHILE ALL FUNCTIONS ARE MAINTAINED

Missing Crewmember	Substitute Crewmember	Replacement Factors			
		Tank Commander	Gunner	Loader	Driver
Tank Commander	Gunner	$1-\alpha_3$ *G	$1-\alpha_4$ G	1 L	1 D
Gunner	Tank Commander	$1-\alpha_2$ TC	$1-\alpha_1$ TC	1 L	1 D
Loader	Tank Commander	$1-\alpha_3$ G	$1-\alpha_4$ G	$1-\beta_1$ TC	1 D
	Gunner	$1-\alpha_2$ TC	$1-\alpha_1$ TC	$1-\beta_1$ G	1 D
Driver	Tank Commander	$1-\alpha_3$ G	$1-\alpha_4$ G	1 L	$1-\beta_1$ TC
	Gunner	$1-\alpha_2$ TC	$1-\alpha_1$ TC	1 L	$1-\beta_1$ G

*Letter indicates which crewmember is filling this position:

TC = Tank Commander
G = Gunner
L = Loader
D = Driver

for the loader, the table indicates that the tank commander's performance of the loader's tasks would degrade by a factor of $1 - \beta_1$. In this example, however, since the tank commander is substituting for the loader, the gunner must substitute for the tank commander while also performing his own tasks as a gunner. This results in replacement factors of $1 - \alpha_4$ for the gunner's position and $1 - \alpha_3$ for the tank commander's position.

Since there has been no precise determination of the magnitute of the replacement parameters α_1, α_2, α_3, α_4, and β_1, various values of these parameters have been selected as inputs to Equation 2, yielding a broad range of results. Table 21 lists the values of the replacement parameters used in Equation 2. Table 19 provides the performance inputs P_1, P_2, P_3, and P_4 for Equation 2.

The combination of 21 replacement parameter values and 10 performance levels results in 210 values of crew reliability. These are shown in Table 22. Table 22 indicates that as the magnitude of the replacement parameter increases and/or the performance level decreases, the crew reliability decreases and falls off to zero.

The uncertainty in the level of performance of an individual crew member may be quite large. Biological variation in Macaca Mulatta monkey, resulting in variance in performance levels indicates that human performance will vary also. It is quite unlikely that an individual crew member's postirradiation performance level would be precisely known. However, the sum of the crew member performance levels is likely to vary less than in individual's performance because of the larger sample size.

Table 24 lists performance levels whose entries sum to a constant. The data in Table 24 were used to generate Figure 38, which shows the relationship between crew reliability and the sum of the four crew members' performance levels.

For example, in Figure 38 the crew reliability of 0.24 when the sum of crew member performance levels equals 2 is a mean reliability based on

TABLE 21. CREW MEMBER REPLACEMENT PARAMETERS
USED IN EQUATION 2

Case #	Replacement Parameters				
	α_1	α_2	α_3	α_4	β
1	0	0	0	0	0
2	0.06	0.02	0.08	0.04	0.01
3	0.08	0.04	0.1	0.06	0.02
4	0.1	0.06	0.1	0.08	0.03
5	0.1	0.08	0.1	0.1	0.04
6	0.1	0.1	0.1	0.1	0.05
7	0.15	0.05	0.2	0.1	0.025
8	0.2	0.1	0.25	0.15	0.05
9	0.25	0.15	0.25	0.2	0.075
10	0.25	0.15	0.3	0.2	0.075
11	0.25	0.2	0.25	0.25	0.1
12	0.25	0.25	0.25	0.25	0.125
13	0.3	0.2	0.35	0.25	0.1
14	0.35	0.25	0.4	0.3	0.125
15	0.4	0.3	0.45	0.35	0.15
16	0.45	0.35	0.5	0.4	0.175
17	0.5	0.4	0.5	0.45	0.2
18	0.5	0.45	0.5	0.5	0.225
19	0.5	0.5	0.5	0.5	0.25
20	0.75	0.75	0.75	0.75	0.375
21	0.9	0.9	0.9	0.9	0.45

TABLE 22. CREW RELIABILITY (FROM EQUATION 2) AS A FUNCTION OF CREW MEMBER PERFORMANCE AND REPLACEMENT PARAMETERS

Case	Performance Levels									
	1*	2	3	4	5	6	7	8	9	10
1**	1.00†	0.94	0.75	0.74	0.52	0.44	0.31	0.27	0.14	0.05
2	1.00	0.90	0.71	0.70	0.48	0.40	0.29	0.25	0.13	0.05
3	1.00	0.89	0.68	0.68	0.47	0.39	0.28	0.24	0.12	0.04
4	1.00	0.87	0.66	0.67	0.45	0.37	0.27	0.23	0.12	0.04
5	1.00	0.86	0.65	0.66	0.44	0.36	0.26	0.22	0.12	0.04
6	1.00	0.85	0.63	0.65	0.43	0.35	0.26	0.22	0.11	0.04
7	1.00	0.86	0.64	0.64	0.43	0.36	0.26	0.22	0.11	0.04
8	1.00	0.82	0.59	0.60	0.40	0.32	0.23	0.20	0.10	0.04
9	1.00	0.78	0.54	0.57	0.36	0.28	0.21	0.17	0.09	0.03
10	1.00	0.78	0.54	0.57	0.36	0.28	0.21	0.17	0.09	0.03
11	1.00	0.77	0.52	0.55	0.35	0.27	0.20	0.16	0.08	0.03
12	1.00	0.75	0.50	0.54	0.33	0.25	0.19	0.15	0.08	0.03
13	1.00	0.75	0.50	0.53	0.33	0.25	0.19	0.15	0.08	0.03
14	1.00	0.72	0.46	0.50	0.30	0.22	0.17	0.14	0.07	0.02
15	1.00	0.70	0.43	0.47	0.28	0.20	0.16	0.12	0.06	0.02
16	1.00	0.67	0.40	0.45	0.25	0.17	0.14	0.11	0.05	0.02
17	1.00	0.65	0.37	0.43	0.24	0.15	0.13	0.09	0.05	0.02
18	1.00	0.64	0.36	0.42	0.23	0.14	0.12	0.09	0.04	0.02
19	1.00	0.63	0.34	0.41	0.22	0.13	0.12	0.08	0.04	0.01
20	1.00	0.58	0.27	0.34	0.16	0.08	0.08	0.04	0.02	0.01
21	1.00	0.56	0.25	0.32	0.14	0.06	0.06	0.04	0.02	0.00

*These level #s correspond to the level #s in Table F-2.

**These case #s correspond to the case #s in Table F-4.

†The cell entries are crew reliabilities for given crew member performance levels and replacement parameters.

input data from Table 24. In this case, the 15 performance levels listed in Table 24 under "sum of performance level = 2" serve as input data to Equation 2. The resulting 15 crew reliability levels are averaged, yielding a crew reliability of .24. The variance of the 15 reliability levels is displayed in the graph. Figure 38 indicates that:

(1) Crew reliability is relatively unaffected by variance in individual crew member performance.

(2) The resulting overall variance in crew reliability is minimal.

(3) There appears to be no need to know precisely individual crew member performance levels.

Figure 39 shows crew reliability as a function of the sum of performance levels for replacement parameter values of 0, .25, .50, and .75. Figure 39 is similar to Figure 38 and is based on the input data of Table 24. The values of the replacement parameters correspond to Cases 1, 12, 19, and 20 in Table 21. Table 23 contains the values of crew reliability plotted in Figure 39, along with the corresponding standard deviations.

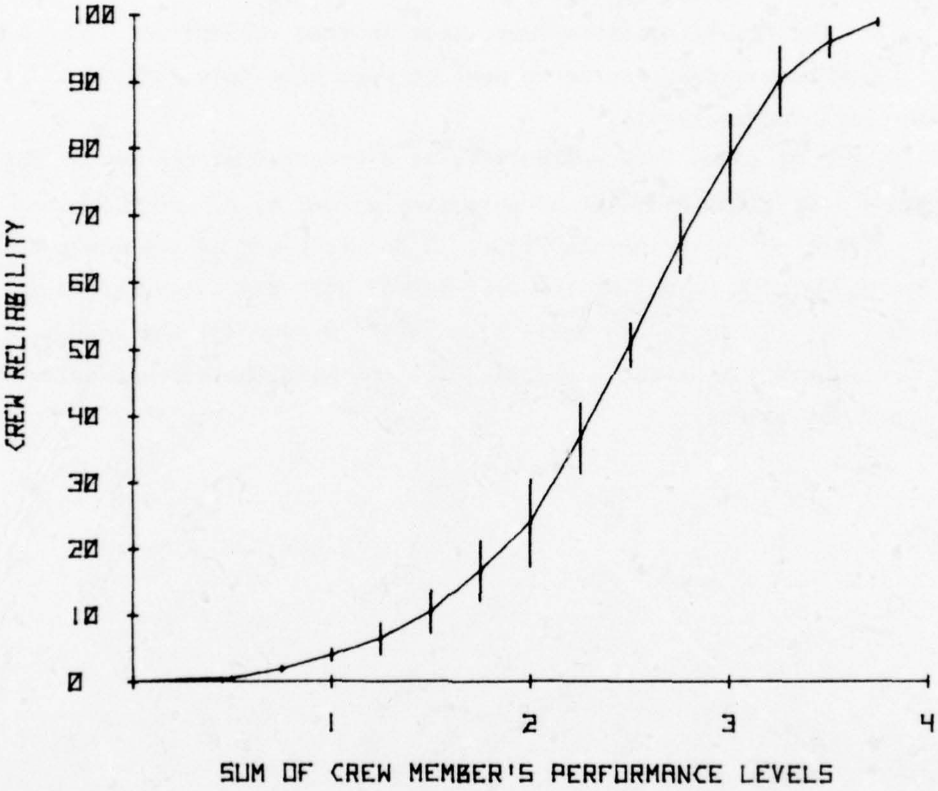

Figure 38. Crew Reliability as a Function of The Sum of Crew Member's Performance Levels (Replacement Parameter = 0).

