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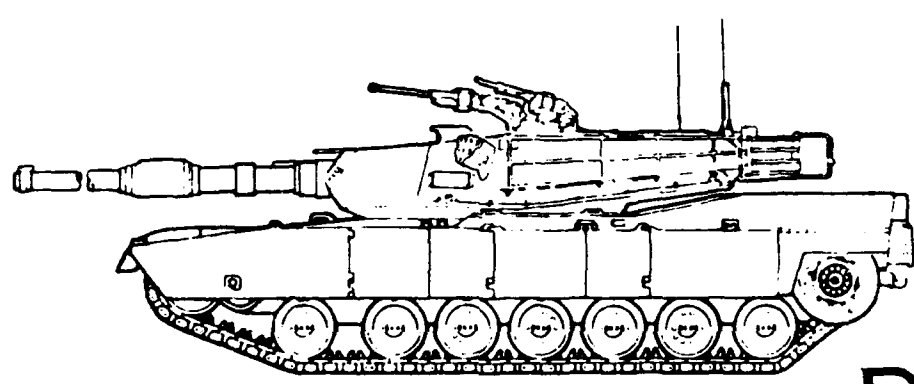
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ROOT CAUSE ANALYSIS, TANK FIRE PROBLEM,  
M1A1 MAIN BATTLE TANK



MAJ John Dowalgo

February 1989

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U.S. ARMY ARMAMENT RESEARCH, DEVELOPMENT AND  
ENGINEERING CENTER

Advanced Systems Concept Office

Picatinny Arsenal, New Jersey

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## EXECUTIVE SUMMARY

### A Background

1. Recently two M1A1 tank fires involving 120mm M865 Target Practice Cone Stabilized Discarding Sabot Tracer (TPCSDS-T) ammunition occurred during tank gunnery exercises in Germany. The first fire, 4 July 88, did not involve any personnel injury. The fire on 14 August 88 was lethal, killing the tank commander and gunner.

2. The failure investigation strategy (described in section III) is a method for increasing the assurance that the root cause of the problem is identified, and provides a detailed record of the study which can be reviewed by management or impartial review boards. This case study provides a summary of the major activities performed by the Root Cause Analysis Team. The methodology identified the most probable root cause of the tank fire problem.

### B. Findings

1. The root cause of both tank fires was the hot cartridge case base primers from the M865 120mm round making contact with the cartridge case or propellant from another round.

a. The most likely cause of the 4 July 88 fire was propellant spilling from a damaged or defective M865 round during the loading process. The fire erupted when loose propellant contacted a hot case base primer in the case base catcher box.

b. The 14 August 88 fire most likely occurred when the loader mishandled a M865 round and it fell onto a hot primer lying on the turret floor. The catcher box was not installed.

### C. Comments

1. The hot M865 cartridge case primer is the root cause, the ignition source, for both fires. It is strongly recommended that a design modification be developed to reduce or eliminate this threat.

2. The case base catcher box with all proposed fixes is inadequate. It has an open top and does not prevent any combustible material, such as a combustible cartridge case, from making contact with a hot primer. A design change directive is highly recommended.

3. Improvements for crew protection and evacuation need to be implemented. Crew members should be issued fire protective clothing. Improvements to the driver's compartment, commander's hatch and gunners seat should be developed to enhance evacuation during an emergency.

4. Crew actions definitely contributed to the 14 August 88 fire and may have been involved with the 4 July 88 fire. Training must emphasize proper ammunition handling and loading procedures. Equipment involving safety, such as the catcher box, should be a readiness reportable item. Inspections should be initiated to insure all equipment is operational prior to any gunnery exercise.

## INTRODUCTION

In September of 1931, the Department of the Army approved a block modification proposal to upgrade the M1 Tank. The modification included a German 120mm gun and various survivability enhancements. The vehicle was type classified standard as the M1A1 in August 1984. The first production vehicle was delivered in August 1985.

## II. BACKGROUND

Two M1A1 tank fires occurred on 4 July 1988 and 14 August 1988 involving M865 TPDS-CS-T 120mm ammunition during gunnery exercises in Germany. The second fire killed the gunner and tank commander. These are the only fires involving 120mm tank ammunition since the tank was fielded in 1985.

A. 120mm Gun- The M1A1 main battle tank is equipped with a 120mm smooth bore German designed gun which is also utilized on the Leopard II tank. A unique feature of the gun is the combustible cased ammunition it fires. When the gun fires, the cartridge case is consumed except for a small cartridge case base. The cartridge case base is ejected from the breech, ricochets off a deflector on the loading tray (fig.1) and is directed downward into a case base catcher box (fig.2). Additional details of gun operation are provided in appendix A.

B. Catcher Box- Also unique to the M1A1 tank is the case base catcher box, mounted on the turret floor under the gun breech (fig.2). The ejected cartridge case base contacts a flipper (paddle wheel) which acts as an energy attenuator, allowing the base to 'gently' fall into the box.

C. 120mm Ammunition Description (M865)- (fig. 3 and 4)

## III. DIAGNOSTIC STRATEGY

### A. Methodology

A root cause diagnostic team was assembled to review the M1A1 fires. Root Cause Analysis is a rigorous and disciplined methodology for the independent examination of possible failure modes, within a system. The technique employs a standard format to classify and isolate relevant information, and in this manner, focuses the attention of the problem solver on the distinctions or the gaps in information. References 1 and 2 describe the methodology in detail.

### B. Implementation

#### 1. Root Cause Team Assignment

The specific mission assigned the Root Cause Analysis Team included reviewing all credible failure modes. Special emphasis was also placed on a review of current procedures/designs to assure that the best corrective measures are identified and implemented to prevent reoccurrence of the problem. MANPRINT domains were considered during the conduct of the assessment.

## 2. Organization

The Root Cause Analysis was conducted by a task team with interdisciplinary skills. The team memberships crossed considerable lines to form a matrix organization. The Root Cause Analysis Team consisted of ten members, convened on 27 September 1988, and completed its efforts on 28 October 1988.

### a. The team members were:

|                    |                            |          |
|--------------------|----------------------------|----------|
| MAJ JOHN DOWALGO   | SMCAR-ASM(Chairman)        | ARDEC    |
| JOSEPH CORALLO     | AMSMC-QAT-M(Co-Chairman)   | ARDEC    |
| JOHN BANKS         | SMCAR-SF                   | ARDEC    |
| WILLIAM WILLIVER   | SMCAR-CCH-V                | ARDEC    |
| JAMES RUTKOWSKI    | SMCAR-AEE-BP               | ARDEC    |
| ROGER BILLINGTON   | AMCPM-TMA-105              | PM- TMAS |
| JACK CARLOCK       | SLCHE-AR                   | HEL      |
| ROBERT ALLAN       | AMSMC-LSA(D)               | AMCCOM   |
| CPT GEORGE SMITH   | AMSMC-ASR                  | AMCCOM   |
| SFC ROBERT WOLFORD | ATSB-WP-GD (MASTER GUNNER) | FT KNOX  |

b. PM Tank Main Armament System was very supportive of the effort. Mr. Ken Russell provided the team with information gathered during initial inquiries. He also gave a thorough briefing on 120mm ammunition design and was available to answer questions generated during the course of the investigation. Additionally, Honeywell and ARDEC invested a considerable amount of time and effort to create cook-off time lines for 120mm cartridge cases and propellant. This information was also provided by PM TMAS. Augustine Magistro, author of references 1 and 2, briefed the team on Root Cause methodology and provided guidance throughout the investigation.

## 3. Failure Analysis Procedures

The Root Cause Analysis process examined all the credible failure modes of the M865 round, including its effect on related systems to establish a list of candidate causes.

a. Furnished with the initial data and tentative problem statements, the team listed every conceivable area which could cause a tank ammunition fire. Discussions and ideas freely evolved and were recorded without evaluation. This procedure permitted a large quantity of failure possibilities to be recorded in a short period of time; therefore, the broadest view of the problem was obtained. This process produced 33 failure modes which could have contributed to the tank ammunition fire problem.

b. Next, the team constructed a chart depicting all possible failure modes, conditions or events which may have contributed to a tank fire (fig. 5). Each contributing failure mode, condition or event was categorized into one of four major problem areas, defined as follows: crew (1.0), ammunition (2.0), gun(3.0), and turret(4.0). Failure modes are indicated by three digit numbers and all 33 failure modes were categorized.

#### 4. Root Cause Analysis Format

Subsequent to the identification of the candidate failure modes, failure sequences were postulated for each candidate failure mode and recorded in a standard columnar format. This format, called the root cause analysis chart, was employed to classify and isolate relevant information related to the failure scenarios (fig. 6). The presentation of information in this format allowed each failure mode description and its supporting and refuting data to be quickly recorded, reviewed and evaluated. The root cause analysis charts for the M1A1 tank fires are depicted in Appendix B, charts 1 through 33.

#### 5. Failure Mode Ranking

The team ranked each root cause for each incident by a voting method and the results are shown in table 1.

TABLE 1  
First Tank Fire (4 July 88)

| Probability<br>Chart # | Failure Sequence         | Rank Order | Estimate |
|------------------------|--------------------------|------------|----------|
| 2.07                   | Protruding Hot Primer    | 1          | ML*      |
| 4.03                   | Catcher Box Design       | 2          | ML       |
| 1.11                   | Loader Damaged Round     | 3          | ML       |
| 2.02                   | Glue Joint Failure       | 4          | VL       |
| 1.12                   | Previously Damaged Round | 5          | L        |
| 2.01                   | Flaming Case Base        | 6          | L        |
| 1.06                   | Loader's Tray Adjustment | 7          | L        |
|                        | All Others               | 8-33       | U        |

Second Tank Fire (14 Aug 88)

|           |                              |      |     |
|-----------|------------------------------|------|-----|
| 2.07      | Protruding Hot Primer        | 1    | ML* |
| 1.03      | Catcher Box Missing          | 2    | ML  |
| 1.04      | Failure to Follow Procedures | 3    | ML  |
| 4.03      | Catcher Box Design           | 4    | ML  |
| 1.14      | Dropped Round                | 5    | ML  |
| 1.07,1.10 | Safe/Fire procedures         | 6    | L   |
| 1.08,1.13 | Loader's Tray Adjustment     | 7    | L   |
| 3.01,3.03 | Loader's Tray Malfunction    | 8    | L   |
|           | All Others                   | 9-33 | U   |

\* Root Cause

ML=MOST LIKELY CAUSE

VL=VERY LIKELY CAUSE

L=LIKELY CAUSE

U=UNLIKELY CAUSE

#### 6. Logic Diagram/Root Cause Analysis Chart Relationship

Figure 5 provided a road map to guide the team to each postulated cause of failure and the root cause analysis charts present a scenario for each of the candidate causes. All the data required to reach a conclusion concerning the likelihood of each scenario is presented on the root cause analysis chart. The root cause analysis charts were reviewed and analyzed to determine the most likely cause of each tank fire. Logic diagrams, illustrated in figs. 7 and 8, depict the most likely sequence of events that resulted in each fire.

#### 7. Failure Analysis Chronology

The failure analysis cycle, followed by the Root Cause Analysis Team and described herein, includes the following events:

- a. PROBLEM SURFACED
- b. PROBLEM STATEMENT
- c. MANAGEMENT DECISION-"ROOT CAUSE" REQUIRED
- d. ROOT CAUSE ANALYSIS TEAM FORMALLY ESTABLISHED
- e. POSTULATED CANDIDATE CAUSES
- f. FAULT CATEGORY CHART PREPARED (FIG.5)
- g. INITIATED ROOT CAUSE FORMAT-ONE FAILURE SEQUENCE PER SHEET (APPENDIX B)
- h. OBTAINED CONFIRMING/REFUTING DATA
- i. EVALUATED DATA
- j. SPECIFIED ADDITIONAL DATA OR TESTS REQUIRED
- k. CATEGORIZED MOST LIKELY/VERY LIKELY/LIKELY/UNLIKELY (TABLE 1)
- l. ESTABLISHED "ROOT CAUSES" (figs. 7 and 8)
- m. ADDRESSED MANPRINT DOMAINS AND MADE RECOMMENDATIONS FOR CORRECTIVE ACTIONS

#### IV. CONCLUSIONS

The conclusions herein are brief summaries. Facts supporting the conclusions are contained on the root cause analysis charts.

##### A. 4 July Fire

The Root Cause Analysis Team has determined that the cause of the 4 July 88 fire was mostly design related, supplemented with human error. During a tank gunnery exercise, the loader either damaged a M865 TPCSDS-T round while loading or drew a defective/damaged round from the bustle. The round separated, allowing propellant to spill throughout the bustle and crew compartment. Some of the propellant fell into the cartridge case base catcher box, and contacted the hot case base primers. The propellant ignited, the loader panicked, dropped the round, and a larger fire started.

##### B. 14 August Fire

The second fire was caused by a combination of crew actions and design shortcomings. The tank was engaged in a multiple target rapid fire gunnery exercise. The cartridge case base catcher box was not installed and all hot case bases were falling to the turret floor. Round #3 of the exercise was fired. The loader immediately chambered round #4 and drew round number #5 from the turret bustle. With round #5 in the loader's hands, he noticed that round #4 was not fully seated in the breech. While attempting to seat round #4, the loader lost control of round #5 and let it fall onto a hot case base primer from a previously fired round which initiated the fire.

#### V. MANPRINT ISSUES AND RECOMMENDATIONS

##### A. Safety

1. Hot Case Base Primers The root cause of both fires is believed to be hot case base primers. The 120mm M865 TPCSDS-T training round and the M829 APFSDS-T service round both have long primers which protrude from the case base. The primers are ejected from the gun breech with a calculated temperature approaching 700 degrees fahrenheit. ARDEC is studying the feasibility of eliminating this source of ignition by insulating the primer, changing the primer body material, changing to a combustible or consumable primer body, or possibly by eliminating the long primer body. A high priority has been given to this issue.

2. Inadequate Catcher Box Design The catcher box is large and open on the top (fig. 2) and does not prevent a nest of hot case base primers from contacting combustible material such as loose propellant or a combustible cartridge case. With the catcher box properly installed in a M1A1 tank, it is conceivable that a loader can lose control of a 120mm round, especially while traversing rough terrain, and drop it into the open catcher box. The box also has a large seam which can allow a hot primer to protrude (fig. 9), exposing the loader to a danger. Additionally, tank crews do not like the box because it interferes with movement and is unreliable.

The flipper (paddle wheel) which acts as an energy attenuator for ejected case bases, frequently sticks or jams. As a result crew members have been known to remove the box, allowing case bases to fall to the floor. PM Abrams has taken the initiative to correct some of the deficiencies with the present catcher box design. Corrective actions include eliminating interference with the turret lock, improving flipper reliability, and reducing the gap where primers can protrude. The Root Cause Analysis Team has concluded that the present design, with all proposed fixes, is still inadequate from a safety standpoint because of the open top. The possibility of crew error and/or propellant spillage is ever present. The case base catcher must isolate hot primers from the crew and any potential fuel source. A new design is strongly recommended, utilizing human factors expertise as stated in paragraphs 5.6, 5.6.3, and 5.7 of Mil Standard 1472C.

3. Strengthen the Combustible Cartridge Case The glued joint, where the case cover and cap assembly is attached to the combustible cartridge case (fig. 4), is suspect of separation and may have been a contributor to the 4 July 88 tank fire. Research to improve the joint is in progress. Efforts have addressed process controls, quality, testing, and improved strength. Additionally, researchers should evaluate the possibility of strengthening the propellant containment bag, especially where the bag is attached to the projectile.

4. Crew Member Liability Per review of conversations of soldiers in Germany with Mr. Ken Russell (PM Tank Main Armament Systems) and Master Gunners at Ft Knox, KY with the Root Cause Analysis Team, soldiers are being told that they will be held pecuniarily liable for damaged rounds. There are indications that crew concerns over liability for damaged ammunition may have led to damaged rounds being fired. This policy should be eliminated except for cases of gross negligence or abuse. Additionally, ammunition turn-in procedures should be changed by eliminating the apparent harrassment (from a soldier's point of view) at ammunition supply points. Rather than being subjected to questions, lengthy delays and threats of liability, soldiers would rather shoot or hide opened ammunition rather than turn it in. It is understood that there is a no questions asked turn in policy at ASP #1 Grafenwoehr. Special efforts must be taken to insure that soldiers are aware of this policy. Also, all training areas should consider similar procedures.

5. Absence of Protective Clothing Tank crew members are not being issued fire protective clothing. The tank commander from the 14 August 88 fire, who exited the tank and subsequently died from his burns, may have survived had he been wearing protective clothing. The Root Cause Analysis Team highly recommends issuing tank crew members, especially those assigned to M1A1 tanks, fire protective clothing.

6. Driver Cannot Escape The driver cannot exit when the gun is depressed over the front center of the tank. This gun position is common when shooting from a hull defilade position. Additionally, the M1 series tank is not equipped with a driver's escape hatch. The driver could be trapped if the crew in the turret is disabled from an accident or by enemy action. Recommend an engineering review to determine the feasibility of improving driver egress.

7. Heavy Commander's Hatch The commander's hatch is heavy and requires a considerable amount of pressure to open. When locked in a partially open (open protected) position, the commander's hatch may not open if pressure is applied to the hatch before pulling the release lever. This is considered a very likely action during a panic situation and could have contributed to the tank commander's death on 14 August 88. Design changes, per a PM Abrams directive, have been initiated to alleviate the problem (fig. 8). The Human Engineering Laboratory should be a role player in the effort.

8. Gunner's Seat The fixed gunner's seat back hinders evacuation. In order to exit, the gunner has to climb over the back of the seat. Recommend a human factors engineering assessment to determine what actions can be taken to make it easier for the gunner to evacuate the tank.

