DISPOSAL OF EXPLOSIVE ORDNANCE AND ENVIRONMENTAL RISK MITIGATION: TIME FOR HUMANITARIAN MINE ACTION TO CATCH UP?

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Humanitarian mine action (HMA) survey and clearance operations have always focused on the contamination that can be seen. Whether it is anti-personnel (AP) mines, anti-vehicles (AV) mines, or explosive remnants of war (ERW), our efforts focus on removing items that pose an immediate blast and fragmentation hazard to humans. However, in certain circumstances, explosive ordnance (EO) also poses a significant environmental hazard, not least from the toxicity of its components, such as heavy metals and explosives. The understanding of contamination from EO in air, soil, and water has developed significantly in recent decades.[1-4] This has mainly been driven by scientists and industry, as well as military users required to focus on the environmental impact of military training, and led to the development of improved management practices to mitigate the associated environmental risk.[5-8] In some countries this has resulted in significant policy change. Notably the tonnage of munitions disposed of by open burning open detonation (OBOD) by the United States Department of Defense decreased by 58 percent during the period 1998–2018.[9] In comparison, it is not clear that HMA is universally applying best practice to mitigate the chemical contamination risk from its clearance and explosive ordnance disposal (EOD) activities. A sector that follows simple principles such as "do no harm" and ostensibly always seeks to apply "all reasonable effort" might wish to review and update its current approach.

HMA often operates in environments where perfection may be deemed the enemy of good. What is practicable on a military range in the United Kingdom might not be so in the complex environments of current HMA operations. Therefore, the task is to develop practical mitigation methods that have a good chance of being applied, no matter the location. Examples of such methods could range from using an inexpensive kit to check the pH of soil for a central demolition area, to more training to recognize and safely dispose of munitions containing heavy metal tungsten alloys (HMTA). A number of practical improvements are possible. The first step for HMA organizations is to recognize the issues and then implement better methods accordingly.

LEGISLATION

Relevant legislation tends to cover broad principles of pollution rather than specific contamination types such as those from EO. Such international legislation that does exist governs the disposal of munitions that cross international borders and, as an example, preclude the dumping of munitions at sea. The European Union's Water Framework Directive 2000/60/EC[10] and the United States Clean Water Act 1972[11] are important reference points. In the United Kingdom, the Water Resources Act 1991[12] and the Environmental Protection Act 1990[13] are the key pieces of legislation. Beneath the level of legislation, the International Ammunition Technical Guideline (IATG) 10.10 specifies the need for national authorities to set the standards governing environmental protection within national borders,[14] but how much this has been applied globally is open to question.[15] IMAS 07.13, Environmental Management in Mine Action, does "not enforce specific practical mitigation measures but is a framework giving the tools for the NMAA to define these."[16]

THE ENVIRONMENTAL IMPACT OF HMA

HMA damages the environment. A certain level of damage is inevitable. Traditionally this damage has been associated with the physical process of clearing land of AP and AV mines. To clear land invariably requires most vegetation to be removed, with the possible exception of trees above a certain size, alongside physical excavation of the topsoil. This damage was, and is, accepted as an inevitable part of the demining process. Typically, the damage would not be permanent, and the land re-used relatively quickly. Locals often welcome the clearance on the basis that the land will be easier to cultivate once mine action has not only removed the mines but also removed much of the vegetation and made the soil easier to work.[17] Clearance operations among sand dunes have required the remediation of the environment, once the clearance is completed, as was the case in Skallingen up to 2012.[18] Aside from the potential physical damage, mine action organizations also impact the environment in the same way most human activity does, be it emissions from vehicles or generators, human waste, etc. It is this generic impact that has been, to a degree, addressed within IMAS 07.13 and in standard operating procedures (SOPs).

The chemical contamination from explosives has often not been recognized or understood by clearance operators. Few SOPs include direction on how to mitigate the environmental impact of burning small arms ammunition (SAA), open burning or open detonation of high explosive natures, destruction of certain types of white phosphorous, or destruction of armor penetrating ammunition containing HMTA. Furthermore, at some point HMA operators will encounter EO containing insensitive explosive formulations, the inherent environmental hazards of which are subject to continuing research. These formulations present a potentially different pollution hazard compared with traditional munitions. Such contamination is or will be part of HMA's environmental impact, and operators are responsible for the contamination that could reasonably have been prevented during clearance and disposal operations.

