Proper Usage of Torch Systems for In-Situ Landmine Neutralization by Burning for Humanitarian Demining

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A present, deminers normally use only two techniques to clear individual mines: manual disarming and destruction by an explosive charge. Manual clearance, in which a mine is found, excavated and manually neutralized without causing detonation, is a very arduous, slow and hazardous operation. Mines may behave unpredictably due to corrosion or other forms of weathering, or may be booby-trapped with anti-handling devices. The second mine-neutralization technique, demolition, is achieved with high explosives such as C-4 blocks or explosive charges with similar characteristics. Unfortunately, this approach suffers from serious drawbacks, such as cost, storage, transportation and training. A partial detonation of a mine may leave considerable component parts in the minefield, including the explosive, detonator or case material. Also, destruction cannot be performed where collateral damage is unacceptable, such as locations on or near bridges, public buildings, railroads, water or oil wells, power lines and highways.

The Night Vision and Electronic Sensors Directorate under the U.S. Army’s HumanitarianDemining Research and Development Program, has been working to develop new non- and low-explosive technologies that have the potential to provide a safer, more reliable and less expensive means of neutralizing mines in humanitarian-demining operations. The HD R&D Program has developed several innovative deflagration (torch) methods using liquid chemicals, propellants, pyrotechnics, thermite and solid reactants. These innovative systems neutralize surface-exposed mines by burning instead of by detonation. Burning can be an effective means of neutralizing both anti-tank and anti-personnel mines. The materials and construction is the essential factor in selecting a safe and effective method of neutralization.

AP and AT Mines

Landmines constitute two general categories: anti-personnel and anti-tank. AP and AT mines are further classified according to case type and function. There are three types of AP mines, blast, fragmentation and directional. Most AP blast mines have waterproof plastic cases, some are scavenge-resistant and resistant to clearance tools, creating an obstacle. Older mines have Bakelite, glass or wooven paper cases, and a few have wooden cases. Most mines contain TNT as a main charge, while some use RDX or Composition B. The main charge weight varies from 28–250 g, depending on the size of the mine. Mines usually have a circular, cylindrical or rectangular shape and are initiated by pressures of 2–20 kPa. The fuse is located either in the center, sides or base of the mine. AP fragmentation mines are divided into two categories: bounding mines and stake mines. Most bounding mines are cylindrical and made of 8–12 mm-thick cast iron or steel. These mines are activated with tripwires or pressure. They are not affected by explosive clearance methods. Most bounding mines contain TNT as a main charge and have 100–525 g of explosive. The mine has two fuses, which are located at the top and bottom. The bottom fuse contains the propellant charge. The mine is waterproof and buried in soil with the top fuse exposed. Bounding mines are initiated by pressures of 0.5–3 kPa. Stake mines are cylindrical in shape and are made from cast iron or steel with a thickness of 8–12 mm. The mine’s main charge is usually 75–440 g of TNT. The stake of the mine is made from wood or metal. These mines are found above ground and are activated by tripwires. Operating pressures vary from 1–10 kPa. Stake mines can be booby-trapped. The fuse is often located on top of the mine. Stake mines with tripwires are also difficult to neutralize with an explosive clearance method based on baric overpressure.

There are three types of AP directional fragmentation mines. The Claymore type is rectangular with one or two detonator wells molded in the top or back surface. The AP directional fragmentation mine with a central detonator well is found above ground and initiated with a propellant charge. These mines are made from cast iron or steel. The directional fragmentation mine case is made of plastic or metal.

AT mines are classified as blast or shaped charge, with most being blast mines. They have metal, plastic (e.g., Bakelite, polystyrene, polyethylene, resin-reinforced fabric or wood cases. AT mines can be circular, square, rectangular or cylindrical in shape. They contain from one to four fuses in various configurations. The fuse is typically initiated with pressure. The fuse body material can be brass/copper or zinc base alloy, plastic, aluminum or sheet metal with a thickness of 1–2 mm. Most mines contain shock-resistant fuses and are scatter-resistant. Shock-resistant mines are difficult to neutralize with explosives-clearance methods based on baric overpressure.