9. Water in Bustle Environmental seals on M1 are not adequate, allowing water (sometimes in large quantities) to enter the bustle where ammunition is stored. Combustible cartridge cases could absorb moisture, swell, and not chamber properly. Additionally, moisture can have an effect on the combustion of the case, degrading performance and creating residue which could enter the turret. The structural integrity of the case may also be adversely affected by excessive moisture. PM Abrams has taken steps to correct this deficiency, both on the production line and by issuing field-fix instructions for older tanks. Command emphasis should be directed toward insuring corrective action is accomplished in an expeditious manner.

10. Tanks not Fully Operational Insure all equipment, in particular the case base catcher box, is properly installed and fully operational prior to commencing gunnery exercises. Equipment should be inspected by a safety Officer/NCO before tanks are allowed to participate in live firing exercises. All equipment which affects crew safety, especially the case base catcher box, should be a readiness reportable item.

## B. Human Factors Engineering

1. Loading Tray The loading tray requires frequent adjustment. An improperly adjusted tray can interfere with the loading and case base ejection processes. PM Abrams has an engineering change proposal in process to address the problem.

## C. Training

1. Evacuation Procedures not Rehearsed Crew members should be instructed and tested in proper evacuation procedures, especially during basic armor training. They also should be required to undergo periodic drills. It is strongly recommended that command emphasis be placed on this frequently neglected training issue.

2. Ammunition Handling Procedures Training must strongly emphasize proper loading procedures to include the inspection of munitions before firing and the dangers of mishandling. Of particular concern is a technique of the loader drawing another round before the gun is fired. Warnings should be added to technical manuals prohibiting loaders from withdrawing a round from the bustle until the previous round is fired and the gun is placed in safe. ARDEC has submitted recommended manual changes to TACOM.

## VI. Overall Team Performance

The Root Cause Analysis Team's overall performance was excellent and their adherence to the concepts and methodology described in references 1 and 2 contributed significantly to the success of the activities.

### References

1. Augustine Magistro, Class Notes, "Failure Analysis Seminar: Techniques and Teams, Vol. 1" US Army Armament Research and Development Command, Dover, NJ, March 1979.
2. Augustine Magistro and Lawrence R. Seggel, "Root Cause Analysis-A Diagnostic Failure Analysis Technique for Managers", Report Number RF-75-2, US Army Missile Command, Huntsville, AL, 26 March 1975.



Figure 1. Gun breech



Figure 2. Cartridge case base catcher box



## **M865 TPCSDS-T**

Because of a unique cone stabilizer design, the M865 provides normal projectile velocity to the maximum target range, with a sharp velocity decay after that point. This safety feature allows use of M865 practice rounds on U.S. and European ranges where permissible projectile travel is limited.

## **CHARACTERISTICS**

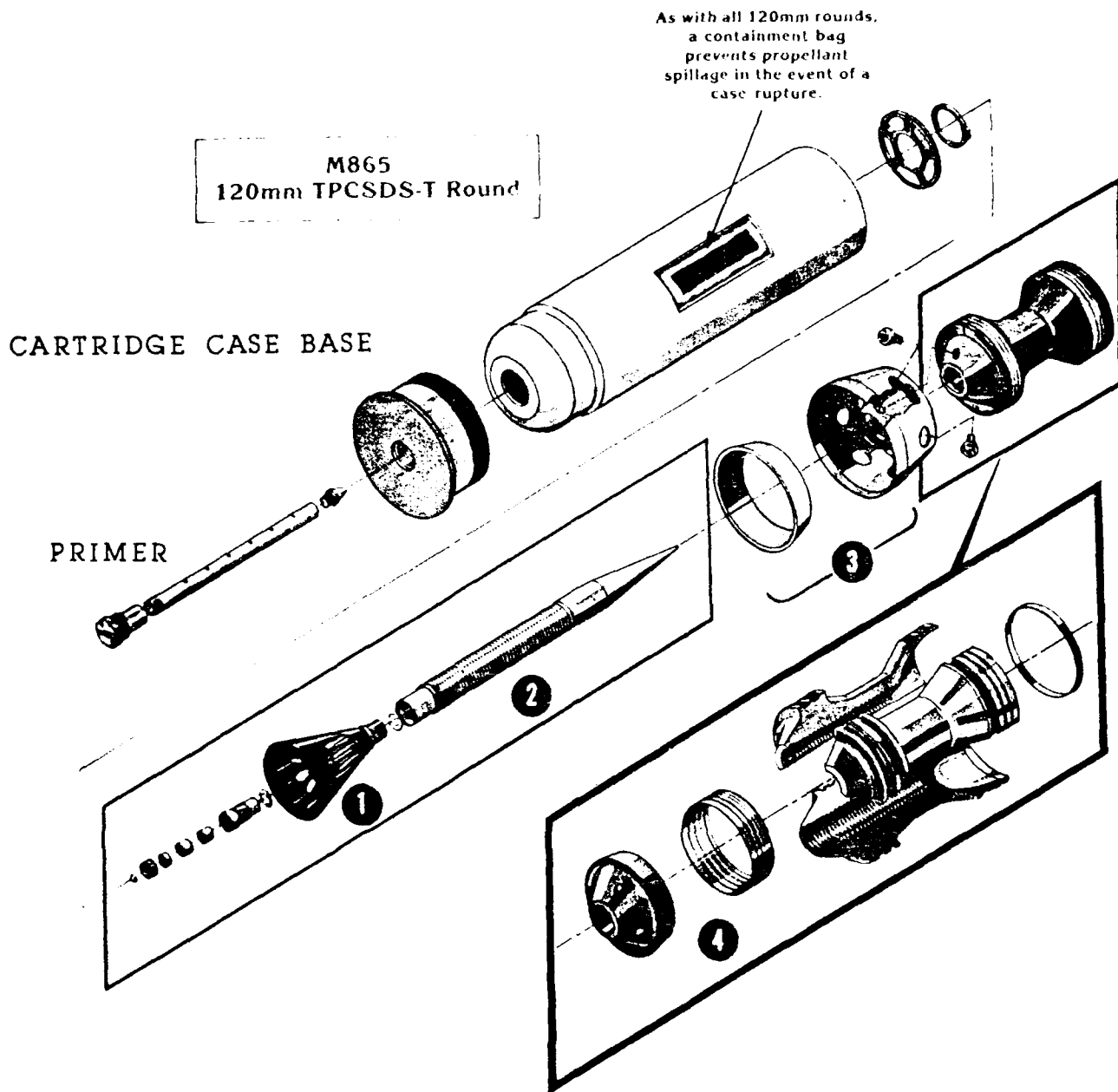
### **CARTRIDGE**

|                   |                      |
|-------------------|----------------------|
| Length            | 881 mm (34.7 in)     |
| Weight            | 19 kg (41.9 lb)      |
| Propellant Type   | Single Base          |
| Propellant Weight | 8.3 kg (18.3 lb)     |
| Chamber Pressure  | 4850 bar (70325 psi) |

### **PROJECTILE**

|                 |                                             |
|-----------------|---------------------------------------------|
| Type            | TPCSDS-T                                    |
| Length          | 468.5 mm (18.4 in)                          |
| Weight          | 3.2 kg (7.1 lb)                             |
| Muzzle Velocity | 1700 $\pm$ 12 m/s<br>(5578 $\pm$ 39 ft/sec) |
| Range           | 2500 m                                      |

Figure 3. M865 TPCSDS-T



1 Cone Assembly

2 Steel Rod (core)

3 Case Cover and Cap Assembly

4 Three-Segment Sabot

Figure 4. M865 cartridge exploded view

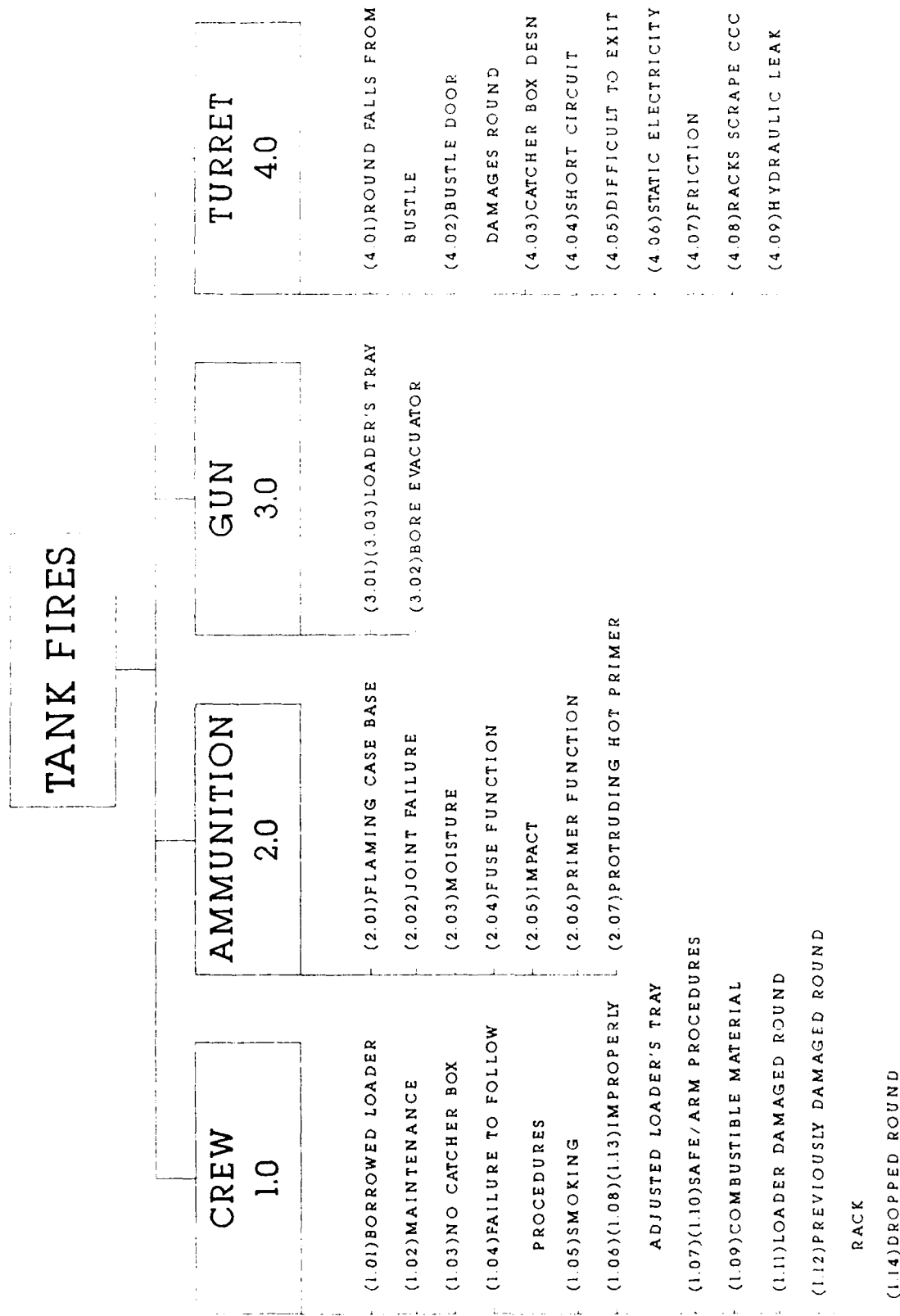


Figure 5. Fault category chart

Date: Rev. No.: **ROOT CAUSE ANALYSIS CHART**  
 Cause Probability Estimate: USED DURING EARLY STAGES TO INDICATE CAUSE PROBABILITY WHEN LITTLE IS KNOWN ABOUT THE FAILURE

Failure Indication: ENTER BRIEF STATEMENT OF FAILURE INDICATION

| SPECULATION                                                                                                                                                                                                                                          |                                                                                                                                                     | EVALUATION                                                                                                                                                                                                                   |                                                                                                                                                           |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------|
| Failure Mode: LIST POSSIBLE MODES OF FAILURE. EXAM- PLES: ITEM SHORT, ITEM OPEN, IMPE- DANCE, FIN FAILURE. LIST ONLY ONE MODE PER PAGE.                                                                                                              | Supporting Data                                                                                                                                     | Refuting Data                                                                                                                                                                                                                | Additional Data Tests Required                                                                                                                            |
| ENTER LOGIC DIAGRAM REFER- ENCE NUMBER.                                                                                                                                                                                                              | ENTER ALL DATA WHICH SUPPORT THE POSTULATED MODE AND SEQUENCES. EACH ENTRY SHOULD BE NUMBERED TO AGREE WITH THE FAILURE SEQUENCE ENTRY IT SUPPORTS. | ENTER ALL DATA WHICH REFUTE THE POSTULATED MODE AND SEQUENCES. EACH ENTRY SHOULD BE NUMBERED TO AGREE WITH THE FAILURE SEQUENCE ENTRY IT SUPPORTS (THERE MAY BE SUPPORTING AND REFUTING ENTRIES FOR EACH MODE AND SEQUENCE.) | AS A RESULT OF ENTRIES IN ANY OF THE COLUMNS ENTER SPECIFIC DESCRIPTION OF WHAT FACTS OR DATA MUST BE COLLEC TED TO COMPLETE THE PROBLEM SOLVING PROCESS. |
| <u>Failure Sequence</u><br>CONCEIVABLE MECHANISMS WHICH COULD CAUSE THE FAILURE MODE TO OCCUR. THERE MAY BE SEVERAL MECH- ANISMS THAT COULD CAUSE A GIVEN FAILURE MODE TO OCCUR.<br><br>DESCRIBE HOW, WHAT, WHERE, WHEN, WHY AND WHO WERE INVOLVED.) |                                                                                                                                                     |                                                                                                                                                                                                                              |                                                                                                                                                           |

WHAT  
 WHERE  
 WHEN  
 WHY  
 HOW  
 WHO

Corrective Action: NONE REQUIRED (Check One) Conclusion:

LIST THE STEPS OR MEASURES THAT CAN BE TAKEN TO PREVENT A FAILURE IN THIS MODE, e.g., DESIGN CHANGE, ADDITIONAL QUALITY CONTROL, TEST OPERATIONS, ETC.