SMALL ARMS AMMUNITION (SAA)

Most SAA contains lead, along with smaller amounts of alloying material such as antimony. Lead slag is classified as Toxic Solid UN 6.1 (UN ID 3288).[19] The U.S. Department of Health and Human Services Food and Drug Administration states that in "humans and animals, exposure to lead may cause neurological, reproductive, developmental, immune, cardiovascular and renal health effects. In general, sensitivity to lead toxicity is greater when there is exposure in utero and in children compared to adults."[20]

The safe disposal of SAA presents a significant ongoing challenge to HMA clearance operators. The days when SAA was added to bulk demolitions are hopefully long in the past. Currently, most SAA is burnt in some way. Open pit burns used to be one technique used, but this method is guaranteed to introduce lead contamination directly into the soil. Organizations have developed improvised or bespoke burning tanks that, if strong enough, are also used to burn the primers and boosters within fuzes of a certain size. Military organizations have increasingly used industrial rotary kilns. The capital expenditure these require has meant they are yet to be deployed in HMA.

Regardless of the method of burning, the slag residue from SAA is typically buried. This is potentially a significant risk to the environment, especially if done in large quantities. Burial without knowledge of local soil and water course conditions is a practice that should cease in HMA. Many operators are unaware of the concept of fate and transport of lead contamination. In simple terms this follows a source-pathway-receptor (SPR) model, with lead being the source in this instance. The pathway would be the means by which the contaminant moves through the environment; by air, soil, or water. The receptor is the entity that can be adversely affected by the contaminant.[21] The transport depends on contaminant solubility, which in turn is governed by pH and oxidation. Lead is an amphoteric metal that exhibits its greatest solubility in acidic ($pH < 4$) and heavily alkaline ($pH > 11$) solutions.[22] "Lead corrodes and leaches readily in acidic conditions to concentrations that can exceed guidelines for human health and controlled waters."[23] Despite this risk, no current HMA SOPs are known to detail even a basic environmental risk assessment prior to the burial of SAA slag residue, or even possible mitigation measures.

HEAVY METAL TUNGSTEN ALLOYS

The concern over the alleged carcinogenic effects of depleted uranium (DU) since 1991 lead to the development of tungsten alloys as an alternative for armor piercing ammunition.[24] Unfortunately, tungsten alloys have been the cause of increasing concern for those charged with mitigating the environmental impact on military firing ranges. Tungsten alloys have been proven to be carcinogenic during animal testing.[25,26] The main risk for HMA staff and civilians who may come into contact with HMTA are sintered[27] splinters piercing the skin and

An SAA burn pit. The SAA was burnt in an open pit with a simple metal cover. The slag residue was subsequently buried. This method is hopefully no longer used by operators. Burying the slag residue from SAA pit burns concentrates the toxic waste and is potentially a significant pollution risk.
Image © Private.

subsequently becoming embedded, especially for alloys combining tungsten with nickel or cobalt.[28] HMTA ammunition, whether it is from SAA or long rod penetrators, is far more likely to sinter if added inadvertently to bulk demolitions. In a worst-case scenario, whether by means of a single item demolition or as part of a bulk demolition, an unknowing operator could spread dangerous WNiCo splinters[29] into the environment posing a risk to themselves, other humans, and animals.

ENVIRONMENTAL IMPACT OF TRADITIONAL EXPLOSIVE FILLS

Most high explosive munitions contain one or both of Cyclotrimethylenetrinitramine (RDX) or Trinitrotoluene (TNT). Munitions containing RDX invariably contain a small percentage of cyclotetramethylene-tetranitramine (HMX) and more modern shaped charges will often have HMX as the key energetic ingredient. All three explosives have some degree of toxicity.[30] The nitro aromatic TNT can undergo degradation to form the 2,4 Dnitrotoluene (DNT) isomer, a common biodegradation product of TNT that displays greater toxicity. DNT can convert haemoglobin to methaglobin[31] at a relatively low threshold limit of 0.13 mg/L and is therefore listed by the United States Environmental Protection Agency (EPA) as hazardous waste.[32] DNT is highly toxic to humans.[33,34]

The nitramine RDX has been designated a possible human carcinogen (categorization C) by the EPA. The EPA has set drinking water advisory limits for TNT, RDX, and HMX.[35,36] TNT and DNT tend to bind to organic matter in the earth and therefore don't transport as readily as RDX, which has greater potential as a pollutant of groundwater.[37]

