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PPE: Effective Protection for Deminers

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

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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 frontal 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

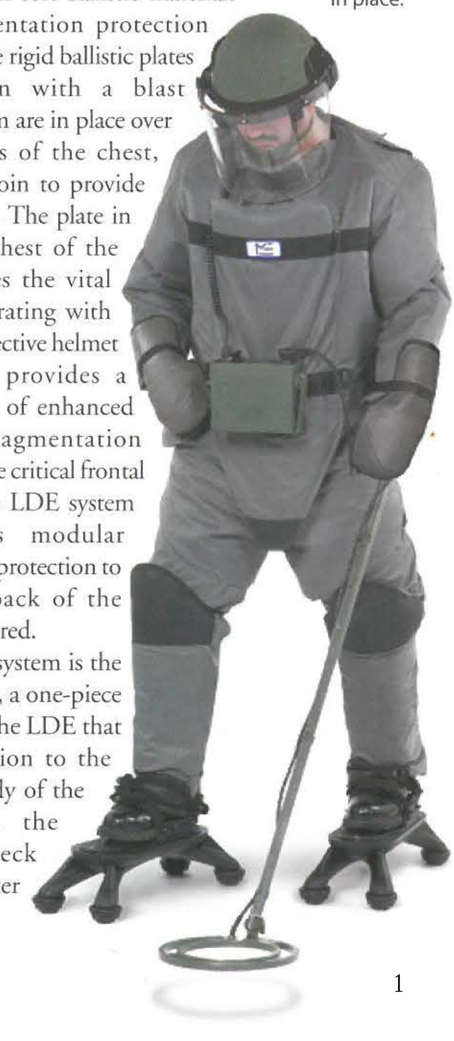
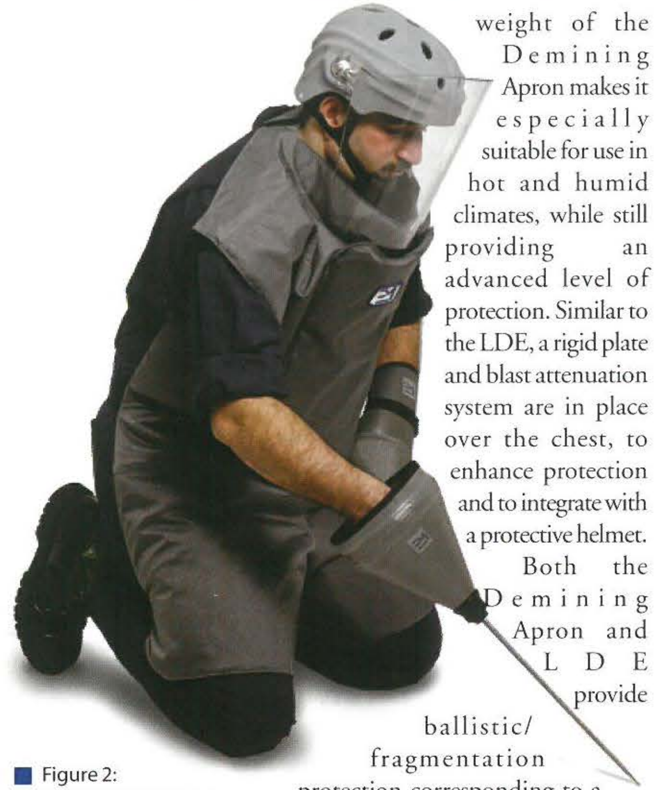


Figure 1: Deminer equipped with LDE, VBS-250 helmet system, the OHP-100 on the hands, and a pair of Spider Boots protecting the feet. Available optional protective sleeves are also in place.



weight of the Demining Apron makes it especially suitable for use in hot and humid climates, while still providing 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 450 m/s (tested in accordance with MIL-STD-662F), when tested with the 17-grain fragment-simulating projectile (FSP). However, due to the presence of the lightweight rigid plates, this increases to 575 m/s over the torso.