ENTER FINAL ESTIMATE OF THE CAUSE PROBABILITY AND SUMMARY STATEMENTS BASED ON THE CONTENT OF EACH MODE ANALYSIS

Figure 6. Root cause analysis chart instruction format

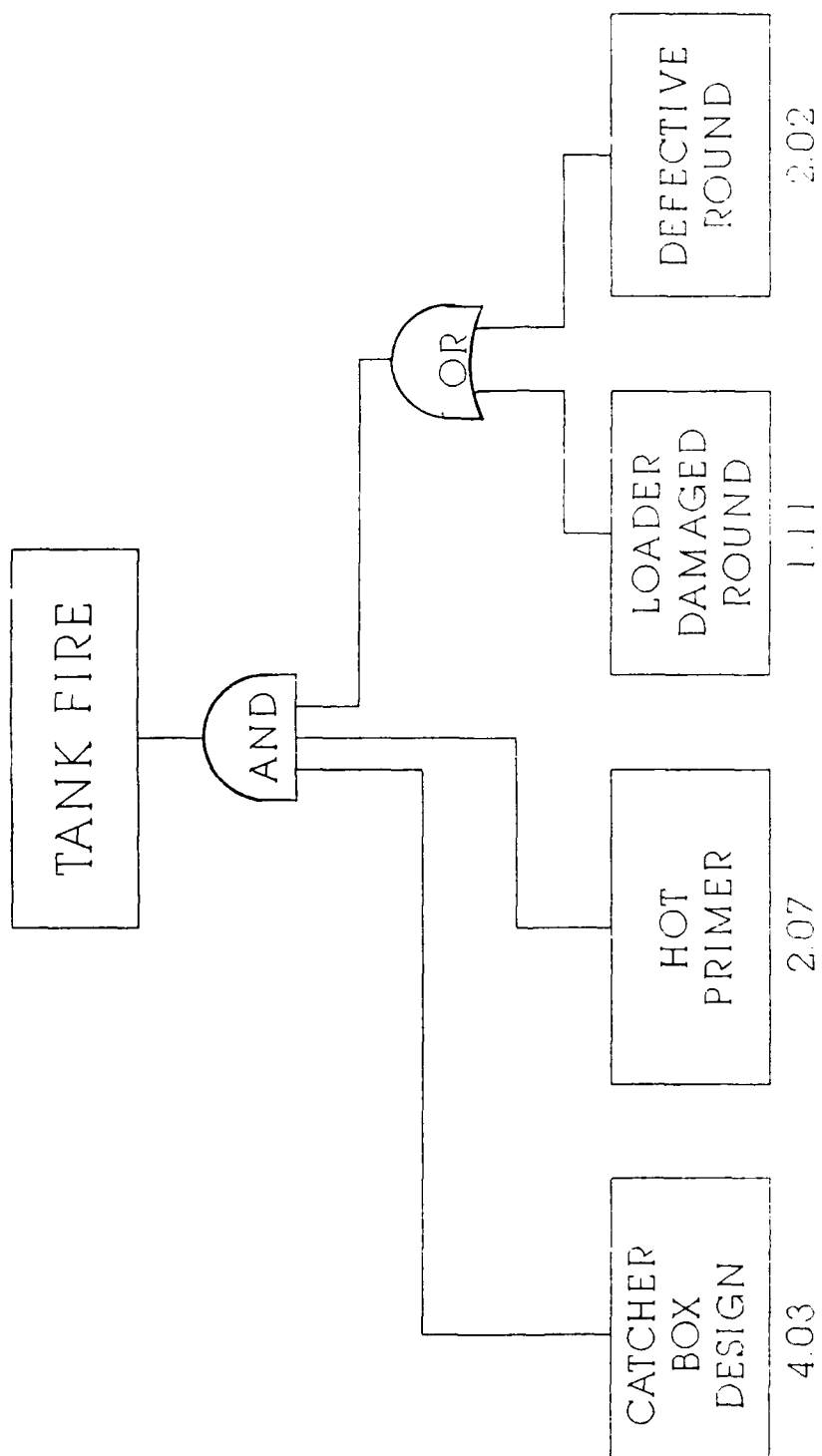


Figure 7. 4 July 1988 tank fire

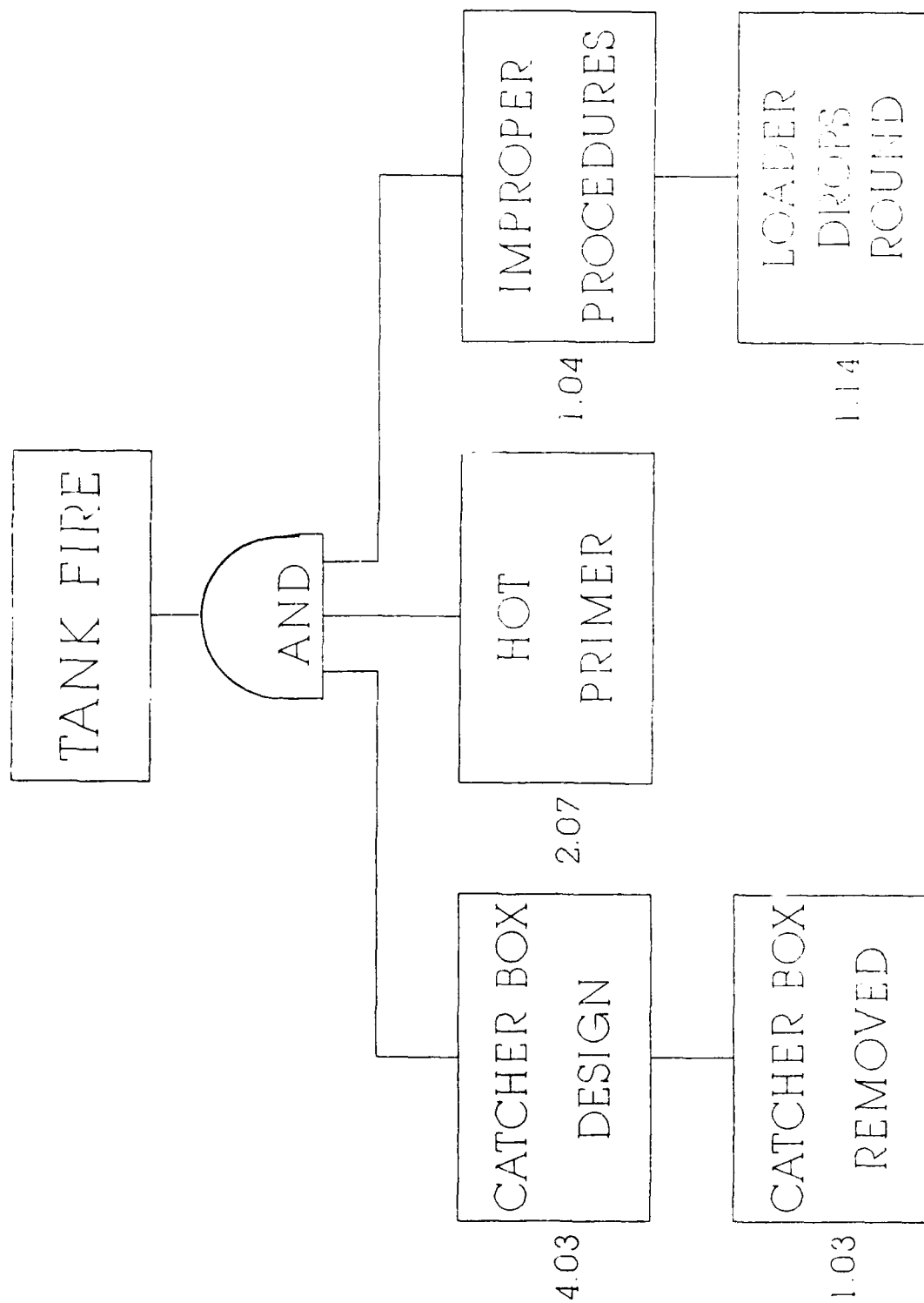


Figure 8. 14 August 1988 tank fire



Figure 9. Catcher box seam

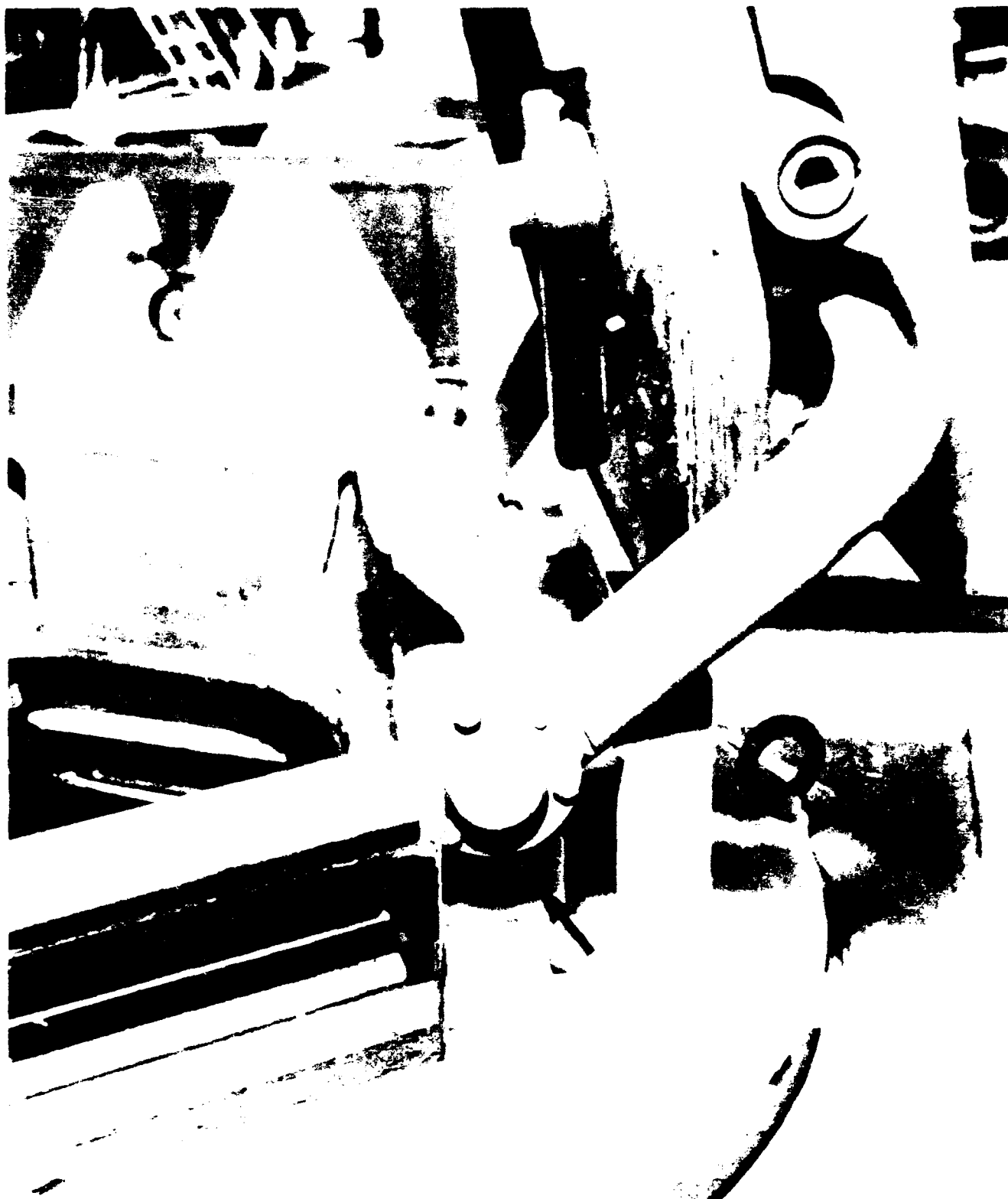


Figure 10. Commander's hatch

APPENDIX A  
GUN SYSTEM DESCRIPTION

## APPENDIX A

### SUBJECT: GUN SYSTEM FUNCTIONING, INTERACTION, AND MALFUNCTIONS

#### SUQUENCE OF OPERATION:

1. INITIAL CONDITIONS: Breech Closed, Chamber Empty, Gun in Battery Position, Safe/Armed Handle in the safe position.

2. The Loader engages the breech operating handle in the breech operating shaft and lifts the handle which opens the breech. The breech block is now held open by the cartridge case extractors which engage a mating surface on the breech block. As the breech is opened, the stub base deflector follows the block down.

3. The Loader now inserts the round into the chamber. As the round nears its chambered position, the rim on the stub base pushes the extractors forward and disengages them from the breech block. The breech closing spring then causes the cross shaft and crank to rotate and lift the block and stub base deflector. Once the block has reached its full up position, the crank continues to rotate, driving the firing pin into contact with the primer and locking the breech shut. Additionally, as the block reaches its full up position, the ignition circuit between the breech pin and block is established. The Loader then moves the Safe/Arm handle to the armed or up position.

4. The Gunner now fires the chambered round. As the projectile starts to move, the cannon begins to recoil. As the projectile passes the bore evacuator jets, a fraction of the propellant gas enters the evacuator chamber. The projectile now exits the muzzle and the hot propellant gases (composed largely of hydrogen, carbon monoxide, carbon dioxide and water) encounter the air surrounding the muzzle. The gases autoignite to produce the muzzle flash. This muzzle flash very often causes the gases remaining in the tube to ignite and burn at the surface where oxygen is available. After the projectile leaves the gun, the gases stored in the evacuator chamber start to reenter the tube. Since the evacuator jets are angled toward the muzzle, they tend to eject the gases remaining in the muzzle region from the tube and cause a partial vacuum at the rear of the tube.

5. As the gun recoils, it is slowly decelerated by the hydraulic braking action of the recoil system and the compression of the counter recoil spring. Also as the gun recoils, the breech opening crank moves the spring loaded breech opening cam out of the way. At max recoil, the cannon reverses direction and is accelerated forward by the counter recoil spring. The breech opening crank then strikes the opening cam which causes the crank to rotate and open the breech block. During the initial stages of this motion, several things occur simultaneously. The breech operating crank unlocks the breech block and withdraws the firing pin. This is necessary in order to avoid firing pin breakage. During the final stages of block motion, the block strikes the camming surface of the extractors and causes them to rotate, extract, and eject the spent case base from the chamber. The case base then encounters the case base deflector. Meanwhile, during the recoil and counter recoil motions, the bore evacuator has continued to discharge the stored propellant gases into the tube. The partial vacuum

caused by this discharge draws turret air into the tube during the case ejection. The deflector has been held in the up position by a latch controlled by the Safe/Arm Handle. The deflector forms a chute which guides the case into the containment box. Meanwhile, the cam continues to hold the breech block down.

6. The loader, prior to loading the next round, places the Safe/Arm Handle in the safe position which simultaneously causes two action to occur: 1. The breech operating cam now moves out from underneath the opening crank and allows the breech closing mechanism to raise the block to be caught by the extractors. 2. The deflector is now unlocked and is allowed to fall to the bottom of the breech block. The cannon is now ready to be reloaded.

Roger Billington

APPENDIX B  
ROOT CAUSE ANALYSIS CHARTS

CHART #1

DATE: OCTOBER 88 REV. NO:

FAILURE DESCRIPTION OR SYMPTOM Crew

Barrowed Loader 1.01

PROBABILITY ESTIMATE:  
(WHAT IS THE PROBABILITY OF THE  
FAILURE MODE BEING THE ROOT CAUSE?)

| SPECULATION                                                                                                                                                                                                                                          | EVALUATION                                              |                      | ADDITIONAL DATA TESTS<br>REQUIRED |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------|----------------------|-----------------------------------|
|                                                                                                                                                                                                                                                      | Fire 1<br>Unlikely                                      | Fire 2<br>Unlikely   |                                   |
|                                                                                                                                                                                                                                                      | SUPPORTING DATA                                         | REFUTING DATA        |                                   |
| <b>FAILURE MODE:</b><br>Barrowed loader did not inspect ammunition.                                                                                                                                                                                  | Loose propellant in turret bustle.<br>9 July testimony. |                      |                                   |
| <b>FAILURE SEQUENCE:</b><br>Loader was a gunner from another tank.<br>Loader did not place rounds in ammunition rack.<br>Defective/damaged round during loading process.<br>Propellant spills from broken round.<br>Propellant contacted hot primer. | No procedures requiring loader to inspect ammunition.   |                      |                                   |
| <b>CORRECTIVE ACTION:</b> XX                                                                                                                                                                                                                         | NONE                                                    | REQUIRED (CHECK ONE) | CONCLUSION: Unlikely              |

Insure crews inspect ammunition before firing table.  
Avoid borrowing people to fill crews.

Figure A1  
Borrowed Loader

WHO  
WHAT  
WHEN  
WHERE  
WHY  
HOW

DATE: OCTOBER 88 REV. NO: 1  
FAILURE DESCRIPTION OR SYMPTOM Crew

PROBABILITY ESTIMATE:  
(WHAT IS THE PROBABILITY OF THE  
FAILURE MODE BEING THE ROOT CAUSE?)

Maintenance 1.02

| SPECULATION                                                                                                                                                                                                                                                                                                                                                                       | EVALUATION                                                                                                                                                                            |                                                                                                                                                                                              | ADDITIONAL DATA TESTS<br>REQUIRED                                                                                                    |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------|
|                                                                                                                                                                                                                                                                                                                                                                                   | Fire 1<br>Unlikely                                                                                                                                                                    | Fire 2<br>Unlikely                                                                                                                                                                           |                                                                                                                                      |
| <p><b>FAILURE MODE:</b><br/>Round ignites while tank is<br/>undergoing unit maintenance.</p> <p><b>FAILURE SEQUENCE:</b><br/>Unit maintainer touches<br/>electrical lead to round<br/>while performing P.M.<br/>Limited space in tank,<br/>maintainer moves wires out of<br/>the way.<br/>Spark hits round igniting<br/>cartridge or hits primer<br/>causing round to ignite.</p> | <p><b>SUPPORTING DATA</b><br/>Round is electrically<br/>initiated in normal fir-<br/>ing sequence.<br/>Heat from electrical<br/>spark should be hot<br/>enough to ignite the case</p> | <p><b>REFUTING DATA</b><br/>In both cases the tanks<br/>were in operation at the<br/>time the fire started.<br/>Heat duration from a<br/>spark is insufficient to<br/>ignite propellant.</p> | <p>Determine the time<br/>required for round to be<br/>exposed to electrical<br/>spark (other than igniter)<br/>before ignition.</p> |
| <p><b>CORRECTIVE ACTION:</b> _____ NONE <input type="checkbox"/> <input type="checkbox"/> REQUIRED (CHECK ONE)</p>                                                                                                                                                                                                                                                                |                                                                                                                                                                                       |                                                                                                                                                                                              | <p><b>CONCLUSION</b> Not Relevant</p>                                                                                                |

WHO  
WHAT  
WHEN  
WHERE  
WHY  
HOW

Figure A2  
Maintenance

CHART # 3

DATE: OCTOBER 88      REV. NO:  
FAILURE DESCRIPTION OR SYMPTOM      Crew

PROBABILITY ESTIMATE:  
(WHAT IS THE PROBABILITY OF THE  
FAILURE MODE BEING THE ROOT CAUSE?)

No Catcher Box 1.03

| SPECULATION                                                                                                                                                                            | EVALUATION                                                                                                                                        |               | ADDITIONAL DATA TESTS<br>REQUIRED |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------|---------------|-----------------------------------|
|                                                                                                                                                                                        | Unlikely                                                                                                                                          | Most Likely   |                                   |
|                                                                                                                                                                                        | SUPPORTING DATA                                                                                                                                   | REFUTING DATA |                                   |
| <b><u>FAILURE MODE:</u></b><br><br>Catcher box not in use in tank.                                                                                                                     | Testimony indicates that catcher box was not being utilized.<br>Visual inspection varies absence of box.<br>Sufficient heat to ignite propellant. |               |                                   |
| <b><u>FAILURE SEQUENCE:</u></b><br><br>Crew removes catcher box because it restricts movement.<br>Case base lands on floor.<br>Loader drops round which hits primer.<br>Round ignites. |                                                                                                                                                   |               |                                   |

WHO  
WHAT  
WHEN  
WHERE  
WHY  
HOW

CORRECTIVE ACTION: XX      NONE      REQUIRED (CHECK ONE)      CONCLUSION:

Make use of catcher box mandatory.  
Reinforce in manuals.  
Redesign box addressing MANPRINT issues.

Crew members do not like the case base catcher box. It is unreliable and hinders movement within the turret.

DATE: OCTOBER 88 REV. NO:  
FAILURE DESCRIPTION OR SYMPTOM Crew

PROBABILITY ESTIMATE:  
(WHAT IS THE PROBABILITY OF THE  
FAILURE MODE BEING THE ROOT CAUSE?)

Failure to Follow Procedures 1.04

| SPECULATION                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | EVALUATION                                                                                                                                                                                                                     |                       | ADDITIONAL DATA TESTS<br>REQUIRED |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|-----------------------------------|
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | Fire 1<br>Unlikely                                                                                                                                                                                                             | Fire 2<br>Most Likely |                                   |
| <p><b>FAILURE MODE:</b><br/>Failure to follow prescribed loading procedures.</p> <p><b>FAILURE SEQUENCE:</b><br/>Loader had a second round in hand prior to firing round in gun.<br/>Round was not fully seated in breech.<br/>Loader attempted to seat round.<br/>Loader lost control of round in his hands and it fell to the floor.<br/>No catcher box present.<br/>Hot case base on floor.<br/>Round which fell from loader hands landed on hot case base and ignited.</p> | <p>Supporting Data:<br/>Extractors will not trip if gun is not safed.<br/>Loader admits having a second round in hand before round in gun has been fired.<br/>Loader testimony recorded on tape.<br/>Burnt round on floor.</p> | Refuting Data         |                                   |

WHO  
WHAT  
WHEN  
WHERE  
WHY  
HOW

## CONCLUSION:

## REQUIRED (CHECK ONE)

NONE

xx

CORRECTIVE ACTION:

Review and enforce procedures. Only load when gun is ready.

