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PPE: Effective Protection for Deminers

This article briefly explains the work that Med-Eng Systems, Inc., has done on personal protective equipment (PPE) over the past few years.

**by Jeffery Nerenberg, Jean-Philippe Dionne and Aris Makris, Med-Eng Systems, Inc.**

**Introduction**

Med-Eng Systems (MES) is the world leader in the research, design and manufacture of PPE for persons facing the threat of an explosive device. Since its inception in 1981, MES has become best known for its explosive ordnance disposal (EOD) suits and helmets, which are in wide use around the world by police and military units. As a natural extension to this line of protective ensembles, MES has chosen to design and produce various lightweight ensembles and equipment for demining. These efforts began in earnest in the late 1990s in collaboration with both the U.S. Army Communications and Electronics Command (CECOM) Research, Development and Engineering Center (RDEC) Night Vision and Electronic Sensors Directorate (NVESD) at Fort Belvoir and the Canadian Centre for Mine Action Technologies (CCMAT), based at Defence Research and Development Canada (DRDC)-Suffield. Aside from developing a wide range of PPE, these continuing cooperative efforts have allowed extensive systematic evaluation of PPE using real and simulated mine threats, new test methodologies to be established, and the measurement of the effect of mines on the human body. This article briefly discusses the features of the created equipment, explains how the equipment was evaluated and provides an overview of test results.

**Designing for the Threats of a Mine Blast**

Before delving into the specific components of PPE, it is useful to briefly review the threats posed to the deminer by the detonation of a mine. This helps to explain many of the features that are built into the PPE. When facing a conventional explosive device such as a landmine, four threats are considered. The first is overpressure, or the sudden and drastic rise in ambient pressure as the blast wave from the detonation emanates from the mine. When very close to the mine, such as when a mine detonates while being stepped on or being handled, the overpressure levels may result in amputations. Overpressure levels decay rapidly with standoff distance; however, they can still cause eardrum injuries and can lead to hemorrhaging of the lungs and bowels when the deminer is in close proximity to the AP mine.

Fragmentation forms the second and most obvious threat from a mine. Pieces of mine casing, fragments, soil or stones can all cause punctures, lacerations and lethal injuries to vital organs. The third threat from a mine is impact. This is a result of the overpressure wave inducing violent levels of acceleration on the head of the victim, which in turn can cause a range of concussive injuries, depending on head positioning relative to the mine and standoff distance. The final threat is the range of heat and flame injuries that can result from the short-lived fireball released upon detonation.

While the four threats are each separate causes of injury, they rarely act in isolation; rather, they operate together to create the overall level of injury. As a result, PPE design needs to account for all the threats from a blast in order to reduce the overall injury level. It should be noted that when a victim is injured by detonating a mine, the obvious open wounds are the ones that receive immediate attention, though other injuries that may be less visible could be more serious.

**Protection for the Torso and Body**

Two lightweight protective ensembles for the torso and body of the deminer have been developed. The Lightweight Demining Ensemble (LDE) is a two-piece system designed to provide continuous front protection to the deminer from the lower legs up to the neck and over the shoulders (Fig. 1). The back of the system is left open to prevent the buildup of heat. A base stacking of soft ballistic materials provides fragmentation protection throughout, while rigid ballistic plates in combination with a blast attenuation system are in place over the vital regions of the chest, abdomen and groin to provide added protection. The plate in place over the chest of the apron also serves the vital purpose of integrating with the visor of a protective helmet system, which provides a continuous layer of enhanced blast and fragmentation protection over the critical frontal torso region. The LDE system also comprises modular accessories to add protection to the arms and back of the deminer, if so desired.

The second system is the Demining Apron, a one-piece system based on the LDE that provides protection to the frontal upper body of the deminer, from the thighs to the neck (Fig. 2). The lighter
weight of the Demining Apron makes it especially suitable for use in hot and humid climates, while still providing, as an advanced level of protection. Similar to the LDE, a rigid plate and blast attenuation system are in place over the chest, to enhance protection and to integrate with a protective helmet. Both the Demining Apron and LDE provide ballistic/fragmentation protection corresponding to a minimum V50 level of 500 m/s tested in accordance with MIL-STD 662E, when tested with the 17-grain fragment-simulating projectile (FSP). However, due to the presence of the lightweight rigid plate, this increases to 575 m/s over the torso.