Figure 2: Deminer equipped with the Demining Apron, the LDH Helmet, a CHP-100 on the left hand, and an OHP-100 on the right. Note the integration between the visor of the LDH and the chest plate of the Demining Apron.

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 positions. A simulated mine—composed of a short cylinder (or puck) 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 PMN. 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).

Figure 3: Test setup for full-scale blast testing. The mannequin, equipped with the LDE, LDH, OHP-100 and CHP-100, is placed in kneeling position with a nose-mine standoff of 80 cm. The mine position is marked by the orange flag.

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 inanimate 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 discrete steps and allows for the mannequins 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 mannequins' initial biofidelic response under blast loading. This test rig proved so effective that its use has been adopted by CCMAT, the U.S. Army (Fort Belvoir), and the Aberdeen Test Center for their own evaluations of demining PPE.

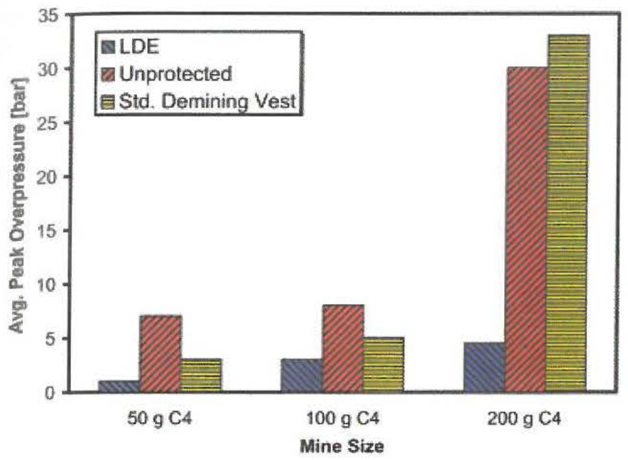
The performance of both the LDE and Demining Apron during full-scale blast mine tests demonstrated their effectiveness as demining protection. In terms of blast integrity and fragmentation resistance, the LDE and Demining Apron have not been penetrated by the fragmentation created by the blast-type AP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

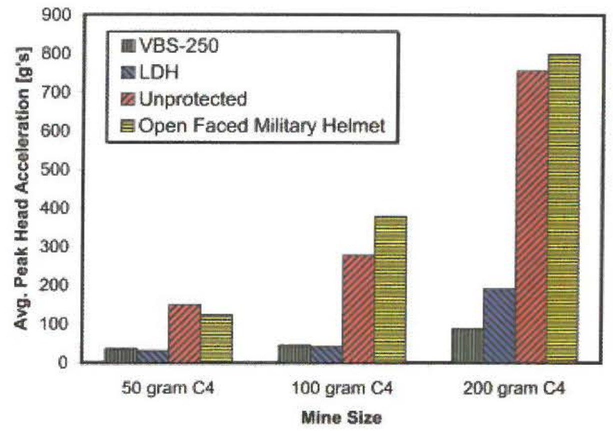
When the overpressure transmitted to the chest is examined (as recorded by a pressure sensor installed at the sternum of the mannequins), the advantage of the rigid chest plate and blast attenuation system becomes readily apparent. Over the range of charge sizes tested, the LDE and Demining Apron provide, on average, in excess of 85 percent attenuation of overpressure (Fig. 4). This serves to greatly reduce the probability of overpressure injury to the torso when in close proximity to a sizeable blast AP mine. Of greater concern is the observed behavior of more standard protection. When a standard demining vest is used, composed essentially of soft ballistic materials only, there exists the potential for the overpressure transmitted to the chest to actually be *amplified* compared to the unprotected case. The mechanism for this is not entirely understood, but it has been observed numerous times in various studies.[1]

