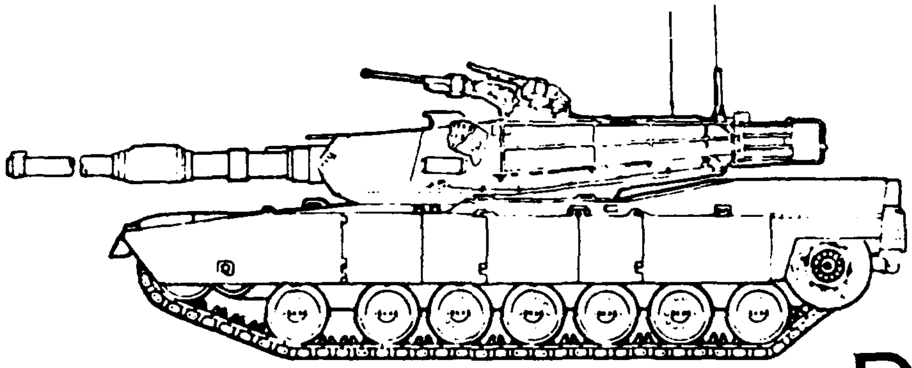
AD

AD-E401 893

Special Publication ARASM-SP-88003

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



MAJ John Dowalgo

February 1989

US ARMY
ARMAMENT MUNITIONS
& CHEMICAL COMMAND
ARMAMENT RDE CENTER

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

Advanced Systems Concept Office

Picatinny Arsenal, New Jersey

Approved for public release; distribution unlimited.

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY 2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited
4. PERFORMING ORGANIZATION REPORT NUMBER Special Publication ARASM-SP-88003	5. MONITORING ORGANIZATION REPORT NUMBER
6a. NAME OF PERFORMING ORGANIZATION ARDEC, ASCO — 6b. OFFICE SYMBOL SMCAR-ASM	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (CITY, STATE, AND ZIP CODE) Mission Area Division Picatinny Arsenal, NJ 07806-5000	7b. ADDRESS (CITY, STATE, AND ZIP CODE)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION ARDEC, IMD STINFO Br — 8b. OFFICE SYMBOL SMCAR-IMI-I	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (CITY, STATE, AND ZIP CODE) Picatinny Arsenal, NJ 07806-5000	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT ACCESSION NO.

11. TITLE (INCLUDE SECURITY CLASSIFICATION)

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

12. PERSONAL AUTHOR(S) MAJ John Dowalgo

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (YEAR, MONTH, DAY)	15. PAGE COUNT
Final	FROM Jul 88 TO Oct 88	February 1989	85

16. SUPPLEMENTARY NOTATION

17. COSATI CODES		
FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS (CONTINUE ON REVERSE IF NECESSARY AND IDENTIFY BY BLOCK NUMBER)
120-mm ammunition, Catcher box, Root cause analysis, Tank fires, Cartridge case base, M1A1 tank fires, M865 ammunition

19. ABSTRACT (CONTINUE ON REVERSE IF NECESSARY AND IDENTIFY BY BLOCK NUMBER)

This analysis identifies the root cause of two M1A1 tank fires involving 120 mm M856 target practice cone stabilized discarding sabot tracer (TPCSDS-T) ammunition during tank gunnery exercises in Germany. The first fire, 4 July 1988, did not involve any personal injury. The fire on 14 August 1988 was lethal, killing the tank commander and gunner. The failure investigation strategy (described in the report) 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.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT	21. ABSTRACT SECURITY CLASSIFICATION
☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS	UNCLASSIFIED

22a. NAME OF RESPONSIBLE INDIVIDUAL	22b. TELEPHONE (INCLUDE AREA CODE)	22c. OFFICE SYMBOL
I. HAZNEDARI	(201) 724-3316	SMCAR-IMI-I

DD FORM 1473, 84 MAR

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

CONTENTS

FIGURES

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 propellent from another round.

a. The most likely cause of the 4 July 88 fire was propellent spilling from a damaged or defective M865 round during the loading process. The fire erupted when loose propellent 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 1981, 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 classifed 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 TPDSCS-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 assesment.

2. Organization

The Root Cause Analysis was conducted by a task team with interdisciplinary skills. The team memberships crossed oconsiderable 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 propellent. 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 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)

Probability Chart #	Failure Sequence	Rank Order	Estimate
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 likley 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 propellent to spill throughout the bustle and crew compartment. Some of the propellent fell into the cartridge case base catcher box, and contacted the hot case base primers. The propellent 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 shortcommings. 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 propellent 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 propellent 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 propellent 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