The LDE and Demining Apron systems have been subjected to extensive testing to evaluate their ability to protect the deminer. The most common testing was to dress instrumented anthropomorphic mannequins with the PPE and place these human surrogates in realistic demining scenarios. A simulated mine—composed of a short cylinder (or pack) of C4 explosive within a plastic casing buried in the ground at a controlled depth—would then be detonated to simulate a demining accident. The simulated mines ranged in size from 50 to 200 g of C4 to represent a wide range of mines including the proliferate PMIN. Full-scale testing like this allows for a comprehensive evaluation in a realistic environment: the blast integrity of the equipment (including helmets, hand protectors and other accessories) can be observed, and the effect of the mine detonation on the body can be measured (Fig. 3).

The concept of these tests is simple. However, to obtain sound data for meaningful evaluation, careful control of all variables is required. Perhaps the most significant challenge was mannequin positioning. A 77-kg surrogate mannequin does not easily adopt a consistent stance. As a result, an advanced positioning apparatus was designed and constructed by MES. The apparatus is fully adjustable in all planes and allows for the mannequin to be placed in a full range of positions, all with precise repeatability. Moreover, the use of small-link chains for support does not interfere with the mannequin’s internal biodynamic response under blast loading. This test rig proved so effective that its use has been adopted by CCMAU, the U.S. Army (Fort Bragg), and the Aberdeen Test Center for their own evaluations of demining PPE.

The performance of both the LDE and Demining Apron during full-scale blast mine tests demonstrated their effectiveness as demining protection. In terms of blast integrity and fragmentation resistance, the LDE and Demining Apron have not been penetrated by the fragmentation created by the blast-type AP mines used. The MIL-STD 662E standard is observed in the form of minor localized ripping of the outer shell that does not compromise protection levels.

For the obvious reason of providing shielding from fragmentation and flame, the head and face of the deminer need to be protected. When subjected to blast- and fragmentation-induced injury, the most common consequence on a person of the confining effect the ground has on a buried mine is when a mine explodes, because it is buried in soil, the majority of the eminently threats are located in a conical region because the ground and soil focus the effects. By placing oneself in a lower position while still maintaining standoff distance, the exposure to this conical region of increased threat can be reduced, and the injurious effect on the deminer can be diminished (Fig. 6).

As an example, during testing it was shown that adopting a relatively low position, while maintaining standoff, could reduce the measured levels of head acceleration by half.

Hand Protectors

During demining operations, the hands of the deminer are often in close proximity to live mines. As a result, the hands become extremely vulnerable and challenging to protect. One solution is to maximize standoff distance; however, this is not always possible. In conjunction with users, MHS has developed a pair of hand-protection devices that can be used during operations.

The Conical Hand Protector (CHP-100) is designed to be used during conical standing with a slender, cylindrical mine probe (Fig. 2). A threaded rubber plug and cap secure the probe in place, so that
The evaluation of the hand protector was done by placing them on the hands of the anthropomorphic manikins used in the blast testing described above (Fig. 3). During the over 240 tests performed, the protectors were placed as close as 15 cm from the simulated mines; however, the most common standoff distances were between 20 and 30 cm.

Results of blast testing indicate that these demining hand protection concepts provide excellent protection and offer the potential to reduce and minimize injury to the hand of a deminer. Throughout the entire span of tests, the hand protectors were never found to reduce fragmentation, and in most tests, they retained their structural integrity. Figure 7 illustrates a typical result from a 200-g Claymore mine, showing increased ripping of the outer shell, but with overall structural integrity intact. A note of caution, however: because these tests have been performed with mannequins and not biological specimens, a precise estimate of injury reduction cannot be performed, despite the encouraging results.