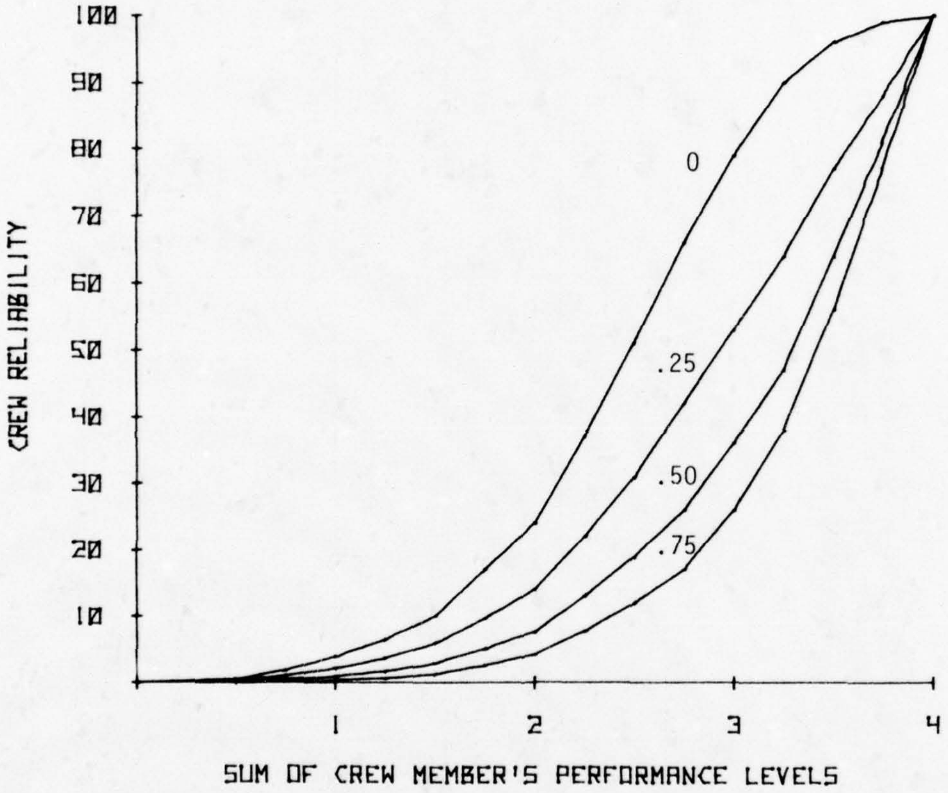

Figure 39. Crew Reliability as a Function of the Sum of Crew Member's Performance Levels for Indicated Values of Replacement Parameters.

TABLE 23. CREW RELIABILITY AS A FUNCTION OF THE SUM OF PERFORMANCE LEVELS OF TANK CREW MEMBERS FOR INDICATED VALUES OF REPLACEMENT PARAMETERS

Replacement Parameter Value	Sum of Performance Levels														
	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	3.25	3.50	3.75	4.00
0	.005*	.019	.039	.064	.100	.170	.240	.370	.510	.660	.790	.900	.960	.990	1.000
	.001	.004	.008	.023	.031	.044	.065	.052	.031	.043	.065	.050	.023	.005	0†
.25	.003	.011	.022	.036	.059	.097	.140	.220	.310	.420	.530	.640	.770	.880	1.000
	.001	.002	.004	.013	.019	.028	.043	.043	.028	.018	.015	.016	.011	.007	0†
.50	.001	.005	.010	.017	.029	.051	.077	.130	.190	.260	.360	.470	.640	.810	1.000
	.000	.001	.003	.007	.011	.018	.029	.035	.033	.034	.039	.040	.021	.008	0†
.75	.000	.002	.004	.007	.013	.026	.042	.078	.120	.170	.260	.380	.560	.770	1.000
	.000	.000	.001	.004	.007	.011	.022	.030	.036	.054	.067	.052	.023	.006	0†
.90	.000	.001	.003	.005	.009	.019	.033	.065	.100	.150	.240	.360	.540	.760	1.000
	.000	.000	.000	.003	.006	.010	.020	.029	.037	.060	.075	.055	.023	.005	0†

*The cell entries are: Crew reliability mean/std.

†The standard deviation is 0 because there is only one way performance levels can sum to 4.

ANNEX TO APPENDIX B

PERFORMANCE LEVEL LISTING

Table 24 lists the performance levels used in Equation 2 to generate Figures 38 and 39, and Table 26. The entries appearing in each row from left to right are performance levels for the tank commander, gunner, loader, and driver, respectively. The values of performance levels were chosen to generate variance in individual performance while the individual entries of rows of a group were constrained to sum to a constant.

Table 24. LISTING OF PERFORMANCE LEVELS AND SUM OF PERFORMANCE LEVELS USED TO GENERATE VARIANCE

Sum of Performance Levels = 0.5

0.25*	0.1	0.05	0.1
0.2	0.1	0.1	0.1
0.05	0.05	0.2	0.2
0.075	0.25	0.075	0.1
0.1	0.1	0.15	0.15
0.175	0.1	0.075	0.15
0.25	0.15	0.05	0.05
0.05	0.05	0.05	0.35

Sum of Performance Levels = 0.75

0.25	0.25	0.1	0.15
0.175	0.175	0.25	0.15
0.2	0.2	0.2	0.15
0.05	0.15	0.25	0.3
0.075	0.275	0.15	0.25
0.05	0.35	0.05	0.3
0.15	0.15	0.2	0.25

Sum of Performance Levels = 1

0.25	0.25	0.25	0.25
0.15	0.1	0.35	0.4
0.15	0.3	0.3	0.25
0.1	0.4	0.1	0.4
0.2	0.3	0.2	0.3
0.5	0.1	0.2	0.2
0.125	0.2	0.475	0.2
0.3	0.4	0.1	0.2
0.175	0.3	0.125	0.4
0.175	0.525	0.1	0.2
0.4	0.5	0.05	0.05
0.075	0.375	0.05	0.5
0.15	0.1	0.35	0.4
0.125	0.4	0.125	0.35

Sum of Performance Levels = 1.25

0.25	0.25	0.25	0.5
0.1	0.1	0.4	0.65
0.1	0.3	0.4	0.45
0.45	0.2	0.3	0.3
0.35	0.4	0.1	0.4
0.75	0.25	0.1	0.15
0.55	0.3	0.25	0.15
0.5	0.5	0.15	0.1
0.6	0.15	0.4	0.1
0.05	0.05	0.65	0.5
0.15	0.55	0.05	0.5
1	0.1	0.1	0.05
0.95	0.1	0.1	0.1
0.45	0.3	0.25	0.25
0.45	0.2	0.2	0.4

*Entries from left to right are performance levels for the tank commander, gunner, loader, and driver, respectively.

Table 24. (Continued)

Sum of Performance Levels = 1.5

0.25	0.25	0.25	0.75
0.5	0.5	0.25	0.25
0.7	0.05	0.5	0.25
1	0.25	0.1	0.15
0.2	0.8	0.4	0.1
0.7	0.05	0.7	0.05
0.6	0.6	0.15	0.15
0.5	0.25	0.6	0.15
0.4	0.35	0.4	0.35
0.6	0.15	0.4	0.35
0.9	0.4	0.1	0.1
0.1	0.9	0.4	0.1

Sum of Performance Levels = 1.75

0.5	0.5	0.5	0.25
0.25	0.25	0.25	1
0.75	0.75	0.1	0.15
0.6	0.25	0.75	0.15
0.45	0.3	0.45	0.55
0.55	0.2	0.7	0.3
1	0.05	0.65	0.05
1	0.35	0.2	0.2
0.2	1	0.2	0.35
0.25	0.25	0.5	0.75

Sum of Performance Levels = 2

0.5	0.5	0.5	0.5
0.25	0.25	0.75	0.75
0.35	0.65	0.25	0.75
0.4	0.4	0.6	0.6
0.5	0.4	0.6	0.5
0.3	0.7	0.3	0.7
1	0.35	0.4	0.25
0.3	0.7	0.2	0.8
0.2	0.2	0.8	0.8
0.2	0.8	0.1	0.9
0.1	0.1	0.9	0.9
0.15	0.85	0.05	0.95
0.95	0.05	0.95	0.05
1	0.15	0.1	0.75
0.25	0.5	0.25	1