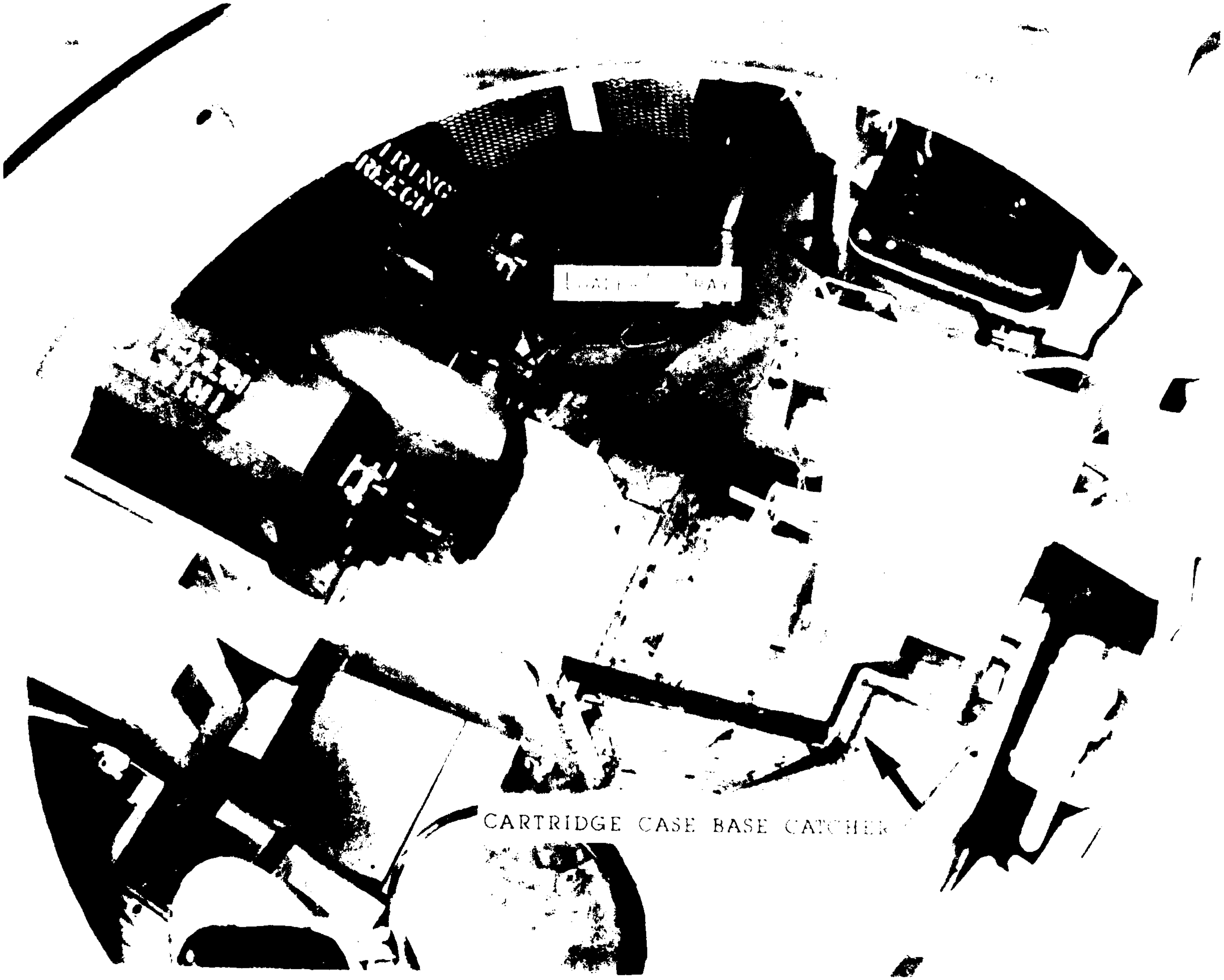


Figure 2. Cartridge case base catcher box

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

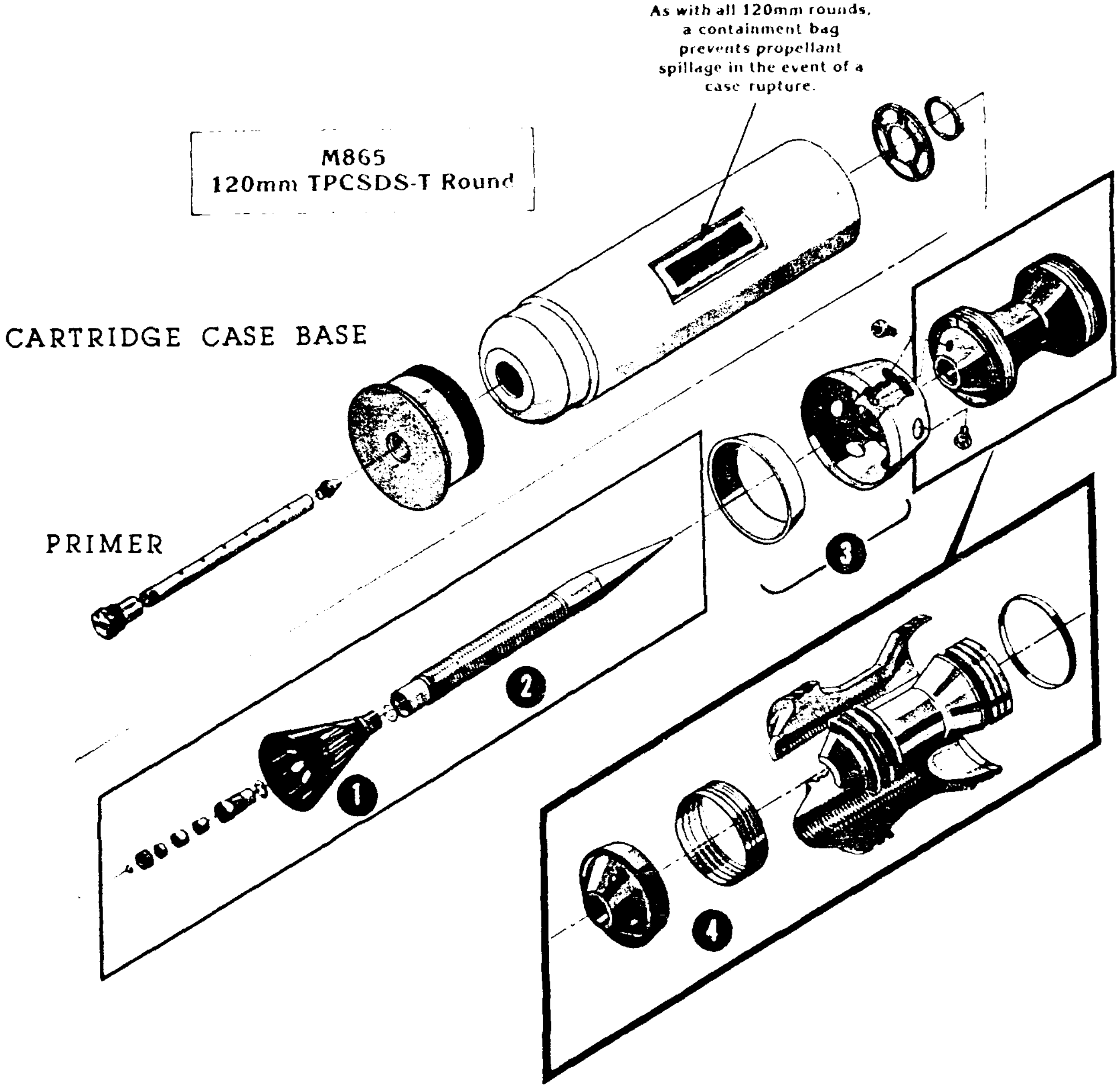
CARTRIDGE

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 ± 12 m/s (5578 ± 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

Failure Indication: ENTER BRIEF STATEMENT OF FAILURE INDICATION

Cause Probability Estimate: USED DURING EARLY STAGES TO INDICATE CAUSE PROBABILITY WHEN LITTLE IS KNOWN ABOUT THE FAILURE

	SPECULATION	EVALUATION		
		Supporting Data	Refuting Data	Additional Data Tests Required
WHAT WHERE WHEN WHY HOW WHO	**Failure Mode:** LIST POSSIBLE MODES OF FAILURE. EXAMPLES: ITEM SHORT, ITEM OPEN, IMPEDANCE, FIN FAILURE. LIST ONLY ONE MODE PER PAGE. ENTER LOGIC DIAGRAM REFERENCE NUMBER. **Failure Sequence** CONCEIVABLE MECHANISMS WHICH COULD CAUSE THE FAILURE MODE TO OCCUR. THERE MAY BE SEVERAL MECHANISMS THAT COULD CAUSE A GIVEN FAILURE MODE TO OCCUR. DESCRIBE HOW, WHAT, WHERE, WHEN, WHY AND WHO WERE INVOLVED.)	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 COLLECTED TO COMPLETE THE PROBLEM SOLVING PROCESS.

