In-Situ Landmine Neutralization Using Chemicals to Initiate Low Order Burning of Main Charge

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ABSTRACT

An estimated 45 to 50 million emplaced landmines in over 60 countries kill or maim approximately 10,000 people annually. An international humanitarian demining effort is underway to eliminate this global problem. Currently, the most common in-situ mine neutralization procedure is demolition using small explosive charges such as C-4 or TNT. However, this method is not suitable for mines placed on or near important structures such as bridges, public buildings, railroads, water or oil wells and power lines. Explosive destruction in these circumstances will also damage these structures. In addition, detonation of metal case mines increases the amount of metal contamination in an area, making post-clearance quality control much more difficult and time consuming. Burning landmines in-situ is an alternative method of neutralization that can avoid these problems. The US Army Communications Electronics Command (CECOM) Night Vision and Electronic Sensors Directorate (NVESD), under the DoD Humanitarian Demining Research and Development (R&D) Program, has been working to develop a chemical solution for non-explosive in-situ mine neutralization. To date the R&D Program has developed four prototype chemical delivery systems. Two systems use diethylene triamine (DETA), which is hypergolic with TNT, Tetryl and TNT based explosives, and the other two are based on binary chemicals. The first DETA system is known as Bullet with Chemical Capsule (BCC). The second DETA based system, the Reactive Mine Clearance (REMIC) device, improved chemical delivery performance over the BCC. The third and fourth systems (Small and Large REMIC-II) use binary chemicals to neutralize a wider range of explosives, and improve performance against a variety of mine case thickness when compared to the DETA based prototypes. This paper summarizes tests of the four devices against anti-personnel (AP) and anti-tank (AT) mines. Each device has advantages and disadvantages involving cost, reliability, terrain, main charge explosive type, target case thickness and type, chemical toxicity, shelf life, shipment and storage. Chemical mine neutralization systems provide a means to make demining safer, more reliable, and less expensive.

INTRODUCTION

Landmines have played an important role in land warfare since their introduction in World War I. They were widely used during World War II, and in many conflicts ever since. The variety of landmines is tremendous. They range from crude mechanical to complex electromechanical systems. They vary in size, shape, case material, fuze design, explosive type, and method of emplacement. The world is polluted with an estimated 45-50 million mines in over 60 countries. Landmines killed or maimed approximately 10,000 people in 2000 alone [1].

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A strong international effort to eliminate the landmine problem has been underway for several years. The most common in-situ mine neutralization procedure used by deminers is demolition, using small explosive charges such as a C-4 or blocks of TNT. However, this method is not suitable against mines emplaced on or near important structures such as bridges, public building, railroads, water or oil wells, and power lines. In addition, detonation of metal case mines increases the amount of metal contamination in the area, making post-clearance quality control much more difficult and time consuming. Other serious drawbacks with removal for detonation include safety, cost, effective destruction, time constraints, storage, transportation, training, and the potential for the explosive to be stolen. Development of a reliable means for in-situ mine neutralization by burning can provide a solution to these problems.

To address this need, the US Army Communications Electronics Command (CECOM) Night Vision and Electronic Sensors Directorate (NVESD), under the DoD Humanitarian Demining Research and Development (R&D) Program, has been actively developing prototype chemical delivery systems for in-situ neutralization of mines by burning.

BACKGROUND

A 2,4,6-Trinitrotoluene (TNT) and TNT-based explosive such as Composition B (TNT + RDX), also known as Comp B, or amatol (TNT + NH4NO3), is the main explosive charge in many anti-personnel (AP) and anti-tank (AT) mines. TNT is a military and secondary explosive. Secondary explosives fall into one of three categories, all of which contain nitro (NO2):

- Nitrate ester - O-NO2, of which PETN is an example.
- Nitroarenes - C-NO2, which includes TNT.
- Nitramines - N-NO2, characterized by RDX.