Sum of Performance Levels = 2.25

0.5	0.5	0.5	0.75
1	0.4	0.4	0.45
0.75	0.75	0.25	0.5
0.65	0.35	0.75	0.5
0.5	0.5	0.6	0.65
0.4	0.4	0.7	0.75
0.6	0.6	0.4	0.65
0.2	0.7	0.6	0.75
0.3	0.85	0.3	0.8
0.3	0.7	0.55	0.7
0.9	0.9	0.2	0.25
1	1	0.05	0.2
0.05	0.95	0.25	1
1	0.3	0.85	0.1
0.25	1	0.7	0.3

Table 24. (Continued)

Sum of Performance Levels = 2.5

0.75	0.75	0.5	0.5
0.65	0.6	0.75	0.5
1	1	0.25	0.25
0.75	0.5	1	0.25
0.1	0.8	0.8	0.8
0.8	0.85	0.8	0.05
0.5	0.5	0.5	1
0.45	0.55	0.7	0.8
0.35	0.65	0.6	0.9
0.9	0.9	0.35	0.35
1	0.25	0.9	0.35
0.9	0.75	0.35	0.5

Sum of Performance Levels = 2.75

1	1	0.5	0.25
1	0.35	0.9	0.5
0.75	0.75	0.75	0.5
0.5	0.5	1	0.75
0.7	0.7	0.7	0.65
0.5	0.9	0.9	0.45
0.05	0.9	0.9	0.9
0.1	0.9	1	0.75
0.85	0.1	0.9	0.9
0.25	0.75	0.8	0.95

Sum of Performance Levels = 3

0.75	0.75	0.75	0.75
0.65	0.65	0.85	0.85
0.95	0.55	0.85	0.65
0.95	0.55	0.95	0.55
0.05	0.95	1	1
0.15	0.85	1	1
0.25	0.75	1	1
0.85	0.4	0.75	1
1	1	0.5	0.5
0.6	0.4	1	1
0.45	0.55	1	1

Sum of Performance Levels = 3.25

1	1	1	0.25
1	1	0.5	0.75
1	0.55	0.95	0.75
1	1	0.4	0.85
1	0.35	1	0.9
1	1	0.3	0.95
1	0.4	0.9	0.95
0.75	0.75	0.75	1
0.85	0.85	0.55	1
0.9	0.9	0.7	0.75

Table 24. (Concluded)

Sum of Performance Levels = 3.5				Sum of Performance Levels = 3.75			
0.75	0.75	1	1	1	1	0.825	0.925
1	1	1	0.5	1	1	1	0.75
0.85	0.65	1	1	0.85	0.9	1	1
1	0.6	1	0.9	1	0.775	1	0.975
0.95	0.55	1	1	0.95	0.8	1	1
1	0.725	1	0.775	1	0.825	0.925	1

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APPENDIX C

NUCLEAR WEAPON EFFECTS

The detonation of a nuclear weapon results in several primary effects that can serve as casualty producers. These include blast, thermal radiation, and nuclear radiation.

1. BLAST EFFECTS

There are two effects of the blast or shock wave. The first is the effect of overpressure on the body, which may cause injury to internal organs or rupture the eardrums. The second is translational acceleration by the strong winds produced by the nuclear burst, together with subsequent deceleration by impact with the ground or other unyielding objects. Such accelerations can cause injury, as can impact with blast-energized debris or with the interior of a vehicle that has been translated or overturned by blast winds.

Casualty production due to blast depends on the hardness of the target and the degree of overpressure arising from the shock wave. Blast radius, R(B), is defined as the distance from ground zero at which a particular target on the ground has a .50 probability of receiving a specified degree of damage. For uniformly distributed, randomly oriented targets, about 85 percent of those within the circle with radius R(B) receive at least the specified degree of damage. A number of targets outside this circle will also receive the specified degree of damage, and this number is equal to about 15 percent of the targets inside the circle. The total number of targets receiving the specified damage is therefore equal to the number of targets within the circle with radius R(B).

Table 25 gives blast radii for several targets and weapon yields. It is germane to consider what happens to the crew of a tank that receives

TABLE 25. DISTANCE (METERS) FROM GROUND ZERO AT WHICH THE PROBABILITY OF BLAST DAMAGE IS 0.5

Target	Blast Damage	Weapon Yield - Kilotons[1]					
		0.01	0.1	1.0	10.0	30	100.0
Tank	Moderate, Class II[2]	31	79	197	494	767	1344
Prone Personnel:							
In the Open	Injury[3] by translation and decelerative tumbling	29	73	184	452	694	1224
In the Open	Ear drum rupture	54	117	252	544	786	1217
Near Structures	Injury by translation and impact with rigid object	36	89	223	559	844	1433
In a Forest	Injury by tree blowdown, impact with blast-energized debris, translation, tree blowdown	59	148	367	912	1407	2366

[1] Height of burst = 100 (yield)$^{.35}$ ft. For 100 kt, height of burst = 180 (100)$^{.35}$

[2] Damaged, nonfunctional, repairable with special tools, skills, and parts. At least half of all subsystems are nonfunctional but repairable. A non-ideal surface is assumed.

[3] Injury to the extent that a person is unable to perform his assigned duties. An ideal surface is assumed. Distances would be somewhat greater for a non-ideal surface.

moderate blast damage, Class II. To undergo such damage from blast, the tank would have to experience overturning, considerable acceleration or tumbling. It is likely that the crew of such a tank would suffer injuries from impact with the vehicle interior.

2. THERMAL RADIATION

Thermal radiation from a nuclear burst can burn the skin of a person, even under clothing, and can ignite clothing, causing further burns. If a person is looking at a burst or a point near it, burns on the retina may be produced, causing various degrees of permanent loss of vision. The visible radiation can also produce "dazzle" or temporary loss of vision.

The production of casualties by thermal radiation is difficult to predict because of the many ways in which a person could be shielded. Figure 40 shows approximate ground distances at which second- and third-degree burns could be produced on exposed skin for a number of weapon yields. Third-degree burns would be incapacitating, as would second-degree burns on critical regions of the body (e.g., around the eyes, retinal burns, and on the hands). However, most kinds of shielding are effective in preventing such burns and personnel inside a tank or APC, or infantrymen shielded by a tree or vehicle would be unaffected.

3. DAZZLE

Dazzle, or flash-blindness, is a term used to designate an immediate temporary loss of visual function resulting from exposure of the human eye to a brilliant flash of light. It occurs when the radiant energy delivered to the retina does not raise the tissue above its critical value, and thereby produce a lesion, but is sufficient to cause bleaching of the photochemical substances within the rods and cones. The physiological response includes the initial dazzle effect and the after-image.

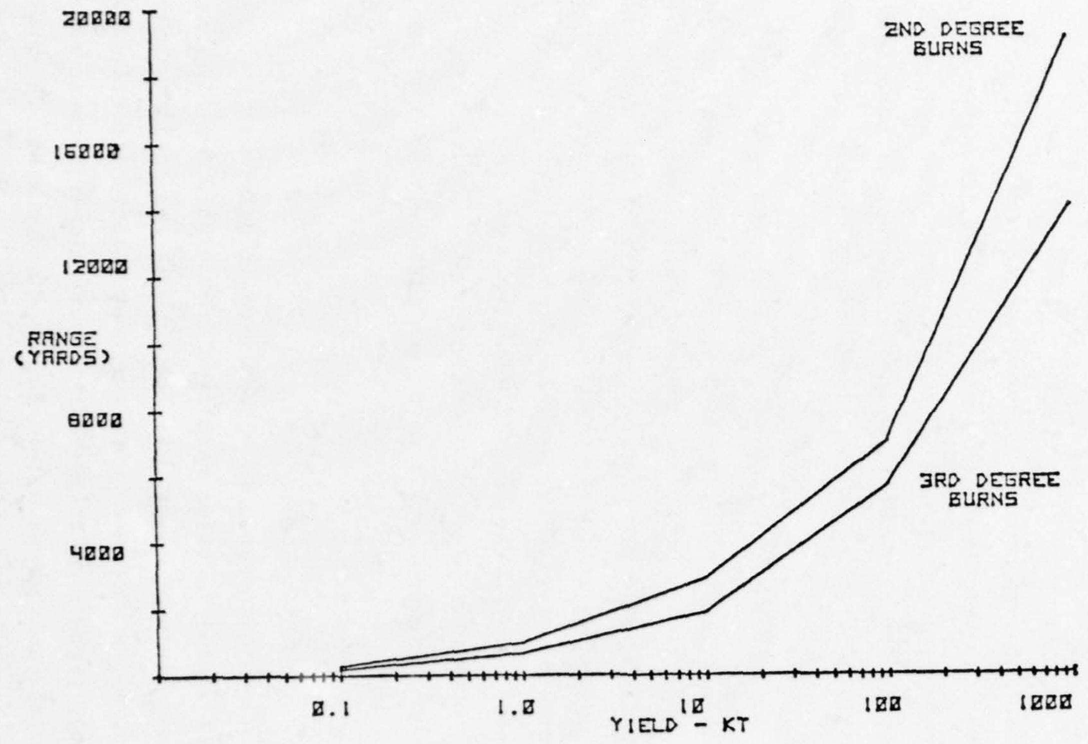

Figure 40. Range at Which 2nd and 3rd Degree Burns Occur on Exposed Skin (Visual Range = 16 Miles).

