

The background of the entire page is a collage of various mine neutralization systems and components. It includes images of green and yellow cylindrical sensors, black and white electronic modules, and other specialized equipment, all set against a sandy, desert-like terrain. The collage is arranged in a grid-like fashion, with some items appearing in multiple panels.

Operational Evaluation Test of Mine Neutralization Systems

April 2005

Prepared by

Institute for Defense Analyses
4850 Mark Center Drive
Alexandria, VA 22311-1882

for

**Humanitarian Demining Research
and Development Program**
Night Vision and Electronic Sensors Directorate
Attn: AMSRD-CER-NV-CM-HD
10221 Burbeck Road
Fort Belvoir, VA 22060

**Office of the Assistant Secretary of Defense
Special Operations and Low-Intensity Conflict**
Attn: OASD/SOLIC (RES)
2500 Defense Pentagon
Washington, DC 20301-2500

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE APR 2005		2. REPORT TYPE		3. DATES COVERED 00-00-2005 to 00-00-2005	
4. TITLE AND SUBTITLE Operational Evaluation Test of Mine Neutralization Systems				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Institute for Defense Analyses, 4850 Mark Center Drive, Alexandria, VA, 22311-1882				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 93	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

Operational Evaluation Test of Mine Neutralization Systems

April 2005

FOREWORD

The success of the Neutralization Systems test program was the result of the efforts of a large team of people from a number of organizations. First and foremost is Colonel Allan Vosburgh, Assistant for Demining and EOD in the Office of the Assistant Secretary of Defense for Special Operations and Low Intensity Conflict. Through his interaction with members of the international demining community, Colonel Vosburgh identified the need and initiated this neutralization test program. Mr. Sean Burke, Program Manager of the Humanitarian Demining R&D Program, provided the direction and support that made all things come together at the right time. The Project Engineer and Test Director, Dr. Divyakant Patel, drafted the test plan and directed the testing of each of the 17 systems tested and reported on in this document. Without his background and knowledge and his ability to adapt to situational requirements caused by the operational differences demanded of each neutralization system, this test program would have taken much longer than 2 months. Special recognition and thanks are also given to those who cheerfully supported the tests on a daily basis over the 2-month period. This included Mr. John Fasulo and Mr. Mel Soult, directors of the Development Test Site, and the explosive experts responsible for test range safety and for setup and detonation initiation of each test. Mr. Ray Blake, Mr. Harold Carr, Mr. Mark Chewning, and SSG Gary Wright, all members of the test site staff, assisted Messrs. Fasulo and Soult during the test. Also, thanks go to Ms. Karin Breiter, Ms. Lawna Mathie, and SSG Gary Wright for photographic and videographic support. Mrs. Sherryl Zounes, Mr. Ben Howe, and Mr. Harold E. Bertrand, all of the Institute for Defense Analyses (IDA), recorded test data during the test, analyzed the test data, and drafted this report. Mr. Tom Milani, also of IDA, provided editorial support. Finally, we want to thank each of the participating neutralization system contractors for supporting this test program and enabling the U.S. Army Night Vision and Electronic Sensors Directorate (NVESD) Humanitarian Demining Program Office to produce an informative document on available neutralization systems for humanitarian demining organizations, worldwide.

CONTENTS

Executive Summary	ES-1
1 Introduction	1
1.1 Background.....	1
1.2 Objective.....	1
2 System Descriptions.....	2
2.1 General	2
2.1.1 Deflagration System Descriptions	3
2.1.1.1 FireAnt®	3
2.1.1.2 Hyperheat® Mine Flare	3
2.1.1.3 Propellant Torch System	4
2.1.1.4 Pyropak	5
2.1.1.5 Pyro-Torch System	6
2.1.1.6 Thiokol Demining Flare™	7
2.1.2 High-Order System Descriptions	9
2.1.2.1 FIXOR®	9
2.1.2.2 HELIX.....	10
2.1.2.3 Kinepak™ (Kinepouch™ and Kinestik™).....	11
2.1.2.4 Liquid Explosive Pouch	12
2.1.2.5 NMX-foam™	13
2.1.2.6 PESCO Humanitarian Demining Perforators.....	15
2.1.2.7 SM-EOD 20 and SM-EOD 33	16
3 Test Description, Procedures, and Results.....	18
3.1 Test Site and Testing Equipment.....	18
3.1.1 Test Environment.....	18
3.1.2 Testing Supplies.....	18
3.1.3 Test Targets.....	18
3.1.3.1 Metal Plates.....	18
3.1.3.2 Antipersonnel Mines	19
3.1.3.3 Antitank Mines.....	20
3.1.3.4 Artillery Shells	21
3.2 Deflagration System Testing and Results.....	22
3.2.1 Preliminary Test Procedures and Results for Deflagration Systems	22
3.2.1.1 Thrust Measurements	22
3.2.1.2 Burning Time Measurements.....	23
3.2.1.3 Plate Penetration Test.....	23

3.2.1.4	Ignition Methods Tests	25
3.2.2	Mine Neutralization Test Procedures for Deflagration Systems	25
3.2.3	Mine Neutralization Test Results of Deflagration Systems.....	27
3.2.3.1	FireAnt [®]	28
3.2.3.2	Hyperheat [®] Mine Flare	30
3.2.3.3	Propellant Torch System.....	31
3.2.3.4	Pyropak	34
3.2.3.5	Pyro-Torch	35
3.2.3.6	Thiokol Demining Flare [™]	35
3.2.4	Mine Neutralization Test Results Summary of Deflagration Systems	37
3.3	High-Order System Testing and Results	38
3.3.1	Preliminary Test Procedures and Results for High-Order Systems.....	38
3.3.1.1	Initiation Methods Test.....	38
3.3.1.2	Plate Penetration Test for Shaped-Charge Systems.....	38
3.3.2	Mine Neutralization Test Procedures for High-Order Systems.....	39
3.3.3	Mine Neutralization Test Results of High-Order Systems	41
3.3.3.1	FIXOR [®]	41
3.3.3.2	HELIX.....	41
3.3.3.3	Kinepouch [™]	42
3.3.3.4	Kinestik [™]	43
3.3.3.5	Liquid Explosive Pouch.....	43
3.3.3.6	NMX-foam [™]	44
3.3.3.7	PESCO Humanitarian Demining Perforators	46
3.3.3.8	SM-EOD	47
3.3.4	Mine Neutralization Test Results Summary of High-Order Systems.....	48
3.3.5	Artillery Shell Neutralization Test Procedures and Results	49
3.4	Test Data Analyses.....	49
3.4.1	Data Collection	49
3.4.1.1	Data Collection for Deflagration Systems	50
3.4.1.2	Data Collection for High-Order Systems.....	50
4	Human Factors Assessment.....	50
4.1	Deflagration Systems	51
4.2	High-Order Systems	51
5	Transportation and Storage	51
6	System Costs	55
6.1	Deflagration System Cost.....	55
6.2	High-Order System Cost	56
7	Test Summary Assessment	57
8	Recommendations	57
9	Conclusions	58

Glossary	GL-1
-----------------------	-------------

Appendixes

Appendix A—System Contact Information.....	A-1
Appendix B—Developmental Systems	B-1
Appendix C—Liquid Explosive Pouch System Cost Planning Chart	C-1

FIGURES

Figure 1: FireAnt [®] against VS-50 Antipersonnel and TMRP-6 Antitank Mine Targets.....	3
Figure 2: HyperHeat [®] Mine Flare against T-AB-1 Antipersonnel and Round Antitank Mine Targets	4
Figure 3: PT-3 against SPM-1 Antipersonnel and TM-46 Antitank Mine Targets	4
Figure 4: PT-12 against Valmara-69 Antipersonnel and Round Antitank Mine Targets	5
Figure 5: Pyropaks and Igniter Systems	6
Figure 6: Pyropak against T-AB-1 Antipersonnel and TMRP-6 Antitank Mine Targets.....	6
Figure 7: Pyro-Torch System	7
Figure 8: Pyro-Torch against an SPM-1 Antipersonnel Mine Target.....	7
Figure 9: Pyro-Torch against a TM-46 Antitank Mine Target	7
Figure 10: Thiokol Demining Flare [™]	8
Figure 11: Thiokol Demining Flare [™] against an SPM-1 Antipersonnel Mine Target.....	8
Figure 12: Thiokol Demining Flare [™] against a TMRP-6 Antitank Mine Target.....	8
Figure 13: FIXOR [®] against VS-50 Antipersonnel and TMRP-6 Antitank Mine Targets	10
Figure 14: HELIX against PMD-6 Antipersonnel and TMRP-6 Antitank Mine Targets.....	11
Figure 15: Kinepak [™] System Components Before Mixing	11
Figure 16: Kinepouch [™] against VS-50 Antipersonnel and TMD-44 Antitank Mine Targets	12
Figure 17: Kinestik [™] against T-AB-1 Antipersonnel and Round Antitank Mine Targets.....	12
Figure 18: HDPE Pouches for Liquid Explosive Pouch System	13
Figure 19: Liquid Explosive Pouch 1/2-pound Charges against T-AB-1 Antipersonnel and Round Antitank Mine Targets	13
Figure 20: NMX-foam [™] Containers and Mixing.....	14
Figure 21: NMX-foam [™] applied to a VS-50 Antipersonnel Mine Target	14
Figure 22: PESCO Humanitarian Demining Perforator	15
Figure 23: PESCO HD 11 g Perforator against PMD-6 Antipersonnel and Round Antitank Mine Targets.....	15
Figure 24: PESCO HD 22 g Perforator against a TM-46 Antitank Mine Target	16
Figure 25: SM-EOD System Setup (33 above, 20 below)	16
Figure 26: SM-EOD 20 against SPM-1 Antipersonnel and Round Antitank Mine Targets....	17
Figure 27: SM-EOD 33 against Antipersonnel Bounding Mine and TMRP-6 Antitank Mine Targets	17
Figure 28: Demolition Pit	18
Figure 29: Laser Components of A-Systems Laser Deflagration System [™]	B-4
Figure 30: ASLD [™] against Antipersonnel and Antitank Mine Targets	B-4
Figure 31: MineBurner against AP and AT Mine Targets.....	B-5
Figure 32: Mine Disarmer against an AP Mine Target.....	B-7

TABLES

Table 1: Deflagration Systems	3
Table 2: High-Order Systems	9
Table 3: Antipersonnel Mine Targets	20
Table 4: Antitank Mine Targets	21
Table 5: Artillery Shell Targets.....	21
Table 6: Thrust Measurements.....	22
Table 7: Burning Time Measurements.....	23
Table 8: Mine Targets for Deflagration Systems Determined by Plate Penetration.....	24
Table 9: Plate Penetration Results for Deflagration Systems	24
Table 10: Ignition Methods for Deflagration Systems.....	25
Table 11: FireAnt [®] Current Test Results	29
Table 12: FireAnt [®] Test Results from 12 April 2000	29
Table 13: FireAnt [®] Test Results Summary.....	30
Table 14: Hyperheat [®] Mine Flare Test Results	31
Table 15: Propellant Torch System (PT-3) Test Results	32
Table 16: Propellant Torch System (PT-12) Test Results	33
Table 17: Pyropak Test Results	34
Table 18: Pyro-Torch Test Results	35
Table 19: Thiokol Demining Flare [™] Test Results	36
Table 20: Antipersonnel Mine Test Results Summary of Deflagration Systems	37
Table 21: Initiation Methods for High-Order Systems	38
Table 22: Plate Penetration Results for Shaped-Charge Systems.....	39
Table 23: FIXOR [®] Test Results.....	41
Table 24: HELIX Test Results.....	42
Table 25: Kinepouch [™] Test Results.....	42
Table 26: Kinestik [™] Test Results.....	43
Table 27: Liquid Explosive Pouch (1/2-pound Charges) Test Results	44
Table 28: Liquid Explosive Pouch (1-pound Charges) Test Results	44
Table 29: NMX-foam [™] Current Test Results	45
Table 30: NMX-foam [™] 22–23 April 2003 Test Results	45
Table 31: NMX-foam [™] against Fuzed Mine Targets.....	46
Table 32: NMX-foam [™] Test Results Summary	46
Table 33: PESCO HD 11 g Perforator Test Results	47
Table 34: PESCO HD 22 g Perforator Test Results	47
Table 35: SM-EOD 20 Test Results.....	47
Table 36: SM-EOD 33 Test Results.....	48
Table 37: Test Results Summary of High-Order Systems	49

Table 38: Artillery Shell Neutralization Test Results of High-Order Systems	49
Table 39: Storage and Shipping Information for Deflagration Systems.....	52
Table 40: Storage and Shipping Information for High-Order Systems	52
Table 41: Shipping Classifications	54
Table 42: Cost per Unit for Deflagration Systems.....	56
Table 43: Cost per Unit for High-Order Systems	56
Table 44: Mine Neutralization Test Results Summary for All Systems.....	57
Table 45: Estimated ASLD™ Cost per Unit based on Purchased Quantity	B-4
Table 46: Estimated MineBurner Cost per Unit based on Purchased Quantity.....	B-6
Table 47: Estimated Mine Disarmer Cost per Unit based on Purchased Quantity	B-7
Table 48: Liquid Explosive Pouch System Cost Planning Chart	C-3

EXECUTIVE SUMMARY

During the Humanitarian Demining Research and Development Program's Fiscal Year 2003 Humanitarian Demining Requirements Workshop, expert deminers expressed a need for a cost-benefit and performance analysis for currently available deflagration (burning) and high-order (non-explosive binary mixture) mine neutralization systems that carry fewer shipping restrictions when compared to tradition explosives commonly used for mine neutralization. In response to this request, the U.S. Army Communications-Electronics Command (CECOM) Acquisition Center-Washington, D.C., published a Federal Business Opportunities (FBO) announcement on January 21, 2004 on behalf of the Communications-Electronics Research, Development and Engineering Center (CERDEC), Night Vision and Electronic Sensors Directorate (NVESD), Countermine Division, Humanitarian Demining Branch, stating that the government was seeking sources for non-developmental high-order or low-order mine neutralization systems suitable for use in humanitarian demining operations. U.S. and foreign companies responded to this FBO announcement.

Of the systems submitted for consideration, six deflagration systems including seven different devices and seven high-order systems including eleven different devices were selected for further evaluation. The deflagration systems tested were FireAnt[®], Hyperheat[®], Propellant Torch System (PT-3 and PT-12 devices), Pyropak, Pyro-Torch System, and the Thiokol Demining Flare[™]. Pyropak, which uses hot liquid thermite, is the only deflagration system that is not a flare- or torch-type technology. The high-order systems tested were FIXOR[®], HELIX, Kinepak[™] (Kinepouch[™] and Kinestik[™] devices), Liquid Explosive Pouch (LEP half-pound and one-pound devices), NMX-foam[™], PESCO Humanitarian Demining Perforator (11-gram and 22-gram devices), and SM-EOD (SM-EOD 20 and SM-EOD 33 devices). FIXOR[®], Kinepak[™], Liquid Explosive Pouch, and NMX-foam[™] are all binary explosive systems. HELIX uses a binary explosive and a shaped charge. PESCO and SM-EOD use RDX-propelled shaped charges.

A capability demonstration of these deflagration and high-order systems was conducted at a government test facility during the August to October 2004 time frame. All systems were tested against a variety of wood-, plastic-, or metal-cased mine targets, which were surface buried on the day of testing. For deflagration system tests, all mine targets were fuzed but not armed. For high-order system testing, mine targets were not fuzed. Against target sets of between 7 and 20 mine targets per system, total mine neutralization success rates ranged from 80% to 100%. For deflagration systems, mine neutralization by deflagration was lower than total mine neutralization with successful deflagrations ranging from 67% to 88%.

When choosing a mine neutralization system for a specific demining situation, neutralization success rates must be weighed against other practical considerations including demining costs. The systems tested ranged in price from \$3.00 to \$120.00 per unit for

deflagration systems and from \$3.00 to \$64.00 per unit for high-order systems when purchased in quantities of 100 units. With such a wide range of prices, cost may be a significant consideration.

Transportation and storage costs and logistical considerations also need to be considered during system selection. Since all systems described in this report contain hazardous materials as described by the U.S. Department of Transportation, all systems carry some transportation and storage restrictions and requirements. Even so, all tested mine neutralization systems do not carry many of the restrictions imposed on Hazard Class 1.1D explosives such as TNT or C-4, which are often used for demolition and demining purposes. This greatly improves ease of storage and transport as well as reducing transportation time and costs. All these systems can be transported via truck, vessel, and cargo aircraft. Pyropak, Pyro-Torch, FIXOR[®], PESCO HD Perforators, and SM-EOD shaped charges can also be transported via passenger aircraft and passenger rail.

In addition to cost considerations, care should be taken when selecting the proper mine neutralization system for a specific demining situation since using a system in a situation beyond its capacity can be ineffective or costly at best and dangerous or deadly at worst. Though all systems were easy to use, experience or training with any system is essential for optimal use. Once an appropriate system has been chosen for a particular demining situation, it is recommended that deminers gain experience with the system prior to attempting its use against live mine targets in order to ensure its safe and effective use. Such experience includes thorough training with a system, paying special attention to device positioning in relation to the target and optimal demolition charge or device requirements for effective mine neutralization.

All mine neutralization systems evaluated in this report were successful in their ability to neutralize antipersonnel and antitank mines. When the systems are used properly, they are an effective, cost efficient alternative to traditional 1.1D explosives such as C-4 or TNT when neutralizing surface laid or surface buried landmines. However, all presented limitations in target set applicability, transportation restrictions, or cost. Given the right target set, any one of the systems evaluated during this test could do the job and be used with confidence by humanitarian deminers, military, and explosive ordnance disposal personnel.

1 INTRODUCTION

1.1 Background

During the Fiscal Year 2003 Humanitarian Demining Research and Development Program Requirements Refinement Workshop, expert deminers expressed a need for a cost-benefit and performance analysis for currently available deflagration (burning) and high-order (non-explosive binary mixture) mine neutralization systems, which carry fewer shipping restrictions compared with tradition explosives commonly used for mine neutralization. In response to this request, the U.S. Army Communications-Electronics Command (CECOM) Acquisition Center-Washington, D.C., published a Federal Business Opportunities (FBO) (formerly Commerce Business Daily) announcement (solicitation number W909MY-04-T-0003) on 21 January 2004 on behalf of the Communications-Electronics Research, Development and Engineering Command (CERDEC), Night Vision and Electronic Sensors Directorate (NVESD), Countermine Division, Humanitarian Demining Branch, stating that the government was seeking sources for nondevelopmental, high-order or deflagration mine neutralization systems suitable for use in humanitarian demining operations. U.S. and foreign companies responded to this FBO announcement. In addition to mature, nondevelopmental systems, three developmental systems were submitted for consideration. These newer systems were deemed promising enough to be evaluated for their demining potential. A description of these devices and a summary of test findings are included in Appendix B. Of the mature, nondevelopmental systems submitted for consideration, 6 deflagration systems, which included 7 different devices, and 7 high-order systems, which included 11 different devices, were selected for further evaluation. Although the original intent had been to evaluate only non-explosive binary mixtures for high-order neutralization, two of the seven high-order systems used RDX-propelled shaped charges.