Review safety procedures in operator's manual.

To cut loading times, loaders obtain a round from the bustle before the previous round is fired. IN the case of a misfire, the loader would have to correct the problem while holding the additional round he obtained from the bustle. The loader lost control of rd he was holding it fell to floor, onto hot primer.

CHART #5

DATE: OCTOBER 88      REV. NO:      Crew  
FAILURE DESCRIPTION OR SYMPTON

PROBABILITY ESTIMATE:  
(WHAT IS THE PROBABILITY OF THE  
FAILURE MODE BEING THE ROOT CAUSE?)

Smoking 1.05

| SPECULATION                                                                                                                                                                                                                                                                                   | EVALUATION                                               |                                                                                                                                                                  | ADDITIONAL DATA TESTS<br>REQUIRED |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------|
|                                                                                                                                                                                                                                                                                               | Fire 1<br>Unlikely                                       | Fire 2<br>Unlikely                                                                                                                                               |                                   |
|                                                                                                                                                                                                                                                                                               | SUPPORTING DATA                                          | REFUTING DATA                                                                                                                                                    |                                   |
| <b>FAILURE MODE:</b><br>Crew member smoking.<br>Cigarette or hot ashes<br>ignite combustible materials<br>on floor.                                                                                                                                                                           | Smoking in turret is<br>common though not<br>authorized. | No evidence of smoking on<br>tank.<br>Unlikely that a cigarette<br>will ignite a round or<br>start a fire. It does<br>not have the intensity to<br>ignite a CCC. |                                   |
| <b>FAILURE SEQUENCE:</b><br><br>A lit cigarette or hot ashes<br>fall onto combustible<br>materials on turret floor,<br>starting a small fire.<br>Loader sees fire, panics,<br>drops round, damaging it,<br>and spilling propellant on<br>floor, or drops round on<br>fire in hurry to escape. |                                                          |                                                                                                                                                                  |                                   |
| CORRECTIVE ACTION: _____ NONE _____ REQUIRED (CHECK ONE)                                                                                                                                                                                                                                      |                                                          |                                                                                                                                                                  | CONCLUSION: _____ None            |

WHO  
WHAT  
WHEN  
WHERE  
WHY  
HOW

Figure A5  
Smoking

CHART #6

DATE: OCTOBER 88 REV. NO: 1  
FAILURE DESCRIPTION OR SYMPTOM Crew

PROBABILITY ESTIMATE:  
(WHAT IS THE PROBABILITY OF THE  
FAILURE MODE BEING THE ROOT CAUSE?)

Improperly adjusted loader's tray 1.06

| SPECULATION                                                                                                                                                                                                                                                                                                                      | EVALUATION                                                                                                                                                             |                                                                                                                                                   | ADDITIONAL DATA TESTS<br>REQUIRED                                                                     |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------|
|                                                                                                                                                                                                                                                                                                                                  | Fire 1<br>Likely                                                                                                                                                       | Fire 2<br>Unlikely                                                                                                                                |                                                                                                       |
| <p><b>FAILURE MODE:</b><br/>Loader's tray out of adjust-<br/>ment, scrapes combustible<br/>case creating residue.</p> <p><b>FAILURE SEQUENCE:</b><br/>Residue collects at breech<br/>or on gun. Back flash or<br/>case base hot primer ignites<br/>material causing loader to<br/>drop round. Round contacts<br/>hot primer.</p> | <p>SUPPORTING DATA<br/>Loader reported seeing<br/>fire on turret floor area<br/>(Testimony).<br/>Known that trays can<br/>scrape ammunition,<br/>creating residue.</p> | <p>REFUTING DATA<br/>No indications of fire<br/>before loading process.<br/>Substantial amount of re-<br/>sidue required to start a<br/>fire.</p> |                                                                                                       |
| CORRECTIVE ACTION: _____                                                                                                                                                                                                                                                                                                         |                                                                                                                                                                        | NONE <u>xx</u> REQUIRED (CHECK ONE)                                                                                                               | CONCLUSION:<br>Burning residue could have frightened<br>the loader, causing him to drop the<br>round. |

Figure A6  
Improperly Adjusted Loader's Tray

CHART #7

DATE: OCTOBER 88 REV. NO:  
FAILURE DESCRIPTION OR SYMPTOM Crew

PROBABILITY ESTIMATE:  
(WHAT IS THE PROBABILITY OF THE  
FAILURE MODE BEING THE ROOT CAUSE?)

Fail to Safe Gun 1.07

| SPECULATION                                                                                           | EVALUATION                                                                                                                                    |                  | ADDITIONAL DATA TESTS<br>REQUIRED |
|-------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------|------------------|-----------------------------------|
|                                                                                                       | Fire 1<br>Unlikely                                                                                                                            | Fire 2<br>Likely |                                   |
|                                                                                                       | SUPPORTING DATA                                                                                                                               | REFUTING DATA    |                                   |
| <u>FAILURE MODE:</u><br>Loader fails to safe gun<br>prior to pickup of next<br>round.                 | Gun breech will not close<br>when not in safe.<br>Loader had round in hands<br>(Testimony).<br>Difficulty to safe gun<br>with round in hands. | None             |                                   |
| <u>FAILURE SEQUENCE:</u><br><br>While loader attempts to<br>safe gun he drops round on<br>hot primer. |                                                                                                                                               |                  |                                   |

WHO  
WHAT  
WHEN  
WHERE  
WHY  
HOW

CORRECTIVE ACTION: \_\_\_\_\_ NONE ☒ REQUIRED (CHECK ONE)

CONCLUSION:

This is a common practice. It  
requires the loader to reach over  
the shoulder guard to safe the gun  
with a round in his hand.

Figure A7 Failure to Safe Gun

DATE: OCTOBER 88 REV. NO:  
FAILURE DESCRIPTION OR SYMPTOM Crew

PROBABILITY ESTIMATE:  
(WHAT IS THE PROBABILITY OF THE  
FAILURE MODE BEING THE ROOT CAUSE?)

Improperly adjusted loader's tray 1.08

| SPECULATION                                                                                                                                                                                                                                                                                                                             | EVALUATION <u>Fire 1</u> <u>Fire 2</u><br>Unlikely Likely |                                                                        |                                   |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------|------------------------------------------------------------------------|-----------------------------------|
|                                                                                                                                                                                                                                                                                                                                         | SUPPORTING DATA                                           | REFUTING DATA                                                          | ADDITIONAL DATA TESTS<br>REQUIRED |
| <p><b><u>FAILURE MODE:</u></b><br/>Loader's tray out of adjustment. Case base hangs after firing.</p> <p><b><u>FAILURE SEQUENCE:</u></b><br/>Case base caught under loading tray.<br/>Loader has round ready to load and attempts to clear case base while holding round.<br/>Drops round.<br/>CCC contacts hot primer and ignites.</p> | Known problems with loader's tray adjustments             | Neither loader reported hung case bases immediately prior to the fire. |                                   |

WHO  
WHAT  
WHEN  
WHERE  
WHY  
HOW

CORRECTIVE ACTION: XX NONE REQUIRED (CHECK ONE) CONCLUSION:

Training emphasise that loaders draw rounds only when the gun is ready to load. Improve reliability of loader's tray.

A hung case base could interrupt the loader's routine, causing him to drop a round.

Figure A8  
Improperly Adjusted Loader's Tray

CHART #9

DATE: OCTOBER 88 REV. NO:   
FAILURE DESCRIPTION OR SYMPTON CREW

PROBABILITY ESTIMATE:   
(WHAT IS THE PROBABILITY OF THE   
FAILURE MODE BEING THE ROOT CAUSE?)

Combustible material in turret 1.09

| SPECULATION                                                                                                                                                                                                             | EVALUATION                                                                                                                                                                                                                        |                                                                                                                                                                                                                                                                       |                                   |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------|
|                                                                                                                                                                                                                         | Fire 1<br>Unlikely                                                                                                                                                                                                                | Fire 2<br>Unlikely                                                                                                                                                                                                                                                    | Unlikely                          |
|                                                                                                                                                                                                                         | SUPPORTING DATA                                                                                                                                                                                                                   | REFUTING DATA                                                                                                                                                                                                                                                         | ADDITIONAL DATA TESTS<br>REQUIRED |
| <p><b>FAILURE MODE:</b><br/>Combustible material in<br/>turret - rags, paper, etc.</p> <p><b>FAILURE SEQUENCE:</b><br/><br/>Matter falls on hot primer.<br/>Fire starts.<br/>Loader drops round, which<br/>ignites.</p> | <p>Photographs show trash on<br/>floor.<br/>Manuals and other paper<br/>material is routinely in<br/>turret.<br/>Hot primers are expelled<br/>onto floor when catcher<br/>box is not used.<br/>This materail will<br/>ignite.</p> | <p>Round will ignite with<br/>this type of ingintion<br/>source but only after<br/>significant time as<br/>opposed to a few seconds<br/>as in this incident.<br/>(Appendix C Figure E9-El3)<br/>This material has been<br/>shown to smolder rather<br/>than burn.</p> |                                   |

CORRECTIVE ACTION: NONE XX REQUIRED (CHECK ONE) CONCLUSION: None  
Area should be clear when firing.  
Material should be stowed.

Figure A9  
Combustible Material In Turret

WHO  
WHAT  
WHEN  
WHERE  
WHY  
HOW

CHART #10

DATE: OCTOBER 88 REV. NO:  
FAILURE DESCRIPTION OR SYMPTOM Crew

PROBABILITY ESTIMATE:  
(WHAT IS THE PROBABILITY OF THE  
FAILURE MODE BEING THE ROOT CAUSE?)

Failure to follow Safe/Arm Procedures 1.10

| SPECULATION                                                                                                                                                                                                                          | EVALUATION         |                                                                                                          | ADDITIONAL DATA TESTS<br>REQUIRED           |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------|----------------------------------------------------------------------------------------------------------|---------------------------------------------|
|                                                                                                                                                                                                                                      | Fire 1<br>Unlikely | Fire 2<br>Likely                                                                                         |                                             |
| <u>FAILURE MODE:</u><br>Loader not following Safe/<br>Arm procedures.                                                                                                                                                                | None               | During the second incident<br>a round was partially<br>chambered indicating the<br>breech remained open. | Determine if tray was<br>properly adjusted. |
| <u>FAILURE SEQUENCE:</u><br>Loader places Safe/Arm<br>handle in safe position<br>before gun returns to<br>battery.<br>Breech fails to remain open.<br>Loader fumbles round,<br>allowing it to fall and<br>encounter ignition source. |                    |                                                                                                          |                                             |

CORRECTIVE ACTION: \_\_\_\_\_ NONE ☒ REQUIRED (CHECK ONE) CONCLUSION:  
Loaders take short cuts. He could have safed the  
weapon too early, causing an interruption in his  
loading sequence.

WHO  
WHAT  
WHEN  
WHERE  
WHY  
HOW

Figure A10  
Failure to Follow Safe/Arm Procedures

CHART #11  
 DATE: OCTOBER 88 REV. NO:  
 FAILURE DESCRIPTION OR SYMPTOM Crew

PROBABILITY ESTIMATE:  
 (WHAT IS THE PROBABILITY OF THE  
 FAILURE MODE BEING THE ROOT CAUSE?)

Loader Damages Round 1.11

| SPECULATION                                                                                                                                                              | EVALUATION                                                                                                                                                                                                                      |                                                                                                                                         | ADDITIONAL DATA TESTS<br>REQUIRED                                                                                                                                                            |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                                                                                                                                          | Fire 1<br>Most Likely                                                                                                                                                                                                           | Fire 2<br>Unlikely                                                                                                                      |                                                                                                                                                                                              |
|                                                                                                                                                                          | SUPPORTING DATA                                                                                                                                                                                                                 | REFUTING DATA                                                                                                                           |                                                                                                                                                                                              |
| <b>FAILURE MODE:</b><br>Round damaged while removing<br>from bustle.                                                                                                     | Loader reports being hit<br>on shoulder when extrac-<br>ting round from rack.<br>Loader reports seeing<br>fire before dropping<br>round.<br>Unburnt propellent in<br>turret.<br>Loader reported seeing a<br>round on the floor. | Difficult to break open<br>a good round.<br>Propellent in bustle<br>behind closed door.<br>Propellent bag should<br>contain propellent. | Determine if propellent<br>was in one location or<br>scattered throughout<br>bustle.<br>Determine time to ignited<br>propellent at 700° F.<br>Try to repeat breaking a<br>round in a turret. |
| <b>FAILURE SEQUENCE:</b><br>In excitement and haste,<br>loader breaks round.<br>Propellent spills, igniting<br>on hot primer.<br>Loader frightened and dropped<br>round. |                                                                                                                                                                                                                                 |                                                                                                                                         |                                                                                                                                                                                              |

WHO  
 WHAT  
 WHEN  
 WHERE  
 WHY  
 HOW

CORRECTIVE ACTION: \_\_\_\_\_ NONE xx REQUIRED (CHECK ONE) CONCLUSION:

The loader was excited and rushed because of an unexpected reengagement. He had NBC equipment on and the turret was dark. He could easily have snapped the projectile portion of the round off while withdrawing it from the bustle.

Figure All Loader Damages Round

DATE: OCTOBER 88 REV. NO: 1  
FAILURE DESCRIPTION OR SYMPTOM Crew

PROBABILITY ESTIMATE:  
(WHAT IS THE PROBABILITY OF THE  
FAILURE MODE BEING THE ROOT CAUSE?)

Previously Damaged Round 1.12

| SPECULATION                                                                                                                                                                           | EVALUATION                                                                                                                                                                                                                       |                    | ADDITIONAL DATA TESTS<br>REQUIRED |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------|-----------------------------------|
|                                                                                                                                                                                       | Fire 1<br>Likely                                                                                                                                                                                                                 | Fire 2<br>Unlikely |                                   |
|                                                                                                                                                                                       | SUPPORTING DATA                                                                                                                                                                                                                  | REFUTING DATA      |                                   |
| <b>FAILURE MODE:</b><br>Previously damaged round<br>laying in bustle.                                                                                                                 | Loader reports being hit<br>on shoulder when extrac-<br>ting round from rack.<br>Loader reports seeing<br>round on the floor.<br>Propellent found in<br>bustle.<br>Loader reports seeing<br>fire before dropping<br>round.       | None               |                                   |
| <b>FAILURE SEQUENCE:</b><br>Loader extracts broken round<br>from bustle.<br>Propellent spills igniting<br>on something burning or<br>primer.<br>Loader frightened and drops<br>round. | It is conceivable that<br>broken rounds are hidden<br>to pass problem to some-<br>one else.<br>Crew members have been<br>threatened with liability<br>Damaged round could have<br>been placed in bustle by<br>a non crew member. |                    |                                   |

CORRECTIVE ACTION: XX NONE

Review liability policy for ammunition turn in  
Avoid borrowing crew members.  
Emphasize ammunition care during training.

REQUIRED (CHECK ONE)

CONCLUSION: Likely

This situation could have contributed to the 4 July  
fire. The borrowed loader may not have known that a  
bad round was loaded in the bustle.

Figure A12  
Previously Damaged Round

CHARE #13

DATE: OCTOBER 88

REV. NO:

FAILURE DESCRIPTION OR SYMPTOM      Crew

PROBABILITY ESTIMATE:

(WHAT IS THE PROBABILITY OF THE

FAILURE MODE BEING THE ROOT CAUSE?)

Improperly Adjusted Loader's Tray 1.13

| SPECULATION                                                                                                                                      | EVALUATION                                   |                                               | ADDITIONAL DATA TESTS<br>REQUIRED                                                          |
|--------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------|-----------------------------------------------|--------------------------------------------------------------------------------------------|
|                                                                                                                                                  | Fire 1<br>Unlikely                           | Fire 2<br>Likely                              |                                                                                            |
| <b>FAILURE MODE:</b><br>Loader's tray not properly<br>adjusted.                                                                                  | Round did not seat during<br>14 August fire. | System was found oper-<br>ational after fire. | It is not known if the<br>post fire inspection<br>covered the loader's<br>tray adjustment. |
| <b>FAILURE SEQUENCE:</b><br><br>Tray drops after ejection.<br>Gun not on safe.<br>Loader attempts to chamber<br>round.<br>Breech will not close. |                                              |                                               |                                                                                            |
| <b>CORRECTIVE ACTION:</b> NONE      xx      REQUIRED (CHECK ONE)<br>Emphasize maintenance to include tray adjustments.                           |                                              |                                               | <b>CONCLUSION:</b> Unlikely                                                                |

WHO  
WHAT  
WHEN  
WHERE  
WHY  
HOW

Figure A13  
Improperly Adjusted Loader's Tray

CHART #14

DATE: OCTOBER 88 REV. NO:  
FAILURE DESCRIPTION OR SYMPTOM

Crew

PROBABILITY ESTIMATE:  
(WHAT IS THE PROBABILITY OF THE  
FAILURE MODE BEING THE ROOT CAUSE?)