Dazzle generally is defined as the initial reaction of the eye to bright light, while the after-image is a transient scotoma caused by a visual impression that lasta after the stimulus has ceased to exist. The light-adapted eye depends entirely on cone response, and, following bleaching, the iodopsin in the cone regenerates promptly. The completely dark-adapted eye depends on the response of only the rods, and rhodopsin regeneration in the rods is negligible for several minutes after bleaching. Objects seen in daylight appear much brighter than when seen at night; thus a lesser degree of recovery is necessary for effective daylight vision. Recovery of effective vision is much faster if eyes are flash-blinded in daylight than when the flash-blindness occurs at night; further, recovery is faster under bright moonlight conditions when there is some cone response, than on a moonless night. It follows that flash-blindness is of longer duration and of more tactical significance for nighttime bursts than for daytime bursts.

EM-1 describes flash-blindness (dazzle) as follows:

> Flash-blindness (dazzle) is a temporary impairment of vision caused by the saturation of the light sensitive elements (rods and cones) in the retina of the eye. It is an entirely reversible phenomena which will normally blank out the entire visual field of view with a bright after-image. Flash-blindness normally will be brief, and recovery is complete.
>
> During the period of flash-blindness (several seconds to minutes) useful vision is lost. This loss of vision may preclude effective performance of activities requiring constant, precise visual function. The severity and time required for recovery of vision are determined by the intensity and duration of the flash, the viewing angle from the burst, the pupil size, brightness necessary to perform a task, and the background and visual complexity of the task. Flash-blindness will be more severe at night since the pupil is larger and the object being viewed and the background are usually dimly illuminated.

Flash-blindness may be produced by scattered light and does not necessarily require eye focusing on the fireball.

3.1 Duration of Effect

3.1.1 Unprotected, Day-adapted

Results of several tests indicate that light-adapted subjects oriented away from line-of-sight of the bursts experienced no visual impairment. Those subjects in aircraft who viewed a 14-kt low-air burst from a distance of about 14.5 km experienced temporarily-impaired vision with recovery in 2 minutes. Other recovery times have been noted as within 5 minutes.

3.1.2 Unprotected, Dark-adapted

The only data available on flash-blindness effects on the dark-adapted unprotected human eye are from Operation TUMBLER-SNAPPER. Those results indicate that viewing from 16 km the fireballs of 30-kt or 18.5-kt low-air bursts for an interval between 46 and 52 msec after burst until blink will require considerable recovery periods and is likely to produce a minimal retinal burn.

3.1.3 TUMBLER-SNAPPER

Subjects who observed two daytime bursts had dark-adapted eyes and were in a light-tight trailer located about 16.1 km from both bursts. Half the observers (total number unstated) were unprotected, and half wore protective red goggles that were estimated to transmit about 22 percent of the energy in the visible and infrared spectrum. All observers viewed through portholes that opened between 46 and 52 msec after flash, and closed after 2 seconds. The tests were discontinued because of two retinal injuries.

TUMBLER-SNAPPER reports do not identify retinal injury with shot, but do state that none of the individuals wearing goggles was injured. Observers wearing red goggles recovered the use of their eyes more rapidly than those who were unprotected.

Some insight into recovery time at night can be gained from the Upshot Knothole data involving protected personnel. Dark-adapted personnel who received about 25 percent of the incident light recovered from flash-blindness in about 4 minutes.

3.2 Directional Effects

Hardtack II: At Shot Hamilton (a fractional kiloton burst), 25 Army and Marine officers were stationed in the open in three groups located 5700 feet from ground zero. They were oriented at 90, 135, and 180 degrees from the line of sight of the daylight shot on a 50-foot wooden tower. Immediately after the shot, all personnel (who were completely light-adapted and unprotected by goggles) demonstrated normal visual acuity, and no subject reported experiencing dazzle.

It was concluded that dazzle is either non-existent or transitory in nature when the individual is light-adapted and that the return of photopic vision is rapid when adequate illumination is provided for performance of visual tasks.

3.3 Military Evaluation of Dazzle

The appropriate Army manual (FM 101-31-1) gives the Army view of the subject as follows:

Visual Effects: The flash of light produced by a nuclear explosion is many times brighter than the sun. This light can dazzle personnel or produce permanent retinal burns. These effects can be produced at greater distances from the burst than can skin burns.

Sufficient thermal energy arrives so fast that reflex actions, such as blinking, give only limited protection.

Dazzle (flash-blindness) is a temporary loss of vision. Dazzle from a burst during daylight hours persists for about 2 minutes. Only the personnel facing directly toward the burst or a reflective surface can be dazzled. At night, dazzle affects almost all personnel in the target area. Recovery may be expected within 10 minutes in personnel facing the burst and within 3 minutes in all others. Loss of night vision persists for longer periods. Recovery of night adaption may be experienced in as little as 15 minutes, depending on the level of visual thermal energy received.

3.4 Conclusion

Flash-blindness (dazzle) is a poorly documented effect; however, there is a general agreement that personnel recover from the effect in a few minutes during daylight. Only those personnel looking in the general direction of the explosion are significantly affected during daylight.

4. INITIAL NUCLEAR RADIATION

Initial nuclear radiation, which occurs within a minute or less after a burst, is ionizing radiation that can damage cells of the body. Residual nuclear radiation from fallout, or from elements in the earth's surface that have become radioactive by neutron capture, also produces ionizing radiation and can damage the body. Such damage manifests itself in a variety of symptoms depending on the amount of radiation absorbed by the body.

Death due to initial nuclear radiation may occur almost immediately or perhaps as much as 12 weeks later, depending upon the dose. The symptoms of cell damage due to ionizing radiation can range from a headache or loss of appetite to incapacitation. Persons experiencing the lower range of such symptoms could be expected to continue their duties, though perhaps at a lower level of performance. These two effects, the occurrence of death days or weeks after exposure, and a period of time following exposure during which a person's performance is degraded, are referred to as "delayed" or time-variable nuclear effects (TNE).

The synergistic combination of two or three nuclear weapon effects could give rise to either prompt casualty production or delayed effects, even if no single effect would have done so. The possibility of the synergistic effect is recognized, however there are insufficient data to support a quantitative treatment of it.

Distances from ground zero (GZ) at which various initial nuclear radiation doses and blast effects would result from a low airburst over a flat plain are illustrated schematically in Figure 41. The probability is 0.5 that a randomly oriented target (in this case, a tank) located at a distance R(B), the blast radius, from GZ would receive moderate blast damage. Crew members inside a tank located a distance of R(18000) from GZ would receive an 18,000 rad dose from initial nuclear radiation. At any point closer to GZ, the dose received would be greater than 18,000 rad. If it is assumed that personnel receiving doses of from 100 rad to 18,000 rad would suffer delayed (time variable) nuclear effects*, the area of the annulus defined by R(18000) and R(100) is an indication of the potential incidence of delayed nuclear effects resulting from the detonation of a single nuclear weapon.

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* i.e., personnel receiving a dose greater than 18,000 rad would suffer immeidate permanent incapacitation; those receiving less than 100 rad would survive, and would exhibit insignificant reduction in performance.