TNT is a popular explosive. It melts at a relatively low temperature (81^0C) and is therefore readily cast. Chemical stability is high and sensitivity to impact is low. Due to its low melting point, TNT is used in a mixture with metal, oxidized and many high explosives such as Tritonal (TNT + Al), Cyclotol (RDX + TNT), Octol (HMX + TNT), Baratol (TNT + Ba(NO3)2, Pentolite (PETN +TNT) [2] etc. Explosives contain considerable oxygen within their metastable molecules; hence they do not need air in order to detonate, deflagrate, or dissociate by autocatalytic decomposition. TNT will generally burn fiercely but without transition to detonation if simply ignited; i.e., without use of a detonator and explosive booster charge to shock-initiate the TNT. Hence, a stimulus means such as a chemical hypergolic or high temperature thermite is capable of causing autocatalytic decomposition instead of detonation. The chemical transformation of TNT, as well as most other secondary explosives, can proceed by four general mechanisms:

1. Burning
2. Heterogeneous chemical reaction
3. Detonation
4. Autocatalytic decomposition

Open-pit burning, by spraying kerosene or fuel oil on propellant and explosive and then igniting it, is a common practice for the disposal of propellants and explosives. Burning of confined, often buried ordnance is not feasible because of its dependence on oxygen. Heterogeneous chemical reaction of explosives with suitable chemical reagents is effective [3] but requires excessive quantities of such reagents, and there is no practical, effective delivery system for in-situ neutralization, especially in the case of buried mines. Detonation of explosive ordnance is a viable option that is in practice, but as discussed previously has several drawbacks.

Autocatalytic decomposition and burning are the simplest, cheapest, and most effective options for chemical neutralization of landmine explosives. These types of chemical neutralization are most readily achieved by using suitable chemicals that are hypergolic or pyrophoric with the explosives; e.g., metal alkyls and aliphatic amines. Very small amounts, even several drops in laboratory tests, cause nearly instantaneous hypergolic ignition of TNT, Comp.B, and Tetryl. However amines and metal alkyls failed to ignite RDX, C-4 and PETN explosives used in several AP and AT mines.

The US Army Communications Electronics Command (CECOM) Night Vision and Electronic Sensors Directorate (NVESD), under the DoD Humanitarian Demining Research and Development (R&D) Program, has developed four prototype chemical delivery systems for in-situ mine neutralization by burning. Two delivery systems use diethylene triamine (DETA), which is hypergolic with TNT, Tetryl, Comp.B and other TNT based explosives. The other two systems use binary chemicals that are effective against a wide range of explosives. The first DETA based system, developed by IIT Research Institute, is the Bullet with Chemical Capsule (BCC). The second, developed by BAE Systems, is the Reactive Mine Clearance (REMIC) System.

BAE developed both binary chemical systems under contract with NVESD. In addition to being based on binary chemicals, the Small REMIC-II and Large REMIC-II fine-tune the original REMIC to different-sized targets. BAE System's Integrated Defense Solutions developed a new binary chemical consisting of solid and liquid chemicals. Separately, both chemicals are safe to handle, transport, and store and they are non-toxic. However, when these chemicals are combined, they react and burn.

Regardless of the type of chemicals used, any chemical neutralization system must have a delivery system that can first expose the explosive inside the mine by cutting into and opening the case without causing detonation, then introduce the chemical(s) into the opening. The next section describes the four delivery systems developed under the Humanitarian Demining R&D Program.