Most AT mines contain TNT or TNT-based explosives such as Composition B, Pentolite (pentamethylene tetranitramine and TNT) or Amatol (ammonium nitrate and TNT). About 10% of mines contain only RDX, tetryl, PETN or C-4. TNT is an exceptionally stable explosive. It is highly resistant to chemical attack by acids and conventional emulsions. Burning is generally the preferred method for destroying the main charge of AT mines. Solid TNT cannot be easily ignited with a match. However, 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 the mine. The TNT. Burning mines in situ is an alternative neutralization method that can avoid collateral damage.

Low-order mine neutralization, accomplished by burning the explosives, is not a technique deminers commonly use. It is a relatively new approach that may be expensive, requires proper training and may require additional sorting on different mine types. Nevertheless, burning can be an appropriate neutralization method for mines, especially in locations that do not allow for manual disarmament or detonation. Understanding the burning process of unconfined and heavily confined secondary explosives and various mine cases, such as metallic, plastic and wood, is essential before developing procedures for such techniques.

Explosive Burning

The burning process of an unconfined explosive itself is a self-sustaining, exothermic reaction. Due to the heat, the resulting hot gases, and the fine particles released in the reaction, the reaction remains constant in the gas phase with emission of light. The transfer of heat generated by such a reaction is conductive and convective. The explosive charge itself burns layer by layer and the temperature within the charge decreases with distance from the reaction zone.

The burning reaction of an explosive starts if the temperature is raised above its ignition temperature. The ignition temperature of an explosive depends on heat production and transfer. If an explosive is heavily confined, the pressure around it rises and the hot gases have no possibility to escape. The heat transfer becomes more efficient and the burning rate accelerates up to a deflagration, and from there, into a detonation (high-order). The burning rate of an explosive depends strongly on the type of explosive, physical condition of the explosive (press versus melt) and on the surface area and confinement. Several physical and chemical properties also control burning such as melting point, boiling point, decomposition temperature, ignition temperature and explosion temperatures. TNT is the main charge of most mines; it melts, boils, ignites and explodes at 85°C, 201–217°C, 285–500°C and 640°C, respectively.

Table 1. Characteristics of Torch Systems

<table>
<thead>
<tr>
<th>System</th>
<th>Steel Plate Penetration (mm)</th>
<th>Burning Time (sec)</th>
<th>Flame Temp. (˚C)</th>
<th>Ignition Methods</th>
<th>Thrust (lb)</th>
<th>DOT Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>TDF</td>
<td>1.5 mm</td>
<td>60–70</td>
<td>1927°C</td>
<td>Electric Match</td>
<td>0.5</td>
<td>1.4C</td>
</tr>
<tr>
<td>PT-1</td>
<td>4.0 mm</td>
<td>25–27</td>
<td>2700°C</td>
<td>Electric Match</td>
<td>3.0</td>
<td>1.4C</td>
</tr>
<tr>
<td>PT-12</td>
<td>12.0 mm</td>
<td>28–30</td>
<td>2700°C</td>
<td>Electric Match</td>
<td>6.0</td>
<td>1.4C</td>
</tr>
</tbody>
</table>

The HD R&D Program has developed three mine-neutralization devices to neutralize mines by burning: the TMRP Demining Flare, Propellant Torch PT-1 and PT-12. In order to use torch systems to neutralize surface-exposed mines, users must know the subject mine’s case type and thickness; the fuse type, number and locations; and the type of explosive. To use safely and effectively, these methods should be able to penetrate the mine case in less than 90 seconds to avoid detonation of the mine.

Figure 3: TMD-02, AP plastic case mine with two TDFs attached to stand. The preferred device burning time is 25 seconds or longer, and the preferred flame temperature is 1,800–3,000˚C. The burning characteristics of mine-case materials will be discussed later. The parameters of the TMD, PT-1 and PT-12 devices are tabulated in Table 1. The TMD-02 Demining Flare is applicable to AP plastic-case blast mines. The flare is used with and without a stand. When it is used without a stand (a 1 lb mine or weight may be used to brace the back of the flare), it is placed on the ground 4–6 cm away from the mine, aiming to cut the corner of the mine. The flare’s flame should never be aimed at the operators.
This torch was developed for hard-case mines and unexploded ordnance. The torch is applicable to AP bounding and staked mines, and a few metal-case AT mines. For staked mines, the torch is used with a stand and a stand-off distance of 1–2 cm from the bottom portion of the mine. The bounding mine is the most difficult to neutralize by burning because it has an extra propellant fuse inside, but it is possible with proper aiming of the flame on the mine. PT-12 can be used with and without a stand. When it is used without a stand, use a 4–8 lb sandbag at the back of the mine. Figures 4–6 show the applications of PT-12 torches against staked, bounding, and AT mines.