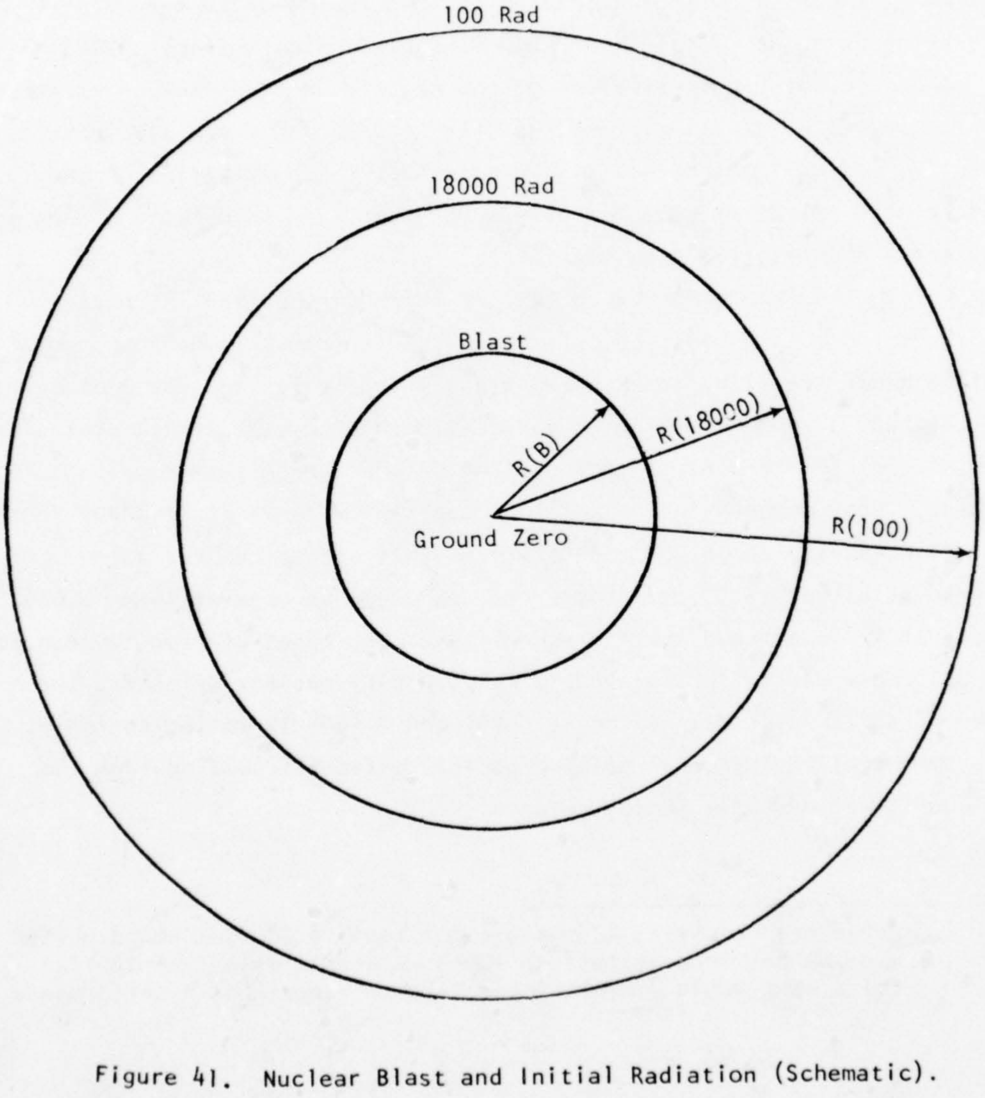

Figure 41. Nuclear Blast and Initial Radiation (Schematic).

As weapon yield increases, the blast radius, R(B), increases at a greater rate than does the distance at which a given initial nuclear radiation dose is received. As yield increases, R(B) will successively exceed R(18000), R(8000), etc. It is assumed that all crew members of a tank that is moderately damaged by blast effects will be injured (from impact with the tank interior) as the tank is accelerated or tumbled by the blast. Further, these injuries are assumed to be of such a degree as to cause the crew members to be declared casualties. (At the very least, the tank itself is out of action for some time). As the blast radius R(B) increases beyond R(100), the number [illegible] personnel in combat suffering delayed nuclear effects would be reduced to zero, provided that all personnel within the blast radius were declared to be casualties from blast effects.

The blast area is shown in Figure 42 for personnel in tanks, and in Figure 43 for unprotected, prone personnel in the open and in a forest. The blast effects for personnel in a forest include injury from translational acceleration and subsequent impact with the ground or a tree, and from being hit with blast-energized debris or with blown-down trees. These figures show the areas for which the initial nuclear radiation dose is greater than 18,000 rad, 8,000 rad, ... 1 rad. A protection factor of 0.6 for neutrons, and 0.4 for fission and secondary gamma is assumed for the tank. The dotted lines indicate the area of the circle with radius R(B), within which prompt casualties from blast effects are produced. As yield increases, blast effects become the dominant casualty producer.

In these figures, nuclear warhead Type 1* was used for yields less than 1 kt; Type 2 was used for yields from 1 kt to 30 kt; and Type 7 was used for yields of 100 kt and greater. Computations were made only

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*See "Capabilities of Nuclear Weapons (U)", DNA-EM-1, Headquarters, Defense Nuclear Agency, dated 1 July 1972 (Private Communications).

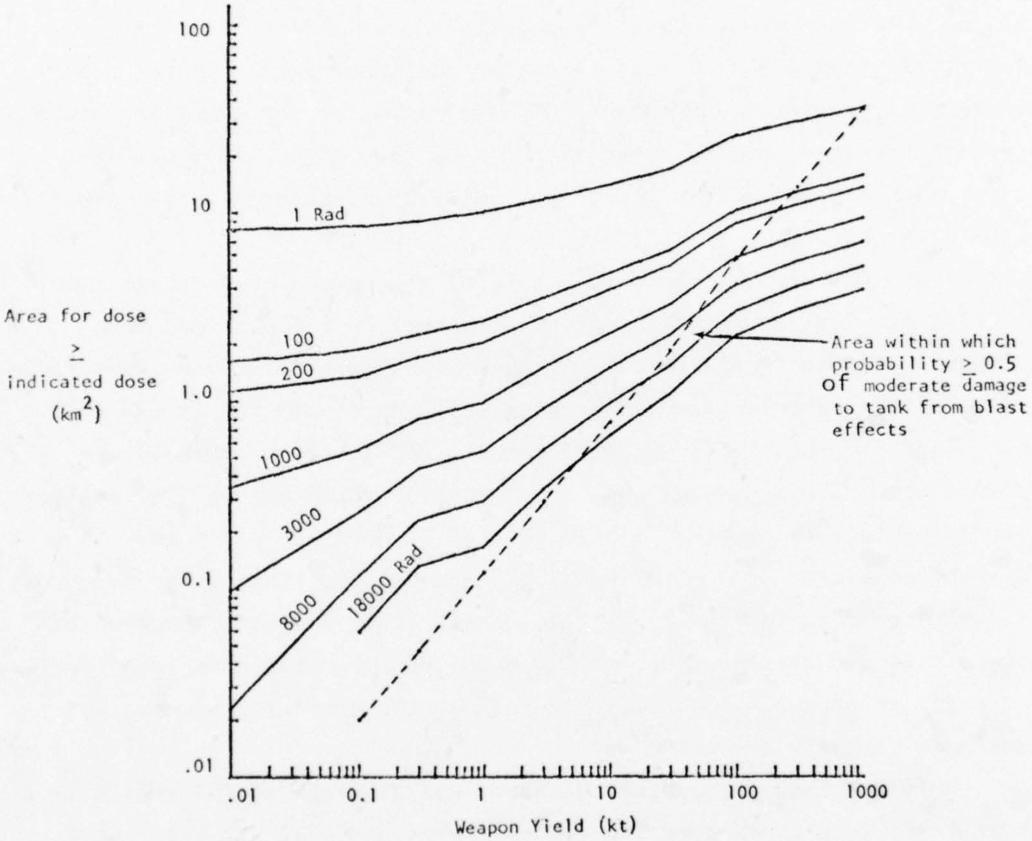

Figure 42. Initial Nuclear Radiation (Tank Crew) and Blast Effects (Tank).

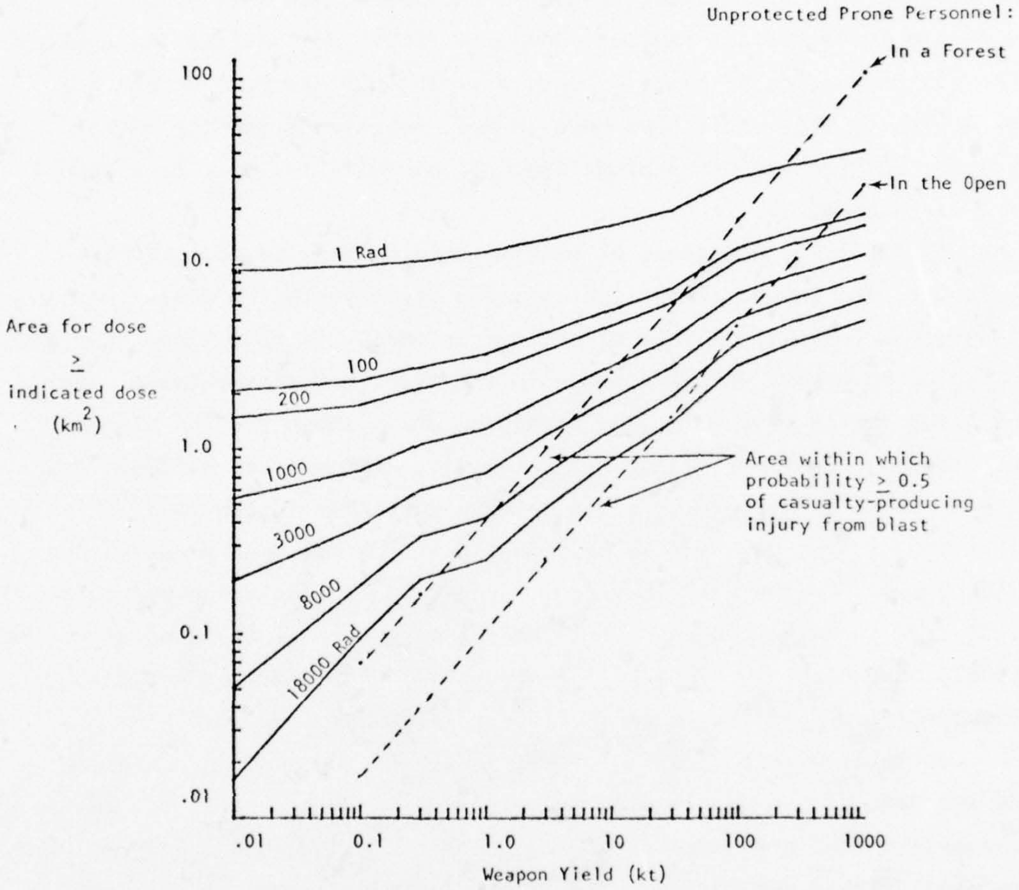

Figure 43. Initial Nuclear Radiation and Blast Effects (Unprotected Personnel)

for yields of 0.01, 0.1, 0.3, 1.0, 3, 10, 30, 100, 300, and 1000 kt. The marked change in slope of the curves from 0.3 kt to 1.0 kt, and from 30 kt to 100 kt, is caused by the change from one warhead type to another.