Dropped Round 1.14

| SPECULATION                                                                                                                                                               | EVALUATION         |                       | SUPPORTING DATA                                                                                                       | REFUTING DATA | ADDITIONAL DATA TESTS<br>REQUIRED |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------|-----------------------|-----------------------------------------------------------------------------------------------------------------------|---------------|-----------------------------------|
|                                                                                                                                                                           | Fire 1<br>Unlikely | Fire 2<br>Most Likely |                                                                                                                       |               |                                   |
| <b>FAILURE MODE:</b><br>Dropped round ignites and<br>burns.                                                                                                               |                    |                       | Loader dropped round 5<br>while trying to seat<br>round 4 (loader test-<br>imony).<br>Burnt round on turret<br>floor. | None          |                                   |
| <b>FAILURE SEQUENCE:</b><br><br>Loader in hast and<br>excitement looses control<br>and dropps round.<br>Round contacted hot primer<br>from previously fires<br>cartridge. |                    |                       |                                                                                                                       |               |                                   |

CORRECTIVE ACTION: \_\_\_\_\_ NONE xx REQUIRED (CHECK ONE) CONCLUSION:

Enforce proper loading procedures during training.

The primer from the previously fired round is  
hot enough to ignite propellant. The hot  
primer is the root cause.

Figure A14  
Dropped Round

WHO  
WHAT  
WHEN  
WHERE  
WHY  
HOW

CHART # 15

DATE: OCTOBER 88

REV. NO:

FAILURE DESCRIPTION OR SYMPTOM

Ammunition

PROBABILITY ESTIMATE:

(WHAT IS THE PROBABILITY OF THE

FAILURE MODE BEING THE ROOT CAUSE?)

Flaming Case Base 2.01

| SPECULATION                                                                                                                                                                                                                                                                                                                                                                                                                        | EVALUATION                                                                                                                                                                  |                                                                |                                                        |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------|--------------------------------------------------------|
|                                                                                                                                                                                                                                                                                                                                                                                                                                    | SUPPORTING DATA                                                                                                                                                             | REFUTING DATA                                                  | ADDITIONAL DATA TESTS REQUIRED                         |
| <p><b>FAILURE MODE:</b></p> <p>Flame in case base (primer or occ) after ejection from gun.</p> <p><b>FAILURE SEQUENCE:</b></p> <p>After firing, spent case base ejected.<br/>Residue on primer or case base continues to burn.<br/>Loader withdraws round from magazine.<br/>Flame from case base causes him to lose composure and drop the round, causing it to spill propellant among the hot primers which causes ignition.</p> | <p>Loader reports seeing a small fire under breech. Loaders attitude -afraid of fire -does not want to be there<br/>Primer after burning was encountered in dev testing</p> | <p>Previous testing indicated rate of occurrence very low.</p> | <p>Fire 1 Fire 2<br/><del>Extremely unlikely</del></p> |

CONCLUSION:

REQUIRED (CHECK ONE)

NONE

xx

CORRECTIVE ACTION:

Increase effectiveness of catcher box.

A flaming case base is uncommon and burns for a short duration. This is not considered a most likely cause.

WHO  
WHAT  
WHEN  
WHERE  
WHY  
HOW

Figure B1  
Flaming Case Base

**PROBABILITY ESTIMATE:**  
(WHAT IS THE PROBABILITY OF THE FAILURE MODE BEING THE ROOT CAUSE?)

Joint Failure 2.02

| SPECULATION                                                                                                                                                                                                                                               | EVALUATION Fire 1 Fire 2<br>Very Likely Unlikely                                                                                                                                                                                                                                                                                                                                                             |                                                                                                                                                                                                         |                                                                                                                                                                                                          |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                                                                                                                                                                                                                           | SUPPORTING DATA                                                                                                                                                                                                                                                                                                                                                                                              | REFUTING DATA                                                                                                                                                                                           | ADDITIONAL DATA TESTS<br>REQUIRED                                                                                                                                                                        |
| <p><b><u>FAILURE MODE:</u></b><br/>Glue joint failure</p> <p><b><u>FAILURE SEQUENCE:</u></b><br/>Round separated or damaged during handling. While loading, propellant spills and contacts an ignition source such as hot primers in the catcher box.</p> | <p>4 Jul 88 Fire had unburnt propellant on floor of tank and bustle. Round was not dropped until after fire was noticed (loader testimony).<br/>Case base catcher box in place and operational--no case bases on floor.<br/>An intense and concentrated heat source is required to burn thru the casing (Honeywell tests).<br/>Loader felt something hit his shoulder during loading (loader testimony).</p> | <p>Propellant would have been spewed throughout the tank if a round caught fire (Honeywell tests)<br/>Testing did not indicate any glue joint problems.<br/>Propellant bag should eliminate spills.</p> | <p>Determine if propellant in bustle was exposed to high temperature.</p> <p>Conclusion: Glue joints have been a problem in the past. It is very possible that a round with a weak joint was loaded.</p> |

| CONCLUSION:                | REQUIRED (CHECK ONE)                                                                                                           | CONCLUSION: |
|----------------------------|--------------------------------------------------------------------------------------------------------------------------------|-------------|
| contaminant bad:           | <input type="checkbox"/> NONE<br><input checked="" type="checkbox"/> review joint-design to improve joint and containment bad: |             |
| joint and containment bad: | <input type="checkbox"/> NONE<br><input checked="" type="checkbox"/> review joint-design to improve joint and containment bad: |             |

**Eliminate threat of liability for crew members. Easy turn-in procedures for unconsumed or damaged munitions.**

Figure B2  
Joint Failure

CHART #17

DATE: OCTOBER 88

REV. NO:

FAILURE DESCRIPTION OR SYMPTOM

Ammunition

PROBABILITY ESTIMATE:

(WHAT IS THE PROBABILITY OF THE

FAILURE MODE BEING THE ROOT CAUSE?)

Moisture 2.03

| SPECULATION                                                                                                                                                                                                                                                                                                                                                              | SUPPORTING DATA                                                                                                                                                                                                                       | REFUTING DATA                                                                                           | EVALUATION                                                                                                                   |                    | ADDITIONAL DATA TESTS REQUIRED |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------|--------------------|--------------------------------|
|                                                                                                                                                                                                                                                                                                                                                                          |                                                                                                                                                                                                                                       |                                                                                                         | Fire 1<br>Unlikely                                                                                                           | Fire 2<br>Unlikely |                                |
| <p><u>FAILURE MODE:</u></p> <p>Round absorbs moisture which reduces or inhibits combustion</p> <p><u>FAILURE SEQUENCE:</u></p> <p>Moisture absorbed from humidity or rain in ammo compartment.<br/>Round is fired, cartridge case is not fully consumed but is flaming and remains in bore or is ejected into the turret.<br/>Loader drops round.<br/>Round ignites.</p> | <p>Loader reports fire on turret floor</p> <p>Rounds not shipped in waterproof containers.</p> <p>Fiber ammunition containers have been known to have moisture problems.</p> <p>Tank environmental seals have been known to leak.</p> | <p>Round coating offer some protection against moisture</p> <p>No previous report of fire or flame.</p> | <p>Was ammo subject to extreme moisture condition?</p> <p>How long was tank uploaded?</p> <p>Review Panama test results.</p> |                    |                                |

WHO  
WHAT  
WHEN  
WHERE  
WHY  
HOW

CORRECTIVE ACTION: XX NONE REQUIRED (CHECK ONE)

CONCLUSION: Unlikely

Not considered causes for both fires; however, environmental seals must be improved to prevent damage to ammunition.

Figure B3  
Moisture

CHART #18

DATE: OCTOBER 88

REV. NO:

FAILURE DESCRIPTION OR SYMPTOM Ammunition

PROBABILITY ESTIMATE:

(WHAT IS THE PROBABILITY OF THE

FAILURE MODE BEING THE ROOT CAUSE?)

Fuse Function 2.04

| SPECULATION                                                                                   | EVALUATION         |                              | ADDITIONAL DATA TESTS<br>REQUIRED |
|-----------------------------------------------------------------------------------------------|--------------------|------------------------------|-----------------------------------|
|                                                                                               | Fire 1<br>Unlikely | Fire 2<br>Unlikely           |                                   |
| <p><u>FAILURE MODE:</u><br/>Premature Fuze Function</p>                                       | Supporting Data    | Refuting Data                |                                   |
| <p><u>FAILURE SEQUENCE:</u><br/><br/>Static discharge sets off fuze.</p>                      | <p>None</p>        | <p>The M865 has no fuze.</p> |                                   |
| <p>CORRECTIVE ACTION: _____ NONE <input checked="" type="checkbox"/> REQUIRED (CHECK ONE)</p> |                    |                              | <p>CONCLUSION: Not Relevant</p>   |

WHO  
WHAT  
WHEN  
WHERE  
WHY  
HOW

Figure B4  
FuseFunction

CHART #19

DATE: OCTOBER 88

REV. NO:

FAILURE DESCRIPTION OR SYMPTOM Ammunition

PROBABILITY ESTIMATE:

(WHAT IS THE PROBABILITY OF THE FAILURE MODE BEING THE ROOT CAUSE?)

Impact 2.05

| SPECULATION                                                                               | EVALUATION         |                                                                                                                                                                                                                            | ADDITIONAL DATA TESTS REQUIRED                       |
|-------------------------------------------------------------------------------------------|--------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------|
|                                                                                           | Fire 1<br>Unlikely | Fire 2<br>Unlikely                                                                                                                                                                                                         |                                                      |
|                                                                                           | SUPPORTING DATA    | REFUTING DATA                                                                                                                                                                                                              |                                                      |
| <p><u>FAILURE MODE:</u></p> <p>Impact starts fire.</p>                                    | None               |                                                                                                                                                                                                                            |                                                      |
| <p><u>FAILURE SEQUENCE:</u></p> <p>Loader drops round.<br/>Impact ignites propellant.</p> |                    | <p>Cartridges subjected to sequential rough handling tests (2.1m package drop, .5m bare drop, and 3m bare drop during DTII.)</p> <p>Cartridges sustained heavy damage, but none of the cartridges burned or detonated.</p> | None                                                 |
| <p>CORRECTIVE ACTION: _____ NONE <input type="checkbox"/> REQUIRED (CHECK ONE)</p>        |                    |                                                                                                                                                                                                                            | <p>CONCLUSION: <input type="checkbox"/> Unlikely</p> |

WHO  
WHAT  
WHEN  
WHERE  
WHY  
HOW

Figure B5  
Impact

Primer Function 2.06

| SPECULATION                                                                                                                                                                                           | EVALUATION      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | ADDITIONAL DATA TESTS<br>REQUIRED |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------|
|                                                                                                                                                                                                       | SUPPORTING DATA | REFUTING DATA                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                                   |
| <p><b><u>FAILURE MODE:</u></b></p> <p>Premature Primer Functions</p> <p><b><u>FAILURE SEQUENCE:</u></b></p> <p>Electrical source ignites primer.</p> <p>(EMR, ESD electrical short faulty wiring)</p> | <p>None</p>     | <p>M830 cartridge electric initiators (primer&amp;fuze) tested for EMR susceptibility. Cartridge considered safe when exposed to EMR fields which are anticipated to be encountered during tactical deployment.</p> <p>-Primers subjected to static electricity test of mil std 322, except voltage applied was 20,000 volts.</p> <p>-Primers were not functioned in the two tank fire incidents.</p> <p>-No evidence of electrical malfunction history of 105mm rd.</p> | <p>Unlikely</p>                   |

CORRECTIVE ACTION: \_\_\_\_\_ NONE ☒ REQUIRED (CHECK ONE) CONCLUSION: Unlikely

Figure B6  
 Primer Function

CHART #21

DATE: OCTOBER 88 REV. NO:  
FAILURE DESCRIPTION OR SYMPTOM

Ammunition

PROBABILITY ESTIMATE:  
(WHAT IS THE PROBABILITY OF THE  
FAILURE MODE BEING THE ROOT CAUSE?)

Hot Primer 2.07

| SPECULATION                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | EVALUATION                                                                                                                                                                                                     |                       | ADDITIONAL DATA TESTS<br>REQUIRED |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|-----------------------------------|
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Fire 1<br>Most Likely                                                                                                                                                                                          | Fire 2<br>Most Likely |                                   |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | SUPPORTING DATA                                                                                                                                                                                                | REFUTING DATA         |                                   |
| <b>FAILURE MODE:</b><br>Hot primers extruding from<br>cartridge case base upon<br>ejection from gun.<br><br><b>FAILURE SEQUENCE:</b><br>M865 and M829 rounds contain<br>long primers which are hot<br>enough to ignite propellant<br>or a CCC (appendix C).<br>4 July 88 Fire-loader spills<br>propellant from round.<br>(1.11 or 2.02).<br>Catcher box allows pro-<br>pellent to contact hot<br>primers (4.03).<br>14 August 88 Fire-Crew member<br>removes catcher box because<br>it hinders movement and is<br>unreliable (4.03, 1.03).<br>Loader not following proper<br>procedures (1.04).<br>Loader lets rd fall (1.14).<br>Round contacts hot primer. | Appendix C- Ignition<br>Data, Crew Member Test-<br>imony.<br>Burnt round on floor of<br>tank for each fire.<br>Cartridge can be<br>punctured by primer.<br>4 July 88 Fire -fig. 7<br>14 August 88 Fire -fig. 8 | None                  | None                              |

CORRECTIVE ACTION: xx NONE        REQUIRED (CHECK ONE) CONCLUSION:

Develop a cartridge case base without a protruding primer or  
find a means to reduce the primer's external temperature.

The root cause for both fires. The primer temp-  
erature is approx. 700° F. when it leaves the gun.  
Information in Appendix C supports this conclusion

Figure B7  
Hot Primer

WHO  
WHAT  
WHEN  
WHERE  
WHY  
HOW

CHART #22

DATE: OCTOBER 88 REV. NO: Gun  
FAILURE DESCRIPTION OR SYMPTON

Loader's Tray 3.01

PROBABILITY ESTIMATE:  
(WHAT IS THE PROBABILITY OF THE  
FAILURE MODE BEING THE ROOT CAUSE?)

| SPECULATION                                                                                                                                                                                                 | EVALUATION         |                                                                                                | ADDITIONAL DATA TESTS<br>REQUIRED |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------|------------------------------------------------------------------------------------------------|-----------------------------------|
|                                                                                                                                                                                                             | Fire 1<br>Unlikely | Fire 2<br>Likely                                                                               |                                   |
|                                                                                                                                                                                                             | SUPPORTING DATA    | REFUTING DATA                                                                                  |                                   |
| <b>FAILURE MODE:</b><br>Loader's tray malfunction.                                                                                                                                                          | None               | Deflector tray mechanism<br>appeared to work<br>satisfactorily upon<br>inspection after fires. |                                   |
| <b>FAILURE SEQUENCE:</b><br>Loader's tray does no follow<br>block.<br>Case base ejected onto<br>loader.<br>Case base does not land in<br>containment box but onto<br>floor.<br>Startled loader drops round. |                    |                                                                                                |                                   |

CONCLUSION:

This could have contributed  
to confusion.

REQUIRED (CHECK ONE)

NONE

XX

CORRECTIVE ACTION:

Loader's tray requires adjustments for proper operation.  
Review design to determine if improvements can be made  
to reduce maintenance requirements.

Figure C1

Loader's Tray

WHO  
WHAT  
WHEN  
WHERE  
WHY  
HOW

CHART #23

DATE: OCTOBER 88 REV. NO: 1  
FAILURE DESCRIPTION OR SYMPTOM Gun

PROBABILITY ESTIMATE:  
(WHAT IS THE PROBABILITY OF THE  
FAILURE MODE BEING THE ROOT CAUSE?)

Bore Evacuator 3.02

| SPECULATION                                                                                                                                                                                                                                                                                                                                                                                                              | EVALUATION                                                                                     |                                                                                                                                                                                             | ADDITIONAL DATA TESTS<br>REQUIRED |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------|
|                                                                                                                                                                                                                                                                                                                                                                                                                          | Fire 1<br>Unlikely                                                                             | Fire 2<br>Unlikely                                                                                                                                                                          |                                   |
|                                                                                                                                                                                                                                                                                                                                                                                                                          | SUPPORTING DATA                                                                                | REFUTING DATA                                                                                                                                                                               |                                   |
| <p><u>FAILURE MODE:</u></p> <p>Bore evacuator does not function properly.</p> <p><u>FAILURE SEQUENCE:</u></p> <p>Gasses and residue from firing are not evacuated from gun.<br/>Wind pushes debris through open breech into turret.<br/>Gasses and flame enters turret and causes a flash which frightens loader and he drops round, or loader sees burning debris on floor and drops round.<br/>Smoke fills turret.</p> | <p>Seals missing from bore evacuator.</p> <p>This type of problem observed during testing.</p> | <p>Flash from burning gasses would not ignite round or exposed propellant.</p> <p>Attempted to load gun several seconds after previously fired round. Residue would have been consumed.</p> |                                   |
| <p>WHO</p> <p>WHAT</p> <p>WHEN</p> <p>WHERE</p> <p>WHY</p> <p>HOW</p>                                                                                                                                                                                                                                                                                                                                                    |                                                                                                |                                                                                                                                                                                             |                                   |

CORRECTIVE ACTION: NONE ☒ REQUIRED (CHECK ONE)

CONCLUSION:

A malfunctioning bore evacuator could have allowed smoke into the turret, contributing to confusion.

Emphasize bore evacuator maintenance.

Figure C2 Bore Evacuator

CHART #24

DATE: OCTOBER 88 REV. NO: Gun  
FAILURE DESCRIPTION OR SYMPTON

PROBABILITY ESTIMATE:  
(WHAT IS THE PROBABILITY OF THE  
FAILURE MODE BEING THE ROOT CAUSE?)