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

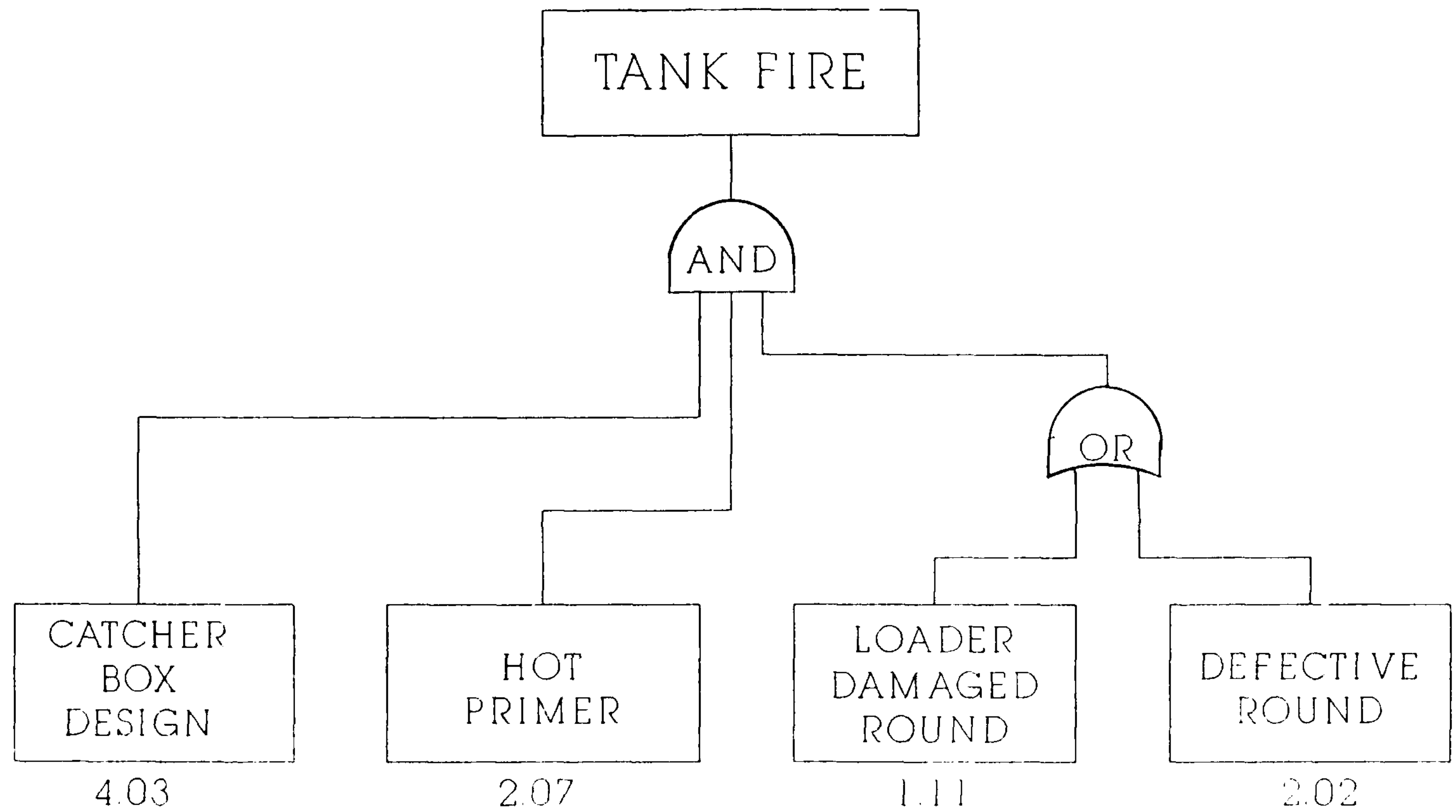


Figure 7. 4 July 1988 tank fire

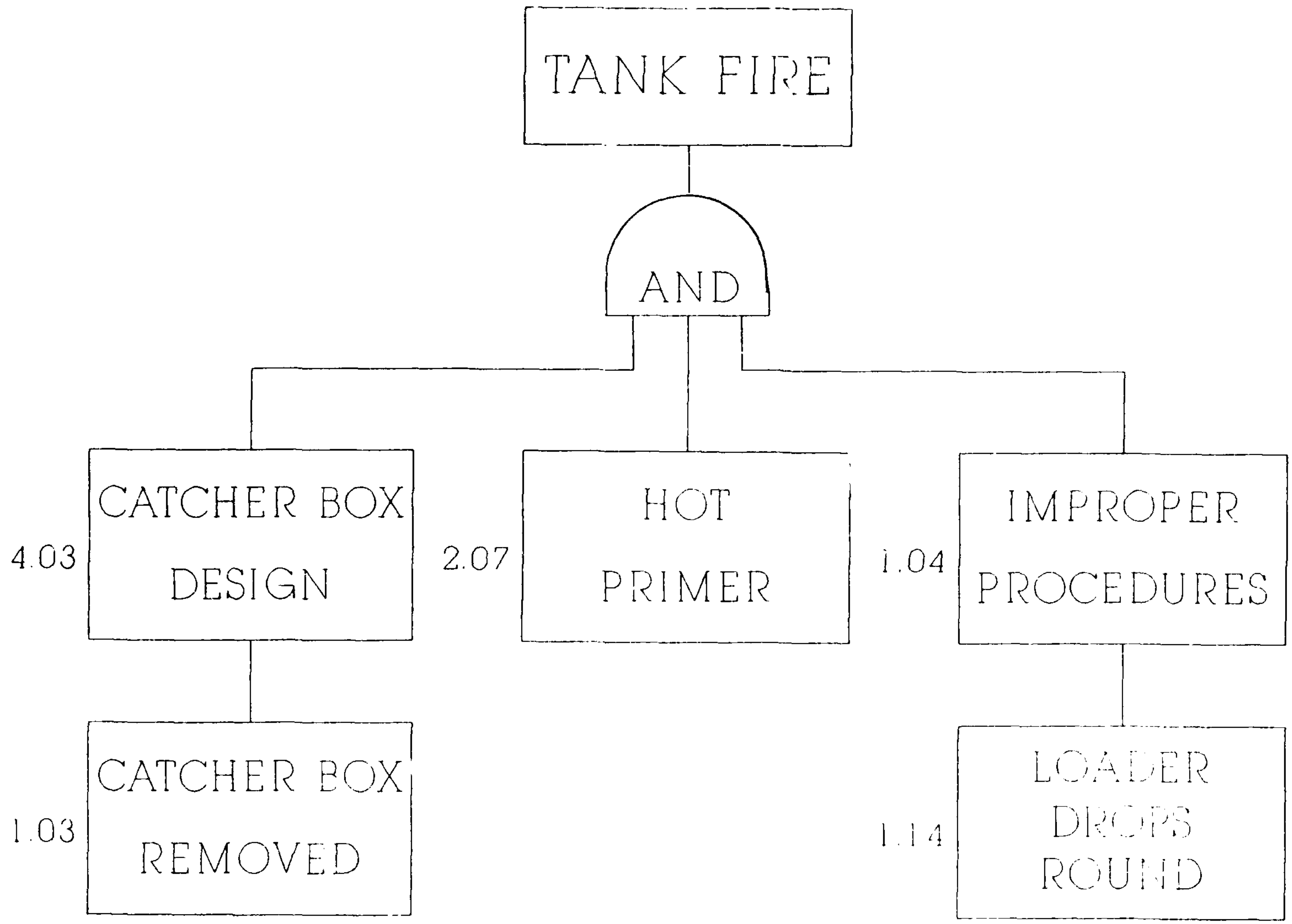


Figure 8. 14 August 1988 tank fire

Figure 9. Catcher box seam

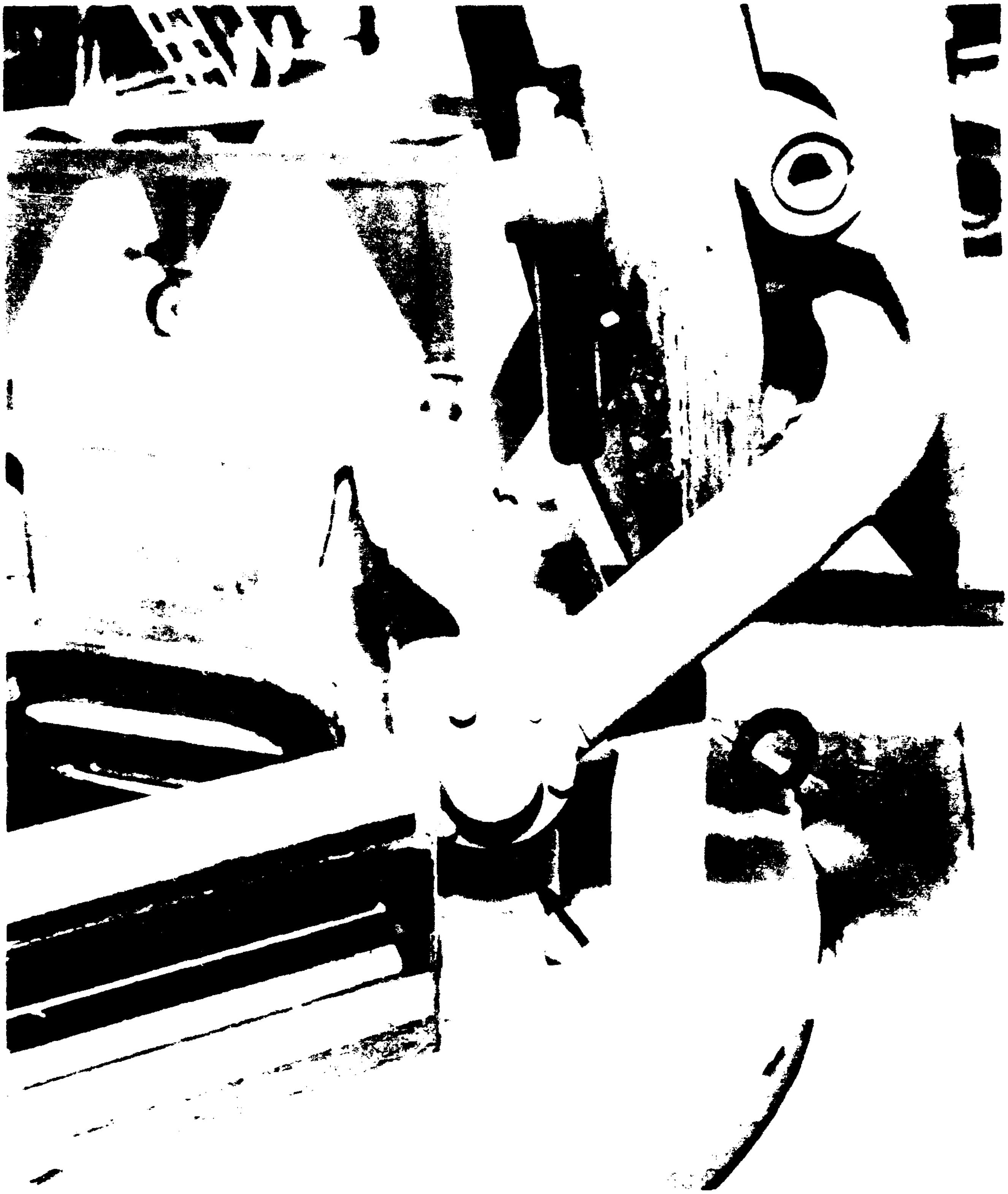


Figure 10. Commander's hatch

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 breechblock. 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 ring 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 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 cause 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 SYMPTON Crew

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

Barrowed Loader 1.01

SPECULATION	EVALUATION Fire 1 Unlikely Fire 2 Unlikely		
	SUPPORTING DATA	**REFUTING DATA**	**ADDITIONAL DATA TESTS REQUIRED**
FAILURE MODE: Barrowed loader did not inspect ammunition.	Loose propellent in turret bustle. 9 July testimony. No procedures requiring loader to inspect ammunition.		
FAILURE SEQUENCE: Loader was a gunner from another tank. Loader did not place rounds in ammunition rack. Defective/damaged round during loading process. Propellent spills from broken round. Propellent contacted hot primer.			

WHO
WHAT
WHEN
WHERE
WHY
HOW

CORRECTIVE ACTION: XX NONE ______ REQUIRED (CHECK ONE) **CONCLUSION:** Unlikely

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

Figure A1
Borrowed Loader

CHART # 2

DATE: OCTOBER 88 **REV. NO:**

FAILURE DESCRIPTION OR SYMPTON Crew Maintenance 1.02

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

SPECULATION	SUPPORTING DATA	REFUTING DATA	ADDITIONAL DATA TESTS REQUIRED
		EVALUATION	Fire 1 Unlikely; Fire 2 Unlikely
FAILURE MODE: Round ignites while tank is undergoing unit maintenance.	Round is electrically initiated in normal firing sequence. Heat from electrical spark should be hot enough to ignite the case	In both cases the tanks were in operation at the time the fire started. Heat duration from a spark is insufficient to ignite propellent.	Determine the time required for round to be exposed to electrical spark (other than igniter) before ignition.
FAILURE SEQUENCE: (WHO, WHAT, WHEN, WHERE, WHY, HOW) Unit maintainer touches electrical lead to round while preforming P.M. Limited space in tank, maintainer moves wires out of the way. Spark hits round igniting cartridge or hits primer causing round to ignite.			

CORRECTIVE ACTION: _____ **NONE** XX **REQUIRED (CHECK ONE)**

CONCLUSION Not Relevant

Figure A2
Maintenance

CHART # 3

DATE: OCTOBER 88 **REV. NO:**

FAILURE DESCRIPTION OR SYMPTON Crew

No Catcher Box 1.03

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

EVALUATION Fire 1: Unlikely; Fire 2: Most Likely

SPECULATION	SUPPORTING DATA	REFUTING DATA	ADDITIONAL DATA TESTS REQUIRED
FAILURE MODE: Catcher box not in use in tank.	Testimony indicates that catcher box was not being utilized. Visual inspection varifies absence of box. Sufficient heat to ignite propellent.		
FAILURE SEQUENCE: (WHO / WHAT / WHEN / WHERE / WHY / HOW) Crew removes catcher box because it restricts movement. Case base lands on floor. Loader drops round which hits primer. Round ignites.			

CORRECTIVE ACTION: XX **NONE** ____ **REQUIRED (CHECK ONE)**

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

CONCLUSION:

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

Figure A3 No catcher Box

CHART # 4

DATE: OCTOBER 88 **REV. NO:**

FAILURE DESCRIPTION OR SYMPTON Crew

Failure to Follow Procedures 1.04

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

SPECULATION	SUPPORTING DATA	REFUTING DATA	ADDITIONAL DATA TESTS REQUIRED
	EVALUATION Fire 1 Unlikely, Fire 2 Most Likely		
FAILURE MODE: Failure to follow prescribed loading procedures. **FAILURE SEQUENCE:** (WHO / WHAT / WHEN / WHERE / WHY / HOW) Loader had a second round in hand prior to firing round in gun. Round was not fully seated in breech. Loader attempted to seat round. Loader lost control of round in his hands and it fell to the floor. No catcher box present. Hot case base on floor. Round which fell from loader hands landed on hot case base and ignited.	Extractors will not trip if gun is not safed. Loaker admits having a second round in hand before round in gun has been fired. Loader testimony recorded on tape. Burnt round on floor.		