DELIVERY SYSTEMS

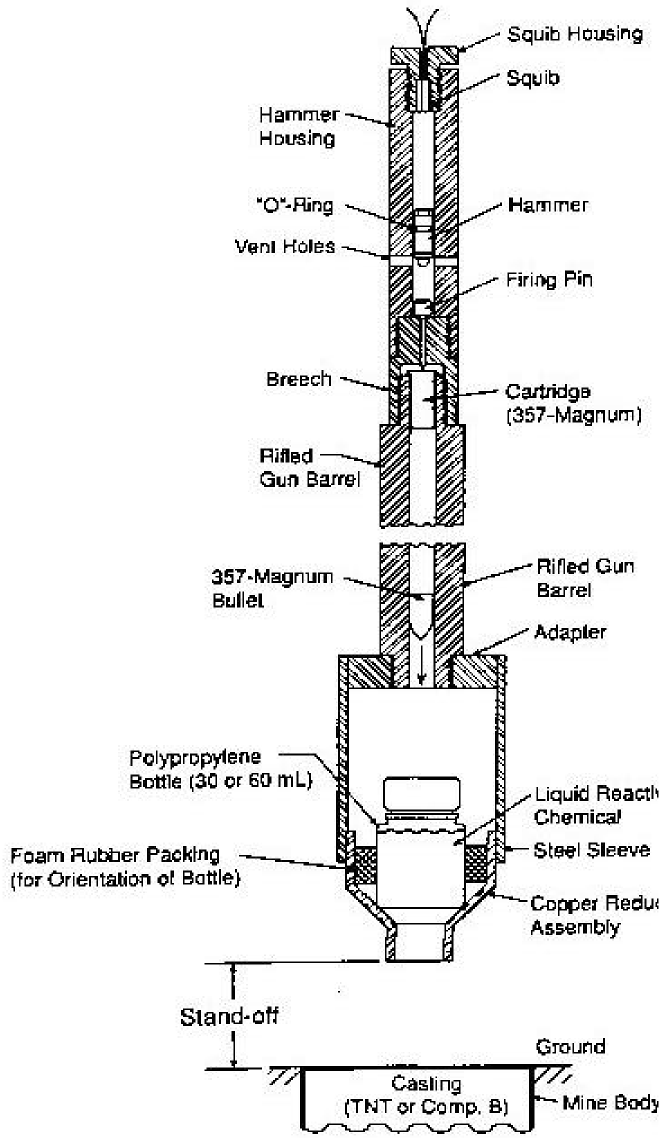
Bullet with Chemical Capsule (BCC)

Dr. Allen Tulis and James Austing, former members of IIT Research Institute, developed the Bullet with Chemical Capsule (BCC) [4]. The BCC uses diethylene triamine (DETA) in a plastic bottle placed just above the landmine, over an area where the main charge is located. The BCC delivery mechanism is a simple tripod as shown in Figures 1a and 1b. A bullet, shot through the capsule and into the mine, ruptures the capsule, penetrates the mine casing and enters into the explosive charge, carrying the dispersed chemical into the explosive charge inside the mine. Within seconds a highly exothermic, hypergolic autocatalytic self-destruction of the explosive charge takes place and the explosive starts to burn. Neutralization is completed within minutes, specific time depending on the size and type of explosive, and type of mine case. The prototype design is robust. It can be operated remotely and it is reusable (Figures 1a and 1b). Remote operation is by an electric squib, and a tripod for positioning the delivery device

Figure 1a: Original BCC Design

Figure 1b: BCC - Improved Tripod

above the mine. The chemical-filled (60 mL) plastic bottle is secured inside a quick-disconnect reducer assembly at the bottom of the gun tube. Once the squib is fired, it produces gas pressure, driving a hammer to impact a firing pin, which in turn fires a cartridge. The bullet penetrates the chemical filled capsule, the mine casing, and the main explosive charge, thereby shattering a portion of the explosive charge. The DETA follows-through behind the bullet and contacts the explosive charge, causing hypergolic ignition and autocatalytic



decomposition of the explosive charge. With fresh consumables (DETA filled plastic bottle, cartridge, bullet, and squib), the delivery system is ready for the next mine. Figure 1c shows across-sectional drawing of the BCC delivery system. The system was tested against AP and AT mines with metal, wood, and plastic casings. The results of this test are shown in Table 1. In test, the BCC proved effective against TNT, Comp.B, Tetryl and TNT-based explosive.

Although the BCC demonstrated the concept of non-explosive neutralization of landmines, testing revealed delivery system design issues that would not be acceptable for field use. In order to prevent damage to the delivery system, it had to be pulled away from the mine as soon as burning commenced. The system had to be cleaned before each use, which would be too inefficient in actual demining operations. In addition, a system that requires a lesser quantity of DETA was desired. Under a CECOM-NVESD contract, TRACOR (now Integrated Defense Solutions Division, BAE Systems) developed the Reactive Mine Clearing System (REMIC) to address these problems.