Protection for the Foot

If a deminer steps on a mine while wearing a conventional boot or even a typical "blast boot," the foot is usually in close proximity to the charge, as only a thickened or reinforced sole separates the foot from the mine. At such small standoff, the overpressure, fragmentation, and heat generated by even small mines overwhelm the integrity of most materials. The result is likely a traumatic amputation of the foot and lower leg, depending on mine size. To address this problem, the Spider Boot was developed. It consists of a shielded platform suspended by four "legs" projecting inwards and outwards (Fig. 1). A regular boot is attached to the platform through an adjustable bonding system. The design of the Spider Boot is such that if a mine is triggered, it is done so by one of the pods, resulting in a much increased standoff distance between the exploding mine and the foot compared to conventional footwear. This results in the blast effects of the mine being allowed to dissipate substantially before interacting with the foot.

The development of the Spider Boot, blast tests were carried out using a mechanical surrogate leg in collaboration with ECMAT, which demonstrated the effectiveness of the Spider Boot (Figs. 8a & 8b). By measuring various parameters on the surrogate leg, the effects transmitted by the blast could be recorded. The Spider Boot, with its built-in standoff, was able to reduce the effects transmitted to the surrogate foot by more than 90 percent compared to select commercially available blast boots.

Further testing was performed by the U.S. Army NVEUSD under the Lower Extremity Assessment Program (LEAP) to evaluate the performance of various types of mine-protective footwear. In these tests, the footwear—including the U.S. Army Combat Boot, two commercially available blast boots (with and without overboot), and the Spider Boot—was placed on the foot of cadaver specimens.

For the Spider Boot, no amputation was deemed necessary for any of the cadavers tested against the large PMN mine (249-g INT). Moreover, in the one test that an amputation might have been the outcome predicted, no contamination of the wound was observed, making the injury less severe.

In contrast, it was found that even for the small M-14 mine (28 g explosive), the commercially available blast boots with overboots provided only limited protection, with three tests out of five resulting in traumatic amputation of the lower leg. (The Spider Boot was not tested against the smaller M-14 mine, as it was deemed unnecessary, due to its proven superior protection for much larger mines). Against the larger mines (the PMN-2 and the PMN), amputation was always required with the blast boot/overboot combination. These limited results seem to confirm the important role of standoff in the design of a mine. There have also been several recent blast blast series of the Spider Boot conducted by military scientists of the North Atlantic Treaty Organization (NATO) and other countries during 2002.

Summary

MES has developed a full range of PPE for use by deminers. If it is desired, the deminer can choose protection to cover the body, the head and face, the hands, and the feet. Aside from the development of this equipment, extensive scientific testing has been carried out to demonstrate its effectiveness. The possibility of concussive injury and overpressure impinging the torso and ears has been shown to be dramatically reduced by the use of a combination of the LDE or Demining Apron with the LDH or VBS-250. Moreover, through the systematic testing performed, it has been demonstrated that even seemingly small changes in demining posture can have a dramatic consequence on the blast effects experienced by the deminer in the case of an accident. Testing has also been able to demonstrate that the hand protection created could significantly reduce injury in certain situations. The foot-protecting Spider Boots, with their unique ability to introduce the essential standoff between the mine and the deminer’s foot, and a further deflection and dispersion of the blast wave and its effects, have been shown to significantly reduce the injury outcome a deminer would experience when a mine is stepped on.

This paper is only able to briefly summarize the extensive programs that MES and its testing/development partners have carried out over the past five years to design effective protection for the deminer. Extensive test reports, papers and documentation are available to expand upon the information provided.

![Figure 8a & 8b: Testing of Spider Boot on instrumented mechanical surrogate leg. First image shows a Spider Boot in place over a PMN-1 mine (200-g explosive). The second photograph was taken after the blast. The force of the blast has removed the front boots, by design, but the standard combat boot remained intact. The standoff distance introduced by the rubber boots helps to dissipate the blast effects of the mine before they can impact with the foot of the user.](image)

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**References**


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**Figure 7: PE-100 after having been exposed to the blast from a 200-g C-4 mine at close range.** The blast has penetrated the surface, and superficial damage has occurred that the overall integrity of the hand protector has remained intact. Note: the force of the blast severely bent the steel mine prod.

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**Figure 6: Photograph and schematic from live blast test demonstrating conical region of increased threat created by mine buried in soil. The green line shows the region and soil serve to confuse and focus the blast effects. By removing the relatively low in orientation while still maintaining standoff distance, the exposure to this region can be reduced.**