**Burning characteristics of metal-case mines**

Metal-case AP or AT mines are made from steel or cast iron. AP bounding and stakes mines are cylindrical, made from 8–12 mm-thick cast iron or steel. Most metal-case mines are made from steel and are 1–2 mm thick. Steel generally does not burn, but it can soften and melt. If melted at about 1,300°C and boils at approximately 3,000°C. For neutralizing AP and staked mines by burning, a more powerful torch system is required due to the very thick mine case. A metal-case AT mine with a TNT main charge can easily be neutralized by burning. Any torch system that generates more than 1,300°C can be used against a metal-case AT mine. The mine will easily soften at a 2–3 mm thick metal case where the flame is striking. At the same time, TNT melts and vaporizes and increases the pressure inside the mine. When it reaches a high pressure, the softened metal part opens to allow vapors to escape. The vapors start burning and the burning continues until all the TNT vapors are gone from the mine. Generally, boosters also burn out and the detonator will pop out at the end. Therefore, any torch system which generates heat at more than 1,300°C is recommended for low-order neutralization by burning of metal-case AT mines.

**Burning characteristics of plastic-case mines**

Most plastic-case mines refer to polymers, and different polymers have different melting points. When burned with a flame, something has to form into a gas. Polymer molecules are far too long to do this in one piece, so one must get them hot enough to actually break down. There are two classes of polymeric mines: thermosetting and thermoplastic. The thermosetting polymers, such as Bakelite, will never soften unless burnt; it will just decompose. Bakelite is a material based on the thermosetting phenol formaldehyde resin; it was the first plastic made from synthetic compounds. Therefore, old AP and AT plastic case mines were made from Bakelite, such as AP mine types TM-62, TM-62P, PTM-62, etc. To neutralize these mines, it is necessary to use a powerful torch, such as the PT-1 shown in Figures 4 and 5. This type of neutralizing torch should not be directed at the center of the mine because the detonator explodes more sensitively to heat and can cause the mine to detonate. The TDF is also applicable to both types of AP directional mines. Two flares are recommended, using a stand with a 2–3 cm stand-off distance from the detonators and directed toward the entrance side (opposite to “front toward enemy” side) of the mine. The TDF will neutralize 90% of metal- and plastic-case AT mines. For metal-case mines, two flares are recommended without a stand and opposite to each other, away from the fuse with a stand-off distance of 1–2 cm. Because low-power torches cannot penetrate these cases, the fuse should never be used against Bakelite-case or wooden-case AT mines. Figures 1–3 show the applications of TDF against various AP and AT mines.

The Propellant Torch PT-1 is recommended for use against all Bakelite, thermosetting, and wooden-case AP and AT mines. When it is used against AP mines, no stand is necessary and the flare should have a stand-off distance of 4–5 cm from the mine. Place a 4–5 lb stone or sandbag at the back of the PT-1 torch. Figures 4 and 5 show the applications of PT-1 against AT and AP mines. The TDF is also effective against plastic-case metal-case AT mines; however, when the explosive is unknown or Amatol is present in a mine, use of PT-1 is recommended.

The Propellant Torch PT-12 has the capability to penetrate a 12 mm thick hard steel plate.