Reactive Mine Clearing (REMIC) System

REMIC was designed using CTH hydrocode. It contains two main components; a linear charge top component, and chemical reservoirs at both sides of the bottom portion. The linear cutting charge is designed to cut through the mine case, thereby exposing the explosive fill without detonating it [5, 6]. The linear charge cuts a larger opening in the mine case compared to the BCC. This improvement reduces the amount of chemical needed, and significantly decreases the burning time. The two reservoirs each contain 7 mL of DETA. The reservoir is designed such that the expanding jet gases break the reservoirs and eject the DETA into the mine. The device is about 7.4 cm wide, 10.2 cm long and 7.4 cm high, and weighs 340 grams. It consists of an aluminum or copper sheet linear shaped charge liner, detasheet explosive (20 g), and Teflon reservoirs for the DETA. Remote initiation is by a blasting cap or detonating cord with the REMIC suspended above the mine at a specified standoff distance with a monopod support (Figure 2). Once the device is initiated remotely, it produces a high velocity jet, which cuts the mine case. Next, hot gas from the jet breaks the chemical reservoirs and the chemical enters the mine. The chemical reacts pyrogolically with the explosive, causing the explosive to start burning. The burning reaction is self-sustained and will not transition to high-order unless a fuze or detonator reacts to the

Figure 2: REMIC device on the left, and burning AT landmine following REMIC initiation.

approaching burn front by detonating, which may initiate any remaining main charge explosives. Burning will typically last for 5 to 12 minutes depending on the amount and type of explosive, type of mine case and size of the opening in the mine case. REMIC was tested against unfuzed AP and AT mines of various cases such as metal, plastic and wood. Both types of mines were either flush buried or had one cm of soil overburden. The test results are tabulated in Table 2.

Though REMIC proved to be simple to operate, it is not effective against hard case metallic and plastic mines, and since it uses DETA alone applicability is limited to mines containing TNT or TNT –based explosive. Teflon, used for constructing chemical reservoirs, is harmful to the environment and to humans when it is depolymerized at high temperature. It is also difficult material work with. To address problems with the REMIC, BAE Systems developed the REMIC II System.

Reactive Mine Clearance II (REMIC-II)

REMIC II will neutralize all types of mines, regardless of explosive type or mine case thickness. BAE developed two variants of REMIC-II. Both use the same binary chemicals, which are effective against a wide range of secondary explosives. Small REMIC-II can cut open steel mine cases up to 0.32 cm thick using a copper linear cutting charge. The large REMIC-II is able to cut open a steel case up to 1.27 cm thick using a heavier version of the linear shaped charge.

Small Reactive Mine Clearance-II (REMIC-II)

The small REMIC-II was developed to fine tune the original REMIC to neutralize thin-cased AT and AP mines. Each small REMIC-II device is made of a castable polyurethane (Figure 3). Dimensions are 6.6 cm long, 5.1 cm wide and 5.1 cm high. Total weight is approximately 62 grams. There are four one (1) mL glass tubes which contain the binary chemical neutralizer. They are located at the bottom of the device, with two pairs at each side, one on top of the other. The solid reagent (oxidizer) tube is on top and the liquid goes into the bottom tube of each pair. The linear cutting charge uses a 2mm thick PETN-based detasheet explosive driver mated to a curved 1mm thick piece of aluminum. The liner is a shallow, curved shaped charge plate that upon detonation develops a high velocity linear cutting jet formed of particles of the liner. The device is placed above the explosive section of a thin case AP or AT mine with a stand that provides versatile orientation and standoff control of the device over the mine. The device is initiated remotely by inserting an electric blasting cap, which is placed inside a holder that accepts the blasting cap and hold it firmly in place. Once the electric cap is initiated with a demolition device, the linear shaped charge jet perforates the mine casing, while the explosive by-products of the cutting charge fracture the reservoir tubes and direct the chemicals into the mine. Once the binary chemicals combine inside the mine, burning begins with sufficient heat to initiate burning of the explosive in the mine. Figure 3 shows the support structure for positioning the device over a mine. The device is designed so it can be used from a side angle (i.e. vertically). The results of Small REMIC-II testing against AP and AT mines and their results are shown in Table 3.