A capability demonstration of these deflagration and high-order systems was conducted at a government test facility during the August to October 2004 time frame. This demonstration evaluated only hand-held systems. The results of this mine neutralization capabilities demonstration are the subject of this report.

1.2 Objective

The mine neutralization tests had these main objectives:

- Test deflagration and high-order mine neutralization systems developed for humanitarian demining to determine if items functioned as advertised and to test effectiveness against common targets.
- Evaluate the neutralization performance of each system.
- Present human factors considerations, transportation and storage information, and cost.

2 SYSTEM DESCRIPTIONS

2.1 General

Mine neutralization systems evaluated during testing fell into two general classes: deflagration, resulting in vigorous burning or low order detonation of a mine, and high-order detonation.

Deflagration is achieved when propellant, thermite, pyrotechnic, or solid reactive materials penetrate a mine's case and burn the mine's main explosive charge. All deflagration systems neutralize mines by burning the explosive inside until the mine is rendered nonfunctional, leaving an empty metal case when used against metal case mines. Many deflagration technologies are similar to that used in signal flares but produce higher temperatures—from 1,500 °C to 3,900 °C (2,732 °F to 7,052 °F)—depending on the type of material used. These humanitarian demining flare- or torch-type devices can be used with or without stands, but when used without a stand, weight at the back is required. Some deflagration systems have built-in ignition systems and some require an electric match, time fuse, or igniting cord. During testing all deflagration systems were remotely ignited using electrical wires and demolition devices.

The second class of systems tested consisted of high-order detonation technologies subdivided into two main classes: those being non-explosive when shipped and those being explosive when shipped.

The non-explosive systems are divided into three classes: single liquid with a liquid sensitizer, liquid mixed with an inert solid sensitizer, and two liquids mixed and dispensed as a foam. All these non-explosive systems become explosive after they are mixed. Except for foam systems, these binary systems require some sort of a container such as a plastic bag or plastic bottle. Once filled, the container is placed next to the mine and is usually initiated with a #6 or #8 blasting cap. Mine neutralization occurs when the pressure and impulse from the neutralizing device's explosion causes the main charge of the mine to explode.

The explosive systems are divided into two classes: pure explosives such as C-4 or TNT blocks and explosive devices such as a shaped charge. Both systems neutralize mines by causing high-order detonation using an electric cap, blasting cap, or detonating cord as an initiator. Deminers generally use C-4 to neutralize mines. Because pure explosives are already in widespread use, this test did not explore this neutralizing technique further. Instead, this test focused on the demining capabilities of two shaped-charge devices with fixed explosive and one shaped charge using a binary explosive mixture.

In the following system descriptions, photographs illustrate system size and placement (standoff, angle of attack, orientation) in relation to mine targets. For safety reasons, photographs were often taken prior to target burial and fuzing (in the case of deflagration devices) or setup of initiation methods (for high-order devices).

2.1.1 Deflagration System Descriptions

Table 1: Deflagration Systems

System	Device Type	Chemical Comp	Packaging
FireAnt[®]	Flare	Pyrotechnic Mixture, Metal	Cardboard Tube
Hyperheat[®]	Flare	Pyrotechnic Mixture, Metal	Phenolic Cardboard Tube
Propellant Torch System	Torch	Propellant Mixture, Metal	Phenolic Cardboard Tube
Pyropak	Hot Liquid	Coated Thermite Mixture	Polypropylene Bag
Pyro-Torch	Torch	Intermetallic Reactive Metal	Phenolic Cardboard Tube
Thiokol Demining Flare[™]	Flare	Propellant Mixture, Metal	Phenolic Cardboard Tube

2.1.1.1 FireAnt[®]

FireAnt[®] is a deflagration device containing 80 g of a pyrotechnic mixture (aluminum, barium nitrate and polyvinyl chloride [PVC]) enclosed in a cardboard case. Its cylindrical casing is 9.33 in. (23.70 cm) long and has a diameter of 1.53 in. (3.89 cm). With a burn time of 23–24 seconds, the flame reaches 1,500 °C (2,732 °F). FireAnt[®] is ignited by a built-in electric match and can penetrate steel plates up to 1/16 in. (1.5 mm) in thickness. The FireAnt[®] performed well against exposed plastic and thin metal case antipersonnel (AP) and antitank (AT) mines. However, it proved ineffective against thick, hard case, bounding fragmentation mines. The system should be placed between 0.6 in. (1.5 cm) and 1.2 in. (3 cm) from the mine.



Figure 1: FireAnt[®] against VS-50 Antipersonnel and TMRP-6 Antitank Mine Targets

2.1.1.2 Hyperheat[®] Mine Flare

The Hyperheat[®] Mine Flare is a self-contained flare device used for *in situ* landmine neutralization by means of incineration. This deflagration device may be placed on the ground or vertically mounted with the torch end close to the target. Flare ignition is started by an electric match activated remotely by a low current, allowing for a safe standoff distance.

Each Hyperheat[®] Mine Flare has an embedded primer and a clip-on electric match. Each measures 1.65 in. (4.19 cm) in diameter by 7.75 in. (19.69 cm) long, and weighs 312 g. The flare mixture consists of 250 g of a solid non-explosive flare mix with a resin binder,

housed in phenolic tubing sealed for water resistance. Flares burn at approximately 2,200 °C (4,000 °F) for 65–75 seconds.

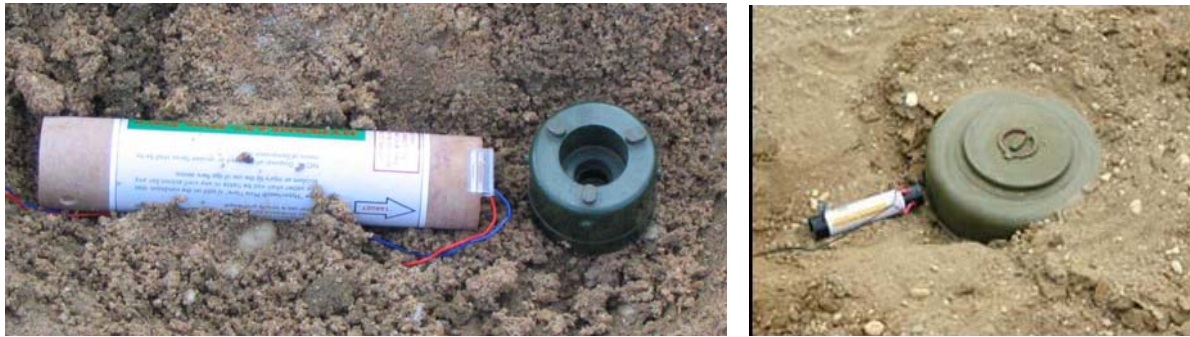


Figure 2: HyperHeat[®] Mine Flare against T-AB-1 Antipersonnel and Round Antitank Mine Targets

2.1.1.3 Propellant Torch System

The Propellant Torch System, which was designed and developed at Applied Research Associates Inc., consists of a propellant formulation in a strong, heat-resistant casing. Once ignited, a jet of hot product exits the torch nozzle; penetrates the mine's casing; and initiates a self-sustained, low-order burning in the mine's main explosive charge. Two variations of the torch were provided to neutralize both thin- and hard-cased mines. The torch for thin-cased mines is designated PT-3 and the torch for hard-cased mines is designated PT-12.

The Propellant Torch is placed at an appropriate standoff and angle relative to the mine, then ignited using an ignition device at the torch opening. The ignition device consists of an electric match attached to a quick-match fuse inserted in the torch nozzle. When the flare is in a downward angle, care must be taken to insure that the quick match doesn't fall out.

The Propellant Torch has proven to be effective in preliminary tests against actual and surrogate mines encased in wood, plastic, or up to 0.5 in. (12.7 mm) of steel.



Figure 3: PT-3 against SPM-1 Antipersonnel and TM-46 Antitank Mine Targets



Figure 4: PT-12 against Valmara-69 Antipersonnel and Round Antitank Mine Targets

2.1.1.4 Pyropak

The Pyropak System consists of a 400 g thermite charge packaged in a non-woven polypropylene bag, which melts during initial reaction into small solid droplets without burning and exposes the thermite powder to the target. The thermite mixture is a dry powder in a miniature pelletized form called “prill” that is coated for water resistance. This prill format allows for the alteration of charge size as required by the user.

The igniter system consists of a pyrotechnic igniter mixture in a pill format or deposited onto a wire. Normal slow-speed igniter cord is used for ignition of either the pill or the coated wire. The igniter cord is wrapped around the coated wire or placed through the hole in the pill and knotted. For this test, commercially available sparklers wrapped with igniting cord were used as igniters in lieu of the igniter pill or coated wire.

The thermite charge is generally placed directly on top of the target or where the container material is the thinnest and at the farthest point from the detonator train. The reason for this is that the molten thermite liquid with a temperature in excess of 3,000 °C (5,432 °F) has a downward action and will burn quickest through the thinnest parts of the case. The explosive is then ignited and will burn at its own rate at a temperature from 2,000–2,500 °C (3,632–4,532 °F). By the time the burning reaches the detonation train, a large proportion of the explosive has already been destroyed. If the detonator is then initiated, the resulting explosion will be much smaller than it would have been with the total explosive mass.

Pyropak thermite applicators have been shown to be effective against metal, plastic and bakelite containers and ineffective against wooden containers. Pyropaks have been used successfully in hot, humid, light rain, and windy conditions. They can only be ignited with a flame temperature of 800–1,200 °C (1,472–2,192 °F) or higher and a contact time of at least 3

seconds (at approximately 1,200 °C [2,192 °F]), depending on the igniter temperature and weather conditions.



Figure 5: Pyropaks and Igniter Systems



Figure 6: Pyropak against T-AB-1 Antipersonnel and TMRP-6 Antitank Mine Targets

2.1.1.5 Pyro-Torch System

General Sciences, Inc. (GSI) developed an intermetallic torch—the Pyro-Torch System—to cut through steel rebar, plates, and pipes. It is now being investigated for use against landmines of various configurations, including plastic and thermoplastic AP mines, large metallic AT mines, and thick-walled stake mines. The Pyro-Torch System consists of a GSI proprietary intermetallic energetic material in the form of a cartridge capable of defeating 0.5 in. (1.27 cm) rebar and steel plates in 3–4 seconds. The device is ignited using a squib and produces a high-temperature-liquid intermetallic flame capable of burning through metal.

For neutralizing mines, the Pyro-Torch System device is placed next to the landmine and ignited. The cartridge, containing 300 g of reactive material, burns for 10–15 seconds. Once the mine case is penetrated, the explosive material is burned.



Figure 7: Pyro-Torch System



Figure 8: Pyro-Torch against an SPM-1 Antipersonnel Mine Target



Figure 9: Pyro-Torch against a TM-46 Antitank Mine Target

2.1.1.6 Thiokol Demining Flare™

The Thiokol Demining Flare™ is a mine deflagration system created from surplus solid propellant rocket fuel manufactured by Thiokol for the Space Shuttle program. It neutralizes mines by quickly burning through the casing and igniting the explosive fill without causing a detonation. The average temperature of its flame is in excess of 1,927 °C (3,500 °F), with a burn time of approximately 70 seconds. The cylinder measures 5 in. (12.7 cm) long and 1 in. (2.54 cm) in diameter, with a 1 in. (2.54 cm) deep hole in the front. The flare's propellant is encased in high-temperature plastic and cardboard. The flare is initiated by an electric

match, time fuse, or igniting cord. The flare is set up on a stand or placed directly on the ground with a half-pound weight on it at the rear.

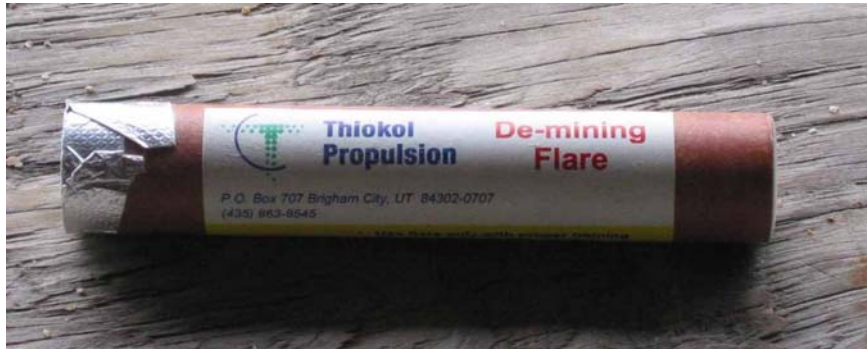


Figure 10: Thiokol Demining Flare™



Figure 11: Thiokol Demining Flare™ against an SPM-1 Antipersonnel Mine Target



Figure 12: Thiokol Demining Flare™ against a TMRP-6 Antitank Mine Target

2.1.2 High-Order System Descriptions

High-order systems are formulated from a variety of substances: solids, liquids, solid-liquid mixtures, liquid-liquid mixtures, and solid-solid-liquid mixtures. Each binary system requires premixing before it can be used. A solid plastic container such as a bottle or a flexible plastic container may be used to contain the final system mixture before its application. In the case of foams, such as NMX-foam™, no container is needed as the final mixture is combined as it is applied to the mine. Because of the system-specific requirements of each high-order device, operators should take time to understand each system before using it.

Table 2: High-Order Systems

System		Device Type	Chemical Comp	Delivery Package
FIXOR®		Binary Explosive (liquid/solid)	Nitroethane and Microbead Powder	HDPE Bottle
HELIX		Binary Explosive (liquid/solid) Shaped Charge	Nitromethane and Aluminum Powder	PVC/Copper Shaped Charge
Kinepak™				
	Kinepouch™	Binary Explosive (liquid/solid)	Nitromethane and Ammonium Nitrate	Foil Pouch
	Kinestik™	Binary Explosive (liquid/solid)	Nitromethane and Ammonium Nitrate	Plastic Bottle
Liquid Explosive Pouch		Binary Explosive (liquid/liquid)	Nitromethane and Diethylenetriamine sensitizer	Flexible HDPE Pouch
NMX-foam™		Binary Explosive (liquid/liquid)	Nitromethane and Hydrocarbons Propellant	None or PVC Tube
PESCO				
	HD 11 g Perforator and HD 22 g Perforator	Fixed Explosive Shaped Charge	RDX	Rubber Jacket with Copper Liner
SM-EOD				
	20 and 33	Fixed Explosive Shaped Charge	RDX	Sealed Plastic Case with Copper Liner

2.1.2.1 FIXOR®

FIXOR® (Field-friendly, Incexpensive, uneXploded Ordnance Remover) is composed of two components contained in high-density polyethylene (HDPE) plastic bottles. One bottle contains FIXOR® flammable liquid, and the other contains FIXOR® inert powder. The liquid is poured into the bottle containing the FIXOR® powder. Once shaken, the mixture becomes a detonator-sensitive 1.1D high explosive that is equivalent to 85% of TNT by weight (as determined by air-blast tests reported by the manufacturer). If FIXOR® components or explosive are spilled, they are not harmful to the deminer or the environment. Unlike ammonium-nitrate-based two-component explosives and traditional explosives, the FIXOR® explosive self-neutralizes after a period of time, becoming a non-explosive. FIXOR® has proven effective against a wide variety of mines and unexploded ordnance, is easily and safely deployable by indigenous deminers, requires no ongoing field technical support, and is fully functional under all demining weather conditions.

Note that because mixing must be done by shaking, an air gap is present in the top of every bottle of FIXOR[®] mixture. If a blasting cap or detonating cord knot were placed within this air gap, a misfire might occur. This air gap may be of little concern for an experienced explosive ordnance disposal (EOD) technician familiar with the requirements of initiating mediums; however, it could present a problem for minimally trained deminers. Because the testing was to replicate in-field situations, the company representative decided to eliminate this air gap, thereby reducing the potential for a misfire when used by minimally trained deminers. To remedy the situation, 1.25 bottles of FIXOR[®] mixture were used in each bottle. That is, five bottles were mixed, and one bottle's contents was divided among the remaining four bottles. The 1.25 mixture bottles were used throughout testing. This configuration is also recommended for in-field use.



Figure 13: FIXOR[®] against VS-50 Antipersonnel and TMRP-6 Antitank Mine Targets

2.1.2.2 HELIX

HELIX (High Energy Liquid eXplosive) is a patent pending binary explosive compound with a mixing time of less than 1 minute. The blast velocity produced is 20,600 feet per second (ft/s) (6,290 meters per second [m/s]). The container is made of PVC plastic and contains no ferrous parts. The liner is made of powdered or stamped metal, primarily copper. The shaped charge will penetrate up to 4 in. of mild steel. After placing the explosive-filled container next to the landmine, HELIX is initiated using any standard blasting cap placed in the specially designed holder in the top of the container or by a detonating cord inserted into the blasting cap holder.

To activate HELIX, the liquid component is poured into the black HDPE bottle containing the activator powder until the bottle is half full or the powder floats to the top. Once the cap is secure, the bottle is shaken vigorously until the powder is completely distributed throughout the liquid. The cap is removed and more liquid is poured in until the bottle is full up to the neck. The cap is replaced and the bottle is shaken briefly, making HELIX active. Once active, the liquid is poured into the shaped-charge container for use against mine targets. The liquid can also be used as a demolition device in its HDPE packaging bottle; however, this configuration was not tested.



Figure 14: HELIX against PMD-6 Antipersonnel and TMRP-6 Antitank Mine Targets

2.1.2.3 Kinepak™ (Kinepouch™ and Kinestik™)

Kinepak™ is a commercially available binary explosive currently being used to support State Department and United Nations (UN) sponsored demining operations around the world. EOD technicians use the product as a bulk explosive for high-order destruction of different types of mines and munitions. The binary system uses two chemical components, a solid and a liquid, that are mixed before use. When the binary mixture is placed in a 1-pound foil bag, it is known as Kinepouch™; when placed in a 1/3-, 1/2-, or 1-pound cylindrical plastic tube, it is known as Kinestik™. Before mixing, the components are non-explosive. Once mixed, they become a 1.1D high explosive with a detonating velocity of 20,100 ft/s (6,126.5 m/s) for Kinepouch™ and 21,500 ft/s (6,553.2 m/s) for Kinestik™. A Material Safety Data Sheet and Department of Transportation Competent Authority Letter are available upon request.



Figure 15: Kinepak™ System Components Before Mixing



Figure 16: Kinepouch™ against VS-50 Antipersonnel and TMD-44 Antitank Mine Targets



Figure 17: Kinestik™ against T-AB-1 Antipersonnel and Round Antitank Mine Targets

2.1.2.4 Liquid Explosive Pouch

Liquid Explosive Pouch is a hand-held, binary-explosive system consisting of flexible plastic pouches and two commercial, non-explosive liquid chemicals: Nitromethane and an amine sensitizer, diethylenetriamine (DETA). Nitromethane becomes an explosive only after it has been “sensitized” by the addition of the DETA. A dye indicator included in the nitromethane changes to purple when the nitromethane is sensitized, creating a positive visual warning that the liquid mixture is an explosive. The explosive liquid mixture is equivalent to TNT on a weight basis; it has a detonation velocity of 20,997.4 ft/s (6,400 m/s) at 13 gigapascals (130 kilobars) of pressure.