CORRECTIVE ACTION: XX **NONE** ____ **REQUIRED (CHECK ONE)**

Review and enforce procedures. Only load when gun is ready.
Review safety procedures in operator's manual.

CONCLUSION:

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:**

FAILURE DESCRIPTION OR SYMPTON Crew Smoking 1.05

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

SPECULATION	EVALUATION (Fire 1: Unlikely; Fire 2: Unlikely)		
	SUPPORTING DATA	**REFUTING DATA**	**ADDITIONAL DATA TESTS REQUIRED**
FAILURE MODE: Crew member smoking. Cigarette or hot ashes ignite combustible materials on floor. **FAILURE SEQUENCE:** A lit cigarette or hot ashes fall onto combustible materials on turret floor, starting a small fire. Loader sees fire, panics, drops round, damaging it, and spilling propellent on floor, or drops round on fire in hurry to escape.	Smoking in turret is common though not authorized.	No evidence of smoking on tank. Unlikely that a cigarette will ignite a round or start a fire. It does not have the intensity to ignite a CCC.	

WHO
WHAT
WHEN
WHERE
WHY
HOW

CORRECTIVE ACTION: ________ **NONE** _xx_____ **REQUIRED (CHECK ONE)**

CONCLUSION: None

Figure A5
Smoking

CHART #6

DATE: OCTOBER 88 **REV. NO:**

FAILURE DESCRIPTION OR SYMPTON Crew

Improperly adjusted loader's tray 1.06

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

EVALUATION Fire 1 Likely, Fire 2 Unlikely

SPECULATION	SUPPORTING DATA	REFUTING DATA	ADDITIONAL DATA TESTS REQUIRED
FAILURE MODE: Loader's tray out of adjustment, scrapes combustible case creating residue. **FAILURE SEQUENCE:** Residue collects at breech or on gun. Back flash or case base hot primer ignites material causing loader to drop round. Round contacts hot primer.	Loader reported seeing fire on turret floor area (Testimony). Known that trays can scrape ammunition, creating residue.	No indications of fire before loading process. Substantial amount of residue required to start a fire.	

WHO
WHAT
WHEN
WHERE
WHY
HOW

CORRECTIVE ACTION: ______ **NONE** xx **REQUIRED (CHECK ONE)**

CONCLUSION:
Burning residue cound have frightened the loader, causing him to drop the round.

Figure A6
Improperley Adjusted Loader's Tray

CHART #7

DATE: OCTOBER 88 **REV. NO:**

FAILURE DESCRIPTION OR SYMPTON Crew

Fail to Safe Gun 1.07

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

EVALUATION Fire 1: Unlikely; Fire 2: Likely

SPECULATION	SUPPORTING DATA	REFUTING DATA	ADDITIONAL DATA TESTS REQUIRED
FAILURE MODE: Loader fails to safe gun prior to pickup of next round.	Gun breech will not close when not in safe. Loader had round in hands (Testimony). Difficulty to safe gun with round in hands.	None	
FAILURE SEQUENCE: While loader attempts to safe gun he drops round on hot primer.			

WHO
WHAT
WHEN
WHERE
WHY
HOW

CORRECTIVE ACTION: ____ NONE __XX__ 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

CHART #8

DATE: OCTOBER 88 **REV. NO:**

FAILURE DESCRIPTION OR SYMPTON Crew

Improperly adjusted loader's tray 1.08

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

SPECULATION	EVALUATION Fire 1 Unlikely, Fire 2 Likely		
	SUPPORTING DATA	**REFUTING DATA**	**ADDITIONAL DATA TESTS REQUIRED**
FAILURE MODE: Loader's tray out of adjustment. Case base hangs after firing. **FAILURE SEQUENCE:** Case base caught under loading tray. Loader has round ready to load and attempts to clear case base while holding round. Drops round. CCC contacts hot primer and igintes.	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)**

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

CONCLUSION:

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	SUPPORTING DATA	REFUTING DATA	ADDITIONAL DATA TESTS REQUIRED
	EVALUATION Fire 1: Unlikely; Fire 2: Unlikely		
FAILURE MODE: Combustible material in turret - rags, paper, etc. **FAILURE SEQUENCE:** Matter falls on hot primer. Fire starts. Loader drops round, which ignites.	Photographs show trash on floor. Manuals and other paper material is routinely in turret. Hot primers are expelled onto floor when catcher box is not used. This materail will ignite.	Round will ignite with this type of ingintion source but only after significant time as opposed to a few seconds as in this incident. (Appendix C Figure E9-E13) This material has been shown to smolder rather than burn.	

WHO
WHAT
WHEN
WHERE
WHY
HOW

CORRECTIVE ACTION: ______ **NONE** XX **REQUIRED (CHECK ONE)**

Area should be clear when firing.
Material should be stowed.

CONCLUSION: None

Figure A9
Combustible Material In Turret

CHART #10

DATE: OCTOBER 88 **REV. NO:**

FAILURE DESCRIPTION OR SYMPTON Crew

Failure to follow Safe/Arm Procedures 1.10

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

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

WHO
WHAT
WHEN
WHERE
WHY
HOW

CORRECTIVE ACTION: ______ **NONE** __XX__ **REQUIRED (CHECK ONE)**

CONCLUSION:
Loaders take short cuts. He could have safed the weapon too early, causing an interruption in his loading sequence.

Figure A10
Failure to Follow Safe/Arm Procedures

CHART #11

DATE: OCTOBER 88 **REV. NO:**

FAILURE DESCRIPTION OR SYMPTON Crew

Loader Damages Round 1.11

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

EVALUATION Fire 1: Most Likely; Fire 2: Unlikely

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

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 A11 Loader Damages Round

CHART #12

DATE: OCTOBER 88 **REV. NO:**

FAILURE DESCRIPTION OR SYMPTON Crew

Previously Damaged Round 1.12

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

EVALUATION Fire 1: Likely Fire 2: Unlikely

SPECULATION	SUPPORTING DATA	REFUTING DATA	ADDITIONAL DATA TESTS REQUIRED
FAILURE MODE: Previously damaged round laying in bustle. **FAILURE SEQUENCE:** Loader extracts broken round from bustle. Propellent spills igniting on something burning or primer. Loader frightened and drops round.	Loader reports being hit on shoulder when extracting round from rack. Loader reports seeing round on the floor. Propellent found in bustle. Loader reports seeing fire before dropping round. It is conceivable that broken rounds are hidden to pass problem to someone else. Crew members have been threatened with liability Damaged round could have been placed in bustle by a non crew member.	*None*	

WHO
WHAT
WHEN
WHERE
WHY
HOW

CORRECTIVE ACTION: XX **NONE** ____ **REQUIRED (CHECK ONE)**

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

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 SYMPTON Crew

Improperly Adjusted Loader's Tray 1.13

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

WHO
WHAT
WHEN
WHERE
WHY
HOW

SPECULATION	EVALUATION Fire 1 Unlikely Fire 2 Likely		
	SUPPORTING DATA	**REFUTING DATA**	**ADDITIONAL DATA TESTS REQUIRED**
FAILURE MODE: Loader's tray not properly adjusted. **FAILURE SEQUENCE:** Tray drops after ejection. Gun not on safe. Loader attempts to chamber round. Breech will not close.	Round did not seat during 14 August fire.	System was found operational after fire.	It is not known if the post fire inspection covered the loader's tray adjustment.

CORRECTIVE ACTION: ______ **NONE** __XX__ **REQUIRED (CHECK ONE)**

Emphasize maintenance to include tray adjustments.

CONCLUSION: Unlikely

Figure A13
Improperly Adjusted Loader's Tray

CHART #14
DATE: OCTOBER 88 **REV. NO:**
FAILURE DESCRIPTION OR SYMPTON Crew

Dropped Round 1.14

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

SPECULATION	SUPPORTING DATA	REFUTING DATA	ADDITIONAL DATA TESTS REQUIRED
	EVALUATION Fire 1 Unlikely; Fire 2 Most LIkely		
FAILURE MODE: Dropped round ignites and burns. **FAILURE SEQUENCE:** Loader in hast and excitement looses control and dropps round. Round contacted hot primer from previously fires cartridge.	Loader dropped round 5 while trying to seat round 4 (loader testimony). Burnt round on turret floor.	None	

WHO
WHAT
WHEN
WHERE
WHY
HOW

CORRECTIVE ACTION: ______ **NONE** XX **REQUIRED (CHECK ONE)**

Enforce proper loading procedures during training.

CONCLUSION:

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

Figure A14
DRopped Round

CHART # 15

DATE: OCTOBER 88 **REV. NO:**

FAILURE DESCRIPTION OR SYMPTON Ammunition

Flaming Case Base 2.Ø1

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

SPECULATION	EVALUATION Fire 1 Fire 2 ~~Likely Unlikely~~		
	SUPPORTING DATA	**REFUTING DATA**	**ADDITIONAL DATA TESTS REQUIRED**
FAILURE MODE: Flame in case base (primer or ccc) after ejection from gun.	Loader reports seeing a small fire under breech. Loaders attitude -afraid of fire -does not want to be there. Primer after burning was encountered in dev testing	Previous testing indictated rate of occurance very low.	
FAILURE SEQUENCE: (WHO, WHAT, WHEN, WHERE, WHY, HOW) After firing, spent case base ejected. Residue on primer or case base continues to burn. Loader withdraws round from magazine. 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.			

CORRECTIVE ACTION: xx **NONE** ____ **REQUIRED (CHECK ONE)**

Increase effectivness of catcher box.