Figure 3: Small REMIC-II positioned over a PMD-6 AP Mine.

Large Reactive Mine Clearance-II (REMIC-II)

The large REMIC-II body is cast in two identical polyurethane halves, connected by four small pins. Dimensions are 10.2 cm long, 11.4 cm high and 13.33 cm wide. Total weight is approximately 500 grams including stripper plate (described below). Four 8.5 mL size glass tubes contain the binary chemical neutralizer at the bottom of the device, arranged in a similar manner to the Small REMIC-II. The 0.94mm thick copper liner is a shallow, curved plate that upon detonation develops a linear cutting jet. The linear cutting charge uses a 6 mm thick RDX-based detasheet explosive driver mated to a curved liner. The assembled device is placed with a stand which enables the user to position the device up and down, and rotate it so it can be used to neutralize stake mines. To neutralize a mine, the device is placed above the explosive section of the mine at standoff distance, 15 to 20 cm depending on the thickness of the mine case (Figure 4). An electric cap is used to initiate the device remotely. Once the device is initiated, the EFP perforates the mine casing via hydrodynamic erosion. The explosive by-products of the cutting charge, in turn, fracture the reservoir tubes and direct the chemicals into the mine to initiate burning. The large REMIC-II can penetrate steel-cased mines up to 1.27 cm thick. However, the penetration force that accomplishes this can pulverize or cause high order detonation in mines with cases that are not so thick. To control the penetration performance of the EFP, and thereby increase effectives against thinner case mines, the large REMIC device uses one of 4 stripper plates depending on the thickness of the target mine case. The width of the opening of the stripper plate determines the degree of disruption of the EFP. The stripper plates with larger openings allow greater penetration. Numbered S1 through S4, the stripper plates have no slot, 1.27, 1.90 and 2.54 cm slots respectively.

Figure 4: Before and after: Large REMIC-II positioned over a VS-50 AP Landmine, and the completely burned mine after REMIC application.

DEMONSTRATION AND TEST RESULTS

All four chemical delivery systems were tested against surface buried, fuzed and unfuzed AP and AT landmines with metal, wood and plastic casings. Simulated metal and wooden case unfuzed mines were also used. Generally, three mines were used for each test, however in some cases low mine availability limited testing to one or two mines. Table 1 contains the results of the Bullet with Chemical Capsule (BCC) test, which took place at an ambient temperature of 10^0C in November 1995. Table 2 shows the results of the DETA based REMIC test, which took place in January 1998. Testing of the Small REMIC-II and Large REMIC-II took place in May 2001. The test results of these systems are tabulated in Table 3.

TABLE 1. Test Results of Bullet with Chemical Capsule against AP and AT mines

Mine Type	Designation	Casing	Explosive	Fuzed	Neutralization
AP	PMD-6	Wood	TNT	No	Completely burned
AP	PMD-6	Wood	TNT	No	Completely burned
AP	PMD-6	Wood	TNT	No	Completely burned
AP	PMN-2	Plastic	TNT/RDX	Yes	Completely burned
AP	PMN-2	Plastic	TNT/RDX	Yes	Completely burned
AP	PMN-2	Plastic	TNT/RDX	Yes	Completely burned
AP	Simulated	Steel	TNT	No	Completely burned
AP	Simulated	Steel	TNT	No	Completely burned
AP	Simulated	Steel	TNT	No	Completely burned
AT	TMD-44	Wood	TNT	No	Completely burned
AT	Large	Plastic	Comp.B	No	Completely burned
AT	Large	Metal	Comp.B	No	Completely burned
AT	Large	Metal	Comp.B	Yes	Completely burned