These explosives present a particular issue for HMA operators since much of the EO destroyed by the sector is by means of second order detonation, i.e., a donor charge is used to shatter the casing and initiate the main charge by means of sympathetic detonation. Some high explosive munitions, especially thin-cased mines, may be destroyed by burning. There is now substantial evidence to suggest that both methods will result in significant levels of energetic residue compared with a first order detonation, where the munition fuzing system detonates the main charge as intended after firing.[38,39] Testing of military firing ranges over time suggests that contamination tends to stay in the topsoil, approximately the first 30 cm, depending on the soil type.[40,41] For HMA operators the risk is highest in areas where high EO is repeatedly destroyed by second order demolition, i.e., a central demolition site (CDS), a process sometimes referred to as "residue loading." This risk is higher in areas with moderate or high levels of precipitation, a shallow water table, slow moving groundwater, and proximity to a water course.[42] What measures do HMA operators currently take to monitor and limit the explosive residue contamination from second order demolitions?

(Above) An inert cutaway of the new HMTA 40 mm telescopic APFS-DS-T round. Ammunition containing HMTA, especially WNiCo alloys, pose a hazard to humans if sintered splinters puncture the skin. Are we training HMA EOD operators to correctly identify and dispose of such ammunition?
Image courtesy of Andrew Duncan.

INSENSITIVE MUNITION EXPLOSIVE FORMULATIONS

Many NATO countries are developing insensitive munitions (IM). Typically, this development concentrates on the high explosive fill, with traditional formulations such as Composition B (60 percent TNT, 40 percent RDX), being replaced by formulations containing reduced vulnerability energetic materials. These will have high thermal stability and will to some degree be resistant to shock. Explosives such as Nitrotriazolone (NTO) and 2,4-Dinitroanisole (DNAN) are key ingredients for the new US insensitive explosives, IMX-101 and IMX-104, being fielded for gun artillery and mortars respectively. Both NTO[43] and DNAN[44] are undergoing further study to assess acute and chronic toxicity on the environment and humans.[45] In terms of residue deposited from IM munitions, recent testing has shown that standard methods of high order for single items of high EO leave significantly more explosive residue.[46,47] For example, PAX-21, an insensitive formulation of RDX, DNAN, and ammonium perchlorate, can deposit residues of up to 28 percent of the perchlorate, even during first order detonations.[48] Ammonium perchlorate residues are also common at firing points, and it may therefore be assumed in areas where HMA operators burn propellant, residues will also be high. The US EPA identifies the chronic exposure to perchlorate, (even at very low levels), as interfering with the iodine uptake into the thyroid gland.[49]

WHAT PRACTICAL STEPS CAN BE TAKEN?

The first and main practical step for HMA operators to take is to ensure that their professional knowledge of explosives remains current, and to update their procedures accordingly. This requires developing SOPs detailing how they will minimize the risk of chemical contamination from the disposal of EO including SAA. These should include direction on the safe disposal of SAA slag residue, ideally contracted through specialized waste disposal companies. Since these are invariably not present in many countries, at a minimum, operators should ensure that no slag residue is buried in acidic soils and should conduct the simple tests to ensure this. (A simple soil pH testing kit can be purchased for as little as USD$10.) If there is no other option but to bury SAA slag residue, it should be sealed in watertight plastic barrels to prevent leaching into the surrounding

Bulk demolition using binary liquid explosive. How much explosive residue may be deposited by repeat bulk demolitions at central demolition sites by HMA operators? Are EOD operators aware that such techniques will need to be adapted for insensitive munitions? Are EOD operators aware of the risks of adding HMTA ammunition to such a demolition?
Image courtesy of Roly Evans.

soil. For destruction of large quantities of SAA associated with a national stockpile this presents a logistical challenge since large quantities of barrels will be required.

Large-scale disposal of propellants and pyrotechnics often leaves an obvious area of contamination on the soil. Most of this contamination stays on the surface until rainwater washes it into the subsoil. Having considered the proximity of local water courses, where deemed practical, consideration may be given to the mechanical excavation and removal of this residue. It can then be treated in the same way as SAA slag is dealt with. The Canadian military developed a burning table technique for their artillery units to avoid open burning of excess propellants following live firing exercises[50] and it is possible the technique could be adapted for use in HMA.