The height of burst (HOB) used was $100W^{0.35}$ feet, where W is yield in kilotons, for yields less than 100 kt. For yields of 100 kt and more, HOB was $180W^{0.35}$ feet. This is the lowest HOB that yields military insignificant fallout, but this HOB is not necessarily optimum for the production of blast effects. If the HOB had been chosen for this effect, R(B) would have been larger, especially for the higher yields, and the incidence of delayed nuclear effects would have been reduced even more.

In Table 26, the areas of annuli corresponding to various dose intervals are shown. These indicate the distribution of doses among tank crews receiving a dose of one rad or more. In this table, the area affected by blast, which is shown in the first row of the table, has been subtracted out; i.e., the remaining areas shown are for blast survivors. For example, for a 10 kt yield, R(B) exceeds R(18000) and there are no blast survivors who receive more than 18,000 rad. This is indicated by the dash in the cell for 10 kt and for dose greater than 18,000 rad. In the next lower entry under 10 kt, for the annulus 18,000 - 8000 rad, the area indicated (.21 km^2) is the area of the annulus defined by R(B) and R(8000), since R(B) exceeds R(18000). The maximum dose for blast survivors in this case is between 18,000 and 8000 rad.

In Table 27, the areas of Table 26 are presented as percentages of the area of the circle with radius R(100). This corresponds to the assumption that personnel receiving doses of less than 100 rad will not exhibit delayed nuclear effects. As in Table 26, when blast radius exceeds R(lower bound) of an interval, no entry is given since blast effects dominate and only prompt casualties are produced. As yield goes

TABLE 26. AREAS WITHIN WHICH TANK CREW BLAST SURVIVORS RECEIVE INDICATED INITIAL NUCLEAR RADIATION DOSES (square kilometers)

Dose Interval (Rad)	Weapon Yield (kt)									
	.01	.1	.3	1.0	3	10	30	100	300	1000
GZ to Blast Radius	.003 (1)	.020	.05	.12	.29	.77	1.85	5.68	13.67	35.83
Blast Radius - 18,000 rad	.005 (2)	.039	.09	.05	.05	- (4)	-	-	-	-
18,000 - 8,000 rad	.02 (3)	.06	.10	.13	.21	.21 (5)	-	-	-	-
8,000 - 3,000 rad	.08	.14	.20	.25	.36	.52	.39 (5)	-	-	-
3,000 - 1,000 rad	.25	.29	.37	.45	.59	.77	1.02	.12 (5)	-	-
1,000 - 200 rad	.78	.80	.90	1.06	1.29	1.62	1.98	3.02	-	-
200 - 100 rad	.51	.52	.55	.63	.74	.88	1.06	1.58	-	-
100 - 1 rad	6.59	6.62	6.80	7.51	8.30	9.36	10.84	15.43	16.99 (5)	.51 (5)

(1) Area of circle with radius equal to blast radius, R(B).

(2) Area of the annulus, in square kilometers, defined by R(B) and R(18,000), when R(B) < R(18,000).

(3) Area of the annulus defined by R(18,000) and R(8,000).

(4) Dash entry indicates that blast radius exceeds R(lower bound) of indicated dose interval.

(5) Area of annulus defined by blast radius and lower bound of indicated interval. Maximum dose for blast survivors is less than upper bound of interval.

TABLE 27. AREAS FOR BLAST EFFECTS AND DOSE INTERVALS, EXPRESSED AS A PERCENTAGE OF THE AREA DEFINED BY R(100) (TANK TARGET)

Dose Interval (Rad)	Weapon Yield (kt) .01	.10	.3	1.0	3	10	30	100	300	1000
GZ to Blast Radius	.2	1.1	2.1	4.6	8.3	16.1	29.3	54.6	100	100
Blast Radius - 18,000 rad	.3	2.1	3.8	1.7	1.4	- (1)	-	-	-	-
18,000 - 8,000 rad	1.0	3.1	4.4	4.8	5.9	4.3 (2)	-	-	-	-
8,000 - 3,000 rad	4.6	7.4	9.0	9.3	10.3	10.9	6.2 (2)	-	-	-
3,000 - 1,000 rad	15.4	15.8	16.4	16.7	16.6	16.2	16.2	1.1 (2)	-	-
1,000 - 200 rad	47.5	43.0	40.0	39.5	36.5	34.1	31.4	29.1	-	-
200 - 100 rad	31.0	27.5	24.3	23.4	21.0	18.4	16.9	15.2	-	-

(1) Dash entry indicates that blast radius exceeds R(lower bound) of indicated dose interval.

(2) Area of annulus defined by blast radius and lower bound of indicated interval. Maximum dose for blast survivors is less than upper bound of interval.

beyond about 30 kt, the percent of casualties produced by blast effects increases rapidly. At 300 kt or more, all personnel receiving 100 rad or more would be prompt casualties from blast effects.

Table 28 shows the distribution of doses only for blast survivors receiving 100 rad or more. For yields of 30 kt or less, about 63 to 79 percent receive doses of 1000 rad or less. From 15 to 23 percent receive doses of 1000 - 3000 rad, and about 6 to 18 percent receive doses from 3000 - 18000 rad. Above 30 kt, blast survivors will experience only the lower range of doses.

The assumption that every tank inside the circle with radius R(B) would be moderately damaged is not strictly true. Some tanks inside R(B) will not be so damaged, and some tanks outside R(B) will be damaged, but the total number damaged is equal to the number of tanks within R(B) under the assumption of a uniform distribution of tanks. Thus, the crew of a tank inside R(B) that is not moderately damaged may not become casualties from the blast effect, and so will suffer an initial nuclear radiation dose higher than indicated in Tables 26, 27 and 28. Tanks outside R(B) that do receive blast damage, and whose crews become prompt casualties from blast effects, will reduce the number of blast survivors receiving lower doses. The tables are therefore biased toward an incidence of lower doses.

Thermal radiation effects have not been included. Their inclusion would increase the number of prompt casualties, especially for personnel who are unprotected. It is difficult to quantify the effect of thermal radiation because many kinds of shielding (e.g., a vehicle or trees) are effective, and the positions of personnel relative to these shields would have to be known. Taking blast and thermal effects together would tend to produce even a more rapid decrease in the percent of survivors experiencing high nuclear radiation doses as weapon yield increases.

Because of lack of performance data on irradiated humans, the response of a person to high doses is difficult to predict. Data on

TABLE 28. AREAS FOR INDICATED DOSE INTERVALS EXPRESSED AS A PERCENTAGE OF THE AREA DEFINED BY R(B) and R(100) (TANK TARGET)

Dose Interval (Rad)	Weapon Yield (kt) .01	0.1	.3	1.0	3	10	30	100
Blast Radius - 18,000 rad	.3(1)	2.1	3.9	1.8	1.5	- (3)	-	-
18,000 - 8,000 rad	.9(2)	3.1	4.5	5.0	6.4	5.1(4)	-	-
8,000 - 3,000 rad	4.6	7.5	9.2	9.7	11.2	13.0	8.7(4)	-
3,000 - 1,000 rad	15.4	15.9	16.7	17.5	18.2	19.4	23.0	2.5(4)
1,000 - 200 rad	47.7	43.5	40.9	41.5	39.7	40.6	44.4	64.0
200 - 100 rad	31.1	27.9	24.8	24.5	23.0	21.9	23.9	33.5

(1) Area of the annulus defined by R(B) and R(18,000), when R(B) < R(18,000).

(2) Area of the annulus defined by R(18,000) and R(8,000).

(3) Dash entry indicates that R(B) exceeds R(lower bound) of indicated dose interval.

(4) Area of annulus defined by blast radius and lower bound of indicated interval. Maximum dose for blast survivors is less than upper bound of interval.

monkeys show, however, that an initial performance decrement in response to high doses is prompt, severe, and long lasting. Such effects, observed in combat personnel, would probably cause them to be declared casualties, even though in the latent phase they may recover sufficiently to perform at a reduced level.

Tables 26, 27, and 28 treat personnel in tanks. From Figure 43 it is seen that for unprotected personnel, the yield at which blast effects begin to dominate as a casualty producer is less than that for personnel in tanks. This would tend to decrease the number of unprotected blast survivors experiencing high doses. Because they are unprotected, such personnel would be more susceptible to thermal radiation than would protected personnel (e.g., personnel in a tank or armored personnel carrier). This would further reduce the number of survivors suffering high initial nuclear radiation doses.

An examination of other warhead types indicates that, except for different dose-versus-distance functions and neutron dose to gamma dose ratios, the same general type of dose distribution among blast survivors exists.

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APPENDIX D
M60A1E3 CREWMEMBER TASKS

Based on the results of tests on the Macaca Mulatta monkey, it can be expected that tank crewmembers whose tasks are primarily physical in nature will suffer greater performance degradation from irradiation than those whose tasks are less physical.

The data contained in this annex have been compiled to establish a basis for the determination of the individual crewmembers' tasks, the percentage of time spent in the performance of tasks, and the degree of physical and nonphysical activity for each crewmember.

