Explosives Ordnance Disposal (EOD) of Insensitive Munitions: Challenges and Solutions

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Abstract

Over the last five years, Defence R&D Canada has explored efficient and clean methods to dispose of Insensitive Munitions. Those munitions, that were designed to withstand various aggressions, are bound to be more difficult to destroy. The results of the work performed to date lead us to believe that the amount of explosives spread during an EOD operation is directly proportional to the insensitiveness of the explosive. Some explosives, such as 3-Nitro-1,2,4-triazol-5-one (NTO) or Ammonium Perchlorate, appear to be difficult to detonate completely during blow-in-place operations. Another observation is related to the difficulties encountered using the current EOD methods when Insensitive Munitions must be destroyed in the field. Results of deposition tests ran on snow will be presented and discussed for their significance. During the tests, snow samples are collected and analyzed to determine the residual amounts of IM ingredients after either a high-order scenario, usually obtained when the munition is fired, or a blow-in-place reaction, occurring when a round is destroyed by a donor charge to eliminate the safety risk. During those tests, many different disposal methods were explored, i.e. one or many blocks of Composition C-4, placed at various locations, and shaped charges aimed at various points on the munitions. For some items tested, only a large shaped charge was efficient enough to eliminate any significant spread of explosives, and results obtained with other configurations always showed larger amounts of explosives residues at the detonation point for blow-in-place scenarios. Our conclusion is that new methods have to be designed to efficiently destroy Insensitive Munitions (IM). Those methods will include shaped charges, cutting charges, thermite mixes, high-power lasers and any other technology that will promote clean high order detonations or clean burning reactions. Our efforts identify those new methods will be presented, including one where the formulations are slightly modified to promote clean disposal. It appears that the EOD operators will have to be better equipped, but also possess higher skill levels than in the past to implement those clean methods.

Introduction

Insensitive Munitions, as per the definition of the term, are designed to be able to withstand external stimuli without adverse reactions, usually in the form of a violent event such as a detonation or, in some cases, an explosion. The energetic materials in the munitions were selected such that they were less sensitive to shocks and thermal aggressions. Intuitively, it was easy to predict that they would be more difficult to destroy in the field when a malfunction would occur. The first generations of energetics for Insensitive Munitions were less sensitive, but to a point which still allowed standard explosive ordnance disposal methods to be applied without great problems. However, the new generation of Insensitive Munitions is now able to withstand stronger aggressions. One good example is the development of IMX-101 [1] which is able to resist to a large shaped charge jet attack. Such new and performant formulations now require tailored methods for the destruction of unexploded ordnance (UXO).

At the same time, in the last decade, a significant amount of work was dedicated to the measurement of the amount of explosives remaining on the ground following the high-order detonation of explosives or the destruction of UXO's using current EOD methods [2-5]. Without any surprise, it was realised that the high-order detonation of IM explosives created larger amounts of residues than standard explosives, albeit at the forensic level in many cases [3]. This was expected of less sensitive ingredients. However, the blow-in-place scenarios (EOD scenarios) of IM explosives were often found to produce amounts of explosive residues that were considered problematic by experts in the field. Percent quantities of the original material were sometimes found [3], or worse, a low-order detonation, which can spread hundreds of grams of explosives. This was a cause for concern for the sustainability of our local training ranges because of intensive use by military personnel combined with the UXO rates of some items. It is also coupled with a tightening of the environmental regulations. There was a realization that new methods are necessary to properly address the EOD problem of IM.

Following decades of developmental work, the fielding of Insensitive Munitions was occurring at a significant rate in the last decade. While IM technology was mostly applied to missile warheads, torpedoes and air dropped bombs before, there are now artillery shells and mortars of all sizes filled by IM explosives. The United States have been a precursor in the world by making the first important step by identifying its IM munitions [6]. The operator finding a shell in the field will now be able to know that it is IM. This is seen by the authors as an absolute necessity. Subsequently, as the development of very insensitive explosives is made, there is a need for new EOD methods for the efficient and clean destruction of IM.

The objective of this paper is to present the work that was performed at our research establishment to identify clean disposal methods for insensitive munitions. Our approach of coupling the testing of EOD methods with residue measurements will be presented. It is felt that it provides information that did not exist before and suggests a way forward for the development and testing of EOD methods for IM munitions.