Loader's Tray 3.03

| SPECULATION                                                                                                                        | EVALUATION         |                                                                                                                                      |                                   |
|------------------------------------------------------------------------------------------------------------------------------------|--------------------|--------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------|
|                                                                                                                                    | Fire 1<br>Unlikely | Fire 2<br>Unlikely                                                                                                                   | ADDITIONAL DATA TESTS<br>REQUIRED |
| <p><b><u>FAILURE MODE:</u></b></p> <p>Loader's tray in-operable.</p>                                                               | None               | Only base cases of stored ammunition is exposed.<br>Gun would have to be depressed for access.<br>Bustle door would have to be open. |                                   |
| <p><b><u>FAILURE SEQUENCE:</u></b></p> <p>Tray remains down.<br/>Ejected case enters bustle causing stored ammunition to burn.</p> |                    |                                                                                                                                      |                                   |

WHO  
WHAT  
WHEN  
WHERE  
WHY  
HOW

CORRECTIVE ACTION: \_\_\_\_\_ NONE xx REQUIRED (CHECK ONE) CONCLUSION: Unlikely

Figure C3  
Loader's Tray

CHART #25

DATE: OCTOBER 88 REV. NO: 1  
FAILURE DESCRIPTION OR SYMPTOM Turret

PROBABILITY ESTIMATE:  
(WHAT IS THE PROBABILITY OF THE  
FAILURE MODE BEING THE ROOT CAUSE?)

Round falls from bustle 4.01

| SPECULATION                                                                                                                                                                                                                  | EVALUATION                                                                                                    |                                                                                                                                                                    | ADDITIONAL DATA TESTS<br>REQUIRED                                   |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------|
|                                                                                                                                                                                                                              | Fire 1<br>Unlikely                                                                                            | Fire 2<br>Unlikely                                                                                                                                                 |                                                                     |
|                                                                                                                                                                                                                              | SUPPORTING DATA                                                                                               | REFUTING DATA                                                                                                                                                      |                                                                     |
| <b>FAILURE MODE:</b><br>Rounds fall out while door<br>is open.                                                                                                                                                               | 105 rounds falling out<br>were common occurrences.<br>Spring latches would<br>bend or fail to hold<br>rounds. | M1A1 ammunition storage<br>rack latches were im-<br>proved.<br>Locking better.<br>Only one round found on<br>floor after fires.<br>Each loader dropped a<br>round. | Inspect fielded units<br>to see if and/or how<br>often this occurs. |
| <b>FAILURE SEQUENCE:</b><br><br>During offensive engagement,<br>round vibrates loose in<br>bustle.<br>When door is opened, round<br>falls to floor, breaking open<br>and spilling propellant<br>onto hot primer and ignites. |                                                                                                               |                                                                                                                                                                    |                                                                     |

WHO  
WHAT  
WHEN  
WHERE  
WHY  
HOW

CORRECTIVE ACTION: XX NONE REQUIRED (CHECK ONE) CONCLUSION: Unlikely  
Determine probability of occurrence.

Figure D1  
Round Falls From Bustle.

DATE: OCTOBER 88 REV. NO: 1  
FAILURE DESCRIPTION OR SYMPTOM Turret

PROBABILITY ESTIMATE:  
(WHAT IS THE PROBABILITY OF THE  
FAILURE MODE BEING THE ROOT CAUSE?)

Bustle door damages round 4.02

| SPECULATION                                                                                                                                                                                                                                                                                                                                      | EVALUATION                                                                                                                                                                                                                                                                                                     |                                                           | ADDITIONAL DATA TESTS<br>REQUIRED                                                                                                                                        |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                                                                                                                                                                                                                                                                                                                  | Fire 1<br>Unlikely                                                                                                                                                                                                                                                                                             | Fire 2<br>Unlikely                                        |                                                                                                                                                                          |
|                                                                                                                                                                                                                                                                                                                                                  | SUPPORTING DATA                                                                                                                                                                                                                                                                                                | REFUTING DATA                                             |                                                                                                                                                                          |
| <p><b><u>FAILURE MODE:</u></b><br/>Round is damaged by door closing on it, spilling propellant on floor.</p> <p><b><u>FAILURE SEQUENCE:</u></b><br/>door closes on a round that slipped out of bustle and ruptures cartridge case. Propellents spill onto floor and hot primers. Propellant ignites, causing loader to panic and drop round.</p> | <p>I door safety switch is not properly adjusted, door will not stop when striking an object. It may stop after crushing a round.</p> <p>Instances in M1's where doors jammed against 105 rounds.</p> <p>Rounds could not be removed and door had to be opened manually after turning circuit breaker off.</p> | <p>Ammunition holding latches on M1A1 are redesigned.</p> | <p>Check with fielded units to see if and how often this occurs with the M1A1 tank.</p> <p>Reinspect the tank involved in the 4 July fire for proper door operation.</p> |
| CORRECTIVE ACTION: _____                                                                                                                                                                                                                                                                                                                         |                                                                                                                                                                                                                                                                                                                | NONE _____                                                | REQUIRED (CHECK ONE) _____                                                                                                                                               |
|                                                                                                                                                                                                                                                                                                                                                  |                                                                                                                                                                                                                                                                                                                | CONCLUSION: Unlikely                                      |                                                                                                                                                                          |

WHO  
WHAT  
WHEN  
WHERE  
WHY  
HOW

Figure D2  
Bustle door Damages Round

CHART #27

DATE: OCTOBER 88      REV. NO:      Turret  
FAILURE DESCRIPTION OR SYMPTON

PROBABILITY ESTIMATE:  
(WHAT IS THE PROBABILITY OF THE  
FAILURE MODE BEING THE ROOT CAUSE?)

Catcher Box Design 4.03

| SPECULATION                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | EVALUATION                                                                                                                                                           |                       |                                   |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|-----------------------------------|
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | Fire 1<br>Most Likely                                                                                                                                                | Fire 2<br>Most Likely | Fire 2<br>Most Likely             |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | SUPPORTING DATA                                                                                                                                                      | REFUTING DATA         | ADDITIONAL DATA TESTS<br>REQUIRED |
| <b>FAILURE MODE:</b><br>Design of catcher box.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | As per conversation with<br>HEL Detachment TACOM.<br>Loader testimony fire 1.<br>Loader testimony fire 2<br>and apparent rationale<br>for box not being in<br>place. | None                  |                                   |
| <b>FAILURE SEQUENCE:</b><br>Catcher box-alleged to have<br>been an evolutionary process<br>Apparently no human factors<br>engineering guidance was re-<br>quested from TACOM HEL Det.<br>Size & configuration of box<br>causes it to impinge on<br>loader's work space.<br>Design of box allows hot<br>primer stem to protrude<br>from box.<br>Open top of box provides<br>enough open space for<br>debris/shavings to be dropped<br>round to fall into box.<br>Box is unreliable. Box re-<br>moved to provide space. Hot<br>base bases land on deck. |                                                                                                                                                                      |                       |                                   |

WHO  
WHAT  
WHEN  
WHERE  
WHY  
HOW

CORRECTIVE ACTION:      NONE      REQUIRED (CHECK ONE)      CONCLUSION:      None

DATE: REV. NO:  
FAILURE DESCRIPTION OR SYMPTON

PROBABILITY ESTIMATE:  
(WHAT IS THE PROBABILITY OF THE  
FAILURE MODE BEING THE ROOT CAUSE?)

Catcher Box Design 4.03

| SPECULATION                                                                                                                                                                                                                               | EVALUATION      |               |                                   |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------|---------------|-----------------------------------|
|                                                                                                                                                                                                                                           | SUPPORTING DATA | REFUTING DATA | ADDITIONAL DATA TESTS<br>REQUIRED |
| <p><u>FAILURE MODE:</u></p> <p><u>FAILURE SEQUENCE:</u></p> <p>cont'd from chart 27<br/>Exposed primers provided<br/>an ignition source for<br/>shaving from cartridge<br/>case, a dropped round,<br/>propellant or other<br/>debris.</p> | None            | None          |                                   |

WHO  
WHAT  
WHEN  
WHERE  
WHY  
HOW

**CORRECTIVE ACTION:** xx **NONE** **REQUIRED (CHECK ONE)** **CONCLUSION:**  
 Redesign box so that case bases are contained and  
 can not expose the hot primer to any combustible  
 material.  
 The catcher box does not isolate hot primers  
 from the crew, ammunition, and any combust-  
 ible material. It is unreliable and  
 restricts crew movement.

Figure D3  
Catcher Box Design

CHART #28  
DATE: OCTOBER 88

REV. NO:

FAILURE DESCRIPTION OR SYMPTOM Turret

Short Circuit 4.04

PROBABILITY ESTIMATE:  
(WHAT IS THE PROBABILITY OF THE  
FAILURE MODE BEING THE ROOT CAUSE?)

| SPECULATION                                                                                                                                                                                          | EVALUATION                                                          |                                                                                                            | ADDITIONAL DATA TESTS<br>REQUIRED |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------|-----------------------------------|
|                                                                                                                                                                                                      | Fire 1<br>Unlikely                                                  | Fire 2<br>Unlikely                                                                                         |                                   |
| <b>FAILURE MODE:</b><br>Electrical short circuit<br>causes fire.                                                                                                                                     | Loader saw fire in the<br>turret (first fire<br>loaders testimony). | In both cases there was<br>no malfunction in equip-<br>ment reported or noted<br>before or after the fires |                                   |
| <b>FAILURE SEQUENCE:</b><br><br>Loader has round in his hand.<br>Drops round when seeing<br>sparks and/or possible fire<br>in the turret.<br>Round comes on contact with<br>hot or burning material. |                                                                     |                                                                                                            |                                   |
| CORRECTIVE ACTION: _____ NONE <input checked="" type="checkbox"/> REQUIRED (CHECK ONE)                                                                                                               |                                                                     |                                                                                                            | CONCLUSION:<br><br>Unlikely       |

WHO  
WHAT  
WHEN  
WHERE  
WHY  
HOW

Figure D4 Short Circuit

DATE: OCTOBER 88 REV. NO: 1  
FAILURE DESCRIPTION OR SYMPTOM Turret

PROBABILITY ESTIMATE:  
(WHAT IS THE PROBABILITY OF THE  
FAILURE MODE BEING THE ROOT CAUSE?)

Difficulty to exit 4.05

| SPECULATION                                                                                                                                                                                                              | EVALUATION                                                                                                |                                                                                                               |                                                                 | ADDITIONAL DATA TESTS<br>REQUIRED |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------|-----------------------------------|
|                                                                                                                                                                                                                          | SUPPORTING DATA                                                                                           | REFUTING DATA                                                                                                 | Unlikely Fire 1<br>Unlikely Fire 2                              |                                   |
| <p><u>FAILURE MODE:</u><br/>Escape timely.</p> <p><u>FAILURE SEQUENCE:</u><br/>Fire occurs.<br/>Crew members try to open hatch and have difficulty.<br/>Commander exits loaders hatch - later dies.<br/>Gunner dies.</p> | <p>Observation of TC exiting loaders hatch.<br/>Dead gunner.<br/>TC hatch in open protected position.</p> | <p>Panic hindered escape.<br/>Rapid manner in which CCC burns would not allow sufficient time for escape.</p> | <p>Determine if Commander's hatch was functioning properly.</p> |                                   |

CORRECTIVE ACTION: xx NONE        REQUIRED (CHECK ONE) CONCLUSION: Unlikely

Evaluate evacuation drills.  
Evaluate exit designs.  
Use fire protective clothing.

Figure D5  
Difficulty to Exit

CHART #30

DATE: OCTOBER 88 REV. NO:   
FAILURE DESCRIPTION OR SYMPTOM Turret

PROBABILITY ESTIMATE:   
(WHAT IS THE PROBABILITY OF THE   
FAILURE MODE BEING THE ROOT CAUSE?)

Static Electricity 4.06

| SPECULATION                                                                                                                          | EVALUATION         |                                                                                                                                                                                                                                                                                                                                                 | ADDITIONAL DATA TESTS REQUIRED |
|--------------------------------------------------------------------------------------------------------------------------------------|--------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------|
|                                                                                                                                      | Fire 1<br>Unlikely | Fire 2<br>Unlikely                                                                                                                                                                                                                                                                                                                              |                                |
|                                                                                                                                      | SUPPORTING DATA    | REFUTING DATA                                                                                                                                                                                                                                                                                                                                   |                                |
| <p><b><u>FAILURE MODE:</u></b><br/>Static electricity from loader ignites cartridge case.</p> <p><b><u>FAILURE SEQUENCE:</u></b></p> | None               | <p>72%nc cases did not ignite when sub-jected to energies up to 41 joules.</p> <p>60%nc cases would require greater energy.</p> <p>Sensitivity tests are performed at 0.25 joule which is believed to be 10 times what can be expected from a human.</p> <p>Loader would discharge to tank or stub base before contacting combustible case.</p> | None                           |
| <p>CORRECTIVE ACTION: _____ NONE <input checked="" type="checkbox"/> REQUIRED (CHECK ONE)</p>                                        |                    |                                                                                                                                                                                                                                                                                                                                                 | CONCLUSION: None               |

WHO  
WHAT  
WHEN  
WHERE  
WHY  
HOW

Figure D6  
Static Electricity

CHART #31

DATE: OCTOBER 88 REV. NO:

FAILURE DESCRIPTION OR SYMPTOM Turret

Friction 4.07

PROBABILITY ESTIMATE:

(WHAT IS THE PROBABILITY OF THE

FAILURE MODE BEING THE ROOT CAUSE?)

| SPECULATION                                                                                                                                                | EVALUATION                                                                                                                                                                                     |                                                                                                                                                                                                                                                           | ADDITIONAL DATA TESTS<br>REQUIRED |
|------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------|
|                                                                                                                                                            | Fire 1<br>Unlikely                                                                                                                                                                             | Fire 2<br>Unlikely                                                                                                                                                                                                                                        |                                   |
| <p><b><u>FAILURE MODE:</u></b></p> <p>Friction between combustible case, rack, and grit ignites cartridge case.</p> <p><b><u>FAILURE SEQUENCE:</u></b></p> | <p>SUPPORTING DATA</p> <p>Laboratory testing ignited frayed 72% nc case material on grit with a load of 420lbs. at 6fps and 240lbs. at 10fps. (3 ignitions/75 tests). Distance was 1 inch.</p> | <p>REFUTING DATA</p> <p>-cases are about 60%nc<br/>-52%nc cases failed to ignite with 1000 lbs at 8fps<br/>-velocity estimated below 2fps.<br/>-Protective coating would increase load/velocity to ignition.<br/>-unfrayed material failed to ignite.</p> | <p>none</p>                       |

CORRECTIVE ACTION: NONE ☒ REQUIRED (CHECK ONE) CONCLUSION: Unlikely

WHO  
WHAT  
WHEN  
WHERE  
WHY  
HOW

Figure D7  
Friction

CHART #32

DATE: OCTOBER 88 REV. NO: Turret  
FAILURE DESCRIPTION OR SYMPTON

PROBABILITY ESTIMATE:  
(WHAT IS THE PROBABILITY OF THE  
FAILURE MODE BEING THE ROOT CAUSE?)

Racks Scrape Cartridge Cases 4.08

| SPECULATION                                                                                                                                                                                                                                                                                             | EVALUATION                                         |                                                                  | ADDITIONAL DATA TESTS<br>REQUIRED                               |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------|------------------------------------------------------------------|-----------------------------------------------------------------|
|                                                                                                                                                                                                                                                                                                         | Fire 1<br>Unlikely                                 | Fire 2<br>Unlikely                                               |                                                                 |
| <p><b>FAILURE MODE:</b></p> <p>Ammo racks scrapes combustible cartridge case.</p> <p><b>FAILURE SEQUENCE:</b></p> <p>Residue is created from ammo racks scraping OCC. Build up of residue is ignited from gun/flashback, spark or cigarette ash. A round is exposed to burning residue and ignites.</p> | <p>Rounds have been observed to have scraches.</p> | <p>Need a large accumulation of scrapings to cause a hazard.</p> |                                                                 |
| <p><b>CORRECTIVE ACTION:</b> _____ NONE <input checked="" type="checkbox"/> REQUIRED (CHECK ONE)</p>                                                                                                                                                                                                    |                                                    |                                                                  | <p>CONCLUSION: <input checked="" type="checkbox"/> Unlikely</p> |

WHO  
WHAT  
WHEN  
WHERE  
WHY  
HOW

Review design of racks to insure no edges for scraping. Periodic inspection of racks. Crew training to avoid scraping of ammunition.