For field operations the nitromethane is dispensed from standard 55-gallon steel drums into 5-gallon HDPE plastic containers with an attached assembly for filling flexible HDPE pouches. Each pouch is fitted with a leak-proof, screw-on HDPE cap. Initiation is achieved by taping a No. 8 or equivalent blasting cap to the outside of the pouch next to the binary-liquid fill.

Before filling the pouch with nitromethane, a metered amount of sensitizer (DETA) is injected into the flexible pouch with a plastic syringe. DETA is supplied in 1-, 4- and 20-liter containers or in bulk 55-gallon drums.

Pouches can be manufactured in a variety of shapes and sizes for general or specific types of applications. Some pouches can be designed to bend around the contours of ordnance items to create a “lens” effect, or they can be used in pairs to create “ear muff” configurations. For most applications a standard 1-pound, tube-shaped pouch is normally employed. For this test, 1/2-pound and 1-pound charges were used.



Figure 18: HDPE Pouches for Liquid Explosive Pouch System



Figure 19: Liquid Explosive Pouch 1/2-pound Charges against T-AB-1 Antipersonnel and Round Antitank Mine Targets

2.1.2.5 NMX-foam™

NMX-foam™ (NitroMethane explosive foam) is formulated from nitromethane stock solution (nitromethane, surfactants, and silica powder) and a mixture of hydrocarbons (propane and isobutane), which form the propellant. The delivery system consists of 505 g

(± 5 g) of nitromethane stock solution in a disposable aerosol can and a second, smaller container containing approximately 50 g of the propellant. Separately, both components are classified as flammable liquids for transportation and storage purposes.

To neutralize a mine using NMX-foam™, a deminer would inject the propellant into the nitromethane stock container (see Figure 20), mix the two components by shaking the container, and then spray the foam onto the explosive (main charge) portion of the mine. When this mixture is exposed to the atmosphere, the liquid propellant expands to a gas, producing foam with a physical consistency of shaving cream. Only after foaming is a highly effective explosive produced. The mine is neutralized when the pressure and impulse of the exploding foam—initiated remotely by an electric cap or a detonating cord—causes the main charge of the mine to explode.

NMX-foam™ is able to make continuous contact with uneven and rounded surfaces and can be more efficiently placed for neutralization than solid blocks of explosives. It also simplifies the placement of the neutralizer on above-ground and awkwardly placed ordnance.



Figure 20: NMX-foam™ Containers and Mixing



Figure 21: NMX-foam™ applied to a VS-50 Antipersonnel Mine Target

2.1.2.6 PESCO Humanitarian Demining Perforators

The PESCO 11 g and 22 g standard oil well perforators were customized for humanitarian demining application and unexploded ordnance range remediation operations. The innovative design of the PESCO HD 11 g Perforator and the PESCO HD 22 g Perforator allows for initiation without detonating cord, using direct initiation by an M-6 electric detonator or an M-7 non-electric detonator. Detonating velocity is 25,000 ft/s. The customized rubber jacket also provides built in standoff to maximize the effects of the jet. It is effective when attacking individual targets ranging from small AP mines to Mk 82 bombs. This product is currently being used to support State Department and UN sponsored demining operations around the world. The 11 g charge is typically used when destroying munitions up to 155 mm. The 22 g charge is used for special applications or destruction of munitions above 155 mm.



Figure 22: PESCO Humanitarian Demining Perforator

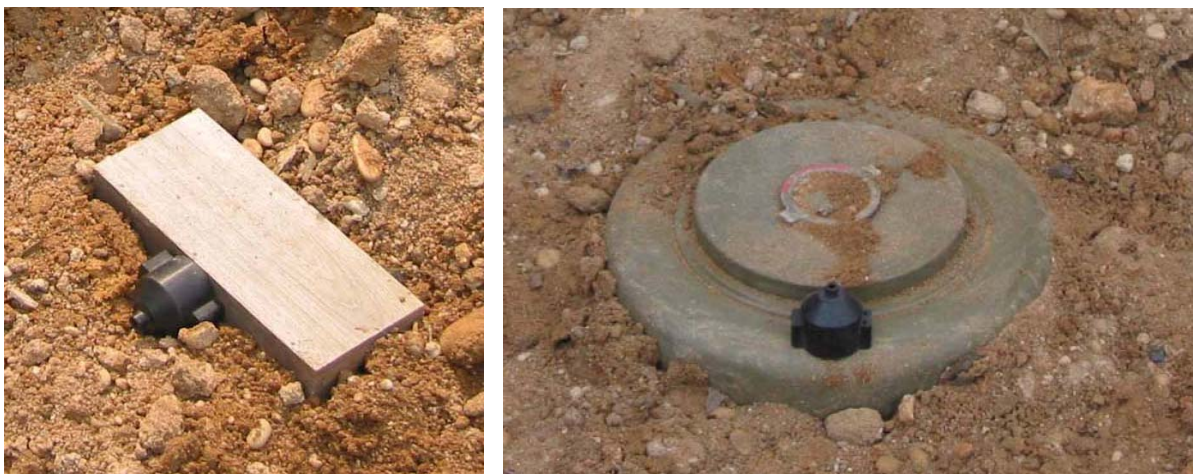


Figure 23: PESCO HD 11 g Perforator against PMD-6 Antipersonnel and Round Antitank Mine Targets



Figure 24: PESCO HD 22 g Perforator against a TM-46 Antitank Mine Target

2.1.2.7 SM-EOD 20 and SM-EOD 33

ATK Ordnance and Ground Systems LLC, in conjunction with its partner RUAG Munitions, produce the SM-EOD family of explosive ordnance disposal systems for disposal of all types of mines and unexploded ordnance. SM-EOD shaped charges demonstrate a high degree of accuracy over their entire temperature range. The SM-EOD explosive charges, consisting of RDX, wax, and graphite, can be initiated either electrically or pyrotechnically (time fuse with a No. 8 or equivalent blasting cap) but cannot be initiated with detonation cord or shock tube. The SM-EOD System is offered with a range of mounting fixtures to permit use in virtually all terrain conditions. Waterproof, the devices can be used in all weather conditions and under water. The SM-EODs were developed, manufactured, and qualified in accordance with MIL and NATO standards and are available in six calibers. The two calibers used during testing were SM-EOD 20 and SM-EOD 33.



Figure 25: SM-EOD System Setup (33 above, 20 below)

SM-EOD 20 (NATO Stock Number 1375-13-117-6273) was designed for the destruction of AP and AT mines and unexploded ordnance. It can also be used for low-order disposal.



Figure 26: SM-EOD 20 against SPM-1 Antipersonnel and Round Antitank Mine Targets

SM-EOD 33 (NATO Stock Number 1375-13-117-6274) is used for the disposal of visible mines and unexploded ordnance, those covered with soil (up to 6.69 in. or 170 mm) or snow, or those under water to depths of 262 ft (80 m).



Figure 27: SM-EOD 33 against Antipersonnel Bounding Mine and TMRP-6 Antitank Mine Targets

3 TEST DESCRIPTION, PROCEDURES, AND RESULTS

3.1 Test Site and Testing Equipment

3.1.1 Test Environment

Mine neutralization tests were conducted in a demolition pit at a government test facility. The soil is predominantly sand with some gravel, clay, and loam. The pit is approximately 350 m × 350 m. Temperatures ranged from a high of 33 °C (92 °F) in August to a low of 14 °C (57 °F) in October.

Figure 28: Demolition Pit



3.1.2 Testing Supplies

In addition to test targets, 600 m of electrical wire, two demolition devices, C-4 blocks, TNT blocks, electric caps (blasting caps), mechanical caps, detonating cord, igniting cord, electric matches, time fuses, and shock tubes were available for use.

3.1.3 Test Targets

3.1.3.1 Metal Plates

Metal plates were used to determine penetrating capability. Steel plates, all measuring 10 cm × 10 cm, and 1.1, 1.5, 3.2, 6.5, 12, or 24 mm (3/64, 1/16, 1/8, 1/4, 1/2, or 1 in.) thick were used. To yield a plate thickness of 2.2 mm (3/32 in.), two 1.1 mm (3/64 in.) thick plates were stacked. To yield a plate thickness of 48 mm (2 in.), two 24 mm (1 in.) thick plates were stacked.

3.1.3.2 Antipersonnel Mines

AP mine cases are made from metal, plastic, or wood. There are four types of AP mines: simple blast mines, directional mines, bounding fragmentation mines, and fragmentation stake mines.

- **Metal Case Blast Mine:** Because there is no single simple blast mine that has a metal case, testing against this mine type was not possible.
- **Plastic Case Blast Mine:** Plastic case AP blast mines may be constructed from Bakelite, thermoplastic or polystyrene. They also may have explosive charges such as TNT, RDX, Comp. B, Pentolite, Tetryl, or Triallene. Nearly all plastic-case blast mines contain solid explosive but a few contain liquid explosive. Plastic-case blast mines may be circular, cylindrical, spherical, rectangular, or irregular in shape. Most mines have a circular or cylindrical shape. All plastic AP blast mines contain one fuze, but its location varies; mines may have a fuze in the center, in the bottom, or in the side. Some plastic case mines are also blast resistant.
- **Wooden Case Blast Mine:** These are the simplest of all mines. All wood case AP blast mines are rectangular boxes having two basic parts, upper and lower, which are connected by a hinge. The lower part contains a TNT explosive charge and a fuze. A wood case mine may contain between 75 g and 200 g of TNT, and the size of the box will vary with the amount of explosive. As wood case mines are exposed to the elements over time, the wood case may retain moisture and undergo other structural changes. These differences, when compared to fresh wood, can greatly increase the difficulty of neutralization by deflagration. To simulate real-world conditions, wood cases were aged outdoors for several months before being used as mine targets. Explosives were placed in the aged mine case on the day of testing.
- **Directional Mine:** These mines use a shaped charge to disperse steel ball fragments in a fan-shaped arc. Most directional mines have plastic casing except for Russian metal mines such as MON-50, MON-100, and MON-200, which have two cases, one inside the other.
- **Bounding Fragmentation Mine:** Most bounding fragmentation mines are made from heavy steel, but some are made from plastic. The internal body of the mine consists of the main charge (more than a pound of explosive, which is generally TNT, but in a few cases is Comp. B), surrounded by more than 500 steel splinters, the booster, and the striker mechanism. It has a combination mine fuze, usually cylindrical, which screws into the center. The fuze can be initiated by tripwire or by pressure. These mines are usually buried with only the fuze mechanism or prongs exposed above the surface. A few varieties of this mine are designed so that they can be used above ground on a metal stake.
- **Fragmentation Stake Mine:** Stake mines (also called picket mines) are typically placed 12 in. (30 cm) to 20 in. (50 cm) above the ground on a wood or metal stake. They are normally activated with metal tripwires. Most of these mines have thick,

cast-iron casings containing a main charge of about 75 g of TNT. When activated they send iron fragments in all directions. They can potentially kill any person within a 4-meter radius and cause serious injury at greater distances. Since no actual fragmentation stake mines were available for use during testing, NVESD machined smooth (non-serrated), steel-case surrogates. Unless the surrogate fragmentation stake mine target was neutralized, the machined surrogates were used for the purpose of measuring the depth of burning penetration for deflagration systems or damage to the mine target for high-order systems and were not included in a system's performance analysis.

Table 3 contains information about AP mine targets used during testing.

Table 3: Antipersonnel Mine Targets

Mine Type	Case	Designation	Main Charge	Expl. Amt.	Fuze Type	No. of Fuzes	Country
Blast	Plastic	RAPM ¹	Tetryl	29 g	Pressure	1	USA
		PMN	TNT	240 g	Pressure	1	USSR
		SPM-1	Triallene	80 g	Integral Pressure	1	Ecuador
		T-AB-1*	Pentolite 50/50	62 g	Pressure	1	Brazil
		VS-50 ^{2*}	RDX	43 g	Pressure	1	Italy
	Wood	PMD-6 ³	TNT	225 g	Electric cap	1	USSR
Directional	Metal	MON-100	TNT	2,000 g	Electric cap	1	USSR
Bounding	Metal	APBM ⁴	TNT	521 g	Tripwire or Pull	1	USA
	Plastic	Valmara 69 ⁵	Comp B	420 g	Tripwire or Pull	1	Italy
Fragmentation	Metal	Stake ⁶	TNT	225 g	Electric cap	1	

*Blast resistant.

¹Not true designation—stands for round AP mine.

²Casing contains some rubber.

³Surrogate.

⁴Not true designation—stands for AP bounding mine.

⁵Outer casing is plastic, inner casing is metal.

⁶Surrogate for USSR's POMZ-2.

3.1.3.3 Antitank Mines

Three types of AT mines (metal, plastic and wooden) were used during testing. AT mines generally contain TNT, RDX, Comp. B, or H-6 composition as a main explosive charge, with the amount of explosive varying from 10 to 25 pounds (4.5 to 11.3 kg). An AT mine has between one and four fuzes. Some mines have a single fuze located in the center of the mine. Some have two fuzes, one located in the center and the other located on the side, and some have three or four fuzes located on the top surface of the mine. During testing, only single-fuze AT mine targets were used except for the TMRP-6, which has two fuzes.

Because wood case mines are exposed to the elements over time, the wood case may retain moisture and undergo other structural changes. These differences, when compared with

fresh wood, can greatly increase the difficulty of neutralization by deflagration. To simulate this real-world condition, wood cases were aged outdoors for several months before being used as mine targets. Explosives were placed in the aged mine case on the day of testing.

Table 4 contains information about AT mine targets used during testing.

Table 4: Antitank Mine Targets

Case	Mine Type	Designation	Main Charge	Expl. Amt.	Fuze Type	No. of Fuzes	Country
Metal	Blast	RATM ¹	Comp B	10.3 kg	M603 Plug	1	USA
		TM-46	TNT	5.7 kg	MVM Pressure	1	USSR
	Shaped Charge	ATSC ²	H-6	4.9 kg	M607 Pressure	1	USA
Plastic	Blast	SATM ³	Comp B	9.53 kg	M606	1	USA
		TMA-5	TNT	5.5 kg	VANO-1 Pressure	1	Yugoslavia
	Shaped Charge	TMRP-6 ⁴	TNT	5.1 kg	Pressure	2	Yugoslavia
	Scatterable	VS2.2	Comp B	2.2 kg	VS-N	1	Italy
Wood	Blast	TMD-44 ⁵	TNT	2.3 kg	Electric cap	1	USSR

¹Not true designation—stands for round AT mine.

²Not true designation—stands for AT mine with shaped charge warhead.

³Not true designation—stands for square AT mine.

⁴Tilt rod mine with magnetic fuze, but no rod or magnetic fuze was used.

⁵Surrogate.

3.1.3.4 Artillery Shells

Although the test was primarily concerned with a demining device's ability to neutralize landmines, manufacturers suggested that several of the devices were suitable for use against unexploded ordnance. In those instances, these claims were verified during the course of this capabilities demonstration against artillery shell targets. Table 5 contains information about the artillery shell targets.

Table 5: Artillery Shell Targets

Designation	Case	Main Charge	Expl. Amt.	No. of Fuzes	Country
105 mm HE	Metal	Comp B	3.9 kg	Multiple	USA
155 mm HE	Metal	Comp B	7.1 kg	Multiple	USA

3.2 Deflagration System Testing and Results

3.2.1 Preliminary Test Procedures and Results for Deflagration Systems

Preliminary tests were conducted to gain information that would aid in target selection and test setup during the mine neutralization test.

3.2.1.1 Thrust Measurements

The purpose of this measurement was to determine if a stand or weight is necessary to anchor a deflagration device during use. Because Pyropak contains no propellant, it was not included in this test.

To measure thrust for each of the deflagration systems, one device representing each deflagration system was placed on flat ground without the use of a stand. A line was drawn in the soil to mark its starting position, then the system was ignited. Once ignition stopped, the distance that the device had moved was measured and recorded. Because of previous experience with the PT-3 and PT-12 devices, as a safety measure, a 50-ft (15 m) length of flexible wire was affixed to the end of each device, and the other end was tied to a metal rod, anchoring it in the soil.

Table 6: Thrust Measurements

System	Movement
FireAnt[®]	1 ft (30 cm)
Hyperheat[®]	0
PT-3	3 ft 3 in. (1 m)
PT-12	Unknown*
Pyro-Torch	4 ft 11in. (1.5 m)
Thiokol Demining Flare[™]	3 in. (8 cm)

*Device moved in all directions on ground and in air up to an approximate height of 3 feet.

Based on the results of the test shown in Table 6, only Hyperheat[®] does not require some type of anchoring device. It is clear that some systems possess more potential for movement than others. While it appears that some weight or restraint is required for each system, the weight or restraint would vary. For testing purposes, it was determined that approximately 1 to 2 pounds would be sufficient for all systems that required anchoring except for PT-12, which was tested using a weighted stand. The weighted stand was equipped with an 8-pound weight.

During testing, Hyperheat[®] and Pyropak were not weighted; all others were weighted appropriately. Since testing was to resemble field conditions as closely as possible, except for those for the weighted stands, the weights used were materials locally available such as stones or 4 in. × 4 in. (10 cm × 10 cm) steel plates of varying thickness.

3.2.1.2 Burning Time Measurements

The test director determined that a device burning less than 15 seconds coupled with a penetrating capability of less than 2 mm would not be an ideal candidate to use against wood case mines or mines containing TNT, which is difficult to ignite.

The burning time of one device from each deflagration system was measured. Devices were secured to the ground by a stand or weight placed at the back of the device before they were ignited. Each device was ignited separately. Burn time, in conjunction with the plate penetration test results, would be used to determine appropriate mine targets for each device during the mine neutralization test.

While the device burned, in addition to timing the burn, notice was taken of the vigorousness of the burn and of any sound or smoke. These observations are included in the test results as a reference. For example, if a device creates a lot of smoke, the smoke may obscure viewing. Also, during a burn, a change in the color of the smoke can indicate the burning of casing or explosive materials.

Table 7: Burning Time Measurements

System	Burn Time (sec)	Burn Vigor	Noise	Smoke (amount and color)
FireAnt®	25	Fast	Yes	Moderate amount of white/pink
Hyperheat®	44	Fast	No	Large amount of white
PT-3	40	Vigorous	Yes	Moderate amount of white/pink
PT-12	28	Vigorous	Yes	Moderate amount of white/pink
Pyropak	74	Fast	No	Moderate amount of gray
Pyro-Torch	10	Fast	Yes	Small amount of tan
Thiokol Demining Flare™	61	Vigorous	Yes	Moderate amount of gray

As indicated by the above results, only Pyro-Torch had a burn time under 15 seconds, but because it proved to penetrate a 6.5 mm-thick steel plate (see plate penetration test results in Table 9), the test director determined that target selection would not be limited for any deflagration system tested based on burn time.