In order to mitigate the actual residue deposition from second order demolition, operators should consider increasing the amount and quality of donor charge used, especially for repeat bulk demolitions at a CDS. If the fuze well is empty, as might be the case for destruction of stockpiled ordnance or abandoned explosive ordnance (AXO), operators are advised to use this for donor charge placement in order to maximize the chance of a first order detonation. Assuming some residue is unavoidable, operators should be careful about the sites selected for CDS. Again, acidic soil is likely to enable greater transport of contaminants and therefore soil at CDS should be tested. Ideally CDS should be a good distance from water courses and known groundwater locations.

Although IM are not yet commonly encountered within HMA, operators should understand the impact of their insensitivity during disposal. When destroying unfuzed ordnance from stockpiles, a donor charge placed in the fuze well should ensure full detonation. This is because the IM requires confinement to fully detonate, and a donor charge that is placed on the outer casing will have reduced the confinement before detonation of the internal explosive occurs. Alternatively, if the fuze well cannot be utilized, a shaped charge aimed at the booster is the best means of minimizing explosive residue.[51,52] Further testing is required to determine if IM can be effectively destroyed through sympathetic detonation by means of bulk demolition.

For both SAA burning sites and CDS (often the same location), operators should consider instituting a soil sampling regime. The time and the cost might be deemed impractical but ultimately HMA operators need to monitor at-risk locations in order to manage the potential contamination their disposal activities may create.

In order to mitigate the potential harm from HMTA, the key action for operators is to ensure all technical staff can accurately identify EO containing HMTA, whether it be SAA or a 125 mm long rod penetrator. Such munitions should not be disposed of through standard OBOD techniques. HMTA should be handed over to the competent authority for processing.

CONCLUSION

As research continues, understanding of the actual chemical contamination risk from EO evolves. Even in defense circles, where most of the funding for this research originates, there is a wide appreciation that there is plenty more left to learn.[53] Nevertheless, those responsible for mitigating environmental contamination in modern defense organizations are far in advance of HMA on these issues, not least since they tend to operate within legal frameworks that are becoming ever more stringent in regard to pollution of the environment.[54] Countries such as Germany and the Netherlands banned domestic use of OBOD in the 2000s[55,56] and elsewhere its use as a demilitarization method is subject to ever more stringent restrictions.[57] OBOD techniques are "strictly prohibited" within the framework of industrial demilitarization contracts managed by the NATO Support and Procurement Agency (NSPA), although they are permitted in other contracts.[58]

HMA operators still have much to do in order to make sure they are applying all reasonable effort in order to minimize the risk of chemical contamination from the munitions they clear. HMA is in no position to stop OBOD, and it is in no way appropriate that it should. However, HMA is able to make sure it is done in a way where risks are responsibly managed. There are practical measures that can be taken, and these should be integrated into the relevant technical documents, including operator SOPs. Hopefully HMA operators will one day not find themselves in a position where their best intentions of removing EO have been undermined by an inadvertent act of pollution that could reasonably have been avoided. We should actively avoid doing the wrong thing in the wrong place under the wrong conditions. While actual

A detonation plume from a high explosive ordnance residue test in Alaska. Snow is the perfect medium for measuring the environmental deposition of energetics. Researchers at the Cold Regions Research and Engineering Laboratory (CRREL) used various techniques to simulate low-order detonations with both traditional and insensitive high explosives fillings.
Image courtesy of Michael Walsh/CRREL.

IMX-104 fill spread after a low-order technique. Second order and low order techniques are prone to leave more residue. Researchers at the CRREL in Alaska have used various techniques to simulate low-order detonations with insensitive high explosives fillings.
Image courtesy of Michael R. Walsh/CRREL.

explosive hazards have arguably a more immediate significance to the people we are trying to help, reputational risk to HMA organizations is real, as of course are the moral and legal risks.

In terms of the environment, it is virtually impossible for HMA organizations to "do no harm." Clearing ground of EO, especially landmines, inevitably has an environmental impact, whether it is vegetation clearance, physical damage to topsoil or contamination of soil and water by toxic energetics. The key will be to show we are making "all reasonable effort" to minimize environmental contamination to a level no more than necessary to remove the immediate blast and fragmentation hazard.

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