Figure D8 Racks Scrape Cartridge Cases

Hydraulic Leak 4.09

| SPECULATION                                                                                                       | EVALUATION                           |                                                                                                                       | ADDITIONAL DATA TESTS REQUIRED |
|-------------------------------------------------------------------------------------------------------------------|--------------------------------------|-----------------------------------------------------------------------------------------------------------------------|--------------------------------|
|                                                                                                                   | Fire 1<br>Unlikely                   | Fire 2<br>Unlikely                                                                                                    |                                |
|                                                                                                                   | SUPPORTING DATA                      | REFUTING DATA                                                                                                         |                                |
| <b><u>FAILURE MODE:</u></b><br>Hydraulic Leak                                                                     | Hydraulic leaks are common in tanks. | FRH is difficult to ignite.<br>Halon system should activate.<br>No evidence of electrical failure or hydraulic leaks. |                                |
| <b><u>FAILURE SEQUENCE:</u></b><br>Hot primer, electrical short, cigarette, etc., contacts leaking hydraulic oil. |                                      |                                                                                                                       |                                |

CORRECTIVE ACTION: \_\_\_\_\_ NONE ☒ REQUIRED (CHECK ONE) CONCLUSION: Unlikely

WHO  
WHAT  
WHEN  
WHERE  
WHY  
HOW

Figure D9  
Hydraulic Leak

APPENDIX C  
IGNITION DATA

# PRIMER COOLING CURVES AFTER GUN FIRING

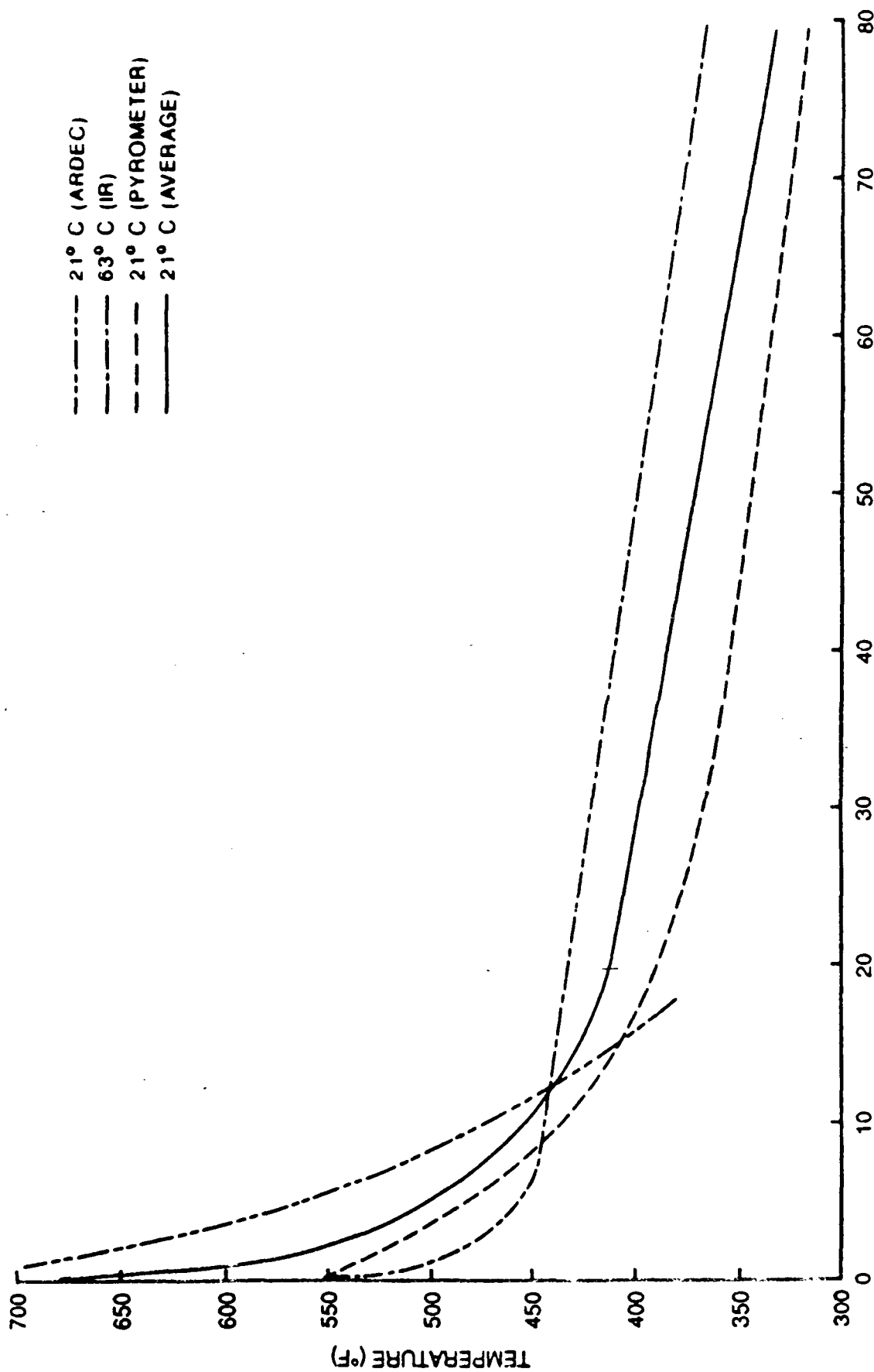


FIGURE E1

# PRIMER COOLING RATE (MID SECTION) FIRING FROM 63°C CARTRIDGE

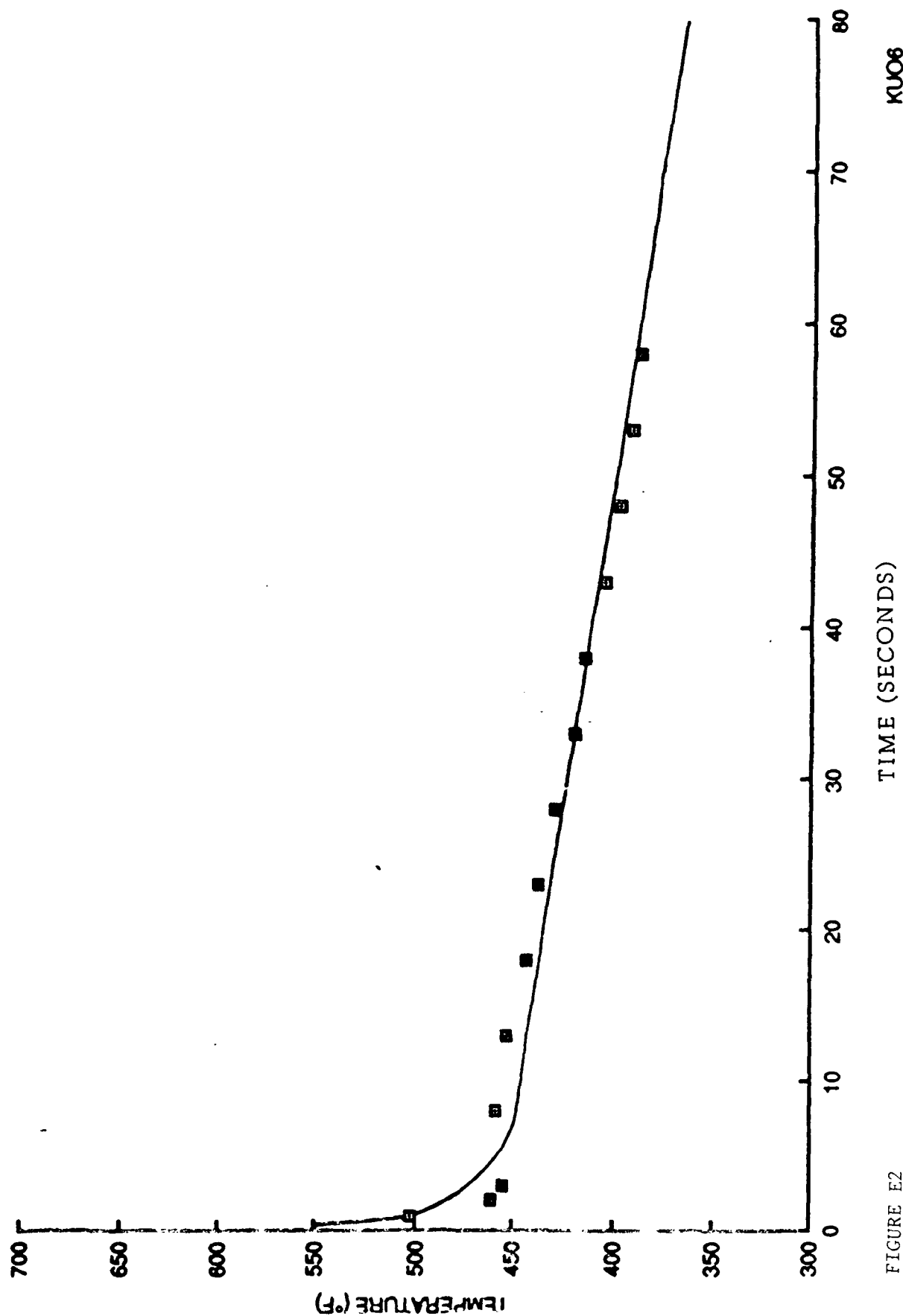


FIGURE E2

TIME (SECONDS)

KUO8

# TIME TO IGNITION STUDY OF CCC (FOE85M100-005)

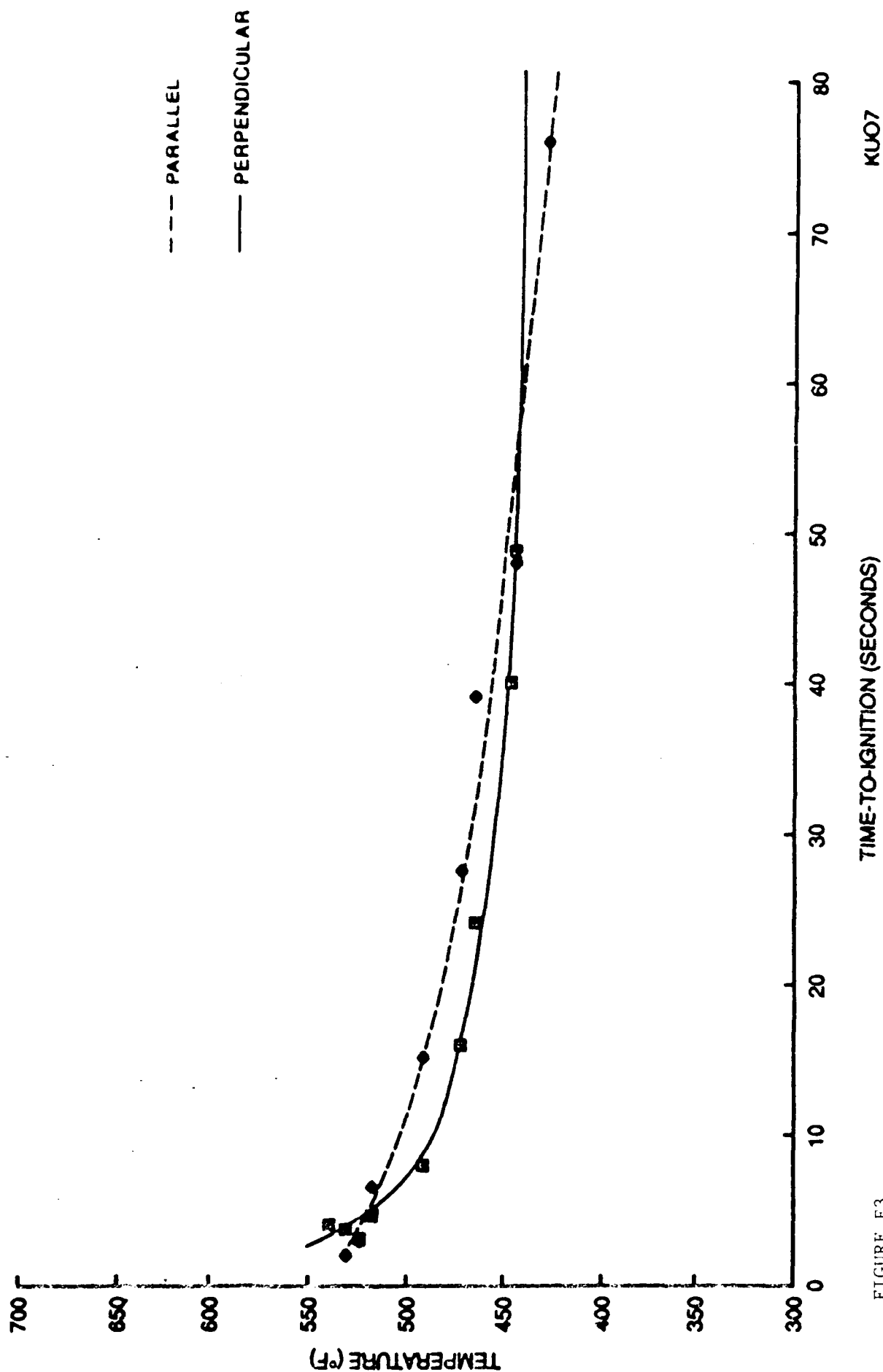


FIGURE E3

KU07

# TIME-TO-IGNITION STUDY OF LKL (RAD84K001S195)

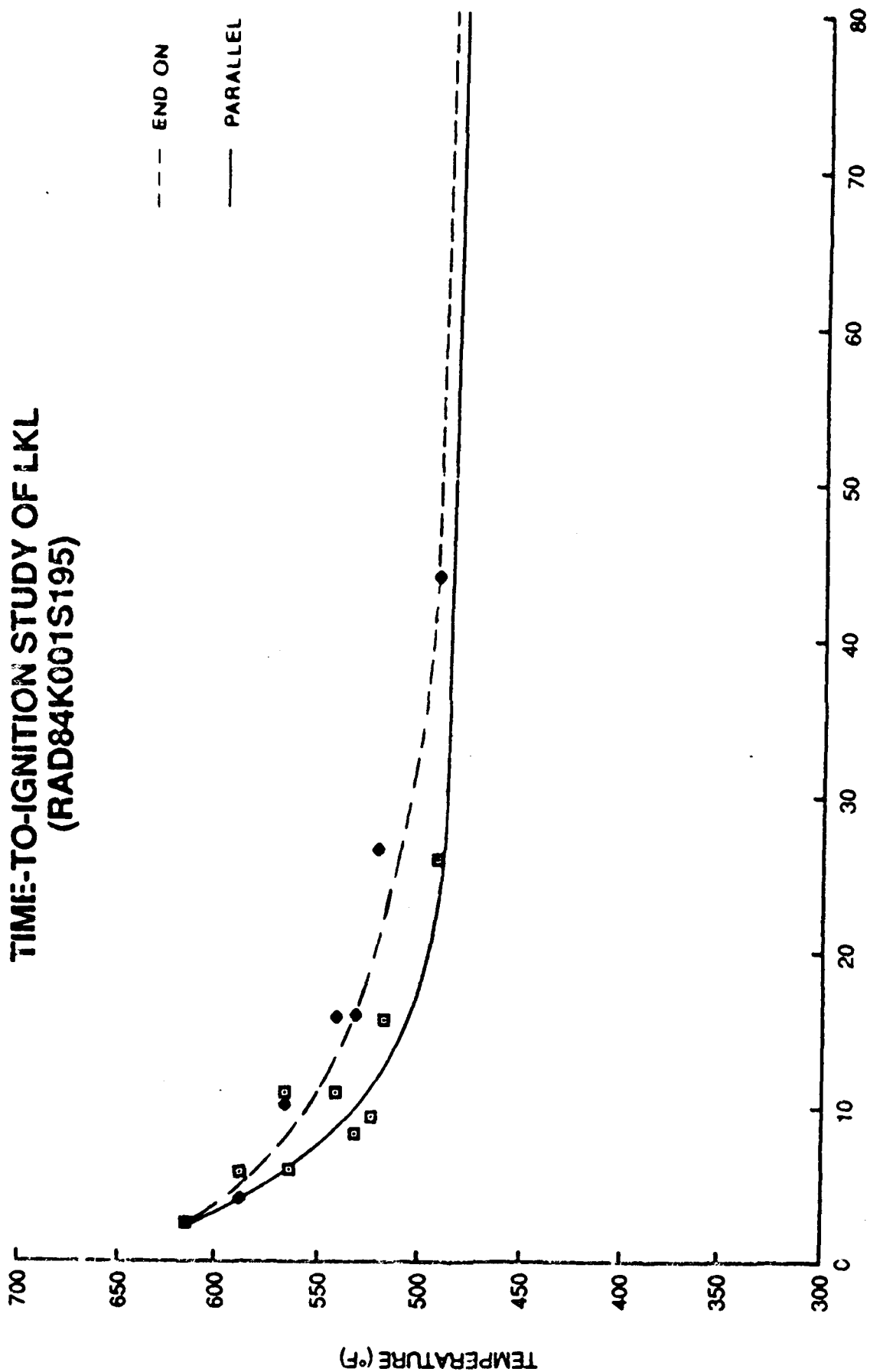


FIGURE E4

TIME-TO-IGNITION (SECONDS)

KU05

**CORRELATION DIAGRAM OF LKL/CCC TIME TO IGNITION  
VS.  
TIME AFTER CASE BASE EJECTION AFTER GUN FIRING**

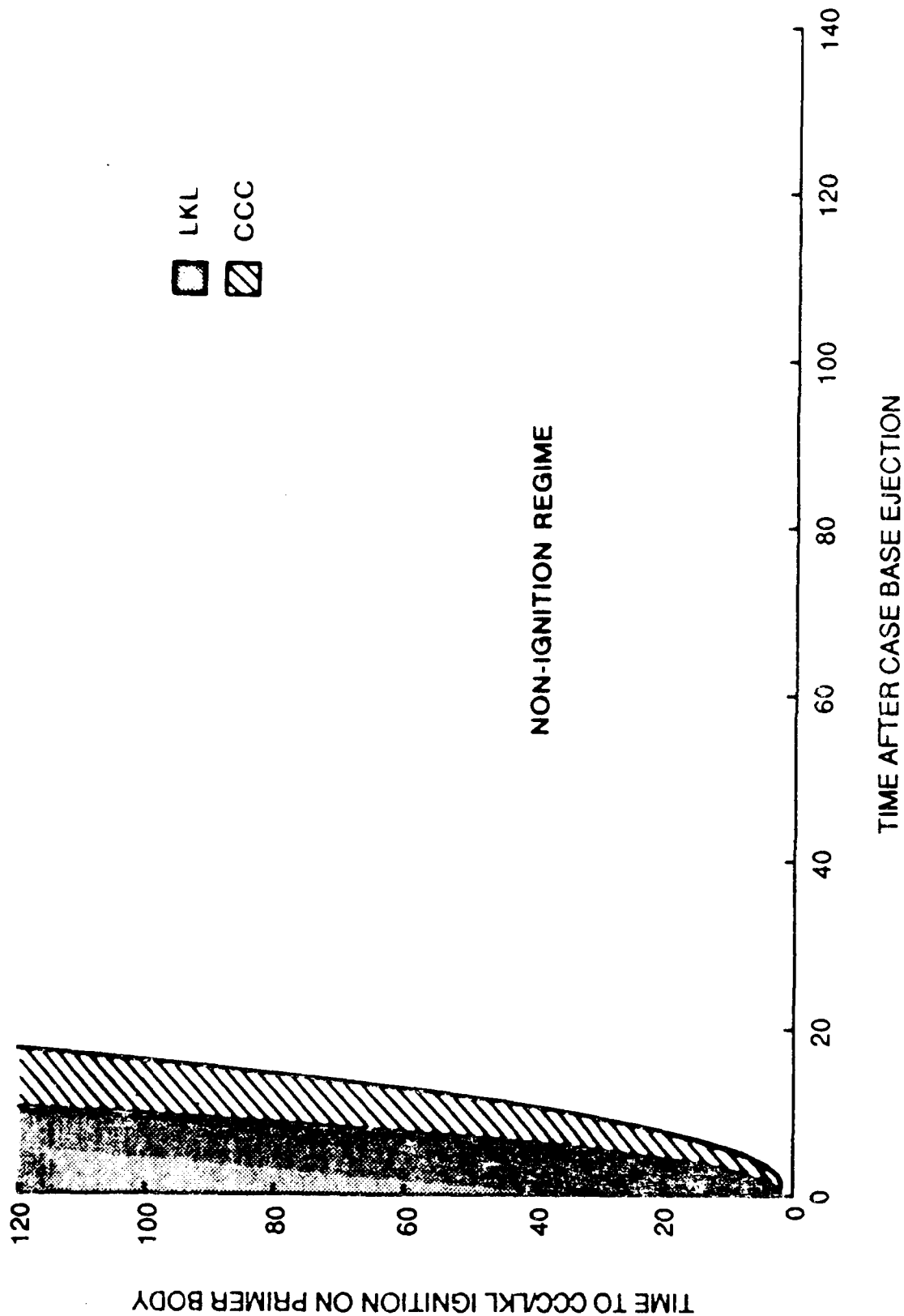


FIGURE E5

29 July 1988

Cookoff Studies

120mm Combustible Cartridge Case - KE (Lot VE116-1100-P)