Table 2. Test Results of Reactive Mine Clearing (REMIC) Device

Burial Depth	Mine type	Designation	Mine case	Explosive	Explosive Burn time, min.
Flush	AP	Small	Plastic	Tetryl	Detonate
Flush	AP	Small	Plastic	Tetryl	Detonate
Flush	AP	Small	Plastic	Tetryl	Detonate
Flush	AP	Medium	Steel	TNT	10 minutes
Flush	AP	Medium	Steel	TNT	20 minutes
One cm	AP	Medium	Steel	TNT	17 minutes
Surface	AP	PMOZ-2	Cast-iron	TNT	No penetration
Flush	AP	TS-50	Plastic	RDX	Five minutes
Flush	AP	TS-50	Plastic	RDX	Five minutes
Flush	AP	VS-50	Plastic	RDX	Five minutes
Flush	AP	PMD-6	Wood	TNT	Five minutes
Flush	AT	Large	Metal	Comp.B	11 minutes
Flush	AT	Large	Metal	Comp.B	12 minutes
Flush	AT	Large	Plastic	Comp.B	Eight minutes
One cm	AT	Large	Plastic	Comp.B	25 minutes
Flush	AT	TM-46	Metal	TNT	Eight minutes
Flush	AT	TM-46	Metal	TNT	One minute
Flush	AT	TMD-44	Wood	TNT	Eight minutes
Flush	AT	VS-2.2	Plastic	Comp.B	No penetration

Table 3. Test Result of a Small REMIC-II and a Large REMIC-II Tested against Fuzed and Unfuzed AP and AT Mines

REMIC Device	Mine Type	Mine	Fuzed	Case	Explosive	Stand-Off, cm	Neutralized, Burned time
Small	AP	Small	No	Plastic	Tetryl	5	Failed
Small	AP	Small	No	Plastic	Tetryl	5	Yes, total 8 min.
Small	AP	Small	Yes	Plastic	Tetryl	5	Detonate aft. 17s
Small	AP	VS-50	No	Plastic	RDX	5	No burned
Small	AP	PMN	No	Plastic	TNT	5	No burned
Small	AP	PMD6	No	Wood	TNT	5	Mine broken up
Small	AP	PMD6	No	Wood	TNT	5	Mine broken up
Small	AT	Large	No	Metal	Comp.B	5	Burned, 18 min
Small	AT	Large	No	Metal	Comp.B	5	Burned, 17.5 min
Small	AT	Large	Yes	Metal	Comp.B	5	Burned, 15 min
Small	AT	Large	No	Plastic	Comp.B	5	Burned, 14 min
Small	AT	Large	Yes	Plastic	Comp.B	5	Burned, 19 min
Small	AT	Large	Yes	Plastic	Comp.B	5	Burned
Small	AT	TM62	No	Metal	TNT	5	Failed
Small	AT	TM62	No	Metal	TNT	6.35	Burned, 16.5 min
Small	AT	TMA5	No	Plastic	TNT	5	Failed
Small	AT	TMA5	No	Plastic	TNT	7.5	Failed
Small*	AT	Large	No	Metal	Comp.B	5	Burned, 25.5 min
Larg. S1	AP	Val.69	No	Plastic	TNT/RDX	20	Burned
Larg.S1	AP	VS-50	No	Plastic	RDX	20	Burned, 8.5 min
Larg.S2	AP	VS-50	Yes	Plastic	RDX	20	High order Deto.
Larg.S2	AP	TS-50	No	Plastic	RDX	20	Burned
Larg.S2	AP	Small	No	Metal	TNT	20	Burned, 8 min
Larg.S2	AP	Small	No	Metal	TNT	20	High order Deto.
Larg. S2	AP	Small	No	Metal	TNT	20	High order Deto.
Large	AP	POMZ**	No	Metal	TNT	21.5	Burned
Large	AP	POMZ**	No	Metal	TNT	19	Burned
Large	AP	POMZ**	No	Metal	TNT	20	Burned
Larg.S1	AT	TMD-44	No	Wood	TNT	20	Burned, 23.5 min
Larg.S1	AT	TMD-44	No	Wood	TNT	20	Burned, 18 min
Larg.S1	AT	TM-46	No	Metal	TNT	20	Burned, 16 min