CONCLUSION:

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

Figure B1
Flaming Case Base

CHART # 16

DATE: OCTOBER 88 **REV. NO:**

FAILURE DESCRIPTION OR SYMPTON Ammunition

Joint Failure 2.02

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

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

WHO
WHAT
WHEN
WHERE
WHY
HOW

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

Evaluate inspection procedures ~~at factory~~. Review ~~joint~~ design to improve joint and containment bag.
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 SYMPTON   Ammunition

Moisture 2.03

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

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

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 SYMPTON Ammunition

Fuse Function 2.04

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

SPECULATION	EVALUATION: Fire 1 Unlikely, Fire 2 Unlikely		
	SUPPORTING DATA	REFUTING DATA	ADDITIONAL DATA TESTS REQUIRED
FAILURE MODE: Premature Fuze Function	None	The M865 has no fuse.	
FAILURE SEQUENCE: (WHO / WHAT / WHEN / WHERE / WHY / HOW) Static discharge sets off fuze.			

CORRECTIVE ACTION: ________ NONE _xx_____ REQUIRED (CHECK ONE)

CONCLUSION: Not Relevant

Figure B4
FuseFunction

CHART #19
DATE: OCTOBER 88 **REV. NO:**
FAILURE DESCRIPTION OR SYMPTON Ammunition

Impact 2.05

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

SPECULATION	SUPPORTING DATA	REFUTING DATA	ADDITIONAL DATA TESTS REQUIRED
	EVALUATION		Fire 1: Unlikely; Fire 2: Unlikely
FAILURE MODE: Impact starts fire.	None	Cartridges subjected to sequential rough handling tests (2.1m package drop, .5m bare drop, and 3m bare drop during DTII.) Cartridges sustained heavy damage, but none of the cartridges burned or detonated.	None
FAILURE SEQUENCE: (WHO, WHAT, WHEN, WHERE, WHY, HOW) Loader drops round. Impact ignites propellent.			

CORRECTIVE ACTION: ________ NONE XX ______ REQUIRED (CHECK ONE)

CONCLUSION Unlikely

Figure B5
Impact

CHART #20
DATE: OCTOBER 88 REV. NO:
FAILURE DESCRIPTION OR SYMPTON Ammunition

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

Primer Function 2.06

SPECULATION	EVALUATION Fire 1 Unlikely Fire 2 Unlikely		
	SUPPORTING DATA	REFUTING DATA	ADDITIONAL DATA TESTS REQUIRED
FAILURE MODE: Premature Primer Functions	None	M830 cartridge electric initiators (primer&fuze) tested for EMR susceptibility. Cartridge considered safe when exposed to EMR fields which are anticipated to be encountered during tatical deployment. -Primers subjected to static electiricity test of mil std 322, except voltage applied was 20,000 volts. -Primers were not functioned in the two tank fire incidents. -No evidence of electrical malfunction history of 105mm rd.	
FAILURE SEQUENCE: WHO WHAT WHEN Electrical source ignites primer. WHERE WHY (EMR, ESD electrical short faulty wiring) HOW			

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

Figure B6
Primer Function

CHART #21

DATE: OCTOBER 88 **REV. NO:**

FAILURE DESCRIPTION OR SYMPTON Ammunition

Hot Primer 2.07

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

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

CORRECTIVE ACTION: XX **NONE** ____ **REQUIRED (CHECK ONE)**

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

CONCLUSION:

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

Figure B7
Hot Primer

CHART #22

DATE: OCTOBER 88 **REV. NO:**

FAILURE DESCRIPTION OR SYMPTON Gun

Loader's Tray 3.01

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

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

WHO
WHAT
WHEN
WHERE
WHY
HOW

CORRECTIVE ACTION: XX NONE ______ REQUIRED (CHECK ONE)

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

CONCLUSION:

This could have contributed to confusion.

Figure C1
Loader's Tray

CHART #23

DATE: OCTOBER 88 **REV. NO:**

FAILURE DESCRIPTION OR SYMPTON Gun

Bore Evacuator 3.02

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

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

CORRECTIVE ACTION: ________ **NONE** XY **REQUIRED (CHECK ONE)**

Emphasize bore evacuator maintenance.

CONCLUSION:

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

Figure C2 Bore Evacuator

CHART #24

DATE: OCTOBER 88 **REV. NO:**

FAILURE DESCRIPTION OR SYMPTON Gun

Loader's Tray 3.03

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

SPECULATION	EVALUATION Fire 1: Unlikely, Fire 2: Unlikely		
	SUPPORTING DATA	REFUTING DATA	ADDITIONAL DATA TESTS REQUIRED
FAILURE MODE: Loader's tray in-operable. **FAILURE SEQUENCE:** Tray remains down. Ejected case enters bustle causing stored ammunition to burn.	None	Only base cases of stored ammunition is exposed. Gun would have to be depressed for access. Bustle doors would have to be open.	

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:**

FAILURE DESCRIPTION OR SYMPTON Turret

Round falls from bustle 4.01

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

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

WHO
WHAT
WHEN
WHERE
WHY
HOW

CORRECTIVE ACTION: XX NONE ______ REQUIRED (CHECK ONE)

Determine probability of occurrence.

CONCLUSION:

Unlikely

Figure D1
Round Falls From Bustle.

CHART #26

DATE: OCTOBER 88 **REV. NO:**

FAILURE DESCRIPTION OR SYMPTON Turret

Bustle door damages round 4.02

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

SPECULATION	EVALUATION Fire 1: Unlikely, Fire 2: Unlikely		
	SUPPORTING DATA	**REFUTING DATA**	**ADDITIONAL DATA TESTS REQUIRED**
FAILURE MODE: Round is damaged by door closing on it, spilling propellent on floor. **FAILURE SEQUENCE:** door closes on a round that slipped out of bustle and ruptures cartridge case. Propellents spill onto floor and hot primers. Propellent ignites, causing loader to panic and drop round.	I door safety switch is not properly adjusted, door will not stop when striking an object. It may stop after crushing a round. Instancesin M1's where doors jammed against 105 rounds. Rounds couldnct be removed and door had to be opened manually after turning circuit breaker off.	Ammunition holding latches on M1A1 are redesigned.	Check with fielded units to see if and how often this occurs with the M1A1 tank. Reinspect the tank involved in the 4 July fire for proper door operation.

WHO
WHAT
WHEN
WHERE
WHY
HOW

CORRECTIVE ACTION: ______ **NONE** __XX__ **REQUIRED (CHECK ONE)**

CONCLUSION: Unlikely

Figure D2
Bustle door Damages Round

CHART #27

DATE: OCTOBER 88 **REV. NO:**

FAILURE DESCRIPTION OR SYMPTON Turret

Catcher Box Design 4.03

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

EVALUATION Fire 1 Most LIkely Fire 2 Most Likely

SPECULATION	SUPPORTING DATA	REFUTING DATA	ADDITIONAL DATA TESTS REQUIRED
FAILURE MODE: Design of catcher box. **FAILURE SEQUENCE:** Catcher box-alleged to have been an evolutionary process Apparently no human factors engineering guidance was requested from TACOM HEL Det. Size & configuration of box causes it to inpinge on loader's work space. Design of box allows hot primer stem to protrude from box. Open top of box provides enough open space for debris/ shavings&a dropped round to fall into box. Box is unreliable. Box removed to provide space. Hot case bases land on deck	As per converstaion with HEL Detachment TACOM. Loader testimony fire 1. Loader testimony fire 2 and apparent rationale for box not being in place. cont'd on next pg.	None	

WHO
WHAT
WHEN
WHERE
WHY
HOW

CORRECTIVE ACTION: ______ NONE ______ REQUIRED (CHECK ONE)

CONCLUSION: None

pg 2 CHART #27

DATE: **REV. NO:**

FAILURE DESCRIPTION OR SYMPTON

Catcher Box Design 4.03

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

SPECULATION	EVALUATION		
	SUPPORTING DATA	REFUTING DATA	ADDITIONAL DATA TESTS REQUIRED
FAILURE MODE:	None	None	
FAILURE SEQUENCE: cont'd from chart 27 Exposed primers provided an ignition source for shaving from cartridge case, a dropped round, propellent or other debris.			

WHO
WHAT
WHEN
WHERE
WHY
HOW

CORRECTIVE ACTION: xx NONE ________ REQUIRED (CHECK ONE)

Redesign box so that case bases are contained and can not expose the hot primer to any combustible material.

CONCLUSION:

The catcher box does not isolate hot primers from the crew, ammunition, and any cumbustible material. It is unreliable and restricts crew movement.