Coated Side in Contact With Hot Plate

| <u>Ignition<br/>Temperature<br/>°F</u> | <u>Time to Ignition</u> |                |
|----------------------------------------|-------------------------|----------------|
|                                        | <u>(sec)</u>            |                |
|                                        | <u>Avg</u>              | <u>Std Dev</u> |
| 375                                    | 99.6                    | 28.3           |
| 400                                    | 39.1                    | 4.1            |
| 425                                    | 22.3                    | 3.1            |
| 450                                    | 10.4                    | 2.3            |
| 475                                    | 9.5                     | 1.8            |
| 500                                    | 5.2                     | 1.3            |
| 525                                    | 2.6                     | 0.3            |
| 550                                    | 2.1                     | 0.1            |
| 575                                    | 1.8                     | 0.2            |
| 600                                    | 1.3                     | 0.2            |
| 625                                    | 1.1                     | 0.1            |

FIGURE E6

## COOKOFF STUDIES

21 July 88

LKL Propellant - Lot No. RAD 84K001S195

| <u>Ignition<br/>Temperature<br/>°F</u> | <u>Propellant Grain on End<br/>Time to Ignition (sec)</u> |                | <u>Propellant Grain on Side<br/>Time to Ignition (sec)</u> |                |
|----------------------------------------|-----------------------------------------------------------|----------------|------------------------------------------------------------|----------------|
|                                        | <u>Avg</u>                                                | <u>Std Dev</u> | <u>Avg</u>                                                 | <u>Std Dev</u> |
| 375                                    | 145.4                                                     | 23.3           | 187.8                                                      | 27.9           |
| 425                                    | 44.2                                                      | 3.6            | 45.4                                                       | 10.4           |
| 475                                    | 11.6                                                      | 2.9            | 11.1                                                       | 2.8            |
| 525                                    | 6.2                                                       | 3.3            | 3.4                                                        | 0.5            |
| 575                                    | 3.1                                                       | 1.0            | 2.9                                                        | 0.6            |
| 625                                    | 1.9                                                       | 0.1            | 2.0                                                        | 0.6            |
| 675                                    | 1.3                                                       | 0.2            | 1.1                                                        | 0.1            |
| 700                                    | 0.9                                                       | 0.3            | 0.8                                                        | 0.4            |

FIGURE E7

# IGNITION TIME OF MATERIALS BY HOT PLATE (PRIMER SIMULATIONS)

| TEMPERATURE *<br>(°F)                         | IGNITED MATERIAL                  | TIME-TO-IGNITION<br>(SECONDS)   | COMMENTS                                                                                                                        |
|-----------------------------------------------|-----------------------------------|---------------------------------|---------------------------------------------------------------------------------------------------------------------------------|
| 439<br>450<br>471                             | CRUMBLED PAPER                    | -<br>-<br>-                     | SMOKE<br>SMOKE                                                                                                                  |
| 516<br>536<br>558<br>617<br>689<br>703<br>752 | 1 SHEET PAPER                     | -<br>-<br>-<br>-<br>-<br>-<br>- | SMOKE<br>SMOKE<br>SMOKE<br>SMOKE<br>SMOKE<br>TURNS BLACK<br>TURNS BLACK                                                         |
| COIL TURNED RED                               |                                   | 3                               |                                                                                                                                 |
| 520<br>662<br>752                             | 10 SHEETS OF PAPER                | -<br>-<br>-                     | SMOKE<br>SMOKE<br>SMOKE                                                                                                         |
| 439<br>450<br>658<br>678<br>687               | COTTON RAG WITH<br>HOPPES SOLVENT | -<br>-<br>-<br>-<br>48.1        | SMOKE FOR WHOLE 1'<br>SMOKE FOR WHOLE 1'<br>SMOKE FOR WHOLE 1'<br>NO IGNITION FOR 3'<br>TEMP DROP TO 657 @ 20", IGNITED @ 660°F |
| 442<br>451<br>667<br>678<br>687               | COTTON WITH M60 OIL               | -<br>-<br>-<br>34.1<br>13.3     | SMOKE IMMEDIATELY<br><br>NOT IGNITE IN 3'<br>AFTER 30" SECOND TEMPERATURE<br>INCREASES TO 694°F                                 |

FIGURE E8 \* IT IS BELIEVED THAT THERE WAS A TEMPERATURE GRADIENT ON THE HOT PLATE WITH THE CENTER BEING SOME 5 TO 10 PERCENT HOTTER THAN THE LISTED VALUE. PRODUK0008

## TIME-TO-IGNITION OF CCC VS IGNITED MATERIALS

| HORIZONTAL<br>DISTANCE BETWEEN<br>EDGES OF FLAME<br>AND CCC (INCHES) | IGNITED<br>MATERIAL                                    | TIME-TO-IGNITION<br>(SECONDS) | COMMENTS                                                                                                    |
|----------------------------------------------------------------------|--------------------------------------------------------|-------------------------------|-------------------------------------------------------------------------------------------------------------|
| .05                                                                  | A FULL SIZE<br>NEWSPAPER<br>CRUMBLED<br>INTO FIST SIZE | 15.4                          | SLIGHTLY SCORCHED AFTER PAPER BURNOUT<br><br>NO SCORCHING MARK<br><br>SLIGHTLY SCORCHED AFTER PAPER BURNOUT |
| 0.75                                                                 |                                                        | 33.0                          |                                                                                                             |
| 0.75                                                                 |                                                        | 13.7                          |                                                                                                             |
| 1.0                                                                  |                                                        | 14.7                          |                                                                                                             |
| 1.0                                                                  | COTTON RAGS<br>WITH M60<br>TRANSMISSION<br>OIL         | NO GO                         | BURNING FLAMES ARE TALLER AND MUCH MORE<br>INTENSE THAN BURNING PAPER                                       |
| 1.0                                                                  |                                                        | NO GO                         |                                                                                                             |
| 1.25                                                                 |                                                        | NO GO                         |                                                                                                             |
| 1.0                                                                  |                                                        | 12.9                          |                                                                                                             |
| 1.5                                                                  | COTTON RAGS<br>WITH HOPPE'S<br>SOLVENTS                | 18.3                          | BURNING FLAMES ARE TALLER AND MUCH MORE<br>INTENSE THAN BURNING PAPER                                       |
| 2.5                                                                  |                                                        | 30.7                          |                                                                                                             |
| 2.5                                                                  |                                                        | 22.9                          |                                                                                                             |
| 3.0                                                                  |                                                        | 30.3                          |                                                                                                             |
| 3.5                                                                  |                                                        | NO GO                         |                                                                                                             |

FIGURE E9

PROCKU001

**(U) TIME TO IGNITION OF OILY RAGS BY HOT PRIMER  
OR RESIDUAL BURNING ENERGETIC MATERIALS**

| MATERIAL                       | TIME TO IGNITION<br>(SECONDS)    | COMMENT                                                                                                                                           |
|--------------------------------|----------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------|
| CLP/RAG<br>HYDRAULIC FLUID/RAG | NO GO; SMOKING<br>NO GO; SMOKING | NO IGNITION UP TO 3 MINUTES OF DIRECT<br>CONTACT WITH 3/4 INCH HOT TUBE AT 842°F                                                                  |
| CLP/RAG                        | ~ 2                              | DROPS RESIDUAL LKL BURNING GRAIN (ABOUT 1/2, 1/3, 1/4 GRAIN)<br>ON RAG. FLAME OF THE GRAIN NEEDS TO SUSTAIN ABOUT<br>2 SECONDS TO IGNITE THE RAG. |
| HYDRAULIC FLUID/RAG            | ~ 4                              | DROPS RESIDUAL LKL BURNING GRAIN (ABOUT 1/2, 1/3, 1/4 GRAIN)<br>ON RAG. FLAME OF THE GRAIN NEEDS TO SUSTAIN ABOUT<br>4 SECONDS TO IGNITE THE RAG. |
| CLP/RAG                        | ~ 4                              | DROP 1/2 IN <sup>2</sup> BURNING CCC WITH MINIMUM FLAME ON RAG; NO<br>DIRECT CONTACT BETWEEN FLAME AND RAG (i.e. WAS SHIELDED<br>BY CCC)          |
| HYDRAULIC RAG                  | NO GO                            | DROP 1/2 IN <sup>2</sup> BURNING CCC WITH MINIMUM FLAME ON RAG; NO<br>DIRECT CONTACT BETWEEN FLAME AND RAG (i.e. WAS SHIELDED<br>BY CCC)          |

FIGURE E10

PROO/KU007

# TIME-TO-IGNITION OF CCC ON/ABOVE BURNING OILY RAGS

| VERTICAL DISTANCE<br>BETWEEN CC AND<br>FLAME<br>(INCHES) | IGNITED<br>MATERIAL                   | TIME-TO-IGNITION<br>(SECONDS) | COMMENTS                                                                                                                                  |
|----------------------------------------------------------|---------------------------------------|-------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------|
| TOUCHING                                                 | COTTON RAG<br>WITH HOPPE'S<br>SOLVENT | 94<br>114<br>135              | FLAME HEIGHT VARIES FROM 1 ± 2" DUE TO<br>EXHAUSTION OF SOLVENTS. THE CCC HAD<br>TO BE ADJUSTED CONSTANTLY TO REMAIN<br>IN TOUCH OF FLAME |
| ENGULF                                                   |                                       | 4                             |                                                                                                                                           |

FIGURE E11

# **TIME TO IGNITION OF CCC VS. EMBER OF CCC (OR BURNING RESIDUE)**

| MATERIAL OF BURNING<br>RESIDUE   | TIME TO IGNITION<br>(SECONDS) | COMMENTS                                         |
|----------------------------------|-------------------------------|--------------------------------------------------|
| EMBER OF 22 IN. <sup>2</sup> CCC | NO GO                         | NO SCORCH MARK<br>AGREED WITH EARLY<br>APG TESTS |
| EMBER OF 1/2 CCC                 | 21                            | EMBER STAYED<br>UNTIL IGNITION<br>STARTED        |
| EMBER OF CCC COVER               | 50                            | EMBER STAYED<br>UNTIL IGNITION<br>STARTED        |

PROD/KU0011

FIGURE E12

# **TIME TO IGNITION OF CCC VS. BURNING LKL GRAIN**

| DISTANCE BETWEEN<br>GRAIN & EDGE OF CCC<br>(INCHES) | NO. OF LKL GRAIN | TIME TO IGNITION<br>(SECONDS) | COMMENTS                        |
|-----------------------------------------------------|------------------|-------------------------------|---------------------------------|
| 2                                                   | 1                | NO GO                         | GRAIN BURNOUT                   |
| 1                                                   | 1                | NO GO                         | GRAIN BURNOUT                   |
| 1                                                   | 2                | 4-5                           | FULL CASE BURNOUT<br>EVENTUALLY |
| 0.5                                                 | 1                | 7                             | FULL CASE BURNOUT<br>EVENTUALLY |

PROCKU0010

APPENDIX D  
ROOT CAUSE ANALYSIS TEAM CHARTER

# DISPOSITION FORM

For use of this form, see AF 340-15; the proponent agency is TAGO.

|                            |                  |
|----------------------------|------------------|
| REFERENCE OR OFFICE SYMBOL | SUBJECT          |
| SMCAR-TD                   | Red Team Charter |

|                            |                           |             |       |
|----------------------------|---------------------------|-------------|-------|
| TO                         | FROM                      | DATE        | CMT 1 |
| SMCAR-ASM<br>(MAJ Dowalgo) | SMCAR-TD<br>(Mr. Lindner) | SEP 23 1988 |       |

1. Recently two tank fires involving 120mm ammunition occurred in the M1A1 Main Battle Tank during Tank Gunnery Exercises in Germany. The most recent fire on 14 Aug 88 involved the deaths of two soldiers.

2. This DF will serve as your Charter to investigate this failure. You will serve as Leader of this Red Team and will conduct a critical assessment in an effort to identify all likely conditions that may have contributed to the problem. Special emphases will also be placed on a review of current procedures/designs in order to assure that the best corrective measures are utilized to prevent reoccurrence of the problem. Special attention will be given to the MANPRINT domains in the conduct of the assessment.

3. Your Red Team will consist of the following members, all of whom will bring expertise to this problem resolution process, while still providing an independent view of the failure under consideration:

| <u>Name</u>                     | <u>Organization</u>              | <u>Extension</u> |
|---------------------------------|----------------------------------|------------------|
| MAJ John Dowalgo (chairman)     | Advanced Systems Concepts Office | AV 880-6044      |
| Joseph Corallo (co-chairman)    | Product Assurance Directorate    | AV 880-5666      |
| John Banks                      | Safety                           | AV 880-4550      |
| William Williver                | Close Combat Armaments Center    | AV 880-6729      |
| James Rutkowski                 | Armament Engineering Directorate | AV 880-5514      |
| Roger Billington                | PM-Tank Main Armament Systems    | AV 880-2648      |
| Jack Carlock                    | Human Engineering Lab            | AV 880-3227      |
| SSG Robert Wolford              | Master Gunner, FT Knox           | AV 464-1736      |
| CPT George Smith                | AMCCOM HQS                       | AV 793-4366      |
| Augustine Magistro (consultant) | Advanced Systems Concepts Office | AV 880-6044      |
| CPT Thomas Kidwell (consultant) | PM Abrams                        | AV 786-6735      |
| Ken J Russell (consultant)      | Tank Main Armament Systems       | AV 880-4375      |

4. The urgency of this problem requires full commitment from you and the team on a full time basis for the period 10 Sep thru 31 Oct 88. It is imperative that an expeditious transfer of information takes place between the Systems Engineers, the User Community and your Red Team. Therefore you are afforded the authority to utilize any ARDEC resources that would be required in order to accomplish your mission.

DA FORM 2496  
AUG 80

PREVIOUS 79

BE USED

001 5 GPO 1982-386 545

SMCAR-TD

SUBJECT: Red Team Charter

5. A fund cite to cover travel and other expenses associated with this Red Team investigation is provided by PM Tank Main Armaments Systems. The fund cite number is 2182040-865-4000-P643639-S28017 211A/219A. Sales Order number is Q8XJ-01-120. Cost Center is 692. Request a copy of all orders, referencing the Red Team, be send to PM-TMAS ATTN: AMCPM-TMA (Jim Richards). Questions about funding should be directed to Jim Richards at AV 880-2646.
6. Root cause analysis methodology will be utilized to identify all possible failure modes, the data to include supporting or refuting arguments and the potential preventative solutions. Your activity will be considered complete when the root cause of each failure mode is determined and a final report is prepared and published.
7. Major milestones in this Red Team investigation will be as follows:
  - a. Form Team 14 - 26 Sep 88. (Provides for administration time.)
  - b. Background and preliminary technical review of incident 27 - 29 Sep 88.(ARDEC)
  - c. Review training procedures and hands-on review 5 - 6 Oct 88.(FT. KNOX)
  - d. Perform final assessment and technical review 11 - 12 Oct 88. (ARDEC)
  - e. Draft report 21 Oct 88.
  - f. Final report 31 Oct 88.
8. A final written report is required which will not only serve to document the problem and its resolution, but also provide for a transfer of data to others outside the immediate sphere of the team. The terms "Red Team" and/or "Root Cause Analysis" will be contained in either the report title or specified as a key phrase on the Report Documentation Page, DD Form 1473, at such time as the report is presented to the Technical Library. You may refer to the following reference materials for guidance:  
Root Cause Analysis - A Diagnostic Failure Analysis Technique for Managers, Technical Report RF-75-2. Augustine E. Magistro/ Lawrence R. Seggel, 26 March 75  
Root Cause Analysis - A New Failure Analysis Technique, Augustine E. Magistro, March 76  
Red Team Guidelines, Augustine E. Magistro, 12 May 76

VICTOR LINDNER  
Acting Technical Director

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