Experimental Method

The objective was to find a suitable EOD method for one particular round, selected because of the current need for identifying an efficient EOD method for this round in Canada. It is a large-calibre Army round filled by a DNAN-based explosive developed at US ARDEC (PAX family), and containing NTO and a nitramine. One particular round was selected, but we feel that it representative of many other IM rounds. It was decided to couple the tests with measurements of post-detonation traces of explosives produced using each tested method. The method used for the collection of explosive residues on snow during an EOD operation was already reported in the past [7-10]. It was based on years of testing performed in the USA and Canada starting in the mid-90's, and it was used extensively in SERDP Project ER-2219 [11], which was a collaboration between the USA and Canada on the characterization of residues from the detonation of Insensitive Munitions. Briefly, the method involves performing detonations on snow, and collecting post-detonation samples after a careful delineation of the area of deposition, using the soot as the marker for the given area. Snow samples are collected using a systematic and multi-incremental approach and the snow samples are melted, filtrated and both fractions are sent to chemical analysis [7]. The detonation is often made on a block of ice to prevent a crater from forming and reaching the ground, to avoid cross-contamination coming from the soil under the snow. Figure 1 presents a generic munition, from a past test, on a block of ice. The black soot trace is a good marker for the extent of the particles produced during the detonation. To ensure that the area delineated was large enough to collect all residues, a wider area is also delineated and sampled as shown in Figure 2.

The chemical analysis of DNAN and the nitramine were performed by High Pressure Liquid Chromatography (HPLC) with a photodiode array detector. When no detectable limits were found, extracts were re-analyzed using a gas chromatographic (GC) method on a DB-1 column of 7.4 m to increase the sensitivity. NTO was analyzed following a method obtained from Ms. Marianne Walsh from CRREL [12].

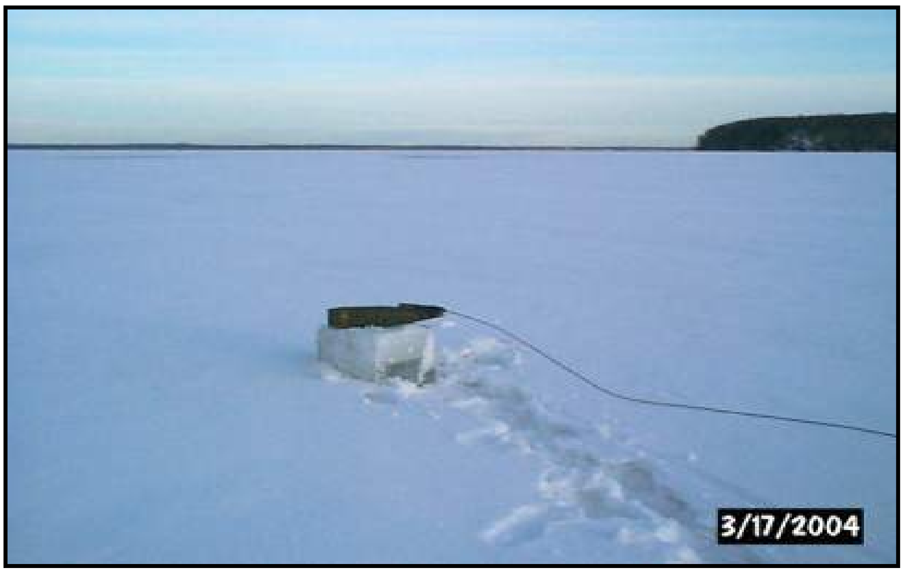

Figure 1: A munition on a block of ice ready for detonation (past test, not the current munition)