Figure D3
Catcher Box Design

CHART #28
DATE: OCTOBER 88 **REV. NO:**
FAILURE DESCRIPTION OR SYMPTON Turret
Short Circuit 4.04

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

SPECULATION	SUPPORTING DATA	REFUTING DATA	ADDITIONAL DATA TESTS REQUIRED
	EVALUATION Fire 1: Unlikely; Fire 2: Unlikely		
FAILURE MODE: Electrical short circuit causes fire. **FAILURE SEQUENCE:** Loader has round in his hand. Drops round when seeing sparks *and/or possible fire* in the turret. Round comes on contact with hot or burning material.	Loader saw fire in the turret (first fire loaders testimony).	In both cases there was no malfunction in equipment *reported or noted* before or after the fires	

WHO
WHAT
WHEN
WHERE
WHY
HOW

CORRECTIVE ACTION: ______ NONE XX REQUIRED (CHECK ONE)

CONCLUSION: Unlikely

Figure D4 Short Circuit

CHART #29

DATE: OCTOBER 88 **REV. NO:**

FAILURE DESCRIPTION OR SYMPTON Turret

Difficulty to exit 4.05

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

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

WHO
WHAT
WHEN
WHERE
WHY
HOW

CORRECTIVE ACTION: __xx__ NONE ______ REQUIRED (CHECK ONE)

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

CONCLUSION:

Unlikely

Figure D5
Difficulty to Exit

CHART #30

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

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

Static Electricity 4.06

SPECULATION	EVALUATION	Fire 1 Unlikely	Fire 2 Unlikely
	SUPPORTING DATA	**REFUTING DATA**	**ADDITIONAL DATA TESTS REQUIRED**
FAILURE MODE: Static electricity from loader ignites cartridge case. **FAILURE SEQUENCE:** WHO WHAT WHEN WHERE WHY HOW	None	72%nc cases did not ignite when subjected to energies up).41 joules. 60%nc cases would require greater energy. Sensitivity tests are performed at 0.25 joule which is believed to be 10 times what can be expected from a human. Loader would discharge to tank or stub base before contacting combustible case.	None

CORRECTIVE ACTION: ______ **NONE** XX **REQUIRED** (CHECK ONE) **CONCLUSION:** None

Figure D6
Static Electricity

CHART #31

DATE: OCTOBER 88 **REV. NO:**

FAILURE DESCRIPTION OR SYMPTON Turret

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

Friction 4.07

SPECULATION	EVALUATION Fire 1 Unlikely / Fire 2 Unlikely		
	SUPPORTING DATA	REFUTING DATA	ADDITIONAL DATA TESTS REQUIRED
FAILURE MODE: Friction between combustible case, rack, and grit ignites cartridge case. **FAILURE SEQUENCE:**	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.	-cases are about 60%nc -52%nc cases failed to ignite with 1000 lbs at at 8fps -velocity estimated below 2fps. -Protective coating would increase load/velocity to ignition. -unfrayed material failed to ignite.	none

WHO
WHAT
WHEN
WHERE
WHY
HOW

CORRECTIVE ACTION: ______ **NONE** XX **REQUIRED (CHECK ONE)**

CONCLUSION: Unlikely

Figure D7
Friction

CHART #32

DATE: OCTOBER 88 **REV. NO:**

FAILURE DESCRIPTION OR SYMPTON Turret

Racks Scrape Cartridge Cases 4.08

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

SPECULATION	SUPPORTING DATA	REFUTING DATA	ADDITIONAL DATA TESTS REQUIRED
	EVALUATION Fire 1: Unlikely; Fire 2: Unlikely		
FAILURE MODE: Ammo racks scrapes combustible cartridge case.	Rounds have been observed to have scraches.	Need a large accumulation of scrapings to cause a hazard.	
FAILURE SEQUENCE: Residue is created from ammo racks scraping CCC. Build up of residue is ignited from gun/flashback, spark or cigarette ash. A round is exposed to burning residue and ignites.			

WHO
WHAT
WHEN
WHERE
WHY
HOW

CORRECTIVE ACTION: ______ NONE __XX__ REQUIRED (CHECK ONE)

CONCLUSION: Unlikely

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

CHART #33

DATE: OCTOBER 88 **REV. NO:**

FAILURE DESCRIPTION OR SYMPTON Turret

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

Hydraulic Leak 4.09

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

WHO
WHAT
WHEN
WHERE
WHY
HOW

CORRECTIVE ACTION: ______ **NONE** XX **REQUIRED (CHECK ONE)**

CONCLUSION: Unlikely

Figure D9
Hydraulic Leak

APPENDIX C

IGNITION DATA

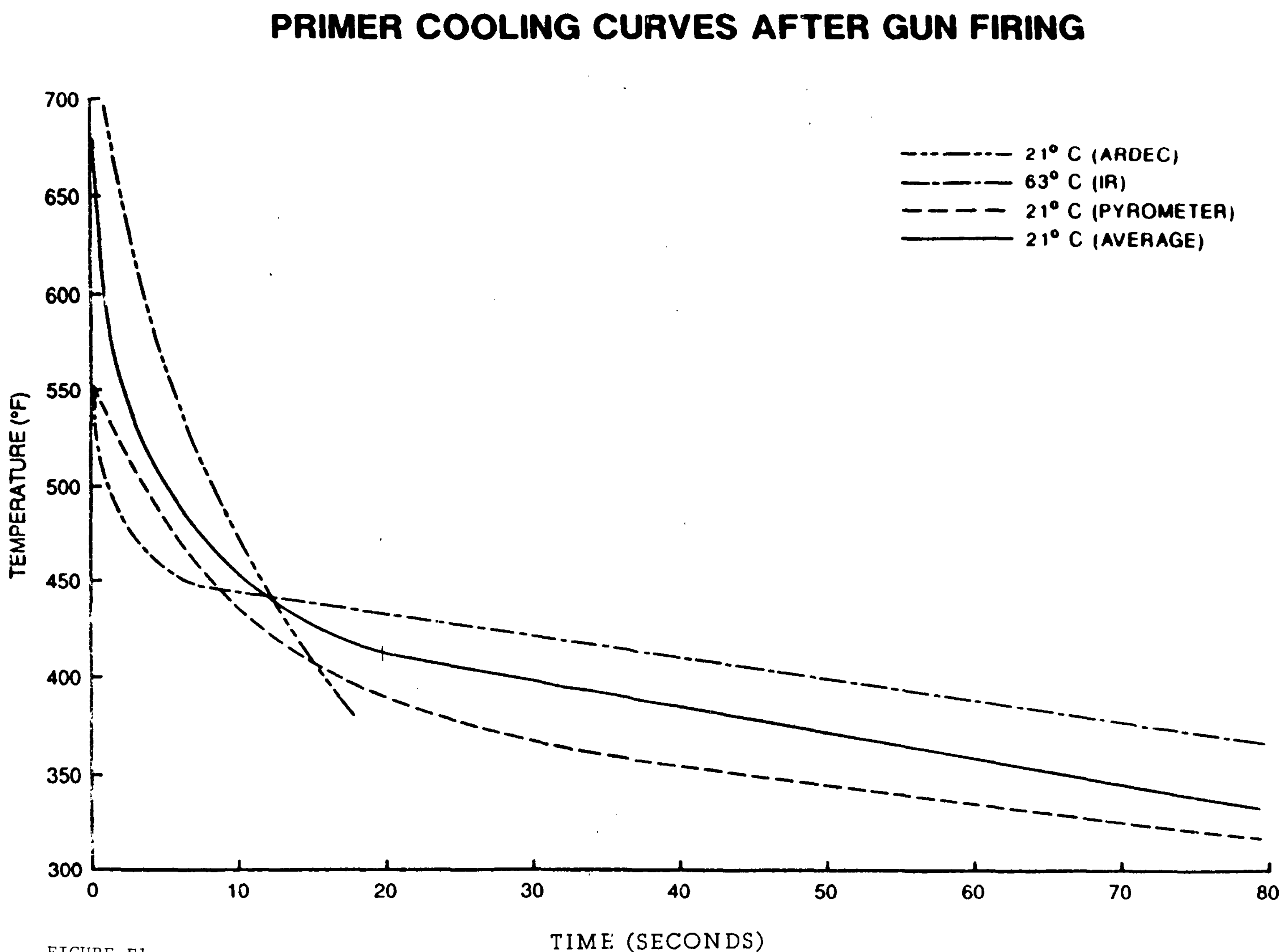

PRIMER COOLING CURVES AFTER GUN FIRING
21° C (ARDEC)
63° C (IR)
21° C (PYROMETER)
21° C (AVERAGE)
TEMPERATURE (°F)
700
650
600
550
500
450
400
350
300
0
10
20
30
40
50
60
70
80
TIME (SECONDS)