* Side attack
** Simulated POMZ-2

S1- Stripper plate 1, no slot
S2- Stripper plate 2, 1.27 cm slot

RESULTS AND DISCUSSION

The Bullet with Chemical Capsule (BCC) was 100% effective against tested AT and AP mines (Table 1). Theoretically, one could use this system to neutralize a mine buried up to six inches in soil as long as the exact location of the mine is known. However, because the BCC uses DETA, it is not effective against mines containing RDX, PETN or plastic explosives. It cannot be used against stake mines, bounding and blast resistant AP mines. The system is reusable, but the gun barrel must be cleaned after every use. Also, the delivery system must be pulled away from the mine once burning starts to prevent it from damage. The BCC requires a large quantity of DETA, and it takes longer to burn the explosive due to the small opening created by the bullet.

The success rate for the REMIC was 75% among tested AT and AP mines (Table 2). The mine burns at twice the speed of the BCC system because it cuts a 1.27 cm x 10.2 cm opening into the mine case. As with the BCC, the REMIC system cannot neutralize stake, bounding or blast resistant mines, or mines containing RDX, PETN or plastic explosive. The system has several drawbacks. The Teflon chemical reservoir is costly, hard to work with, and generates toxic fumes during burning. Since it uses 20 gm of detasheet explosive, it must be transported and stored as an explosive. It cannot be used from a side angle if the mine is above ground.

In test, Small REMIC-II neutralized only 13 % of AP and 73% of AT mines (Table 3). It did not do well against AP or AT mines containing TNT. This may be because the quantity of binary chemical is not sufficient to ignite the TNT, which has a high auto-ignition temperature. The device is good for neutralizing AT mines. It is not effective against stake, bounding and blast resistance mines, though it can be used vertically. Small REMIC-II uses PETN detasheet, which requires it to be shipped and stored as an explosive. The glass tube chemical reservoirs avoid the environmental problem with Teflon. Two separate storage facilities are required for the solid and liquid components.

Large REMIC-II was tested against thirteen AP and three AT mines, with a standoff distance of approximately 20cm. It neutralized 70% of AP and 100% of AT mines (Table 3). Its larger size enables it to neutralize mines with steel cases up to ½ inch thick. Stripper plates S1 and S2 were the only ones used. Knowing which stripper plate to use on any given mine requires knowledge of the mine and its thickness. Shipping and storage requirements are similar to the Small REMIC-II.

During burning of fuzed, metallic AT mines, very low order detonation takes place after more than ¾ of the explosive is consumed. However, this can be avoided or minimized with the use of two similar mine neutralization systems placed above the main charge of the mine, opposite to each other and away from fuzes. It also reduces burning time by nearly half.

Table 4 provides an overall comparison of all four systems in term of cost, reliability, terrain, main charge explosive type neutralize, target case thickness and type, chemical toxicity, shelf life, shipment and storage.

Comparison Among BCC, REMIC, Small-REMIC-II and Large-REMIC-II Neutralization Systems

Parameters	**BCC**	**REMIC**	**Small-REMIC-II**	**Large-REMIC-II**
Mine neutralize.	Burn	Burn	Burn	Burn
Chemicals used	DETA	DETA	Oxidizer & Solvent	Oxidizer (Solid) & Solvent
Penetration by	Bullet	Linear charge	EFP	EFP
Penetration Material	Copper	Copper & Aluminum	Copper	Copper
Chemical Reservoir mat.	Plastic	Teflon	Glass	Glass
Case material	Steel	Plastic, Teflon	Polyurethane	Polyurethane
Explosive need	Squib	20 gm PETN Detasheet	2mm thick PETN Detasht.	6mm thick RDX detasheet
Amount of Chemical	60 mL liquid	14 mL liquid	2 mL solid 2mL liquid	17 mL solid 17 mL liquid
Initiation method	Squib	Electric cap or Detonation cord	Electric cap or Detonation cord	Electric cap or Detonation cord
Placement of Device	On explosive portion of mine	Abve explosive In mine	Abov explosive In mine	Above explosiv In mine
Standoff of distance	Touching mine case	10 cm above mine surface	5 to 7.5 cm abo. Mine surface	18.75 to 21.25 cm above mine
Types of explos neutralized	Tetryl, TNT & TNT based expl	Tetryl, TNT & TNT based expl	Tetryl, PETN TNT,RDX, etc	Tetryl, PETN, TNT, RDX, etc.
Perf. against Stake mines	No	No	No	Yes
Perform against Bounding mine	No	No	No	Yes
Maxim. steel penetration	3 mm	4 mm	6 mm	13 mm
Chemical self-life	Unlimited shelf life in unopend Original contan	Unlimited shelf life in unopend original contain	Both solid & liquid are stable under ord.conds	Both solid and liquid are stable under ord. cond
Toxicity of Chemicals	Corrosive to skin and eyes	Corrosive to skin and eyes	Both solid and liquid are slight toxic	Both solid and liquid are slight toxic
System use	Reusable	One time use	One time use	One time use
Human factors	Easy to use, min. training	Easy to use min. training	Easy to use, min. training	Easy to use min. training
Transportation Requirements	No explosive Trans. needed	Explosive trans. needed	Explosive tran-Sport needed	Explosive trans. Needed