3.2.1.3 Plate Penetration Test

A mine's case material and thickness, fuze location, explosive content, mine shape, and mine type are all factors that must be considered when attempting to neutralize a mine by deflagration; however, a deflagration device must penetrate a mine's case to begin the burning process. Two factors affecting a device's ability to penetrate a mine's case are case material and thickness. Before testing, the test director determined that a device's ability to penetrate a steel plate would be useful for estimating what mine cases a device might successfully penetrate. Table 8 was constructed based on an understanding of the combined factors of case material and thickness in relation to successful steel-plate penetration. Since many mine cases are not constructed of steel, the steel-plate penetration test was not expected to yield an exact correlation to successful case penetration. An "X" in a column indicates that a successful steel-plate penetration may be indicative of a device's ability to penetrate the indicated target's case.

Table 8: Mine Targets for Deflagration Systems Determined by Plate Penetration

Target	Plate Thickness			
	1 mm	2 mm	3 mm	6 mm
AP Blast Plastic		X	X	X
AP Blast Wood		X	X	X
AP Bounding			X	X
AP Stake				X
AP Directional	X	X	X	X
AP Directional (USSR)		X	X	X
AT Metal	X	X	X	X
AT Plastic		X*	X	X
AT Wood			X [†]	X

*Bakelite

[†]Function of standoff distance and burning time.

Several devices from each deflagration system were tested for their penetrating capability against 4 in. × 4 in. (10 cm × 10 cm) steel plates that were 1.1, 1.5, 2.2, 3.2, 6.5, or 12 mm (3/64, 1/16, 3/32, 1/8, 1/4, or 1/2 in.) thick. Each plate was either inserted vertically into the ground, with 3/4 of the plate above the ground, or on a stand, depending on what was required for optimal positioning in relation to the device being tested. Each device was oriented (with or without a stand) horizontally and aimed at the center of the plate. Standoff distances were based on manufacturers' recommendations. Devices were ignited remotely.

Plate thickness for the first test of each system was determined by the test director based on past experience with the system (if any) and results reported by the manufacturer. If the device successfully penetrated the plate, it was then tested against the next higher plate thickness. This continued until the device failed to penetrate the plate or until it penetrated the thickest plate. Even though a 6 mm-plate penetration would be the maximum needed to determine target candidacy, 12 mm plates were used during this test at the request of the contractor.

Table 9: Plate Penetration Results for Deflagration Systems

System	Thickness in. (mm)					
	3/64 (1.1)	1/16 (1.5)	3/32 (2.2)*	1/8 (3.2)	1/4 (6.5)	1/2 (12)
FireAnt [®]	Yes	Yes		No		
Hyperheat [®]		Yes	Yes	No		
PT-3				Yes	Yes	
PT-12						Yes
Pyropak		No [†]		No [†]		
Pyro-Torch					Yes	No
Thiokol Demining Flare [™]	Yes	Yes		No		

*Two stacked 1.1 mm plates.

[†]Thermite flowed around the plate.

Based on the results of the plate penetration test and the information contained in Table 8, appropriate mine targets were chosen for each of the devices being tested. The test

director decided that all devices would be tested against TMD-44 wood case AT mines, however. Because these mine targets are surrogates built and aged at the test facility, preservation of the mine target inventory was not an issue. Since FireAnt[®], Hyperheat[®], and Pyropak would not be considered likely candidates for use against wood case AT mine targets based on plate penetration results, the results of the wood case AT mine tests would be for informational purposes only and would not be included in the systems' performance analyses. Since the Thiokol Demining Flare[™] had undergone earlier testing against wood case targets, the test director and Thiokol representative agreed that a repeat of this test was not necessary (see Section 3.2.3.6).

3.2.1.4 Ignition Methods Tests

Each system was tested using a variety of ignition methods unless the system had a built-in igniter or special igniting requirements. This test was used to verify or amend manufacturer's recommendations. Because of the inherent danger of testing using actual mines, this testing was done before testing the device against real mine targets. Devices were placed on a stand or on the ground (weighted, if necessary) before they were ignited. Each device was ignited separately.

In Table 10, a "Yes" means that the ignition method was successfully tested with the indicated system. All tests were successful; the table notes provide further details.

Table 10: Ignition Methods for Deflagration Systems

System	Time Fuse	Electric Match	Igniter Cord	Electric Charge
FireAnt [®]				Yes
Hyperheat [®]	Yes	Yes	Yes	
PT-3 ¹	Yes	Yes	Yes	
PT-12 ¹	Yes	Yes	Yes	
Pyropak ²			Yes	
Pyro-Torch	Yes ³	Yes	Yes ³	
Thiokol Demining Flare [™]	Yes ⁴	Yes ⁴	Yes	

¹Required manufacturer's "quick match."

²Required sparkler.

³Company-supplied wires to the "first fire" were not used.

⁴Not conducted during this test, but based upon previous experience of the test director.

3.2.2 Mine Neutralization Test Procedures for Deflagration Systems

The purpose of this test was to determine the extent each deflagration system was able to neutralize mines and whether neutralization was done through deflagration or detonation.

The mine targets were buried on the day of testing so that the top of the mine was nearly even with the ground surface and the top of the mine was exposed. All AP and AT mines were equipped with fuzes but were not armed. The fuzing was to simulate the most difficult circumstance a deminer might face when attempting to neutralize mines by deflagration.

Because of its considerable thrust, only PT-12 devices were used with a stand. All other devices were placed on the ground after carefully removing the soil from the side of the mine. Devices were then weighted down, as necessary, with locally available materials such as steel plates or rocks. This was done to simulate in-field conditions where available resources might be limited.

The standoff distance between the side of a mine and the device was suggested by the contractor or by the test director and based on product specifications or previous testing data. All devices were placed horizontally with a 0° angle of attack (with one noted exception), aiming off center at the side of the mine or as far away from the detonator as possible. If more than one device was used—as was the case against most AT mine targets—the devices were placed opposite each other unless another configuration was preferable due to the location of the fuze or fuzes. Each device was remotely ignited using any suitable ignition system. When two or more devices were used, ignition was simultaneous.

In general, a device was tested against AP mine targets and then against AT mine targets. Mine targets were selected based on a system's plate penetration performance.

Once a deflagration device is ignited, it ideally would penetrate the mine case and ignite the explosive. The burning of the mine depends upon several factors, such as amount of explosive, type of explosive, type of casing material, and the size of the opening in the case. The deflagration process may transition from burning to detonation if the fuze or main charge is initiated as a result of heat or pressure accumulation. Because of the intense heat created by the deflagration device in proximity to the detonator, mines with small cases frequently detonate.

One device from each deflagration system was used against each AP mine. In general, two devices from each deflagration system were used against each of three types of AT mine targets (metal, plastic, or wood). Two devices were used to reduce burning time of the explosive in the mine and to reduce the chances that the mine would detonate due to heat or pressure accumulation. Under certain circumstances, either one device or four devices were used against AT mines. For details about why these deviations occurred, refer to the test results in Section **Error! Reference source not found.** for FireAnt®, Section 3.2.3.3.2 for PT-12, and Section **Error! Reference source not found.** for Pyropak. Each system was tested against at least one of each AT mine type unless special circumstances arose during testing. These decisions were based on test performance and the availability of mine targets. For details about why two devices were not tested against all three AT mine types, refer to the test results in Section 3.2.3.3.2 for PT-12 and Section 3.2.3.6 for the Thiokol Demining Flare™.

During testing, the time from system ignition to flame extinction was measured; mines often continued to generate smoke beyond this point. If the mine detonated at any time during the trial, the time and type of detonation were noted. Each trial was classified as a high-order detonation, a partial high-order detonation, a low-order detonation, a deflagration, or a failure to burn.

The following criteria were used to evaluate the method by which a deflagration device neutralized a mine:

- High-Order Detonation—Mine exploded before or at the time of case penetration before any noticeable burning. A large crater (exact size dependent on the amount of explosive in a mine) was formed, and there were no recoverable mine components.
- Partial High-Order Detonation (or high order with partial filler)—After stable burning of the main explosive charge, or partial deflagration, all remaining explosive material was consumed during detonation, with mine remains blown out of their original place (with or without the presence of a crater). Only mine casing fragments remained.
- Low-Order Detonation—After most of the explosive charge had burned, the detonator fired, causing the mine components to break apart while igniting some or all of the remaining explosive material. Large case fragments were left behind; no functional fuze or booster remained inside the casing and the mine was not capable of operation. Some explosive material might have been present in or near the mine casing.
- Deflagration—The mine casing was penetrated, and the main charge explosive burned. This might have led to a nonviolent pressure rupture of the case. The mine case might have been split or largely opened, but most of the case was still present, and if any explosive material remained, it was within the case. During deflagration, the detonator may have fired, but did not result in a detonation. Deflagration may have transitioned to a simple burning, which is nonpropulsive and consumes the explosive and wood or plastic casing materials.

If a mine target did not detonate, once the mine stopped burning, the remains were observed to determine whether the explosive was completely or partially burned and whether the mine was neutralized. If the explosive did not burn, the trial was considered a failure even if the case was penetrated. If the detonator did not initiate during the burn, range safety personnel verified the range's safety before test personnel could observe the remains. Once observed, the mine target was cleared from the area to allow for further testing.

If a target detonation occurred, crater size was noted, as well as any explosive material residue.

3.2.3 Mine Neutralization Test Results of Deflagration Systems

The rate of success for each device was determined based on the number of mine neutralizations by high-order detonation, the number of neutralizations by deflagration, and the number of times a device failed to neutralize a mine.

Under ideal circumstances, a deflagration device neutralizes a mine by deflagration. However, especially in the case of AP mines, a burn may transition from deflagration to detonation. Since a low-order or partial high-order detonation occurs after some portion of the explosive material has already been consumed, it can be assumed that the explosion is of lower magnitude than a high-order detonation of the same mine type. As a result, the severity of possible injury or damage is lessened, even if only marginally. Based on this rationale, if a mine that detonated during testing was determined to be a partial high-order detonation or a low-order detonation, it was counted as a complete success equivalent to a neutralization by deflagration because the device neutralized the mine and lessened the danger when compared to a high-order detonation.

If a mine underwent a high-order detonation during testing, it was considered a partial success; the mine was neutralized, but with no reduction of blast magnitude compared with high-order neutralization techniques.

Crater measurements were used as confirmation that a detonation took place and as an indicator of how much damage may have occurred had the detonation taken place during in-field mine neutralization. Crater measurements are included in the individual deflagration systems' test results for informational purposes but were not used in evaluating mine neutralization performance.

3.2.3.1 FireAnt[®]

On 12 April 2000, FireAnt[®] was tested against mine targets under similar test conditions as those of the current test. It is important to include these prior test results as they clearly illustrate the increase in a neutralization system's effectiveness based solely on the application of experience gained by the system's user. The system underwent no changes between the two tests but the test director, who conducted both tests, gained experience that was useful in selecting standoff distances and device positioning with the greatest likelihood of successful neutralization by deflagration. As a result, the success rate increased during this test over that of the previous test (see discussion below). Because conditions and procedures were similar, the 12 April 2000 test results were included in this analysis to give a more accurate depiction of total test results for this system for purposes of comparison to other systems being tested for the first time.

During the current test, FireAnt[®] was tested against 5 AP mines, 2 AT mines, and 1 TMD-44 wood case AT mine, which is included in Table 11 for informational purposes (see Section 3.2.1.3) but is not included in the system's performance analysis.

FireAnt[®] neutralized all the mines in this test, resulting in a 100% success rate for both AP and AT mine targets. However, since one of the AP mines underwent a high-order detonation, it can only be considered a partial success. As a result, 80% of AP mines were neutralized by deflagration.

During the current test, detonators were initiated in 7 mine targets, including the 2 mines that detonated. In one instance, a small amount of unreacted explosive material was

expelled from the case when the detonator initiated. Another mine's casing was found in two parts. Three mines continued to burn after the detonator initiated; four mines ceased to burn.

Table 11: FireAnt[®] Current Test Results

Mine Type	Mine Designation	No. of Devices	Standoff (cm)	Time min:sec	Neutralized	Detonated	Crater d × w* (in)
AP	RAPM	1	2	0:16	Yes	High Order	†
	SPM-1	1	4	5:32	Yes	No	
	T-AB-1	1	4	0:39	Yes	Partial High Order	2.25 × 4.5
	VS-50	1	2	2:50	Yes	No	
	PMD-6	1	2	3:30	Yes	No	
AT	RATM	2	2	4:40	Yes	No	
	TMRP-6	2‡	2	20:00	Yes	No	
	TMD-44§	2‡	2	10:15	Yes	No	

* Depth × width.

† Crater not measurable.

‡ Flares placed on the same side of mine.

§ Included for informational purposes only.

During the 12 April 2000 testing, FireAnt[®] was tested against 5 AP mines and 3 AT mines. FireAnt[®] neutralized three of the AP mines and two of the AT mines, resulting in neutralization success rate of 60% for AP mines and 67% for AT mines. All mines were neutralized by deflagration.

Table 12: FireAnt[®] Test Results from 12 April 2000

Mine Type	Mine Designation	No. of Devices	Standoff (cm)	Time min:sec	Neutralized	Detonated
AP	RAPM	1	2.5–3	1:00	Yes	No
	PMN	1	1	5:00	Yes	No
	VS-50	1	2.5–3	1:00	No	No
	PMD-6	1	2.5–3	5:00	Yes	No
	PMD-6	1	2.5–3		No	No
AT	RATM	1	1	13:00	Yes	No
	SATM	1	1	15:00	Yes	No
	VS2.2	1	1	0:24	No	No

* Depth × width.

During the 12 April 2000 test, the FireAnt[®] was also tested against wood case PMD-6 and TMD-44 mines and PROM-1 and APBM bounding fragmentation mines. The trial results from these four mines were not included in the above analysis for three reasons:

- The wood case of the PMD-6 was fresh wood, which is far easier to penetrate than an aged wood case.
- The TMD-44 was attacked using one flare placed 1 cm (0.4 in.) away from the top of the mine case in the center of the mine, using a stand.

- Since FireAnt[®] failed to penetrate the 1/8 in. (3.2 mm) steel plate during the current test, it would not have been considered a likely candidate for use against both PROM-1 and APBM bounding fragmentation mines.

Of the above four mine targets, neutralization results were mixed. Both wood case mines were successfully neutralized by deflagration. For both bounding fragmentation mines, the FireAnt[®] was not able to penetrate the case and failed to neutralize either mine.

When analyzing the results from both tests together, FireAnt[®] was tested for performance against 10 AP mines and 5 AT mines. FireAnt[®] neutralized seven AP mines by deflagration and one by high-order detonation. Four AT mines were neutralized by deflagration. The success rate of AP mine neutralization was 80%; 70% of the AP mines were neutralized by deflagration. The success rate of AT mine neutralization by deflagration was 80%. Total success rate for mine neutralization was 80%; 73% of the mines were neutralized by deflagration.

Table 13: FireAnt[®] Test Results Summary

FireAnt [®] System	AP Total		AT Case Type			AT Total	Mine Total %	
	Neut.	Defl.	Metal	Plastic	Wood		Neut.	Defl.
12 April 2000 Test	3/5	3/5	1/1	1/2		2/3	63	63
Current Test	5/5	4/5	1/1	1/1	*	2/2	100	86
All Mine Targets	8/10	7/10	2/2	2/3	*	4/5	80	73

Note: Neut. refers to all neutralized mines; Defl. refers to mines neutralized by deflagration or partial deflagration prior to detonation.

*Did not penetrate required plate thickness but successfully neutralized the mine.

Of all the neutralized mines, only two had explosive material remaining—the small amount of expelled explosive noted above and in one PMD-6 trial approximately 40 g of TNT did not burn although the mine was considered neutralized.

3.2.3.2 Hyperheat[®] Mine Flare

The Hyperheat[®] Mine Flare was tested against eight AP mines, three AT mines, and one TMD-44 wood case AT mine, which is included in Table 14 for informational purposes (see Section 3.2.1.3) but is not included in the system's performance analysis.

The Hyperheat[®] Mine Flare neutralized six AP mines by deflagration and two by high-order detonation. All three AT mines were neutralized by deflagration. The success rate of AP mine neutralization was 100%, and AP mine neutralization by deflagration was 75%. The success rate of AT mine neutralization (all by deflagration) was 100%. Total success rate for mine neutralization was 100%, and mine neutralization by deflagration was approximately 82%.

Table 14: Hyperheat[®] Mine Flare Test Results

Mine Type	Mine Designation	No. of Devices	Standoff (cm)	Time min:sec	Neutralized	Detonated	Crater d × w* (in)
AP	RAPM	1	2.5	0:43	Yes	Partial High Order	2 × 8
	RAPM	1	2.5	0:41	Yes	High Order	3 × 8
	SPM-1	1	3	4:15	Yes	No	
	SPM-1	1	2	0:45	Yes	No	
	T-AB-1	1	2	0:42	Yes	High Order	2 × 6
	VS-50	1	1.5	3:12	Yes	Partial High Order	1 × 4
	PMD-6	1	1	5:53	Yes	No	
	PMD-6	1	1.5	8:15	Yes	Partial High Order	2 × 10
AT	RATM	2	1.5/1.7	5:52	Yes	No	
	TM-46	2	1.5/1.5	10:57	Yes	No	
	SATM	2	2.1/1.7	12:00	Yes	No	
	TMD-44 [†]	2	1.5/1	1:12	No	No	

* Depth × width.

[†] Included for informational purposes only.

One mine target was not neutralized by deflagration or by detonation: The flare was unable to penetrate the wood case of an AT mine. This was the only circumstance where the angle of attack was not perpendicular to the mine case. In this instance, the flare was placed at approximately a 30-degree downward angle, aimed at the top edge of the mine case. Although it is possible that angle of attack contributed to this failure to neutralize, further testing would be required to determine whether it was a failure of positioning or of flare capability.

In two instances the flares did not perform as intended. In the first, only one-quarter of the flare burned, but because the AP mine target was neutralized without detonation, the incident did not have a negative effect on trial outcome. In the second instance, the “first match” lit but the flare did not ignite. A new flare and match were used in a second attempt that resulted in a successful ignition and mine neutralization.

During this test, detonators were initiated in seven mine targets, including the five mines that detonated. Three mines continued to burn after the detonator fired; four mines ceased to burn. Of all the neutralized mines, no residual explosive material remained.

3.2.3.3 Propellant Torch System

The Propellant Torch System was tested against 10 AP mines and 5 AT mines (see Table 15 and Table 16). Nine AP mines and five AT mine were neutralized. All AT mines and eight of the nine AP mines were neutralized by deflagration. The success of AP mine neutralization was 90%; neutralization by deflagration was 80%. All AT mines were neutralized by deflagration.

The test director had prior experience with both the PT-3 and PT-12 devices. This previous experience was useful in recommending standoff distances with the greatest likelihood for successful neutralization by deflagration.

3.2.3.3.1 PT-3

The manufacturer of PT-3 recommends its use against thin-cased mines. During our plate penetration test, the PT-3 performed well enough to be considered for use against more difficult mine targets.