---

**Table 2.**

<table>
<thead>
<tr>
<th>Origin</th>
<th>Designation</th>
<th>Case Material</th>
<th>Explosive Weight (g)</th>
<th>Fuse Type and Fuzing</th>
<th>Activation Pressure (kg)</th>
<th>Body Trip Possible</th>
<th>No. of Torches Type of Torch</th>
<th>Standard Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>Type 69</td>
<td>Metal</td>
<td>TNT 0.105</td>
<td>Pressure or Autodeton</td>
<td>3–15 or Full</td>
<td>Yes</td>
<td>One PT-12</td>
<td>No</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>PP-68-Sr</td>
<td>Steel</td>
<td>TNT 0.245</td>
<td>Pressure or RO1</td>
<td>3–4 or Full</td>
<td>Yes</td>
<td>One PT-12</td>
<td>Yes (Except Surface or Buried)</td>
</tr>
<tr>
<td>Serbia (Yugoslavia)</td>
<td>FROM1</td>
<td>Steel</td>
<td>TNT 0.245</td>
<td>Pressure or UP-45</td>
<td>3–5 or Full</td>
<td>No</td>
<td>One PT-12</td>
<td>Attack at Neck</td>
</tr>
<tr>
<td>USSR (CSS)</td>
<td>OZM3</td>
<td>Cast Iron</td>
<td>TNT 0.185</td>
<td>RO1 or MUV</td>
<td>None</td>
<td>Yes</td>
<td>One PT-12</td>
<td>Above Ground</td>
</tr>
<tr>
<td>USSR (CSS)</td>
<td>OZM4</td>
<td>Cast Iron</td>
<td>TNT 0.185</td>
<td>RO1 or MUV</td>
<td>None</td>
<td>Yes</td>
<td>One PT-12</td>
<td>Attack at Neck</td>
</tr>
<tr>
<td>USSR (CSS)</td>
<td>MON 100</td>
<td>Steel</td>
<td>TNT 0.185</td>
<td>MUV or VPF</td>
<td>None</td>
<td>Yes</td>
<td>Two TDF Convex</td>
<td>Yes</td>
</tr>
<tr>
<td>Belgium</td>
<td>NBH-109</td>
<td>Plastic</td>
<td>TNT, PETN or TNT 0.058</td>
<td>Pressure</td>
<td>8–12 or Full</td>
<td>No</td>
<td>One TDF</td>
<td>No</td>
</tr>
<tr>
<td>China</td>
<td>Type 72</td>
<td>Plastic</td>
<td>TNT 0.051</td>
<td>Pressure</td>
<td>5–10 or Full</td>
<td>Yes</td>
<td>One TDF</td>
<td>No</td>
</tr>
<tr>
<td>Germany</td>
<td>PPM-2</td>
<td>Bakelite</td>
<td>TNT 0.11</td>
<td>Pressure or NO</td>
<td>3–15 or Full</td>
<td>No</td>
<td>One PT-1</td>
<td>No</td>
</tr>
<tr>
<td>Italy</td>
<td>VS-60</td>
<td>Bakelite</td>
<td>TNT 0.11</td>
<td>Pressure or NO</td>
<td>3–15 or Full</td>
<td>No</td>
<td>One PT-1</td>
<td>No</td>
</tr>
<tr>
<td>Italy</td>
<td>V-86</td>
<td>Bakelite</td>
<td>TNT 0.11</td>
<td>Pressure or NO</td>
<td>3–15 or Full</td>
<td>No</td>
<td>One PT-1</td>
<td>No</td>
</tr>
<tr>
<td>USSR</td>
<td>PMN</td>
<td>Bakelite</td>
<td>TNT 0.240</td>
<td>Pressure or NO</td>
<td>5–15 or Full</td>
<td>No</td>
<td>One PT-1</td>
<td>No</td>
</tr>
<tr>
<td>USSR</td>
<td>PNM-2</td>
<td>Bakelite</td>
<td>TNT 0.240</td>
<td>Pressure or NO</td>
<td>5–15 or Full</td>
<td>No</td>
<td>One PT-1</td>
<td>No</td>
</tr>
<tr>
<td>Serbia (Yugoslavia)</td>
<td>FPM2</td>
<td>Bakelite</td>
<td>TNT 0.10</td>
<td>Pressure or NO</td>
<td>5–15 or Full</td>
<td>No</td>
<td>One PT-1</td>
<td>No</td>
</tr>
<tr>
<td>Serbia (Yugoslavia)</td>
<td>FPM3</td>
<td>Bakelite</td>
<td>TNT 0.10</td>
<td>Pressure or NO</td>
<td>5–15 or Full</td>
<td>No</td>
<td>One PT-1</td>
<td>No</td>
</tr>
<tr>
<td>USSR</td>
<td>MON 50</td>
<td>Bakelite</td>
<td>TNT 0.10</td>
<td>Pressure or NO</td>
<td>5–15 or Full</td>
<td>No</td>
<td>One PT-1</td>
<td>No</td>
</tr>
</tbody>
</table>

**Note:**

- *PTM-62* is polyvinyl chloride (PVC) or polyethylene (PE) in core, polypropylene (PP) in outer jacket, polyethylene (PE), or polyethylene terephthalate (PET) in outer jacket.
- *TM-62* is polyethylene (PE) in core, polyethylene (PE), or polyethylene terephthalate (PET) in outer jacket.