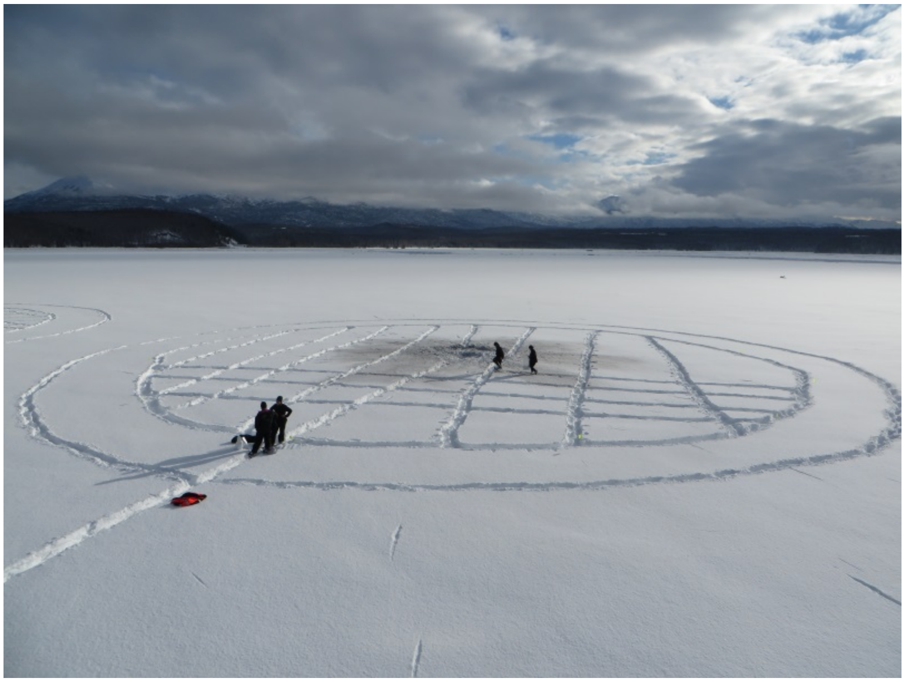

Figure 2: Sampling of area post-detonation

Both full-order detonations and EOD of munitions (attack from the outside) were made on the munition, for comparison. The number of repetition was kept from one to five for each scenario, given the significant costs and resources necessary for the chemical analysis of all the samples.

Different methods were tested for the EOD of the rounds, in order to find the ones that would produce the smallest amounts of explosive residues. They were selected using past experience, or through suggestions made by scientific staff or military EOD personnel. It should be noted that no simulation of these scenarios has been performed yet at DRDC-Valcartier Research Center. The explosive used to attack the round was Composition C-4, commercially available shaped charges or a military shaped charge. The list of scenarios tested is given in Table 1.

Table 1: Scenarios used for the EOD of an IM round

Scenario number	Scenario	Comment
1	Full-order detonation	Explosive (C-4, 100g) in the fuze well for initiation. Five repetitions.
2	5 blocks of C-4 around the charge	Simultaneous detonation of the five blocks, causing the shocks to meet inside the round. Four repetitions.
3	2 blocks of C-4	Test to try to reduce the amount of explosives for EOD. Only one repetition.
4	2 blocks of C-4, at the nose, optimized	Targeting the booster from the

	configuration	outside. Simultaneous detonation on each side, causing the shock to meet inside the round and compress the booster. Three repetitions.
5	67-mm shaped charge on the side	Going through the largest diameter, perpendicular to the axis of the shell. Three repetitions.
6	33-mm shaped charge aimed at the booster	Targeting the booster. Two repetitions.
7	67-mm shaped charge aimed at the booster	Targeting the booster. Two repetitions.
8	67-mm shaped charge aimed at the back	Going through the round from the back. Two repetitions.
9	84-mm shaped charge aimed at the back	Going through the round from the back. Military shaped charge. One repetition.

The idea of using shaped charges came from DRDC work with a commercial product (SM-EOD series from Saab Bofors) for the destruction of conventional ammunition (TNT-based). This method worked extremely well with 33-mm shaped charges, and produced high-order detonations every time. It was also appreciated by the EOD workers that performed the tests because of the stand-off offered and the ease of setting up the EOD operation. However, since we only had 20-mm and 33-mm shaped charges, it was found difficult to apply with IM explosives. It created partial detonations. The decision was then made to either seek a larger shaped charge (67- and 84-mm), or attack the booster. From IM shaped charge jet tests reported in the literature, it was found that a number of recent IM formulations could not pass the test with large shaped charges (RPG-7 size) that had significant v^2d values. There appeared to always be a shaped charge that would be large enough to obtain a detonation. The second option, attacking the booster, comes from the fact that a more sensitive explosive is usually placed in the explosive train, as the booster for the main charge, or as a supplementary charge. By targeting this explosive, which should be more sensitive, there is a good chance to initiate the booster and then detonate the complete round.