Table 15: Propellant Torch System (PT-3) Test Results

Mine Type	Mine Designation	No. of Devices	Standoff (cm)	Time min:sec	Neutralized	Detonated	Crater d × w* (in)
AP	RAPM	1	15	0:45	Yes	Partial High Order	1 × 4
	SPM-1	1	15	1:47	No	No	
	SPM-1	1	10	0:32	Yes	Partial High Order	1.5 × 6
	T-AB-1	1	10	1:02	Yes	Low Order	3 × 6.5
	VS-50	1	15	6:18	Yes	No	
	PMD-6	1	5	0:16	Yes	High Order	2 × 9
	MON-100	2 [†]	7.5	13:42	Yes	No	
AT	RATM	2	2.5	7:48	Yes	No	
	TM-46	2	5	8:29	Yes	No	
	SATM	2 [†]	2.5	20:27	Yes	No	
	TMD-44	2	5	9:23	Yes	No	

* Depth × width.

[†]Only one flare ignited

Detonators were initiated in nine mine targets, including the four mines that detonated. Of those remaining five that fired during test trials but did not detonate, all were sufficiently burned so as not to cause detonation of the mine. In one instance, the top popped off the mine. For a second mine, approximately 5 g of unreacted explosive material came out of the case. Other than this one instance, no residual explosive material remained for all the neutralized mines. Four mines continued to burn after the detonator fired; five mines ceased to burn.

For the two trials where only one of two flares ignited, it was determined that the difficulty was most likely due to an error in setup including the possibility that there was insufficient voltage passing through the common series hook up. The failure to ignite two devices did not affect the system's ability to neutralize the mine targets but did increase burn time for both mine targets.

3.2.3.3.2 PT-12

Since PT-12 is specifically recommended for hardened mines, and in the interest of target inventory conservation, the test director decided that PT-12 be tested only under conditions for which the PT-3 had not been tried. For this reason, PT-12 was tested against the more difficult AP bounding fragmentation mine and AP fragmentation stake mine. The

PT-12 successfully penetrated the casing and neutralized the surrogate fragmentation stake mine target. Since neutralization of the more difficult surrogate indicates that the system would be successful against an actual POMZ-2 mine target, the test data have been included in the PT-12 performance analysis.

Although PT-3 successfully neutralized all AT mine types, during one trial only one of two flares functioned, resulting in a considerably longer mine burn time. The test director questioned whether one PT-12 flare might be used against an AT mine and successfully neutralize the mine by deflagration in less time than by use of one PT-3 flare. This was found to be the case for the single AT mine neutralized during this trial, suggesting that using one PT-12 device against an AT mine might be preferable to using two PT-3 devices. This would reduce required inventory and, because two PT-3 devices cost more than one PT-12 device (see Table 42), reduce the cost of AT mine neutralization. Further testing would be required to determine if using one PT-12 flare against AT mine targets would result in a greater number of pressure-induced explosions or detonations.

Table 16: Propellant Torch System (PT-12) Test Results

Mine Type	Mine Designation	No. of Devices	Standoff (cm)	Time min:sec	Neutralized	Detonated
AP	APBM	1	2	3:53	Yes	No
	Val-69	1	2	5:45	Yes	No
	Stake	1	0.6	0:45	Yes	No
AT	ATSC	1	2	3:22	Yes	No

The booster detonated in two mine targets. One caused burning to cease and blew out a small amount of unreacted explosives. The second continued to burn after the booster detonated. Although no pressure release was observed, the unexploded blasting cap from the stake mine was found about 1 foot from the mine.

3.2.3.4 Pyropak

Pyropak was tested against five AP mines, four AT mines, and two TMD-44 wood case AT mines, which are included in Table 17 for informational purposes (see Section 3.2.1.3) but are not included in the system's performance analysis.

Pyropak neutralized three AP mines by deflagration and two by high-order detonation. All four AT mines were neutralized by deflagration. The success rate of AP mine neutralization was 100%, and AP mine neutralization by deflagration was 60%. The success rate of AT mine neutralization (all by deflagration) was 100%. Total success rate for mine neutralization was 100%; mine neutralization by deflagration was 78%.

Table 17: Pyropak Test Results

Mine Type	Mine Designation	No. of Devices	Standoff (cm)	Time min:sec	Neutralized	Detonated	Crater d × w* (in)
AP	RAPM	1	0.3	0:32	Yes	High Order	2.5 × 5
	SPM-1	1	0.3	5:28	Yes	No	
	T-AB-1	1	0.3	3:28	Yes	No	
	VS-50	1	0.3	1:58	Yes	High Order	3 × 5
	PMD-6	1	0.3	3:35	Yes	Low Order	
AT	RATM	2	0.3	6:20	Yes	Low Order	
	RATM	2	0.3	11:36	Yes	No	
	SATM	2	0.1	12:42	Yes	No	
	TMRP-6	2	0.1	12:00	Yes	No	
	TMD-44 [†]	2	0.3	5:21	No	No	
	TMD-44 [†]	4	0.1	3:20	No	No	

* Depth × width.

[†] Included for informational purposes only.

Pyropak's manufacturer indicated that the system was ineffective against wood case targets. The test director, with agreement from the contractor's representative, tested the system against wood case mine targets to verify this claim. Two tests were scheduled, one against a wood case AP mine, one against a wood case AT mine. Pyropak was able to successfully neutralize the wood case AP mine, but it was not successful at neutralizing the wood case AT mine with two devices. The system was tried against the wood case AT mine again, this time with four devices. The system again failed to neutralize the AT mine target.

The detonator fired in eight mine targets, including the two mines that went high order and the two mines that went low order. Of the remaining four mines whose detonators were initiated during test trials, most or all of the main charge had already burned, so mine detonation did not result. In one instance, the plate popped off the top of the mine. Three mines continued to burn after the detonator fired; five mines ceased to burn. No residual explosive material remained for any of the neutralized mines.

3.2.3.5 Pyro-Torch

Pyro-Torch was tested against five AP mines and four AT mines as shown in Table 18. Pyro-Torch neutralized three AP mines by deflagration and two by high-order detonation. Three of four AT mines were neutralized by deflagration. One AT mine was not neutralized. The success rate of AP mine neutralization was 100%; AP mine neutralization by deflagration was 60%. The success rate of AT mine neutralization by deflagration was 75%. Total success rate for mine neutralization was 89%; mine neutralization by deflagration was 67%.

Table 18: Pyro-Torch Test Results

Mine Type	Mine Designation	No. of Devices	Standoff (cm)	Time min:sec	Neutralized	Detonated	Crater d × w* (in)
AP	RAPM	1	2	0:04	Yes	High Order	1 × 4
	SPM-1	1	3	5:40	Yes	No	
	T-AB-1	1	4	3:32	Yes	No	
	VS-50	1	1	1:36	Yes	No	
	PMD-6	1	4	0:07	Yes	High Order	5 × 10
AT	RATM	2	2	6:40	Yes	No	
	TM-46	2	2	11:05	Yes	No	
	SATM	2	2	18:11	Yes	No	
	TMD-44	2	3	0:40	No	No	

* Depth × width.

Detonators initiated in seven mine targets, including the two mines that went high order. Of the remaining five mines whose detonators initiated during test trials, most or all of the main charge had already burned, so mine detonation did not result. Three mines continued to burn after the detonator fired; four mines ceased to burn. Of all the neutralized mines, no residual explosive material remained.

3.2.3.6 Thiokol Demining Flare™

The Thiokol Demining Flare™ was tested against five AP mines and three AT mines as shown in Table 19. The flare neutralized four AP mines by deflagration and one by high-order detonation. All three AT mines were neutralized by deflagration. The success rate of AP mine neutralization was 100%; AP mine neutralization by deflagration was 80%. The success rate of AT mine neutralization by deflagration was 100%. Total success rate for mine neutralization was 100%; mine neutralization by deflagration was 88%.

During a previous test, the Thiokol Demining Flare™ was not able to penetrate the wood case of an AT mine. As a result, the test engineer did not test the flare against the TMD-44 wood case AT mine.

Table 19: Thiokol Demining Flare™ Test Results

Mine Type	Mine Designation	No. of Devices	Standoff (cm)	Time min:sec	Neutralized	Detonated	Crater d × w* (in)
AP	RAPM	1	7	0:44	Yes	High Order	4 × 11
	SPM-1	1	11	9:20	Yes	No	
	T-AB-1	1	12	7:14	Yes	No	
	VS-50	1	5	6:10	Yes	No	
	PMD-6	1	2	0:45	Yes	Partial H.O.	
AT	RATM	2	2	5:04	Yes	No	
	SATM	2	3	18:00	Yes	No	
	TMRP-6	2	3	12:00	Yes	No	

* Depth × width.

The detonator fired in seven mine targets, including the mine that went high order. All three AT mines continued to burn after the detonator fired; the four AP mines ceased to burn. Prior to the detonator firing in the RATM mine, the lid of the case was blown off due to internal pressure. No residual explosive material remained for any of the neutralized mines.

The Thiokol Demining Flare™ was tested earlier under similar conditions on 17–19 August 1999. The flare was tested against a TM-46 AT mine that contained a booster but no fuze. Because the mine was not fuzed like mine targets in the current test, the information presented here is an additional point of reference.

During the first attempt, from a standoff distance of 0.5 in. (12 mm), one flare penetrated the case of the TM-46 mine. The mine burned for 10 minutes. Approximately half of the main explosive charge was consuming before burning ceased. The same mine was then attacked using two flares placed opposite each other at a standoff distance of 0.5 in. (12 mm). This time the flares penetrated the mine case and completely burned all remaining explosive content, leaving an empty metal case. The mine was completely neutralized.

Because the Thiokol Demining Flare™ failed to penetrate the 1/8 in. (3.2 mm) steel plate during the current test, it was not considered a likely candidate for use against bounding fragmentation or fragmentation stake mines and so was not tested against these mine targets. However, during the test performed in August 1999, the flare was tested against a PMOZ-2 stake mine and a PROM-1 AP bounding fragmentation mine. It was also tested against BLU-97 (a small, aerially dispensed, decelerator-stabilized, shaped-charge, antimaternal/AT bomblet) and Mk 118 Rockeye shaped-charge bomblets. The flares destroyed all munitions either by burning or by high-order detonation. For additional information on this test, refer to the test report, *Humanitarian Demining Flare Against Cluster Munitions and Hard Cased Land Mines*, by Divyakant L. Patel, Jason J. Regnier and Sean P. Burke, available on the U.S. Department of Defense Humanitarian Demining Research and Development Program Web site: http://www.humanitarian-demining.org/demining/pubs/neutral/hd_flare.asp.

3.2.4 Mine Neutralization Test Results Summary of Deflagration Systems

Based on plate penetration test results, four of the six deflagration systems (FireAnt[®], Hyperheat[®], Pyropak, and the Thiokol Demining Flare[™]) would not have been considered likely candidates for use against wood case AT mine targets. Nevertheless, three systems (FireAnt[®], Hyperheat[®], and Pyropak) were tested for informational purposes. Although the results of those tests are included in the test results sections for the individual systems, they are not included in this summary so as not to skew effectiveness data.

The Propellant Torch (PT) System (PT-3 and PT-12) was the only deflagration system tested against AP directional, bounding fragmentation, and fragmentation stake mines. The Propellant Torch System was able to successfully neutralize by deflagration all four of the mines it was tested against in these three categories. For a breakdown of specific mine target trial results for the Propellant Torch System, refer to Section 3.2.3.3. All other deflagration systems, when tested against AP mines, were only tested against blast mines, so the AP totals listed in Table 20 represent AP blast mines for all systems except for the Propellant Torch System, where the totals include data for all four AP mine types.

No deflagration system neutralized all mine targets by deflagration. Deflagration success rates for the six deflagration systems ranged from 67% to 88%. Hyperheat[®], Pyropak, and the Thiokol Demining Flare[™] neutralized 100% of mine targets either through deflagration or high-order detonation. The other three systems neutralized most mine targets either through deflagration or high-order detonation: FireAnt[®] successfully neutralized 80% of mine targets; Propellant Torch System, 93%; and Pyro-Torch, 89%. In addition, Pyro-Torch successfully neutralized 100% of AP mine targets, and the Propellant Torch System successfully neutralized 100% of AT mine targets. All AT mines that were successfully neutralized were neutralized by deflagration.

In Table 20, fractions represent successful mine neutralizations over total mine targets. The results in the table below, if not indicative of mine neutralization success rate, do illustrate test results often achieved the first time a device is used to attack a specific mine target.

Table 20: Antipersonnel Mine Test Results Summary of Deflagration Systems

System	AP Total		AT Case Type			AT Total	Mine Total %	
	Neut.	Defl.	Metal	Plastic	Wood		Neut.	Defl.
FireAnt[®]	8/10	7/10	2/2	2/3	*	4/5	80	73
Hyperheat[®]	8/8	6/8	2/2	1/1	†	3/3	100	82
Propellant Torch	9/10	8/10	3/3	1/1	1/1	5/5	93	87
Pyropak	5/5	3/5	2/2	2/2	†	4/4	100	78
Pyro-Torch	5/5	3/5	2/2	1/1	0/1	3/4	89	67
Thiokol Demining Flare[™]	5/5	4/5	1/1	2/2	Not tested	3/3	100	88

Note: Neut. refers to all neutralized mines; Defl. refers to mines neutralized by deflagration or partial deflagration prior to detonation.

*Did not penetrate required plate thickness but successfully neutralized the mine.

†Did not penetrate required plate thickness and did not neutralize the mine(s).

3.3 High-Order System Testing and Results

Although shaped charges are high-order systems, they are unique in that they produce a shaped-charge projectile upon detonation. All test results for shaped charges follow the criteria for other high-order systems, with the exception of the plate penetration tests. For these tests, shaped-charge systems were evaluated independently of other high-order systems.

3.3.1 Preliminary Test Procedures and Results for High-Order Systems

Preliminary tests were conducted to gain information that would aid in target selection and test setup during the mine neutralization test.

3.3.1.1 Initiation Methods Test

To determine which initiation method would be suitable for use with each of the high-order systems, each system was tested using a variety of initiation methods unless the system had special initiating requirements. These tests were used to verify or amend each manufacturer's recommendations.

Because of the inherent danger of testing using actual mines, this testing was done for each high-order system before it was used against real mine targets. Devices were placed on the ground before they were remotely initiated using a demolition device. Each device was initiated separately.

In Table 21, a "Yes" indicates that the initiation method was successfully tested with the indicated system; all initiation method tests were successful.

Table 21: Initiation Methods for High-Order Systems

System	Det. Cord	Shock Tube	Time Fuse	Electric Cap
FIXOR [®]	Yes	Yes		Yes
HELIX				Yes
Kinepouch [™]	Yes		Yes	Yes
Kinestik [™]	Yes			Yes
Liquid Explosive Pouch	Yes			Yes*
NMX-foam [™]	Yes	Yes*		Yes
PESCO HD 11 g Perforator				Yes
PESCO HD 22 g Perforator				Yes
SM-EOD 20				Yes
SM-EOD 33				Yes

*Not conducted during this test, but based upon previous tests conducted by the test director.

3.3.1.2 Plate Penetration Test for Shaped-Charge Systems

Each shaped-charge system was tested to determine its penetrating capability against 10 cm × 10 cm steel plates placed horizontally on the ground. Plate thickness was 1/2 in. (12 mm), 1 in. (24 mm), or 2 in. (48 mm) (composed of two stacked 1 in. [24 mm] plates). Using a stand above each plate, the shaped charges were placed at a standoff distance generally dependent on the diameter of the shaped charge. The shaped charge was then remotely initiated. These test data were used as a guide for selecting AP and AT mines for testing.

The following is the reference used to determine potential mine targets during testing. If a shaped charge had a penetrating capability greater than 3 mm (roughly 1/8 in.), then it was judged to be a good candidate for use against all mines, including AP bounding mines but not necessarily AP fragmentation stake mines. If a shaped charge had a penetrating capability greater than 6 mm (roughly 1/4 in.), then it was judged a good candidate for use against all mines, including AP fragmentation stake mines. If a shaped charge could penetrate 24 mm (1 in.), then it was considered for use against all mines or unexploded ordnance. If a slug remains in the plate, however, neutralization of mines or unexploded ordnance with a similar casing thickness cannot be assured.

Shaped charges were initially tested against plate thicknesses suggested by past test performance data and device specifications.

Based on the results in Table 22, all devices were considered for use against all mine targets. HELIX and PESCO HD 22 g Perforator could be considered for use against unexploded ordnance as well.

Table 22: Plate Penetration Results for Shaped-Charge Systems

System	Standoff (cm)	Plate Thickness (in.)	Penetrated	Hole Diameter (cm)	
				Entry	Exit
HELIX	5	2	Yes	2.0	1.9
PESCO HD 11 g Perforator	0	1/2	Yes	0.8	1.5
	5	1/2	Yes	1	1.5
PESCO HD 22 g Perforator	0	1	Yes	0.8	2.4
	5	1	Yes	2	2.3
SM-EOD 20	7.5	1	Yes	1	
SM-EOD 33	12.5	1	Yes	1.5	

Note: For both SM-EOD's, the slug remained in the hole. Hole diameter was measured only on the entry side of the plate.

3.3.2 Mine Neutralization Test Procedures for High-Order Systems

The purpose of this test was to determine to what extent the high-order detonation systems would completely neutralize mines.

AP and AT mines having wood, plastic, and metal cases were used as test targets. To simulate the most difficult circumstance a deminer might face when using a high-order system, only non-fuzed mines were used. This condition ensured that all mine neutralization resulted from the neutralizing system itself and not by detonation of the mine. Mines were buried on the day of testing so that the top of the mine was nearly even with the ground surface and the top of the mine was exposed.

Once a device is initiated, it may undergo a high-order detonation, it may be partially initiated, or nothing may happen to it. If a device undergoes a high-order detonation, it will generate a blast wave with high pressure, impulse, and temperature. As a result, the mine may undergo a sympathetic high-order detonation or a partial high-order detonation, it may

explode, or nothing may happen. If the mine was neutralized, the following criteria were used to determine whether the device neutralized a mine through high-order detonation, partial high-order detonation, or explosion.

- High-Order Detonation—If high-order detonation took place, a crater should be present (size varies with the amount of explosive in the mine) with no recoverable mine components.
- Partial High-Order Detonation—If partial high-order detonation takes place, then after the test some portion of the explosive in the mine should be observed to have been consumed during detonation, the mine or its remains should be blown out of its original location, and small to large mine casing fragments should be recovered. A crater may or may not be present.
- Explosion—If an explosion takes place, then the mine case should be broken and the explosive broken into pieces and scattered. The mine should be incapable of operation and no crater should be present.

The proper placement of a device—whether on top of the mine or to the side, in contact or at a standoff distance—depended upon target and system specifications. Foam was sprayed directly on the mine over the location of the main charge. Plastic bottle and pouch systems were placed directly on or next to the mine. One or two devices were used against each mine target depending on the target and system specifications. Devices were initiated remotely. If two or more devices were used, they were initiated simultaneously.