FIGURE E1

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

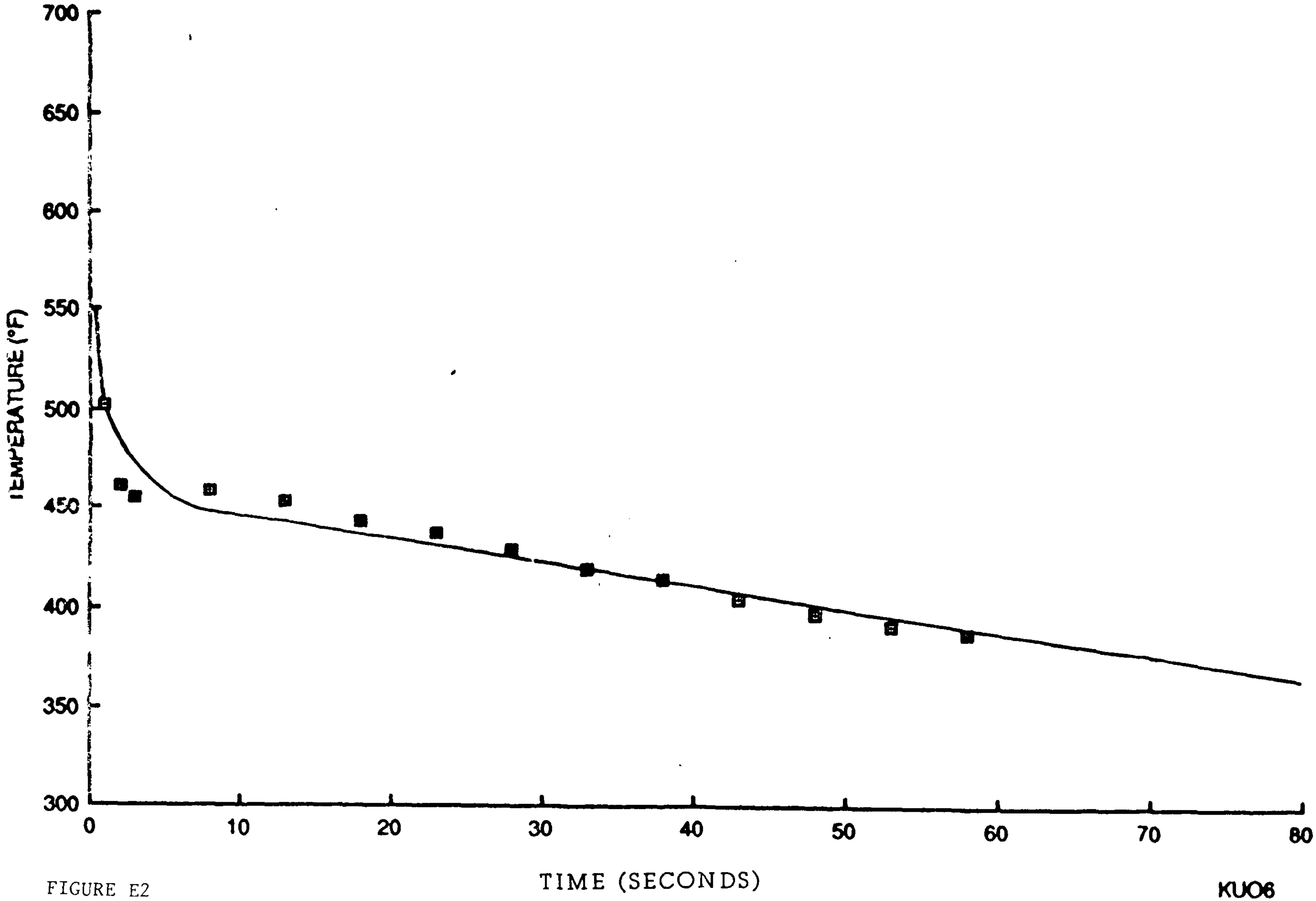
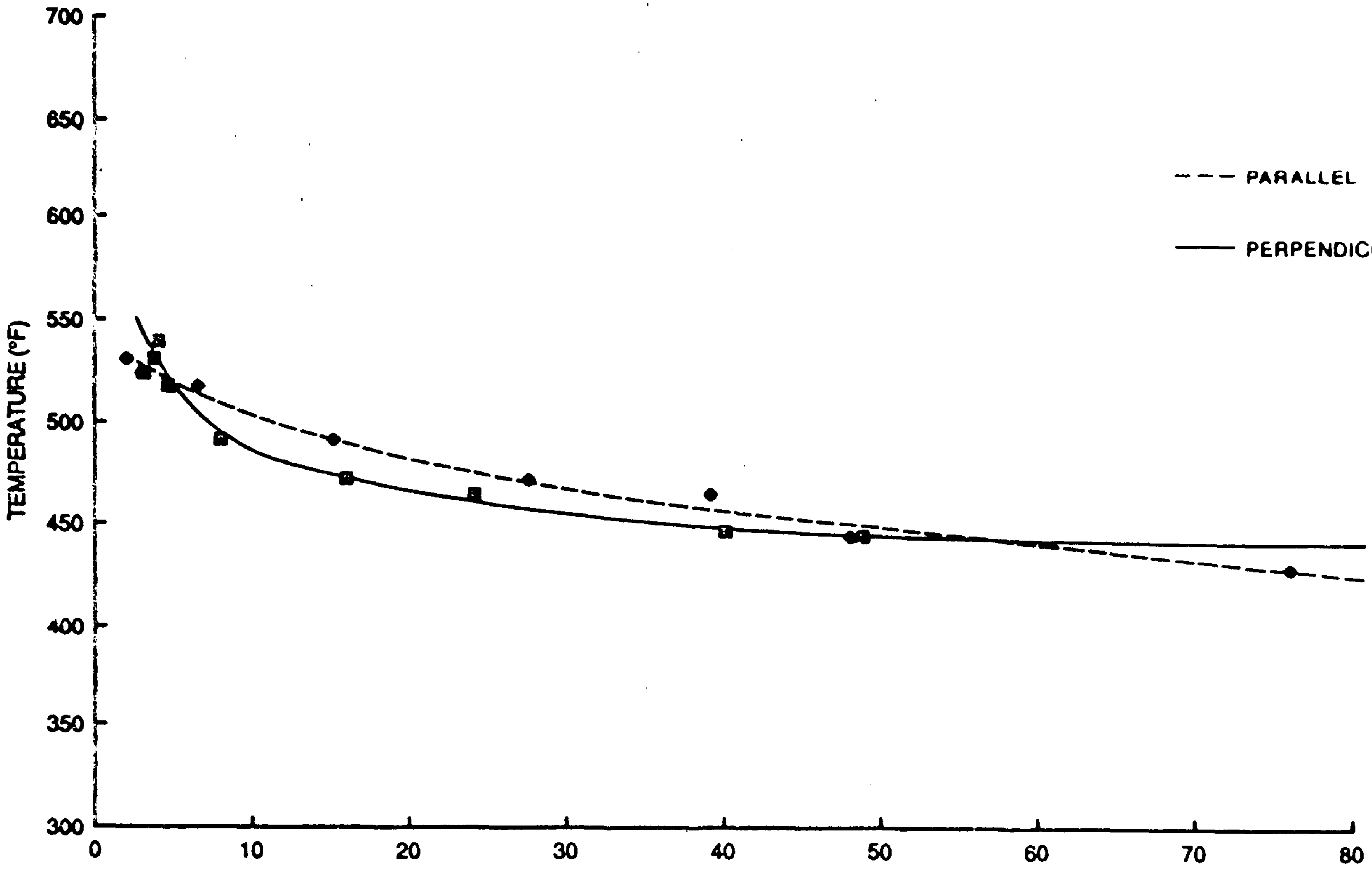


FIGURE E2

TIME TO IGNITION STUDY OF CCC (FOE85M100-005)



KUO7

FIGURE E3

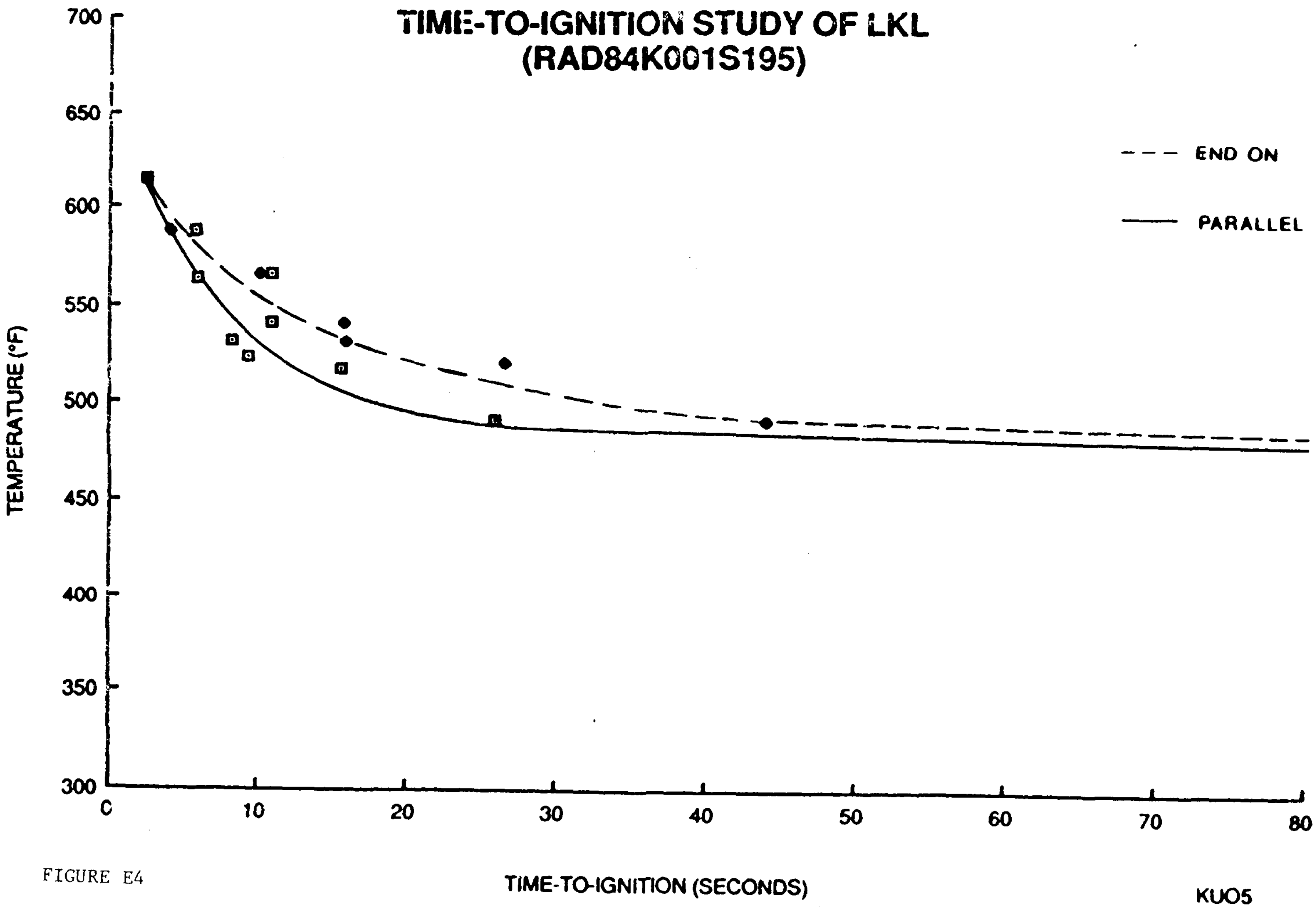

TIME-TO-IGNITION STUDY OF LKL
(RAD84K001S195)
END ON
PARALLEL
TEMPERATURE (°F)
700
650
600
550
500
450
400
350
300
0
10
20
30
40
50
60
70
80
TIME-TO-IGNITION (SECONDS)
KUO5