Protection for the Head

Two head and face protection systems have been designed and tested. The Lightweight Demining Helmet (LDH) provides head and face protection by having a 5.7-mm visor mounted onto a lightweight, yet stable, helmet platform (Fig. 2). The visor is designed to protect the entire frontal profile of the head, while also integrating with the rigid chest plate of both the LDE and Demining Apron. By having the visor fit in behind the top of the chest plate, overpressure is inhibited from directly reaching the inside of the visor, helping to ensure that the visor and helmet remain in place over the head and face of a user throughout a blast event. The Visor Band System (VBS-250) is designed for those users who desire to use, or are already equipped with, a military-style helmet (such as a PASGT helmet or similar). The VBS-250 (Fig. 1), through a four-point mounting bracket, rigidly attaches a 5.7-mm visor to an infantry helmet. In the same fashion as the LDH, the visor is designed to integrate with the chest plate of the LDE or Demining Apron. Both helmet systems offer a V50 rating of 250 m/s over the face of the deminer (according to MIL-STD-662F).

For the obvious reason of providing shielding from fragmentation and flame, the head and face of the deminer need protection. However, the threat of concussive injury from blast-induced head acceleration also needs to be considered. For this reason, when the mannequin blast





(Left to Right) Figure 4: Average overpressure measured at sternum of mannequins placed in kneeling position, facing mines at an 80-cm nose-mine standoff. This demonstrates the ability of the LDE to dramatically attenuate overpressure and shows that a standard demining vest composed essentially of soft ballistics only can actually amplify the overpressure levels experienced.
Figure 5: Average peak head acceleration measured in mannequins placed in kneeling position, facing mines at an 80-cm nose-mine standoff. This demonstrates the ability of the LDH and VBS-250 to dramatically reduce blast-induced head acceleration. Moreover, this chart illustrates that using an open-faced helmet without a visor can actually serve to amplify head acceleration over the unprotected case.

tests were carried out, sensors to measure head acceleration were employed. From these measurements, the ability of the LDH and VBS-250 to reduce head acceleration becomes apparent. Both systems attenuate head acceleration by a factor of 75–90 percent, compared to facing a mine unprotected (Fig. 5).

The importance of using a visor to protect the face becomes especially apparent when tests are carried out with an open-faced military helmet. Since the circumference of the helmet is greater than the head it is protecting, the helmet acts as a trap for the incoming blast winds, which can result in the head being accelerated at a greater rate than an unprotected head.

In an attempt to determine the effect of head acceleration on the deminer, the Head Injury Criterion (HIC) was used to estimate injury outcome.[2] While a full description of these studies is beyond the scope of this paper, from the HIC it was shown that an unprotected deminer faces a high probability of fatal concussive injury, particularly when facing larger mines. Moreover, according to the HIC, the LDH and VBS-250 are able to significantly reduce injury severity. As an example, in tests when the mannequins faced a 200-g C4 mine in a kneeling position at an 80-cm nose-mine standoff, the unprotected deminer was predicted to experience a 100 percent probability of a fatal concussive injury. On the other hand, when equipped with the LDH, the injury prediction changed radically, with a predicted 64 percent probability of *no* injury. With the VBS-250 in place, the likelihood of no injury increased to 88 percent.[1] While the HIC has not been validated as an applicable means to assess blast-induced head acceleration injuries, the data presented illustrate a relative effectiveness of the different helmet systems in providing protection.

The use of a full-faced visor mounted on a helmet also leads to significant reductions in the overpressure that acts on the ear. By mounting a pressure sensor at the area of the ear on the mannequins, it was measured that, compared to the unprotected case, the LDH and VBS-250 both reduce the peak levels of overpressure by between 40 and 85 percent.

Deminer Positioning

Through an examination of head acceleration measurements, the importance of subtle changes in the deminer's position was assessed. One aspect that was studied was changing standoff position by 10-cm increments. For example, it was found that by increasing standoff from 70 cm to 80 cm, in a kneeling position, could cut head acceleration levels measured by more than half—when unprotected *or* equipped with a helmet system. This, of course, also results in corresponding reductions in probable injury.[3]

The orientation of the mannequin was also varied in testing, while still maintaining constant standoff in a kneeling position. The mannequins were either placed in a relatively upright position or a lower position. This was done to examine the consequence on a person of the confining effect the ground has on a buried mine. When a mine explodes, because it is buried in soil, the majority of the emanating threats are located in a conical region because the ground and soil focus the effects. By placing oneself in a lower position while still maximizing 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.[3]