When a device was placed on the side of a mine, it was aimed at the main charge. If two devices were placed on the sides of a mine, they were placed opposite each other to create a balanced blast. When a single device was placed on or aimed at the top of the mine, it was aimed at the main charge. Devices were generally aimed off center for circular mines and aimed at one corner for square mines.

To ensure the safety of test observers and the surrounding environment, bounding mines and mines with shaped-charge warheads were tested under conditions that would contain the blast fragments. Initially, these mines were placed in holes drilled in the demolition pit's earthen perimeter wall. Although this contained blast fragments, occasional collapsing of the hole as a result of the blast made it difficult to assess experimental results. In later trials these mine types were placed under a large steel blast plate surrounded by an earthen berm. Although crater measurement was not possible, experimental results were more easily assessed using this method.

After each trial, the site was examined to determine whether the mine was fully neutralized with a crater present. A mine was not considered neutralized if it could still be considered potentially functional. That is, the mine may have been damaged, but there was not enough damage to render the mine nonfunctional. If a mine's detonator was still functional and had any significant amount of the main charge attached to it, then the mine was considered functional.

3.3.3 Mine Neutralization Test Results of High-Order Systems

3.3.3.1 FIXOR[®]

FIXOR[®] was tested against four AP mines and four AT mines as shown in Table 23. FIXOR[®] neutralized all eight mines through high-order detonation. Total success rate for mine neutralization was 100%.

Table 23: FIXOR[®] Test Results

Mine Type	Mine Designation	No. of Devices	Device Placement	Standoff (cm)	Neutralized	Detonation
AP	T-AB-1	1	Side	0.5	Yes	High Order
	VS-50	1	Side	0.1	Yes	High Order
	PMD-6	1	Side	0.5	Yes	High Order
	APBM	2	Side	0.5	Yes	High Order
AT	RATM	1	Top	0	Yes	High Order
	SATM	1	Top	0	Yes	High Order
	TMRP-6	2	Side	0.2	Yes	High Order
	TMD-44	2	Side	0.5	Yes	High Order

The manufacturer of FIXOR[®] recommends using the product soon after mixing. Premixing of the product is not recommended for two reasons. First is safety—once the product is mixed, it is an explosive and should be treated as such. Second is product viability—the product must be thoroughly mixed for proper initiation. According to the manufacturer, FIXOR[®] explosive self-neutralizes after a period of time, becoming a non-explosive. To test the viability of the product after extended premixing and settling periods, two bottles (mixed approximately 24 hours earlier) were used. Bottles were set upright on the ground to test if the product would detonate. One bottle was shaken just before initiation. A second bottle was shaken 3 hours before initiation and was allowed to settle. The shaken bottle underwent a low-order detonation then burned; the settled bottle was broken apart by the blasting cap, but only burned without detonating.

3.3.3.2 HELIX

HELIX was tested against two AP mines and five AT mines as shown in Table 24. HELIX neutralized both AP mines and four AT mines through high-order detonation. The single metal-cased AT mine that was not neutralized was broken apart, but the shaped charge passed through the mine without causing detonation. In one instance, a cap fired but did not initiate the device's explosive. It is believed that cap misplacement or an air bubble caused the misfire. The second attempt resulted in a successful mine neutralization. The mine neutralization success rate was 100% for AP mines and 80% for AT mines. Total success rate for mine neutralization was 86%.

Table 24: HELIX Test Results

Mine Type	Mine Designation	No. of Devices	Device Placement	Standoff (cm)	Neutralized	Detonation
AP	PMD-6	1	Top	5	Yes	High Order
	APBM	1	Side	5.1	Yes	High Order
AT	RATM	1	Top	5	Yes	High Order
	ATSC	1	Top	5	No	None
	SATM	1	Top	5	Yes	High Order
	TMRP-6	1	Side	5.1	Yes	High Order
	TMD-44	1	Side	5.1	Yes	High Order

3.3.3.3 Kinepouch™

Kinepouch™ was tested against three AP mines and three AT mines as shown in Table 25. Kinepouch™ neutralized two AP mines and all three AT mines through high-order detonation. The third AP mine exploded and was successfully neutralized. Total success rate for mine neutralization was 100%.

Table 25: Kinepouch™ Test Results

Mine Type	Mine Designation	No. of Devices	Device Placement*	Standoff (cm)	Neutralized	Detonation
AT	VS-50	1	Side	0.1	Yes	High Order
	PMD-6	1	Side	0.1	Yes	High Order
	APBM	2	Side	0.1	Yes	Explosion
AP	RATM	2	Side	0.1	Yes	High Order
	SATM	2	Side	0.1	Yes	High Order
	TMD-44	2	Side	0.1	Yes	High Order

*Pouches were placed vertically.

3.3.3.4 Kinestik™

Kinestik™ was tested against five AP mines and three AT mines as shown in Table 24. Devices were placed horizontally except against the AP bounding mine, where the two devices were positioned vertically on opposite sides of the mine. Kinestik™ neutralized all five AP mines and one AT mine through high-order detonation. Two AT mines exploded and were successfully neutralized. Total success rate for mine neutralization was 100%.

Table 26: Kinestik™ Test Results

Mine Type	Mine Designation	No. of Devices	Device Placement	Standoff (cm)	Neutralized	Detonation
AP	RAPM	1	Side	0.1	Yes	High Order
	T-AB-1	1	Side	0.1	Yes	High Order
	VS-50	1	Side	0.1	Yes	High Order
	PMD-6	1	Side	0.1	Yes	High Order
	APBM	2	Side	0.1	Yes	High Order
AT	RATM	2	Side	0.1	Yes	High Order
	SATM	1	Side	0.1	Yes	Explosion
	TMD-44	2	Side	0.1	Yes	Explosion

3.3.3.5 Liquid Explosive Pouch

Two different sizes of the Liquid Explosive Pouch were tested against mine targets. The 1/2-pound and 1-pound charges were based on their estimated weight. For this reason, the description should not be considered an exact charge weight, but rather an identifier of approximate weight.

3.3.3.5.1 Liquid Explosive Pouch: Half-pound Charges

Half-pound Liquid Explosive Pouches were tested against four AP mines, four AT mines, and one surrogate fragmentation stake mine, which is included in Table 27 as additional system information (see Section 3.1.3.2) but is not included in the system's performance analysis.

Each half-pound Liquid Explosive Pouch neutralized all mine targets—four AP mines and four AT mines—through high-order detonation. Total success rate for mine neutralization was 100%.

The fragmentation stake mine was attacked using two 1/2-pound Liquid Explosive Pouches placed on opposite sides of the mine. After Liquid Explosive Pouch detonation, it was observed that the stake mine's body was severely distorted and the steel plug along with approximately 50% of the main charge were squeezed out through the top. The surrogate mine was not neutralized but range personnel believed that had this stake mine been an actual cast iron stake mine with a serrated body instead of the surrogate steel mine, it may very well have been completely destroyed. Please note, when the same stake mine was attacked again using two 1-pound Liquid Explosive Pouches, it was successfully neutralized (see Section 3.3.3.5.2).

Table 27: Liquid Explosive Pouch (1/2-pound Charges) Test Results

Mine Type	Mine Designation	No. of Devices	Device Placement	Standoff (cm)	Neutralized	Detonation
AP	RAPM	1	Side	0.1	Yes	High Order
	T-AB-1	1	Side	0.1	Yes	High Order
	VS-50	1	Side	0.1	Yes	High Order
	PMD-6	1	Side	0.1	Yes	High Order
	Stake*	2	Side	0.1	No	None
AT	RATM	1	Side	0.1	Yes	High Order
	ATSC	1	Side	0.1	Yes	High Order
	SATM	1	Side	0.1	Yes	High Order
	TMRP-6	1	Side	0.1	Yes	High Order

* Included for informational purposes only (see Section 3.1.3.2).

3.3.3.5.2 Liquid Explosive Pouch: One-pound Charges

One-pound Liquid Explosive Pouches were tested against two AP mines and one AT mine as shown in Table 28. One-pound Liquid Explosive Pouches neutralized all three mines through high-order detonation. Total success rate for mine neutralization was 100%.

Table 28: Liquid Explosive Pouch (1-pound Charges) Test Results

Mine Type	Mine Designation	No. of Devices	Device Placement	Standoff (cm)	Neutralized	Detonation
AP	APBM	1	Side	0.1	Yes	High Order
	Stake	2	Side	0.1	Yes	High Order
AT	TMD-44	1	Side	0.1	Yes	High Order

3.3.3.6 NMX-foam™

On 22–23 April 2003, NMX-foam™ was tested against mine targets under similar test conditions as those of the current test. It is important to include these prior test results as they clearly illustrate the increase in a neutralization system's effectiveness based solely on the application of experience gained by the system's user. The system underwent no changes between the two tests but the test director, who conducted both tests, gained experience that was useful in selecting appropriate charge quantities and positioning while still maintaining the greatest likelihood of successful neutralization. As a result, the success rate increased during this test over that of the previous test (see discussion below). Because conditions and procedures were similar, the 22–23 April 2003 test results were included in this analysis to give a more accurate depiction of total test results for this system for purposes of comparison to other systems being tested for the first time.

During the current test, NMX-foam™ was tested against 6 AP mines and 1 AT mine. NMX-foam™ neutralized 5 AP mines and 1 AT mine through high-order detonation. One AP mine exploded and was successfully neutralized. Total mine neutralization success rate 100%.

Experience gained by the test director during the previous testing of NMX-foam™ against AT mines resulted in a change in technique for testing against the single AT mine used as a target during this test. For this test, a PVC tube approximately 2 in. (5 cm) in diameter and 6 in. (15 cm) long was placed standing on end on the mine, then filled with NMX-foam™. It is believed that the tube, which contained the foam, directed the blast more efficiently than using the unconfined foam, resulting in a successful neutralization while using less foam. Since this test was only run once, it would be necessary to conduct additional tests before this procedure could be recommended as an operational standard.

Table 29: NMX-foam™ Current Test Results

Mine Type	Mine Designation	No. of Devices [†]	Device Placement	Standoff (cm)	Neutralized	Detonation
AP	RAPM	1/3 can	Top and Side	0	Yes	High Order
	SPM-1	1/3 can	Top and Side	0	Yes	High Order
	T-AB-1	1/3 can	Top and Side	0	Yes	High Order
	VS-50	1 can	Top and Side	0	Yes	High Order
	PMD-6	1/3 can	Top and Side	0	Yes	High Order
	Val-69	1 can	Top and Side	0	Yes	Explosion
AT	RATM	3/4 can [‡]	Top	0	Yes	High Order

[†]Partial can amounts are estimates

[‡]Foam was sprayed into a PVC tube approximately 2 in. (5 cm) in diameter and 6 in. (15 cm) in length.

During the 22–23 April 2003 testing, NMX-foam™ was tested against 7 AP mines and 6 AT mines. NMX-foam™ neutralized all 7 AP mines and two of the 6 AT mines. Mine neutralization success rate was 100% for AP mines and 33% for AT mines. Total success rate for mine neutralization was 69%.

Table 30: NMX-foam™ 22–23 April 2003 Test Results

Mine Type	Mine Designation	No. of Devices [†]	Device Placement	Standoff (cm)	Neutralized	Detonation
AP	RAPM	1/3 can	Top	0	Yes	High Order
	RAPM	1/3 can	Top	0	Yes	High Order
	VS-50	1/2 can	Top	0	Yes	High Order
	VS-50	1/2 can	Top	0	Yes	High Order
	PMD-6	1/2 can	Top	0	Yes	High Order
	APBM	1/2 can	Top	0	Yes	High Order
	APBM	1/2 can	Top	0	Yes	High Order
AT	RATM	1 can	Side	0	No	None
	RATM	1 can	Side	0	No	None
	SATM	1 can	Side	0	No	None
	SATM	2 cans	Side	0	Yes	High Order
	TMA-5	2 cans	Side	0	No	None
	TMD-44	2 cans	Top	0	Yes	High Order

[†]Partial can amounts are estimates

During the 22–23 April 2003 testing, NMX-foam™ was also tested against several mines that were fuzed but not armed. As shown in Table 31 below, all trials resulted in successful mine neutralization. Because the fuzing of these mine targets did not conform to the current test procedures, these mine test results are included here for informational purposes only but are not included in the analysis presented in this report.

Table 31: NMX-foam™ against Fuzed Mine Targets

Mine Type	Mine Designation	No. of Devices	Device Placement	Standoff (cm)	Neutralized	Detonation
AP	RAPM	1/3 can	Top	0	Yes	High Order
	SPM-1	1/4 can	Top	0	Yes	High Order
	SPM-1	1/4 can	Top	0	Yes	High Order
	VS-50	1/2 can	Top	0	Yes	High Order
AT	RATM	1 can	Side	0	Yes	High Order
	ATSC	1 can	Top	0	Yes	High Order
	SATM	1 can	Side	0	Yes	High Order

When analyzing the results from both tests together, NMX-foam™ was tested against 13 AP mines and 7 AT mines. NMX-foam™ neutralized 12 AP mines by high-order detonation and 1 AP mine by explosion. Three AT mines were neutralized by high-order detonation. The success rate of AP mine neutralization was 100%. The success rate of AT mine neutralization was 43%. Total success rate for mine neutralization was 80%.

Table 32: NMX-foam™ Test Results Summary

	Blast	Bounding	AP Total	AP %	AT Total	AT %	Total Mines	Total %
NMX-foam™ System								
22–23 April 2003 Test	5/5	2/2	7/7	100	2/6	33	9/13	69
Current Test	5/5	1/1	6/6	100	1/1	100	7/7	100
All Mine Targets	10/10	3/3	13/13	100	3/7	43	16/20	80

3.3.3.7 PESCO Humanitarian Demining Perforators

Both of PESCO's shaped-charge devices were tested against mine targets.

3.3.3.7.1 PESCO HD 11 g Perforator

PESCO HD 11 g Perforator was tested against one AP mine and three AT mines as shown in Table 33. PESCO HD 11 g Perforator neutralized the AP mine and two AT mines through high-order detonation. One AT mine was neutralized through partial high-order detonation, with some pieces of the wood case remaining. Total success rate for mine neutralization was 100%.

Table 33: PESCO HD 11 g Perforator Test Results

Mine Type	Mine Designation	No. of Devices	Device Placement	Standoff (cm)	Neutralized	Detonation
AP	PMD-6	1	Side	0.1	Yes	High Order
AT	RATM	1	Top	0	Yes	High Order
	SATM	1	Top	0	Yes	High Order
	TMD-44	1	Side	0.1	Yes	Partial High Order

3.3.3.7.2 PESCO HD 22 g Perforator

PESCO HD 22 g Perforator was tested against one AP mine and three AT mines as shown in Table 34. PESCO HD 22 g Perforator neutralized all four mines through high-order detonation. Total success rate for mine neutralization was 100%.

Table 34: PESCO HD 22 g Perforator Test Results

Mine Type	Mine Designation	No. of Devices	Device Placement	Standoff (cm)	Neutralized	Detonation
AP	Stake	1	Top	0.1	Yes	High Order
AT	TM-46	1	Side	0	Yes	High Order
	TMRP-6	1	Side	0.1	Yes	High Order
	TMD-44	1	Side	0.1	Yes	High Order

3.3.3.8 SM-EOD

Both SM-EOD 20 and SM-EOD 33 shaped-charge devices were tested against mine targets.

3.3.3.8.1 SM-EOD 20

SM-EOD 20 was tested against five AP mines and two AT mines as shown in Table 35. SM-EOD 20 neutralized three AP mines and one AT mine through high-order detonation. Two AP mines exploded and were successfully neutralized. One AT mine was not neutralized. Mine neutralization success rate was 100% for AP mines and 50% for AT mines. Total success rate for mine neutralization was 86%.

Table 35: SM-EOD 20 Test Results

Mine Type	Mine Designation	No. of Devices	Device Placement	Standoff (cm)	Neutralized	Detonation
AP	SPM-1	1	Top	7.5 cm	Yes	High Order
	T-AB-1	1	Top	7.5 cm	Yes	High Order
	VS-50	1	Top	7.5 cm	Yes	Explosion
	PMD-6	1	Side	2 cm	Yes	Explosion
	PMD-6	1	Top	7.5 cm	Yes	High Order
AT	RATM	1	Top	7.5 cm	Yes	High Order
	SATM	1	Top	7.5 cm	No	None

3.3.3.8.2 SM-EOD 33

SM-EOD 33 was tested against two AP mines and four AT mines as shown in Table 36. SM-EOD 33 neutralized both AP mines and three AT mines through high-order detonation. One AT mine was neutralized through partial high-order detonation, with mine case material remaining. Total success rate for mine neutralization was 100%.

Table 36: SM-EOD 33 Test Results

Mine Type	Mine Designation	No. of Devices	Device Placement	Standoff (cm)	Neutralized	Detonation
AP	APBM	1	Side	12.5 cm	Yes	High Order
	Stake	1	Side	12.5 cm	Yes*	High Order
AT	RATM	1	Top	12.5 cm	Yes	High Order
	SATM	1	Top	12.5 cm	Yes	High Order
	TMRP-6	1	Top	12.5 cm	Yes	Partial H.O.
	TMD-44	1	Top	12.5 cm	Yes	High Order

*Part of the base of the mine was still connected to the stake

3.3.4 Mine Neutralization Test Results Summary of High-Order Systems

As shown in Table 37, seven high-order systems successfully neutralized all mine targets, and three systems neutralized between 80% and 89%. Fractions represent successful mine neutralizations over total mine targets. Equivalent percentages are listed. Percentages listed in the table, although not indicative of likely mine neutralization success, do illustrate test results achieved, in most cases, the first time a device was used to attack a specific mine target. In those instances where total mine neutralization was not achieved, either better device positioning or a larger demolition charge would most likely have resulted in full neutralization. It could be expected that as additional trials are conducted or as field experience with a system is gained, optimal charge size and device positioning could be predicted with greater accuracy, potentially yielding higher success rates for mine neutralization.

Table 37: Test Results Summary of High-Order Systems

System	Blast	Bounding	Fragmentation	AP Total	AP %	AT Total	AT %	Total Mines	Total %
FIXOR[®]	3/3	1/1		4/4	100	4/4	100	8/8	100
HELIX	1/1	1/1		2/2	100	4/5	80	6/7	86
Kinepouch[™]	2/2	1/1		3/3	100	3/3	100	6/6	100
Kinestik[™]	4/4	1/1		5/5	100	3/3	100	8/8	100
Liquid Explosive Pouch ½ lb	4/4		*	4/4	100	4/4	100	8/8	100
Liquid Explosive Pouch 1 lb		1/1	1/1	2/2	100	1/1	100	3/3	100
NMX-foam[™]	10/10	3/3		13/13	100	3/7	43	16/20	80
PESCO HD 11 g Perforator	1/1			1/1	100	3/3	100	4/4	100
PESCO HD 22 g Perforator			1/1	1/1	100	3/3	100	4/4	100
SM-EOD 20	5/5			5/5	100	2/2	100	7/7	100
SM-EOD 33		1/1	1/1	2/2	100	4/4	100	6/6	100

* System did not neutralize the surrogate target. See Section 3.3.3.5.1 for details.