The tasks enumerated for each tank crewmember (see Table 29) relate to the requirements of the M60A1E3 main battle tank and encompass both operational and support functions within a simulated 24-hour battlefield day (see Table 31). The M60A1E3 was selected as the basic weapon system because it will be in the greatest number in the U.S. near-future tank inventory. The basis for the task breakout is a study by HumRRO[1] on crew duties and tasks for operation of the General SHERIDAN Tank, M551. This data base was used as a guide for developing tasks for the M60A1E3 crewmembers.

The percentage of time spent in the performance of crewmember tasks and the number of physical, nonphysical, and neutral task elements for each task are given in Table 30. A physical task element is one that principally requires physical strength to perform (e.g., loading a 105mm round, or lifting a hatch cover). A nonphysical task element is one that requires much cognitive activity (e.g., observing for targets). A neutral task element may contain both physical and nonphysical components, but requires little physical effort (e.g., pushing a button).

These data are based on technical references and judgments made by experienced tankers. A 24-hour battlefield day exercise, conducted by the British Royal Armored Center in conjunction with its evaluation of the Swedish S-tank in 1968, was used as a basis for establishing percentage of time performing the various combat activities (Table 32).

TABLE 29. FUNCTIONS AND DUTIES OF THE M60A1 CREW

TANK COMMANDER

1.0 Acquiring Targets/Observing
    1.1 Searching for Targets
    1.2 Designating Target to Gunner
    1.3 Overriding the Gunner
    1.4 Displacing the Power Control Handle
    1.5 Preparing the Range Card
    1.6 Operating Laser Rangefinder
2.0 Loading and Unloading Vehicle Weapons
    2.1 Half-loading the Cal. .50 Machine Gun
    2.2 Fully-loading the Cal. .50 Machine Gun
    2.3 Unloading the Cal. .50 Machine Gun
3.0 Engaging Targets
    3.1 Issuing Fire Command
    3.2 Issuing a Coaxial Machine Gun Fire Command
    3.3 Issuing a Subsequent Fire Command
    3.4 Issuing a Range Card Fire Command
    3.5 Preparing to Fire the Cal. .50 Machine Gun
    3.6 Firing the Cal. .50 Machine Gun Semi or Fully Automatic
    3.7 Securing the Cal. .50 Machine Gun after Firing
4.0 Responding to Weapon Malfunction
    4.1 Responding to Cal. .50 Machine Gun Stoppage
5.0 Operating the Cupola
    5.1 Preparing to Operate the Cupola
    5.2 Activating and Deactivating Cupola-Power Operation
    5.3 Traversing Cupola Electrically from Inside Cupola
    5.4 Traversing Cupola Electrically from Outside Cupola
    5.5 Activating and Deactivating the Cupola-Manual Operation
    5.6 Traversing Cupola Manually

TABLE 29. (Continued)

6.0 Operating the Night Vision Instrument (NVI)
    6.1 Installing the NVI
    6.2 Activating and Deactivating, Adjusting the NVI
    6.3 Boresighting the NVI with the Cal. .50 Machine Gun
    6.4 Removing the NVI
    6.5 Installing the NVI Low Temperature Adapter
    6.6 Removing the NVI Low Temperature Adapter
7.0 Replenishing Ammunition Supply
    7.1 Reloading Main Gun Ammunition into Vehicle
8.0 Operating Auxiliary Equipment
    8.1 Opening and Closing *Cupola Hatch*
    8.2 Adjusting Tank Commander's Sub-floor and Seat Vertically
    8.3 Installing the Cal. .50 Machine Gun Carrier Assembly
    8.4 Removing the Cal. .50 Machine Gun Cover Assembly
    8.5 Installing the Cal. .50 Flash Hider
    8.6 Removing the Cal. .50 Flash Hider
    8.7 Engaging and Disengaging Cal. .50 Travel Lock
    8.8 Checking and Adjusting Cal. .50 Machine Gun Headspace
    8.9 Checking and Adjusting Cal. .50 Machine Gun Timing
    8.10 Installing and Operating Xenon (AM/VVS-3A) Searchlight
9.0 Maintenance
    Preventive
    9.1 Checking Turret (Exterior)
    9.2 Checking Turret (Interior)
    9.3 Checking Hull (Exterior)
    9.4 Checking Crew Compartment
    9.5 Checking Fire Control System

TABLE 29. (Continued)

Required

- 9.6 Maintaining the Turret (Interior)
- 9.7 Maintaining the Turret (Exterior)
- 9.8 Maintaining the M2 Cal. .50 Machine Gun

10.0 Communications (Command and Control)

11.0 Messing

- 11.1 Stowage and Removal of Rations
- 11.2 Setting-up/Operating Cook Stove and Utensils
- 11.3 Preparation of Meal (Heating)
- 11.4 Cleaning and Restowing of Cooking Gear

DRIVER

1.0 Driving the Vehicle

- 1.1 Performing Pre-starting Checks
- 1.2 Starting the Engine - Moderate or Hot Weather
- 1.3 Starting the Engine - Cold Weather
- 1.4 Starting the Engine - Slaving
- 1.5 Braking
- 1.6 Accelerating
- 1.7 Steering
- 1.8 Pivoting
- 1.9 Fording
- 1.10 Shifting
- 1.11 Towing a Disabled Vehicle
- 1.12 Stopping the Vehicle
- 1.13 Stopping the Engine
- 1.14 Operating the Driving Lights
- 1.15 Observing

TABLE 29. (Continued)

2.0 Responding to Warning Lights

- 2.1 Responding to Engine Temperature Warning Light
- 2.2 Responding to Low-Oil Temperature Warning Light
- 2.3 Responding to Transmission Oil-Temperature Warning
- 2.4 Responding to Transmission Low-Oil Pressure Warning Light

3.0 Operating the Sighting Equipment

- 3.1 Installing/Operating/Removing the Periscope
- 3.2 Operating the Periscope Washers and Wipers
- 3.3 Installing/Adjusting/Removing the Headset Assembly
- 3.4 Installing/Removing Periscope Head Assembly

4.0 Operating Auxiliary Equipment

- 4.1 Opening/Closing Driver's Hatch
- 4.2 Opening/Closing Escape Hatch
- 4.3 Adjusting the Driver's Seat
- 4.4 Operating Driver's Dome Light
- 4.5 Operating Personnel/Winterization Kit Heaters
- 4.6 Operating Fixed Fire Extinguishers
- 4.7 Installing Tow Shackles, Tow Cable or Tow Bar
- 4.8 Removing Tow Shackles, Tow Cable or Tow Bar
- 4.9 Opening and Closing Engine Compartment Exhaust Grills
- 4.10 Operating Instrument Panel Light Switch
- 4.11 Installing/Removing Driver's CBR Equipment

5.0 Maintenance

Preventive

- 5.1 Checking the Hull (Exterior)
- 5.2 Checking the Suspension
- 5.3 Checking the Engine Compartment
- 5.4 Checking the Crew Compartment

TABLE 29. (Continued)

Required

- 5.5 Maintaining the Hull (Exterior)
- 5.6 Maintaining the Hull (Interior)
- 5.7 Maintaining the Engine Compartment
- 5.8 Maintaining the Suspension System

6.0 Communications

7.0 Messing

- 7.1 Stowage and Removal of Rations
- 7.2 Setting-up/Operating Cook Stove and Utensils
- 7.3 Preparation of Meals
- 7.4 Cleaning and Restowing of Cooking Gear

GUNNER

1.0 Operating the Turret

- 1.1 Preparing to Operate the Turret
- 1.2 Activating/Deactivating Turret Power Control
- 1.3 Activating/Deactivating Turret Stabilization Mode
- 1.4 Nulling Out Elevation and Azimuth Drift
- 1.5 Displacing the Power Control Handle
- 1.6 Activating/Deactivating/Operating Turret Manual Controls

2.0 Operating Gunner's Sighting Equipment

- 2.1 Placing the M105E1 Telescope into Operation
- 2.2 Opening and Closing Ballistic Shield
- 2.3 Operating the Periscope Washer/Wiper
- 2.4 Placing the M35E1 Periscope into Operation
- 2.5 Activating/Operating/Deactivating Laser RF

TABLE 29. (Continued)

- 3.0 Boresighting and Zeroing Vehicle Weapons
  - 3.1 Boresighting Main Gun
  - 3.2 Boresighting 7.62mm Machine Gun
  - 3.3 Performing Parallax Adjustment of M105E1 Telescope and Mount
  - 3.4 Align Laser RF with M35E1 Reticle Making Parallax Adjustment
  - 3.5 Activate/Operate XM21 Computer for Zeroing
  - 3.6 Zeroing Main Gun
  - 3.7 Zeroing the 7.62mm Machine Gun
- 4.0 Engaging Targets
  - 4.1 Firing in Power Mode
  - 4.2 Firing in Manual Mode
  - 4.3 Firing 7.62mm Machine Gun in Power Mode
  - 4.4 Firing 7.62mm Machine Gun in Manual Mode
  - 4.5 Range Card Firing on Plotted Target
  - 4.6 Range Card Lay to Direct Fire
  - 4.7 Range Card Firing at an Area Target
- 5.0 Employing Methods of Fire Adjustment
  - 5.1 Applying Primary Method of Fire Adjustment - Burst on Target
  - 5.2 Applying Alternate Method of Fire Adjustment
- 6.0 Operating Indirect Fire Control Instruments
  - 6.1 Zeroing Azimuth Indicator
  - 6.2 Determing Deflection to a Given Target
  - 6.3 Making Small Deflection Changes
  - 6.4 Laying Gun in Elevation with M13A1C Elevation Quadrant
  - 6.5 Laying Gun in Elevation with M1A1 Gunner's Quadrant
  - 6.6 Laying Gun in Elevation
  - 6.7 Testing Azimuth Indicator for Accuracy
  - 6.8 Testing Azimuth Indicator for Slippage