Parameters	BCC	REMIC	Small-REMIC-II	Large-REMIC-II
Storage requirements	Squib & liquid storages	Explosive & Liquid storages	Explosive, liquid & solid storages	Explosive, liquid & solid storages
Initiation power requirement	Blasting machine	Blast machine or firing device	Blast machine or firing device	Blast machine Or firing device

SUMMARY AND CONCLUSIONS

The Humanitarian Demining R&D Program developed four prototype chemical mine neutralization technologies to neutralize mines by burning. A key advantage to this form of in-situ neutralization is the avoidance of damage to important structures such as roads, bridges, oil wells, power lines and public buildings.

The Bullet with Chemical Capsule (BCC) uses a single chemical, diethylene triamine (DETA), which is pyrogolic with TNT and TNT based explosive. Therefore, the system is only applicable to mines containing TNT, Tetryl and Comp.B. Also, due to lack-of penetration of the bullet into thick mine cases, it is effective against only thin cases AP and AT mines. The delivery system is reusable but requires cleaning after each use, and it must be pulled away once the mine starts burning. The system may be work against a buried AT mine if the exact location of the mine is known.

The Reactive Mine Clearance (REMIC) System was developed to address the problems associated with the BCC. REMIC also uses DETA chemical and a linear shaped charge. The delivery system is an improvement over the BCC system, but since it is still based on DETA it cannot be used against stake, bounding, hard case blast resistant mines, and mines containing RDX, PETN and plastic explosives. The Teflon chemical reservoir is toxic when it burns, is costly and hard to machine. The PETN-detasheet explosive driver requires REMIC to be shipped and stored as an explosive.

Small and Large REMIC-II are capable of neutralizing all types of mines and all explosives in mines. They use explosive forming penetrators made from copper sheet to cut and open mine cases without causing detonation, and they use binary chemicals which can neutralize most explosives found in mines. The small REMIC-II is good for thin case AP and AT mines while the large REMIC-II is designed for thick case AP and AT mines. Stripper plates allow the large-REMIC-II to be used against mines with cases of varying thickness. It can also be used to attack mines from the side or at an angle. The Small REMIC-II proved effective against AT mines containing Composition B or RDX, but it failed to neutralize AP or AT mines containing TNT because the quantity of binary chemicals is not sufficient to ignite TNT due to its higher auto-ignition temperature. Very small AP mines with fuzes are difficult to neutralize with burning. However, these systems use explosive and binary chemicals, therefore handing, shipping, storing and safety restriction are required.

To summarize, we investigated four non-explosive technologies for low order mine neutralization. Two of these technologies use a single chemical, while the other two are binary chemical systems. In test, each system successfully demonstrated the feasibility of neutralizing a mine by burning.

Each chemical system has unique performance characteristics against tested mines. Several constraints were identified, such as reliability, repeatability and use of explosive. At present, none of the tested prototype systems meet military countermine or humanitarian demining requirements. However, they demonstrated the potential exists for development of a usable and effective chemical neutralization technology in the near future.

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