FIGURE E4

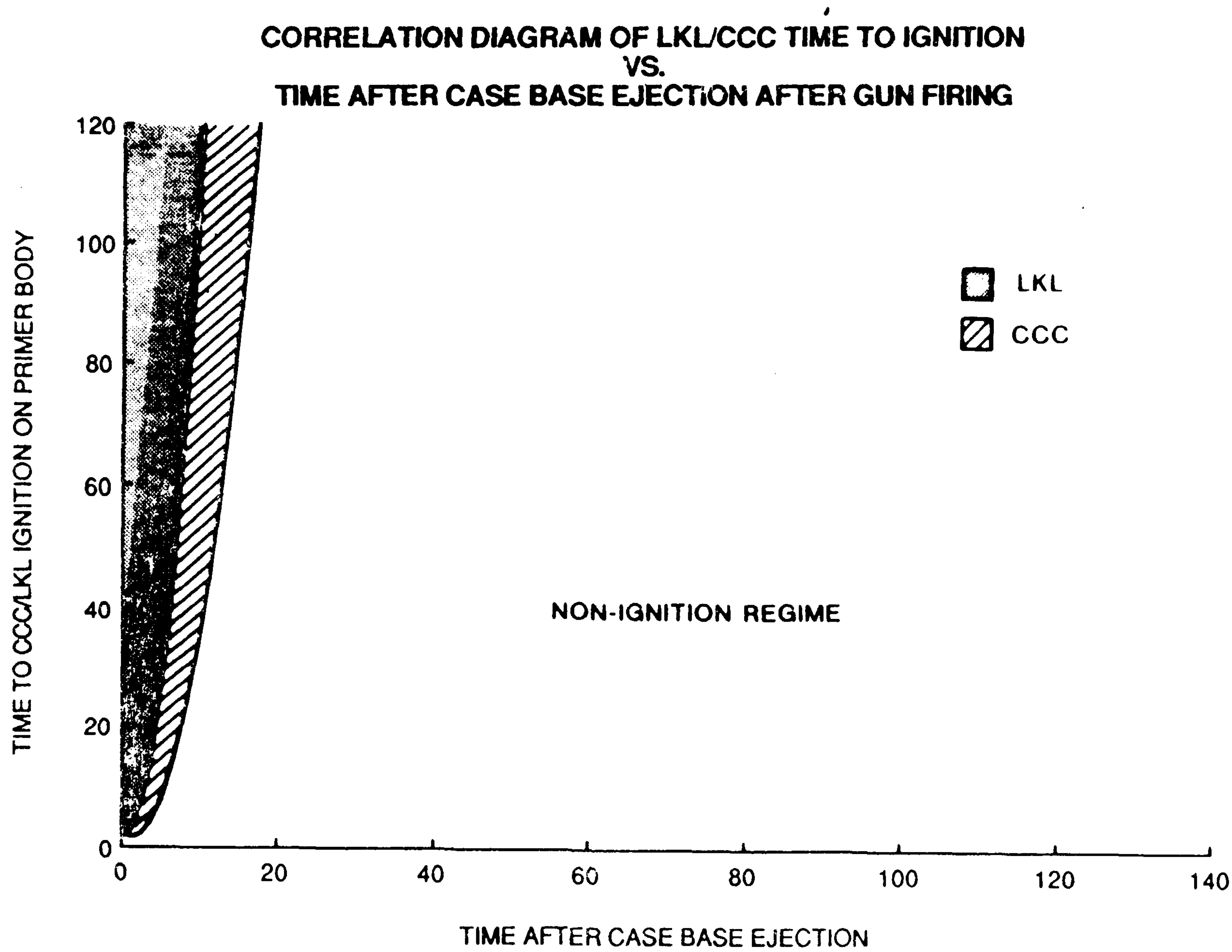

CORRELATION DIAGRAM OF LKL/CCC TIME TO IGNITION
VS.
TIME AFTER CASE BASE EJECTION AFTER GUN FIRING
TIME TO CCC/LKL IGNITION ON PRIMER BODY
120
100
80
60
40
20
0
0
20
40
60
80
100
120
140
TIME AFTER CASE BASE EJECTION
LKL
CCC
NON-IGNITION REGIME

FIGURE E5

29 July 1988

Cookoff Studies

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

Coated Side in Contact With Hot Plate

Ignition Temperature °F	Time to Ignition (sec) Avg	Std Dev
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

LKL Propellant - Lot No. RAD 84K001S195

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

* 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.

PROD/KUO/08

FIGURE E8

TIME-TO-IGNITION OF CCC VS IGNITED MATERIALS

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

PROD/KUO/01

FIGURE E9

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

MATERIAL	TIME TO IGNITION (SECONDS)	COMMENT
CLP/RAG HYDRAULIC FLUID/RAG	NO GO; SMOKING NO GO; SMOKING	NO IGNITION UP TO 3 MINUTES OF DIRECT 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) ON RAG. FLAME OF THE GRAIN NEEDS TO SUSTAIN ABOUT 2 SECONDS TO IGNITE THE RAG.
HYDRAULIC FLUID/RAG	~ 4	DROPS RESIDUAL LKL BURNING GRAIN (ABOUT 1/2, 1/3, 1/4 GRAIN) ON RAG. FLAME OF THE GRAIN NEEDS TO SUSTAIN ABOUT 4 SECONDS TO IGNITE THE RAG.
CLP/RAG	~ 4	DROP 1/2 IN ^{2} BURNING CCC WITH MINIMUM FLAME ON RAG; NO DIRECT CONTACT BETWEEN FLAME AND RAG (i.e.WAS SHIELDED BY CCC)
HYDRAULIC RAG	NO GO	DROP 1/2 IN ^{2} BURNING CCC WITH MINIMUM FLAME ON RAG; NO DIRECT CONTACT BETWEEN FLAME AND RAG (i.e.WAS SHIELDED BY CCC)

PROD/KUO/07

FIGURE E10

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

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

FIGURE E11

PROD/KUO/32

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

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

PROD/KUO/011

FIGURE E12

TIME TO IGNITION OF CCC VS. BURNING LKL GRAIN

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

PROD/KUO/010

FIGURE E13

APPENDIX D

ROOT CAUSE ANALYSIS TEAM CHARTER

DISPOSITION FORM

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

REFERENCE OR OFFICE SYMBOL	SUBJECT
SMCAR-TD	Red Team Charter

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

1. Recently two tank fires involving 120mm ammunition occured 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 reoccurance 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:

Name	Organization	Extenstion
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.

U.S. G.P.O. 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 proceedures 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

DISTRIBUTION LIST

Commander
Armament Research, Development and Engineering Center
U.S. Army Armament, Munitions and Chemical Command
ATTN: SMCAR-IMI-I (5)
SMCAR-AE
SMCAR-AEE-BP, James Rutkowski
SMCAR-ASM (20), MAJ J. Dowalgo
SMCAR-CC
SMCAR-CCH-V, William Williver
SMCAR-FS
SMCAR-SF, John Banks
Picatinny Arsenal, NJ 07806-5000

Commander
U.S. Army Armament, Munitions and Chemical Command
ATTN: AMSMC-GCL
AMSMC-LSA, Robert Allen
AMSMC-QAT-M, Joseph Corallo
Picatinny Arsenal, NJ 07806-5000

Office of the Project Manager
Tank Main Armament Systems
ATTN: AMCPM-TMA
AMCPM-TMA-105, Roger Billington
Picatinny Arsenal, NJ 07806-5000

U.S. Army Human Engineering Lab Det
ATTN: SLCHE-AR, Jack Carlock
Picatinny Arsenal, NJ 07806-5000

Administrator
Defense Technical Information Center
ATTN: Accessions Division (12)
Cameron Station
Alexandria, VA 22304-6145

Director
U.S. Army Materiel Systems Analysis Activity
ATTN: AMXSY-MP
Aberdeen Proving Ground, MD 21005-5066

Commander
Chemical Research, Development and Engineering Center
U.S. Army Armament, Munitions and Chemical Command
ATTN: SMCCR-MSI
Aberdeen Proving Ground, MD 21010-5423

Commander
Chemical Research, Development and Engineering Center
U.S. Army Armament, Munitions and Chemical Command
ATTN: SMCCR-RSP-A
Aberdeen Proving Ground, MD 21010-5423

Director
Ballistic Research Laboratory
ATTN: AMXBR-OD-ST
Aberdeen Proving Ground, MD 21010-5423

Chief
Benet Weapons Laboratory, CCAC
Armament Research, Development and Engineering Center
U.S. Army Armament, Munitions and Chemical Command
ATTN: SMCAR-CCB-TL
Watervliet, NY 12189-5000

Commander
U.S. Army Armament, Munitions and Chemical Command
ATTN: SMCAR-ESP-L
Rock Island, IL 61299-6000

Director
U.S. Army TRADOC Systems Analysis Activity
ATTN: ATAA-SL
White Sands Missile Range, NM 88002

Commander
U.S. Army Armor School
ATTN: ATZK-CO
ATSB-WP-GD, SFC Wolford
Ft. Knox, KY 40121

Commander
U.S. Army Armament, Munitions and Chemical Command
ATTN: AMSMC-CG
AMSMC-ASR-A, CPT Smith
AMSMC-RT
AMSMC-AP
Rock Island, IL 61299-6000

Program Executive Officer
Close Combat Vehicles
ATTN: AMCPEO-CCV
U.S. Army Tank Automotive Command
Warren, MI 48397-5000

Project Manager for Abrams Tank Systems
ATTN: AMCPM-ABMS
U.S. Army Tank Automotive Command
Warren, MI 48397-5000