TABLE 29. (Continued)

7.0 <u>Responding to a Misfire</u>
    7.1 Responding to a Main Gun Misfire
    7.2 Responding to a 7.62mm Machine Gun Misfire
8.0 <u>Operating Auxiliary Equipment</u>
    8.1 Adjusting Gunner's Seat
    8.2 Adjusting Height of Power Control Handle
9.0 <u>Replenishing Ammunition Supply</u>
    9.1 Assist in Reloading Ammunition into Vehicle
10.0 <u>Maintenance</u>
    <u>Preventive</u>
    10.1 Checking Mount and Turrent Systems
    10.2 Checking Fire Control System
    10.3 Checking Crew Compartment
    <u>Required</u>
    10.4 Maintaining Turret (Interior)
    10.5 Maintaining Turret (Exterior)
    10.6 Maintaining the Gun
    10.7 Maintaining the M73 7.62mm Machine Gun
11.0 <u>Communications (Intercom)</u>
12.0 <u>Messing</u>
    12.1 Stowage and Removal of Rations
    12.2 Setting-up/Operating Cook Stove and Utensils
    12.3 Preparation of Meal (Heating)
    12.4 Cleaning and Restowing of Cooking Gear

LOADER

1.0 <u>Operating the Breech</u>
    1.1 Opening and Closing the Breech Manually

TABLE 29. (Continued)

2.0 Loading and Unloading Vehicle Weapons
    2.1 Loading the 105mm Round
    2.2 Loading the 7.62mm Coaxial Machine Gun
    2.3 Unloading the Main Gun
    2.4 Unloading the 7.62mm Coaxial Machine Gun
3.0 Engaging Targets
    3.1 Preparing the Gun for Firing
    3.2 Preparing the 7.62mm Coaxial Machine Gun for Firing
    3.3 Responding to a Fire Command
    3.4 Responding to a 7.62mm Coaxial Machine Gun Fire Command
    3.5 Firing the 7.62mm Coaxial Machine Gun Manually
    3.6 Securing the Main Gun after Firing
    3.7 Securing the Coaxial Machine Gun after Firing
4.0 Responding to a Weapon Malfunction
    4.1 Responding to a Misfire
    4.2 Removing a Stuck Round of 105mm Ammunition
    4.3 Removing a Live Round from 7.62mm Coaxial Machine Gun
    4.4 Controlling a Runaway Coaxial Machine Gun
    4.5 Removing a Ruptured Cartridge Case from 7.62mm Coaxial Machine Gun
5.0 Operating the Loader's Sighting Equipment
    5.1 Installing, Operating and Removing the XM37 Periscope
6.0 Replenishing Ammunition Supply
    6.1 Handling Ammunition for Stowage
    6.2 Stowing Ammunition into Hull Racks
    6.3 Removing Ammunition from Hull Racks
    6.4 Stowing Ammunition into Turret Bustle Racks
    6.5 Removing Ammunition from Turret Bustle Racks
    6.6 Stowing Ammunition into Turret Floor Racks
    6.7 Removing Ammunition from Turret Floor Racks
    6.8 Stowing Ammunition into Turret Ready Racks
    6.9 Removing Ammunition from Turret Ready Racks

TABLE 29. (Concluded)

7.0 <u>Operating Auxiliary Equipment</u>
  - 7.1 Opening and Closing Loader's Hatch
  - 7.2 Operating the Loader's Dome Light
  - 7.3 Locking and Unlocking the Turret
  - 7.4 Adjusting Pressure in Recoil Mechanism
  - 7.5 Installing, Operating and Removing Turret CBR Equipment
  - 7.6 Removing and Installing AN-VVS-3A Xenon Searchlight

8.0 <u>Maintenance</u>

<u>Preventive</u>
  - 8.1 Checking Turret (Exterior)
  - 8.2 Checking Turret (Interior)
  - 8.3 Checking Fire Control System
  - 8.4 Checking Crew Compartment

<u>Required</u>
  - 8.5 Maintaining the Turret (Interior)
  - 8.6 Maintaining the Turret (Exterior)
  - 8.7 Maintaining the Fire Control System

9.0 <u>Communications</u>
  - 9.1 Turning-on, Operating and Turning-off AN/VRC Radio

10.0 <u>Messing</u>
  - 10.1 Stowage and Removal of Rations
  - 10.2 Setting-up/Operating Cook Stove and Utensils
  - 10.3 Preparation of Meal (Heating)
  - 10.4 Cleaning and Restowing of Cooking Gear

11.0 <u>Observing/Detecting Targets</u>
  - 11.1 Viewing thru Periscope
  - 11.2 Viewing thru Binoculars
  - 11.3 Viewing Unassisted

TABLE 30. PHYSICAL, NONPHYSICAL, AND NEUTRAL TASK ELEMENTS, AND PERCENT OF TIME SPENT, BY TASK

Task	Number of Task Elements			Percentage of Time Spent
	Physical	Non-Physical	Neutral	
Tank Commander				
1.0 Acquiring Targets/ Observing	4	24	4	44.0
2.0 Loading & Unloading Weapons	14	18	0	1.0
3.0 Engaging Targets	5	13	23	7.0
4.0 Responding to Weapon Malfunction	4	7	5	0.5
5.0 Operating Cupola	7	15	0	10.0
6.0 Operating Night Vision Instrument	7	46	1	10.0
7.0 Replenishing Ammunition	4	8	1	2.0
8.0 Operating Auxiliary Equipment	64	49	0	2.0
9.0 Maintenance				
a. Preventive	26	43	3	7.8
b. Required	37	36	0	4.2
10.0 Communications	0	8	1	10.0
11.0 Messing	3	2	1	1.5
Driver				
1.0 Driving the Vehicle	53	59	5	33.0
2.0 Responding to Warning Lights	15	18	5	0.5
3.0 Operating Sighting Equipment/Observing	25	16	0	46.5
4.0 Operating Auxiliary Equipment	56	41	4	1.0

TABLE 30. (Continued)

Task	Physical	Non-Physical	Neutral	Percentage of Time Spent
5.0 Maintenance				
a. Preventive	100	102	0	10.1
b. Required	121	32	1	5.4
6.0 Communications	0	6	1	2.0
7.0 Messing	8	2	1	1.5
Gunner				
1.0 Operating Turret	3	28	0	7.0
2.0 Operating Gunner's Sights	7	18	0	3.0
3.0 Boresighting and Zeroing Weapons	31	77	5	1.0
4.0 Engaging Targets	16	48	33	5.0
5.0 Employing Methods of Fire Adjustment	0	7	6	2.0
6.0 Operating Indirect Fire Control Equipment	14	30	1	0.5
7.0 Responding to Misfires	0	15	9	0.5
8.0 Operating Auxiliary Equipment	4	5	0	2.5
9.0 Replenishing Ammunition Supply	14	3	1	2.0
10.0 Maintenance				
a. Preventive	12	74	7	9.8
b. Required	58	27	0	5.2
11.0 Communication	0	6	1	6.0
12.0 Messing	5	2	1	1.5
13.0 Observing	1	3	0	54.0

TABLE 30. (Concluded)

Task		Physical	Non-Physical	Neutral	Percentage of Time Spent
Loader					
1.0	Operating Breech	4	4	0	0.5
2.0	Loading and Unloading Vehicle Weapons	15	18	0	5.0
3.0	Engaging Targets	15	17	8	5.0
4.0	Responding to Weapon Malfunction	14	8	3	5.0
5.0	Operating Loader's Sight	3	4	0	12.0
6.0	Replenishing Ammunition Supply	15	3	0	4.0
7.0	Operating Auxiliary Equipment	26	12	2	4.0
8.0	Maintenance				
	a. Preventive	53	84	1	9.8
	b. Required	20	12	0	5.2
9.0	Communications	2	10	1	10.0
10.0	Messing	10	5	3	1.5
11.0	Observing/Target Detection	7	5	0	38.0

TABLE 31. RESULTS OF ROYAL ARMORED CORPS TRIAL SIMULATING A 24-HOUR BATTLEFIELD DAY*

Activity	Time (Hr/Min)	Percentage of Time
Movements	3:35	14.9
Engagements	1:10	4.9
Halts/Alerts Stand-Tos	15:05	62.8
Observation	4:10	17.4

*Reference 2

TABLE 32. PERCENTAGE OF PHYSICAL, NONPHYSICAL, AND NEUTRAL ELEMENTS OF CREW TASKS WEIGHTED BY TIME SPENT PERFORMING TASKS AS A FUNCTION OF CREW POSITIONS

Crew Member	Task Elements		
	Physical (%)	Nonphysical (%)	Neutral (%)
Tank Commander	19	69	12
Gunner	25	69	6
Loader	50	47	3
Driver	54	44	2

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