3.3.5 Artillery Shell Neutralization Test Procedures and Results

Because all artillery shell trials were conducted underneath a blast plate to minimize blast effects; crater measurements were not possible. Four high-order systems were tested against artillery shell targets, resulting in the successful neutralization of all five targets through high-order detonation (see Table 38).

Table 38: Artillery Shell Neutralization Test Results of High-Order Systems

System	105 mm Target	155 mm Target	No. of Devices	Device Placement	Standoff (cm)	Neutralized	Detonation
FIXOR[®]		X	3	Side	0.1	Yes	High Order
HELIX		X	1	Side	5.1	Yes	High Order
Kinepouch[™]		X	2	Top*	0	Yes	High Order
Liquid Explosive Pouch 1 lb	X		1	Side	0.1	Yes	High Order
		X	1	Side	0.1	Yes	High Order

*Pouches stacked on top of each other.

3.4 Test Data Analyses

3.4.1 Data Collection

U.S. Army personnel or contractors not associated with the development or manufacture of the systems tested collected data generated during the test program. All test data were recorded on prepared data sheets. Manufacturers were required to provide the test director with system specifications.

3.4.1.1 Data Collection for Deflagration Systems

Test date, system name, air temperature, and ignition method were recorded for all tests. Data collected for the four deflagration system tests (thrust, burning time, plate penetration, and mine neutralization) are as follows:

- Thrust—the distance the device moved from its original position.
- Burning time—burning time of the device, whether or not a stand was used, and the nature of the burning (with or without noise; vigorous, fast, or slow; color of smoke, if present).
- Plate penetration—plate thickness, position of plate on stand (if a stand was used), standoff distance between plate and device, and if the device successfully penetrated the plate.
- Mine neutralization—mine type and mine designation, case type, explosive type and amount, fuze type and quantity, number of devices used, if a stand was used, standoff distance between the mine and the front surface of the device, the angle of attack, system burn time, explosive burn time, burn time before transition to detonation, total burning time, mine neutralized (yes or no), how mine was neutralized (deflagration or detonation—high order, partial high order, or low order), residual materials identification, and comments.

3.4.1.2 Data Collection for High-Order Systems

Test date, system name, air temperature, and initiation method were recorded for all tests. Data collected for the two high-order system tests (plate penetration and mine neutralization) are as follows:

- Plate penetration (for shaped charges only)—plate thickness, position of plate on stand (if a stand was used), standoff distance between plate and device, and if the device successfully penetrated the plate.
- Mine neutralization—mine type and mine designation, case type, explosive type and amount, number of devices used, placement of device(s), standoff distance between the mine and the device, detonation type (high order, partial high order, or explosion), mine neutralized (yes or no), crater size (depth and width), and comments.

4 HUMAN FACTORS ASSESSMENT

There are no major human factor issues, such as health hazards, for any of the tested systems. Issues for consideration include training and safety.

All mine neutralization systems tested in this program are easy to use and require minimal training or instruction for readying the device for use. However, training or experience with these systems in use against live mines is mandatory because any mine that undergoes a high-order detonation can kill. Although these systems are effective, their effectiveness can be significantly diminished if devices are placed improperly. Placement factors include proper standoff distances, angles of attack, knowledge of a target's main

charge and fuze(s) locations, and any specific charge or device requirements for effective mine neutralization.

4.1 Deflagration Systems

There is an inherent risk with deflagration systems when demining. Although a system may be relatively effective at neutralizing mines through deflagration, there is always the possibility that a mine will undergo a high-order detonation or that a mine may not be completely neutralized, and in either case could represent a threat to deminers. Safety precautions should always be taken for the eventuality of a mine detonation. Deminers should also be sufficiently trained to understand the potential risks associated with a mine that has not been completely neutralized by deflagration and how to safely deal with the situation.

Pyropak uses an ignition device that requires the high-temperature flame created by an igniter cord. Although igniter cord provides a time delay dependent upon the length of the cord, it must be ignited manually and is not as safe as a remote or on-command electrical ignition mechanism. When using Pyropak or any system utilizing igniter cord, deminers must plan ahead to be sure they can achieve a safe standoff distance before the system ignites.

4.2 High-Order Systems

For safety reasons, the two components of binary systems are transported separately. This may be beneficial in minimizing transportation restrictions but requires some care on the part of the end user in that there must be an equal number of each component available on site to create the explosive compounds.

All binary systems are easy to mix, but HELIX and FIXOR[®] must be shaken to ensure a homogenous mixture, and special care should be taken to ensure that no air bubbles are present. Liquid Explosive Pouch devices are easy to mix, but because liquids are shipped and stored in bulk, this system requires the added step of measuring out single-device quantities of the two liquid components.

Binary systems, once mixed, are explosive. Training should emphasize that all binary systems should be treated as explosive.

5 TRANSPORTATION AND STORAGE

All systems described in this report contain hazardous materials as described by the U.S. Department of Transportation. As a result, each system has transportation and storage restrictions and requirements. Some systems can be shipped without additional consideration provided they are packed properly. Other systems require special packaging and have limitations placed on modes of transportation. Table 39 and Table 40 give storage and shipping information for each high-order mine neutralization system. The total weight and measurements are for a single device. Shelf life is an estimate assuming systems are stored under conditions stated by the manufacturer. Hazard Class is the hazardous materials classification for a given system. The UN number is an international identification number assigned to dangerous goods.

Table 39: Storage and Shipping Information for Deflagration Systems

System	Total Weight	Measurements [†] in. (cm)	Shelf Life	Hazard Class	UN No.
FireAnt[®]	270 g	9.3 × 1.5 (23.7 × 3.9)	3 years	1.3G	0092
Hyper Heat Mine Flare	312 g	7.8 × 1.7 (19.7 × 4.2)	5 years	1.4G	0197
Propellant Torch System					
PT-3	285 g	4.5 × 2 (11.4 × 5)	5 years	1.4C	0491
PT-12	385 g	5 × 2 (12.7 × 5)	5 years	1.4C	0491
"Quick Match" Fuse	<5 g	5 (12.7)	Unknown	1.4S	0368
Pyropak	405 g	2 × 1.2 (5 × 3)	5 years	4.3	1396
Igniter	<5 g	*	*	1.4S	0454
Pyro-Torch	670 g	17 × 1.5 (43 × 3.8)	5 years	4.1	3178
Thiokol Demining Flare[™]	150 g	5 × 1 (12.7 × 2.54)	Indefinite	1.4C	0351 [‡]

*Indicates information not provided or unavailable.

[†]Length × width × height or length × diameter

[‡]When shipped with igniter; UN0491 if shipped without the igniter.

In Table 40, storage container refers to the container in which a substance is stored and shipped. This container may or may not be used as part of the neutralization system. The storage container contains a pre-measured amount of a given substance for a single neutralization device except for the Liquid Explosive Pouch substances, which are shipped in bulk, then measured on site.

Table 40: Storage and Shipping Information for High-Order Systems

System	Total Weight	Measurements [†] in. (cm)	Storage Container	Shelf Life	Hazard Class	UN No.
FIXOR[®]						
Nitroethane	400 g	6 × 3 × 2.25 (15.2 × 7.6 × 5.7)	HDPE Bottle	Indefinite	3	2842
Microbead Powder	105 g	6 × 3 × 2.25 (15.2 × 7.6 × 5.7)	HDPE Bottle	Indefinite	None [‡]	N/A
HELIX						
Nitromethane	136 g	4 × 1.5 (10.2 × 3.8)	HDPE Bottle	Indefinite	3	1261
Aluminum Powder	34 g	8 × 1.125 (20.3 × 2.9)	HDPE Bottle	Indefinite	4.1	1309
Shaped Charge	230 g	6 × 2 (15.2 × 5.1)	N/A	Indefinite	None [‡]	N/A
Kinepouch[™]						
Nitromethane	104 g	6.75 × 1.1875 (17.1 × 3)	Plastic Tube	Indefinite	3	1261
Ammonium Nitrate	330 g	4.5 × 5 × 1.5 (11.4 × 12.7 × 3.8)	Foil Pouch	Indefinite	5.1	1942
Kinestik[™]						
Nitromethane	51 g	4.875 × 1 (12.4 × 2.54)	Plastic Tube	Indefinite	3	1261
Ammonium Nitrate	165 g	1.375 × 8 (3.5 × 20.3)	Plastic Bottle	Indefinite	5.1	1942

System	Total Weight	Measurements [†] in. (cm)	Storage Container	Shelf Life	Hazard Class	UN No.
Liquid Explosive Pouch						
Nitromethane	*	*	55-Gallon Steel Drum	Indefinite	3	1261
Diethylenetriamine	*	*	Glass Bottle	Indefinite	8	2079
HDPE Pouch	<5 g	7 × 4 (17.8 × 10.2)	N/A	Indefinite	None [‡]	N/A
NMX-foam™						
Chemical A	598 g	9.5 × 2.6 (24.1 × 6.6)	Aluminum Can	10 years	3	1261
Chemical B	75 g	5.2 × 1.5 (13.2 × 3.8)	Aluminum Can	10 years	3	2037
PESCO HD 11 g Perforator	140.1 g	2 × 1.75 (5.1 × 4.4)	N/A	Indefinite	1.4S	0441
PESCO HD 22 g Perforator	289.2 g	2.25 × 1.875 (5.7 × 4.8)	N/A	Indefinite	1.4S	0441
SM-EOD 20	72 g	2.2 × 0.94 (5.5 × 2.4)	N/A	Indefinite	1.4S	0441
SM-EOD 33	185 g	3.3 × 1.5 (8.5 × 3.7)	N/A	Indefinite	1.4S	0441

*Indicates information not provided or unavailable.

[†]Length × width × height or length × diameter

[‡]Non-hazardous items are not assigned to a Hazard Class

A Hazard Class 1.1D explosive such as TNT or C-4, which is often used for demolition and demining, carries significant transportation and storage restrictions, including the need for an explosives truck for ground transport, restrictions on vessel storage, and the inability to ship by passenger or cargo aircraft or passenger rail. In addition to the restrictions placed on movement of explosive materials, there are considerable packaging and storage requirements to keep the explosives safe and secure. These restrictions can greatly increase the cost of transporting and storing such items, as well as greatly extend the time to transport if shipped overseas.

All tested mine neutralization systems carry few of these restrictions, greatly improving ease of transport as well as reducing transportation time and costs. All these systems can be transported by truck, vessel, and cargo aircraft. Many can also be transported by passenger aircraft and passenger rail. Table 41 lists the restricted components contained in any of the mine neutralization systems presented in the main body of this report. Information for the table was taken from the U.S. Department of Transportation's Hazardous Materials Regulations (Title 49 CFR Parts 100-185).

Table 41: Shipping Classifications

UN Number	Restricted Components	Hazard Class	Packing Group	Carrier Restrictions
UN0092	Flares, surface	1.3G	II	Passenger aircraft/rail forbidden
UN0197	Signals, smoke	1.4G	II	Passenger aircraft/rail forbidden
UN0351	Article, explosive n.o.s.	1.4C	II	Passenger aircraft/rail forbidden
UN0368	Fuzes, igniting	1.4S	II	*
UN0441	Charges, shaped, without detonator	1.4S	II	*
UN0454	Igniters	1.4S	II	*
UN0491	Charges, propelling	1.4C	II	Passenger aircraft/rail forbidden
UN1261	Nitromethane	3	II	Passenger aircraft/rail forbidden
UN1309	Aluminum Powder	5.1	II, III	*
UN1396	Aluminum Powder, uncoated	4.3	II, III	*
UN1942	Ammonium Nitrate	5.1	III	*
UN2037	Gas cartridges, (flammable) without a release device, non-refillable	2.1		*
UN2079	Diethylenetriamine	8	II	*
UN2842	Nitroethane	3	III	*
UN3178	Flammable solid, inorganic, n.o.s.	4.1	II, III	*

*Restricted components that can be shipped by passenger aircraft/rail may have quantity or weight restrictions.

The Hazard Class is a designation given to dangerous goods so that goods with similar hazards can be classified together, sharing the same shipping and packaging restrictions and requirements. The following list includes descriptions of all hazard classes referred to in Table 40 and Table 41.

Class 1: Explosives

- Division 1.1: Substances and articles which have a mass explosion hazard
- Division 1.3: Substances and articles which have a fire hazard and either a minor blast hazard or a minor projection hazard, or both, but not a mass explosion hazard
- Division 1.4: Substances and articles which present no significant hazard

Class 2: Gases

- Division 2.1: Flammable gases

Class 3: Flammable liquids

Class 4: Flammable solids; substances liable to spontaneous combustion; substances which, on contact with water, emit flammable gases

- Division 4.1: Flammable solids, self-reactive substances and solid desensitized explosives
- Division 4.3: Substances which in contact with water emit flammable gases

Class 5: Oxidizing substances and organic peroxides

- Division 5.1: Oxidizing substances

Class 8: Corrosive substances

For packing purposes, substances other than those of Class 2 are assigned to three packing groups in accordance with the degree of danger they present:

- Packing group I: Substances presenting high danger
- Packing group II: Substances presenting medium danger
- Packing group III: Substances presenting low danger

In those instances where more than one packing group is listed in Table 41 above, the packing group is determined by the quantity shipped. Proper packing reduces the risks associated with transporting and storing items classified as hazardous materials.

The above hazard class and packing group information was taken from *UN Recommendations on the Transport of Dangerous Goods. Model Regulations*, 13th Revised Edition, published by the United Nations Economic Commission for Europe (UNECE) in 2003. Although the UNECE has published transportation recommendations and model regulations, individual countries may have their own packing, shipping, and storage restrictions and regulations regarding the transportation and handling of these items classified as dangerous goods.

6 SYSTEM COSTS

System costs were submitted by the manufacturer at the time of testing. Costs listed in Table 42 and Table 43 are per-unit prices based on the quantity ordered. These prices are subject to change at any time and do not include fees, taxes, transportation, or other related costs. Transportation costs can add considerably to the total cost of a mine neutralization system. For more information on shipping restrictions, see Section 5.

6.1 Deflagration System Cost

When reviewing prices, keep in mind that one device is usually sufficient to neutralize an AP mine by deflagration, but two devices are generally required to successfully neutralize an AT mine by deflagration. If only one device is used against an AT mine target, it would cost less per AT mine neutralization, however the probability of the mine undergoing high-order detonation or explosion due to pressure buildup increases and burn time may be more than twice as long compared with neutralization using two devices. Should a mine detonate, costs associated with mine blast damage could greatly increase mine neutralization costs. The two-device requirement for AT mines may not be the case when using PT-12.

At the time of testing, Pyro-Torch was not mass produced. The price reflects this and may change should Pyro-Torch become a mass-produced item.

Table 42: Cost per Unit for Deflagration Systems

System	Quantity				
	1	100	1,000	10,000	100,000
FireAnt[®]	\$10.00	*	*	*	*
Hyper Heat		\$18.32	\$17.40	\$16.56	\$15.70
PT-3		\$56.00	\$21.00	\$18.00	\$18.00
PT-12		\$85.00	\$32.00	\$26.00	\$26.00
Pyropak		\$3.00	\$3.00	\$2.70	\$2.40
Pyro-Torch	\$120.00	\$120.00	\$70.00	\$55.00	*
Thiokol Demining Flare[™]		\$15.00	\$13.00	\$10.00	\$7.00

*Information not provided

6.2 High-Order System Cost

Most targets require that either one or two high-order devices be used against them for successful neutralization by detonation. For all three shaped-charge systems, one device was used against each mine target. Liquid Explosive Pouch and NMX-foam[™] are unique in that partial amounts could be used. The amount of liquid explosive used with the Liquid Explosive Pouch System can be varied and is determined based on the characteristics of the target to be neutralized. The amount of NMX-foam[™] to be used is also variable. Between one-fourth can and two cans of NMX-foam[™] were used, depending on target type. These requirements, based on target type and system used, can greatly affect the total cost of mine neutralization.

Table 43: Cost per Unit for High-Order Systems

System	Quantity			
	100	1,000	10,000	100,000
FIXOR[®]	\$19.95	\$9.95	\$6.95	\$5.95
HELIX[†]				
Binary Explosive	\$3.55	\$3.55	\$3.20	\$2.66
Shaped Charge	\$14.75	\$13.28	\$11.06	\$8.85
Kinepouch[™]	\$5.20	\$4.90	\$4.75	\$4.50
Kinestik[™]	\$3.00	\$2.85	\$2.75	\$2.65
Liquid Explosive Pouch[‡]	\$3.67	\$2.19	\$1.69	\$1.03
NMX-foam[™]	\$25.00	\$25.00	\$10.00	\$7.00
PESCO HD 11 g Perforator	\$7.20	\$7.05	\$6.90	\$6.50
PESCO HD 22 g Perforator	\$9.95	\$9.70	\$9.30	\$9.00
SM-EOD 20	\$24.00	\$22.00	\$21.50	*
SM-EOD 30	\$64.00	\$59.00	\$55.00	*

*Information not provided

[†] Although HELIX is a shaped-charge system, it is sold in two parts because the binary explosive in its HDPE packaging bottle can be used as a demolition device without the shaped charge. This configuration was not tested.

[‡] For comparison purposes, pricing is for a 250-g charge. According to the supplier, field test results indicate this charge size is sufficient to destroy all AP mines, AT mines, and projectiles up through 155 mm. Cost includes HDPE pouch but locally available containers could also be used. For a more comprehensive price list, see Appendix C.

7 TEST SUMMARY ASSESSMENT

Total mine neutralization success rates across all neutralization systems tested ranged from 80% to 100%. For deflagration systems, mine neutralization by deflagration was lower than total mine neutralization across all systems tested, with successful deflagrations ranging from 67% to 88%. Percentages are listed for individual systems in Table 44. These percentages represent the percentage of mines that each system successfully neutralized either by deflagration or high-order detonation for deflagration devices and by high-order detonation for high-order devices. Because total mine targets and target types varied between the systems tested, performance comparisons must be qualified. For specific target amounts and types, refer to the systems' individual test results listed in Sections 3.2.3 and 3.3.3.

Table 44: Mine Neutralization Test Results Summary for All Systems

System		AP Total %		AT Total %		Mine Total %	
		Neut.	Defl.	Neut.	Defl.	Neut.	Defl.
Deflagration							
	FireAnt[®]	80	70	80	80	80	73
	Hyperheat[®]	100	75	100	100	100	82
	Propellant Torch System	90	80	100	100	93	87
	Pyropak	100	60	100	100	100	78
	Pyro-Torch	100	60	75	75	89	67
	Thiokol Demining Flare[™]	100	80	100	100	100	88
High-Order							
	FIXOR[®]	100		100		100	
	HELIX	100		80		86	
	Kinepouch[™]	100		100		100	
	Kinestik[™]	100		100		100	
	Liquid Explosive Pouch 1/2 pound	80		100		89	
	Liquid Explosive Pouch 1 pound	100		100		100	
	NMX-foam[™]	100		43		80	
	PESCO HD 11 g Perforator	100		100		100	
	PESCO HD 22 g Perforator	100		100		100	
	SM-EOD 20	100		100		100	
	SM-EOD 33	100		100		100	

Note: Neut. refers to all neutralized mines; Defl. refers to mines neutralized by deflagration or partial deflagration prior to detonation.