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**References:**

- Journal of Conventional Weapons Destruction, Vol. 13, Iss. 1 [2009], Art. 43
the flame in such a way to allow run-off of the melted plastic to let the thermic energy genera-
ted by the torch flame come in direct contact with the explosive charge of the landmine.

Burning characteristics of wood-case landmines: Some old AP and AT mines use wood cases. The types of wood cases used in landmines vary from tree to tree, to the point that some AP and AT mines have wood cases. The higher the susceptibility, the more easily a material is magnetized. The most important soil properties influencing the performance of metal detectors are magnetic susceptibility and electric conductivity.

Metal Detectors and Soil Influence

Metal detectors are the most widely used devices for landmine detection. This technology is based on the principle of electromagnetic induction. An alternating current is fed to a transmitter coil, which excites a magnetic field called the primary field. If the MD is operated in air, this field will not affect any field other than the primary field. If there is a metallic object, such as the fuze of a mine, in the vicinity of the detector, a current is induced within this object. This current in turn induces a secondary field, which is measured with a second coil and depending on its strength, may trigger an alarm.

Conclusions

The most common AP and AT mines used in landmines are represented in Table 1 (on the next page). One can see that, due to their high sus-
ceptibility, even small amounts of ferro- and ferrimagnetic minerals or materials substantially decrease the magnetic signature of soil.

Possible Fuse

The magnetic properties of some minerals and materials are listed in Table 2 (previous page) and Table 3 (above). One can assign minerals and materials to different categories of magnetic behavior:

- Diamagnetic: weak negative susceptibility
- Paramagnetic: weak positive susceptibility
- Ferrimagnetic: strong positive susceptibility
- Ferrimagnetic: strong positive susceptibility
- Anti-ferrimagnetic: moderate positive susceptibility

The magnetic properties of some minerals and materials are listed in Table 2 (previous page) and Table 3 (above).

The magnetic susceptibility of a material describes how likely this material is to become magnetized when it is placed in a magnetic field. The higher the susceptibility, the more easily a material is magnetized. The magnetic susceptibility of matter depends on its structure on the atomic scale. One can assign minerals and materials to different categories of magnetic behavior:

- Diamagnetic: weak negative susceptibility
- Paramagnetic: weak positive susceptibility
- Ferrimagnetic: strong positive susceptibility
- Ferrimagnetic: strong positive susceptibility
- Anti-ferrimagnetic: moderate positive susceptibility

Besides metallic objects, the soil itself may also excite a secondary field as a reaction to the detector's primary field. The strength of the soil signal depends on its magnetic susceptibility and, to a lesser de-
gree, on its electric conductivity. If the soil signal is strong, it can mask the mine signal and detection becomes difficult. The problem is getting worse with the decreasing content of modest remnants in the cu-
ing magnetic susceptibility of soils. The extent of deterioration in detector

tor performance depends on its basic layout and the specific model that is used.2

In this study we concentrate on characterizing the soil that is causing the problem.

Magnetic Properties of Soils

The magnetic susceptibility of a material describes how likely this material is to become magnetized when it is placed in a magnetic field. The higher the susceptibility, the more easily a material is magnetized. The magnetic susceptibility of matter depends on its structure on the atomic scale. One can assign minerals and materials to different categories of magnetic behavior:

- Diamagnetic: weak negative susceptibility
- Paramagnetic: weak positive susceptibility
- Ferrimagnetic: strong positive susceptibility
- Ferrimagnetic: strong positive susceptibility
- Anti-ferrimagnetic: moderate positive susceptibility

The magnetic properties of some minerals and materials are listed in Table 2 (previous page) and Table 3 (above).

One can see that, due to their high sus-
ceptibility, even small amounts of ferro- and ferrimagnetic minerals or materials substantially decrease the magnetic signature of soil.

Ferre-
magnetic materials like pure iron, nickel and cobalt do not occur in soils naturally. Their presence is due to anthropogenic input in the form of metallic clutters, which often causes false alarms.

Soil is the uppermost layer of the solid earth. It is the product of the weathering of rocks by physical, chemical and biological processes over very long time periods. Soil is a mixture of mineral and organic material, which is formed by the weathering of the parent rock from which the soil was formed by weathering, or of pedogenic origin (i.e., they are formed during soil genesis). When magma cools, it solidifies and forms igneous rocks. The types of minerals in these rocks depend on the chemical composition of the magma. The higher the iron content of the mag-