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. The best solution is to maximize standoff distance; however, this is not always possible. In conjunction with users, MES 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 mine prodding with a slender, cylindrical mine probe (Fig. 2). A threaded rubber plug and cap secure the probe in place, so that

Figure 7: CHP-100 after having been exposed to the blast from a 200-g C4 mine at close range. While superficial damage has occurred, the overall integrity of the hand protector has remained intact. Note that the force of the blast severely bent the steel mine prodder.

prodding can take place with the hand shielded behind the cone. The conical shape is designed to deflect the force of the blast away from the hand, wrist and lower arm. The second hand protector, the Overhand Protector (OHP-100) covers the top of the hand, allowing the fingers, thumb and palm to move freely (Fig. 1). This device is designed for more general use, and can be used on both hands while operating a metal detector, on the passive hand while prodding, or while clearing vegetation.

The construction of the two hand protectors is similar as they use a combination of soft and rigid ballistic materials to both supply maximum penetration resistance from a range of particle sizes and provide a rigid structure to maintain the protectors' shape during a blast. Both protectors have a V50 rating of 300 m/s when tested with the 17-grain FSP (according to MIL-STD-662F).

The evaluation of the hand protectors was done by placing them on the hands of the anthropomorphic mannequins 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 penetrated by fragmentation, and in most tests, they retained their structural integrity. Figure 7 illustrates a typical result from a 200-g C4 simulated 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.[1]

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" protruding frontwards and backwards (Fig. 1). A regular boot is attached to the platform through an adjustable binding 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.

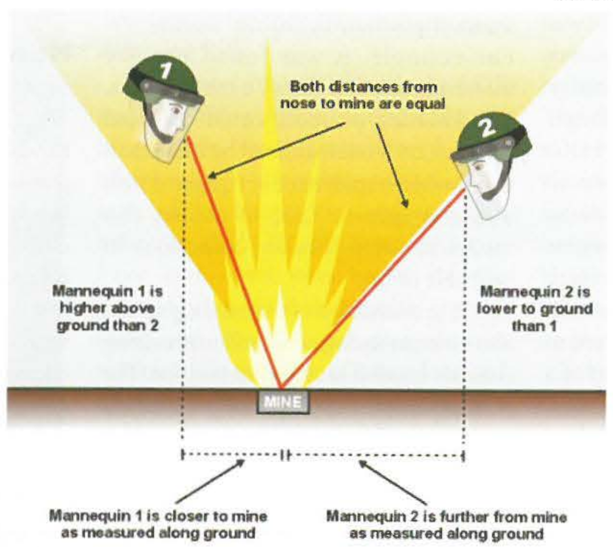
During the development of the Spider Boot, blast tests were carried out using a mechanical surrogate leg in collaboration with CCMAT, which demonstrated the effectiveness of the Spider Boot (Figs. 8a & 8b). By measuring various parameters on the surrogate leg, the forces transmitted by the blast could 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.[4]

Further testing was performed by the U.S. Army NVESD 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 feet of cadaver specimens.[5]

For the Spider Boot, no amputation was deemed necessary for two of the three tests performed against the large PMN mine (249 g TNT). Moreover, in the only case 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 of 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 PMA-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 boot. There have also been several recent blast test series of the Spider Boot conducted by military scientists of the North Atlantic Treaty Organization (NATO) and other countries during 2002.

Figure 6: Photograph and schematic from live blast test demonstrating conical region of increased threat created by mine buried in soil. The ground and soil serve to confine and focus the blast effects. By remaining relatively low in orientation while still maximizing standoff distance, the exposure to this region can be reduced.



Summary

MES has developed a full range of PPE for use by deminers. If so 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 ejecta, 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 PMA-1 mine (200-g explosive). The second photograph was taken after the blast. The force of the blast has removed the front pods, by design, but the standard combat boot remained intact. The standoff distance introduced by the legs of the boots helps to dissipate the blast effects of the mine before they can interact with the foot of the user.

All graphics courtesy of the authors.

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