8 RECOMMENDATIONS

To ensure safe and effective use of mine neutralization systems, deminers should gain experience with these systems before using them against live mine targets. Such experience includes thorough training with a system, paying special attention to standoff distances, angles of attack, main charge and fuze(s) locations, and minimum demolition charge or device requirements for effective mine neutralization.

Proper positioning of a mine neutralization device (or devices) is vital for maximizing a device's effectiveness, but using a device in a situation beyond its capacity can be

ineffective or costly at best and dangerous or deadly at worst. Therefore, care should be taken when selecting the proper mine neutralization device for a specific demining situation. To aid selection of the appropriate system, users should have information regarding target type and minefield environment. Users should also be aware of shipping restrictions for the importing and exporting countries as well as all countries through which the neutralization system must pass prior to reaching its destination.

9 CONCLUSIONS

All mine neutralization systems evaluated in this report were successful in their ability to neutralize AP and AT mines. When the systems are used properly, they are an effective, cost-efficient alternative to traditional 1.1D explosives such as C-4 or TNT for neutralizing surface-laid or surface-buried landmines. However, all systems have limitations in target set applicability, transportation restrictions, or cost. Given the right target set, any one of the systems evaluated during this test could do the job and be used with confidence by humanitarian deminers, military, and explosive ordnance disposal personnel.

GLOSSARY

AP	antipersonnel
ASLD™	A-Systems Laser Deflagration System™
AT	antitank
CECOM	U.S. Army Communications-Electronics Command
CERDEC	Communications-Electronics Research, Development and Engineering Command
COTS	commercial off-the-shelf
DETA	Diethylenetriamine
EOD	explosive ordnance disposal
FBO	Federal Business Opportunities
FIXOR®	<u>F</u> ield-friendly, <u>I</u> nexpensive, <u>u</u> ne <u>X</u> ploded <u>O</u> rdnance <u>R</u> emover
ft/s	feet per second
ft	feet
g	gram
GSI	General Sciences, Inc.
HD	humanitarian demining
HDPE	high density polyethylene
HDPMO	Humanitarian Demining Program Management Office
HD R&D	Humanitarian Demining Research and Development
HELIX	<u>H</u> igh <u>E</u> nergy <u>L</u> iquid <u>e</u> Xplosive
IDA	Institute for Defense Analyses
in.	inch
kg	kilogram
m	meter
mm	millimeters
m/s	meters per second
NATO	North Atlantic Treaty Organization
NMX	<u>N</u> itro <u>M</u> ethane <u>e</u> Xplosive

NVESD	Night Vision and Electronic Sensors Directorate
PVC	Polyvinyl chloride
RDECOM	U.S. Army Research, Development and Engineering Command
RDX	Royal Demolition eXplosive (also known as Cyclotrimethylene trinitramine, cyclonite, or hexogen)
TNT	trinitrotoluene
UN	United Nations
UNECE	United Nations Economic Commission for Europe

APPENDIX A
SYSTEM CONTACT INFORMATION

APPENDIX A

SYSTEM CONTACT INFORMATION

FireAnt®

Mr. Lee Fuller, International Business
Manager
PW Defence
Wilne Mill, Draycott, Derby
DE72 3QJ, England

Phone: +44 (0)1332 871100
Fax: +44 (0)1332 875562
Email: info@pwdefence.com
Web: www.pwdefence.com

HELIX

Omni Distribution, Inc.
Explosive Products Division
PO Box 171154
Memphis, TN 38187

Phone: (800) 277-6664
Fax: (800) 508-8534
Email: info@omniexplosives.com

Technical Contact: Bill Nixon, President
Administrative Contact: Danielle Nixon, Vice
President

FIXOR®

Mr. A. W. (Bill) Bauer, Vice President
MREL Specialty Explosive Products, Ltd.
1555 Sydenham Rd.
Kingston, Ontario K7L 4V4
Canada

Phone: (613) 545-0466 ext.101
Fax: (613) 542-8029
Email: bbauer@mrel.com
Web: www.mrel.com

Hyperheat® Mine Flare

Ron Hitchler, Managing Director
Security Search Product Sales
7 Amaranth Drive
Littleton, CO 80127-2611

Phone: (303) 933-7955
Fax: (303) 933-7990
Email: ssps@securitysearch.us
Web: www.securitysearch.us

**Kinepak™ (Kinepouch™ and Kinestik™)
and
PESCO Humanitarian Demining Perforators**

John Johnson
Ordnance Disposal International
2240 Belleair Road, Suite 115
Clearwater, Florida 33764

Phone: (727) 539-7299
Fax: (727) 507-7578
Email: jjohnson@oditechnologies.com
Web: www.oditechnologies.com

Propellant Torch System

Dr. Allen Tulis
Applied Research Associates, Inc.
10720 Bradford Rd., Suite 110
Littleton, CO 80127

Phone (303) 795-8106
Fax: (303) 795-0125
Email: atulis@ara.com
Web: www.ara.com

Pyro-Torch System

General Sciences Incorporated
205 Schoolhouse Road
Souderton, PA 18964-2416

Phone: (215) 723-8588
Fax: (215) 723-8875
Email: genscience@aol.com

Technical: Charles Files
Administrative: Evelyn C. Downs

**Liquid Explosive Pouch
and
NMX-foam™**

Golden West Humanitarian Foundation
6355 Topanga Canyon Blvd, Suite 517
Woodland Hills, CA 91367-2102

Phone: (818) 703-0024
Fax: (818) 703-1949
Email: GoldenWestHF@aol.com

Technical: Joseph L. Trocino
Administrative: Michael L. Trocino

Pyropak

CSIR, Defence Technology
Mr. Dennis Kappetijn
Meiring Naude Road
P.O. Box 395
Pretoria 001, South Africa

Phone: +27 12 841 2570
Fax: +27 12 841 4683
Email: dkappeti@csir.co.za
Web: www.csir.co.za

**SM-EOD
and
Thiokol Demining Flare™**

ATK Alliant Techsystems
PO Box 707, M/S 244
Brigham City, UT 84302-0707

Technical: Brad Cragun
Phone: (435) 863-6157
Fax: (435) 863-2271
Email: brad.cragun@atk.com

Administrative: Mike Conrad
Phone: (763) 744-5540
Fax: (763) 744-5816
Email: mike.conrad@atk.com

APPENDIX B
DEVELOPMENTAL SYSTEMS

APPENDIX B

DEVELOPMENTAL SYSTEMS

1. Introduction

In response to the Federal Business Opportunities announcement seeking mature, nondevelopmental deflagration and high-order mine neutralization systems for humanitarian demining operations, three developmental systems were submitted for consideration. Although these systems were not far enough along in the developmental process to be considered for inclusion in the main report, the test director deemed these systems promising enough to investigate further. These three systems—A-Systems Laser Deflagration System™, MineBurner, and Mine Disarmer—were evaluated for their humanitarian demining potential. It is anticipated that each system will be investigated further in the future.

2. Developmental Systems

2.1 A-Systems Laser Deflagration System™

The A-Systems Laser Deflagration System™ (ASLD™) consists of a laser transmitter, a laser receiver, and disposable deflagration cartridges. The receiver and transmitter are small, rugged pieces of equipment, each slightly larger than a pack of cigarettes. Each operates using a 9 V battery as a power supply, and the laser transmitter is rated eye-safe. The range of the transmitter is 1,800 feet (549 m), although this range may be extended by up to an additional 1,000 feet by attaching the receiver to the deflagration cartridges with a wire. A deflagration cartridge with its built-in igniter is slightly larger than a ballpoint pen. Cartridge and igniter ship as a DOT 4.1 flammable substance and are rated non-explosive. Based on the typical case size the shipments meet the Small Quantity Exception of U.S. Hazardous Materials Regulations (Title 49 CFR Section 173.4). The system is compatible with some standard triggering methods such as blasting caps and electric matches.

Cartridges are placed above mines or unexploded ordnance using stands and then attached to laser receivers. After placing cartridges and receivers on as many targets as desired, the operator moves to a safe standoff distance with required line of sight to each receiver. Each receiver is equipped with a time delay to block out all signals so that the operator may achieve a safe distance between himself and the mine before using the transmitter to activate each receiver in turn.

A shock tube adapter is also under development. The shock tube adapter will permit the ASLD™ transmitter/receiver portion of the system to trigger shock tubes at up to 600 yards from the operator without wires or long shock tube home runs. The shock tube adapter was not investigated during the current test.



Figure 29: Laser Components of A-Systems Laser Deflagration System™



Figure 30: ASLD™ against Antipersonnel and Antitank Mine Targets

During testing, there was mixed success when using the 75 g, 200 g, and 500 g cartridges against mine targets. Cartridges are still under development and optimal cartridge sizes are being investigated. Use of the laser transmitter and receiver resulted in successful ignition of the cartridges.

Table 45: Estimated ASLD™ Cost per Unit based on Purchased Quantity

Components	Quantity			
	100	1,000	10,000	100,000
Receiver	\$400.00	\$280.00	\$220.00	\$200.00
Transmitter	\$550.00	\$380.00	\$300.00	\$250.00
Cartridge	\$22.00	\$15.50	\$12.70	\$12.40

Contact: Floyd M. Artrip
2030 Avon Court, Suite 8
Charlottesville, VA 22902

Phone: (434) 295-7200
Fax: (434) 295-7201
Email: floyd@a-systems.com

2.2 MineBurner

The MineBurner is a prototype deflagration system to be used against both AP and AT mines. The system uses a combination of oxygen and butane, which allows for a burning time of over 1 minute for each application. There are no hazardous goods or restricted cargo considerations with MineBurner. The only consideration for transportation is the wet cell, non-spillable 12 V battery (UN2800). MineBurner consists of the following components:

- **Steel Nozzle**—The steel nozzle has an integral lightweight twin-copper ignition cable and an attached 3 m long, 3 mm outside diameter flexible hose. Total unit weight is 50 g. This unit is disposable, requiring one unit per landmine or unexploded ordnance item.
- **Gas Storage Bag**—The nylon storage bag is 50 cm in length, has a diameter of 10 cm, and weighs 300 g. The storage bag is reusable and can be used a minimum of 20 times.
- **Initiation Box**—The reusable ignition box contains a wet cell, non-spillable 12 V battery with integral remote switched 12 VDC power supply containing a gas tap and a spark ignition system. The box is 12 in. × 6 in. × 4 in. (30 cm × 15 cm × 10 cm) and weighs 2 pounds plus the weight of three 2-foot electric cables. The number of uses per unit is estimated to be 10,000.
- **Remote Transmitter**—The reusable 12 V remote transmitter has a 500-meter range. The transmitter is an 18 in. (46 cm) long, 2 in. (5 cm) diameter plastic cylinder and weighs 220 g. The number of uses per unit is estimated to be 10,000.

Butane, oxygen, and compressed air are needed in addition to the above required components. The butane must be secured locally. The oxygen can be obtained from a locally available oxygen tank or generated using an oxygen generator, which is available for purchase. The compressed air can be generated using an air compressor or it can be generated using a tire pump, which is also available for purchase. Relevant parameters for the oxygen generator and tire pump are as follows:

- **Oxygen Generator**—The reusable 12 V oxygen generator in a box with controls and electrical connection for an auto battery weighs 5 pounds. The box measures 24 in. × 15 in. × 15 in. (61 cm × 38 cm × 38 cm). The number of uses per unit is estimated to be 300,000.
- **Tire Pump**—The reusable, 12 V/24 V, oil-free tire pump weighs 5 pounds and measures 12 in. × 6 in. × 10 in. (30 cm × 15 cm × 25 cm). The number of uses per unit is estimated to be 10,000.



Figure 31: MineBurner against Antipersonnel and Antitank Mine Targets

Like more mature systems, the MineBurner was fairly successful at neutralizing both AP and AT mine targets. This prototype system demonstrated its ability to neutralize mines, but the current setup is not field ready. It is expected that modifications made to the existing system may be so extensive that the system component descriptions given here may not apply to a commercially produced model.

Table 46: Estimated MineBurner Cost per Unit based on Purchased Quantity

Components	Quantity					Use
	1	100	1,000	10,000	100,000	
Steel Nozzle	\$1.00					Single use
Gas Storage Bag		\$15.00	\$3.50	\$3.00	\$2.50	Minimum use: 20 times
Initiation Box	\$100.00					Est. uses: 10,000 times
Transmitter	\$30.00					Est. uses: 10,000 times
O₂ Generator	\$2,000.00					Est. uses: 300,000 times
Tire Pump	\$300.00					Est. uses: 10,000 times
Butane	Local market price					

Contact: Paul Richards
Airogym SA (Pty) Ltd
223 Main Road
Hermanus
Cape Town, South Africa 7200

Phone: ++27 (0)28 312 4801
Fax: ++27 (0)28 312 1935
Email: info@airogym.com

2.3 Mine Disarmer

The Mine Disarmer is a disposable, single-use item developed to eliminate antipersonnel mines and cluster bombs armed with proximity fuzes. It can destroy mines and other similar devices in situations where normal mine clearance measures are unsuitable. It functions by projecting a shock wave toward the mine, causing its detonation.

The Mine Disarmer has a cartridge case body and holder, a brass fuse bush and electrodes, a base and legs, and a charge that consists of 12 g of fast-burning shotgun powder.

The cartridge case body is produced from glass-reinforced plasticized engineering nylon with flame-retardant, antistatic and slipping agents added. The fuse bush and electrodes are produced from computer numerically controlled machined brass rod stock. The fuse bush has been machined to hold a Remington Etronx electronic primer; this can be changed easily to fit other electronic primer sizes. The base is produced from polyethylene plastic, with the legs fabricated from general-purpose plastic.

Once fired, the Mine Disarmer can be returned to the manufacturer for recycling. Because of its nature, the Mine Disarmer is a controlled item.



Figure 32: Mine Disarmer against an Antipersonnel Mine Target

During testing, the Mine Disarmer was tested against several AP mines. Since no antipersonnel mines or cluster bombs armed with proximity fuzes were used as targets during testing, the Mine Disarmer's full potential could not be evaluated. The manufacturer plans to modify the system before further testing, which is planned for the summer of 2005.

Table 47: Estimated Mine Disarmer Cost per Unit based on Purchased Quantity

Quantity			
100	1,000	10,000	100,000
\$10.00	\$6.00	\$5.60	\$4.82

Contact: John McCarty
McCarty Joyce Ltd.
93 Winchester St
Ashhurst
Palmerston North
New Zealand

Phone: +64 6 326 8116
Fax: +64 6 326 9916 (fax)
Email: JohnMcCarty@xtra.co.nz

APPENDIX C
LIQUID EXPLOSIVE POUCH SYSTEM COST PLANNING CHART

APPENDIX C

LIQUID EXPLOSIVE POUCH SYSTEM COST PLANNING CHART*

The Liquid Explosive Pouch System is unique in that the binary liquid components are sold and shipped in bulk and can be dispensed in a variety of charge sizes depending on a particular demining situation. A standard price estimate for the 250-g charge was included in Table 43. Below is a cost planning chart provided by the Golden West Humanitarian Foundation for a variety of quantities and charge sizes.

Though prices are listed for sensitized nitromethane, the nitromethane and the sensitizer are shipped separately. Nitromethane is shipped in 5-gallon containers or 55-gallon drums. Sensitizer is shipped in sturdy glass jugs when ordered in small quantities. It is also available in 55-gallon drums. Prices for the flexible HDPE pouches are listed separately at the bottom of the chart.

Table 48: Liquid Explosive Pouch System Cost Planning Chart*

@ 5 Gal						
Drum weight (kg)	Cost per	Charge size (kg)	Charge size (lb)	Amount per drum	Total possible	Cost per charge
with sensitizer	\$277.00	1	2.21	23	23	\$12.04
23		0.5	1.10	46	46	\$6.02
Total weight		0.25	0.55	92	92	\$3.07
23		0.125	0.28	184	184	\$1.51
@ 1 Drum						
Drum weight (kg)	Cost / drum	Charge size (kg)	Charge size (lb)	Amount per drum	Total possible	Cost per charge
with sensitizer	\$1,425.00	1	2.21	234	234	\$6.09
234		0.5	1.10	468	468	\$3.04
Total weight		0.25	0.55	936	936	\$1.59
234		0.125	0.28	1872	1872	\$0.76
@ 4 Drums						
Drum weight (kg)	Cost / drum	Charge size (kg)	Charge size (lb)	Amount / drum	Total possible	Cost per charge
with sensitizer	\$1,162.00	1	2.21	234	936	\$4.97
234		0.5	1.10	468	1872	\$2.48
Total weight (kg)		0.25	0.55	936	3744	\$1.24
936		0.125	0.28	1872	7488	\$0.62
@ 8 Drums						
Drum weight (kg)	Cost / drum	Charge size (kg)	Charge size (lb)	Amount / drum	Total possible	Cost per charge
with sensitizer	\$1,087.00	1	2.21	234	1872	\$4.65
234		0.5	1.10	468	3744	\$2.32
Total weight (kg)		0.25	0.55	936	7488	\$1.16
1872		0.125	0.28	1872	14976	\$0.58
@ 12 Drums						
Drum weight (kg)	Cost / drum	Charge size (kg)	Charge size (lb)	Amount / drum	Total possible	Cost per charge
with sensitizer	\$1,037.00	1	2.21	234	2808	\$4.43
234		0.5	1.10	468	5616	\$2.22
Total weight (kg)		0.25	0.55	936	11232	\$1.11
2808		0.125	0.28	1872	22464	\$0.55
@ 20 Drums						
Drum weight (kg)	Cost / drum	Charge size (kg)	Charge size (lb)	Amount / drum	Total possible	Cost per charge
with sensitizer	\$987.00	1	2.21	234	4680	\$4.22
234		0.5	1.10	468	9360	\$2.11
Total weight (kg)		0.25	0.55	936	18720	\$1.05
4680		0.125	0.28	1872	37440	\$0.53

Usage Guidelines:

- 125g (¼ pound) charges are suitable for light cased munitions such as most blast-type antipersonnel mines, many anti-tank mines, and shoulder fired antitank weapons.
- 250g (½ pound) charges are suitable for heavier cased munitions such as bounding antipersonnel mines and 105-155 mm high explosive artillery projectiles.
- Charges ranging between 500g (one pound) to 2 kg (four pounds) are suitable for thick cased munitions such as APHE projectiles, aircraft bombs, and bulk demolition operations.

Accessory Costs:

Flexible Pouches	Up to 5,000	\$0.60 each	30,000	\$0.54 each
	10,000	\$0.58 each	40,000	\$0.52 each
	20,000	\$0.56 each	50,000	\$0.50 each

* Based on current pricing. Costs are subject to change without advance notice.