Results and Discussion

To assess the performance of each scenario at destroying the explosives, two ratios were defined. The first one is the Deposition Rate (DR). The DR is in percentage, and it is defined as:

DR = (total mass of ingredient deposited/initial mass of ingredient in the round) * 100 %

It is calculated for each separate explosive species in the composition. However, in this paper, only the Deposition Rates of NTO and DNAN are reported and compared. These were the most relevant, since the nitramine is more sensitive.

The second ratio is called the Detonation Efficiency (DE). It is also reported in percentage, and it is defined as:

DE = 100 – ((the total masses of products deposited divided by the original total mass of ingredients in the round) X 100).

Both are useful to analyze the data collected. In an ideal world, the deposition rate of all ingredients would be zero and the detonation efficiency would then be 100%. While it is known that all detonations release at least forensic traces of explosives, we should try to reach as close as possible to this 100%, in order to minimize the contamination on training ranges and increase the sustainability of those ranges.

The results are presented in Table 2 for the various scenarios. It is very interesting to note that the full-order detonation of this round appears very efficient, with only traces of explosives being present. It is then possible to have clean detonations of IM rounds, when they are properly initiated. At 99.999% efficiency, the round compares well to conventional rounds filled in Composition B [3].

The second general observation that can be made is that the deposition rate of NTO is almost always larger than that of DNAN. This is a little counter-intuitive, given that DNAN is more a flammable solid than an explosive and does not detonate well. NTO is a good explosive in itself, with a good performance.

Table 1: Results of the deposition rates and detonation efficiency for the EOD scenarios of an IM round

Scenario	Number of replicates	DNAN DR (%)	NTO DR (%)	Detonation Efficiency (%)
1. Full-order detonation	5	0.001	0.002	99.999
2. 5 blocks of C-4 around the charge	5	6	26	83.7
3. 2 blocks of C-4, one on each side	4	13	43	72.1
4. 2 blocks of C-4, at the nose, optimized configuration	3	6	0.3	97.4
5. 67-mm shaped charge on the side	3	1	10	93.9
6. 33-mm shaped charge aimed at the nose	2	0.6	1	99.1
7. 67-mm shaped charge aimed at the nose	2	53	74	40.5
8. 67-mm shaped charge aimed at the back	2	29	26	74.3
9. 84-mm shaped charge aimed at the back	1 3	0.4 0.001	0 0.0001	99.8 99.999

Repetition of the test in following year				

The results of EOD scenarios using C-4 were rather discouraging. While it appeared, during the tests, to create full-order detonations and get rid of the rounds, the detonation efficiency was rather low for two of the scenarios, despite the fact that no large fragments were found at detonation point and everything indicated that they were high order events. Our modification (scenario 4) raised the efficiency to 97.4%, which is much better. However, it is rather low compared to the blow-in-place results of Walsh et al. for 60 mm mortars and 81mm mortars filled in Composition B, as examples (99.93% and 99.998%, respectively) [3]. However, at those levels of efficiency, the difference would be difficult to catch in practice, even with pressure sensors. It is only by performing those deposition rates studies at the same time as the EOD testing that we were able to identify the problem. Scenario 4 still releases tens of grams of explosives on the range for each detonation. Depending on the range location, use, hydro-geological behaviour, this could compromise the sustainability of the range. The other two methods with Composition C-4 (scenarios 2 and 3) generate hundreds of grams of explosives residues.

The results using C-4 encouraged the exploration of alternative methods for EOD of IM rounds. The use of shaped charges was already being investigated for conventional rounds at DRDC. It was decided to try with IM rounds as well. A 67-mm shaped charge on the side of the round produced promising results, with a detonation efficiency of 94%. This was still not the ideal result, but it was a step in the right direction. A 33-mm shaped charge pointed at the booster gave very good results in scenario 6 (detonation efficiency of 99%), but a 67-mm shaped charge doing the same job did very poorly. We assumed that we did not aim correctly and missed the booster, hitting instead the dummy fuse, or that the large amount of explosives was making the munition move on the block of ice during the attack. This demonstrated how complicated this operation would be in practice, to try to target the booster. Finally, a shaped charge aimed at the back of the round produced also mixed results. The 84-mm shaped charge gave a spectacular detonation efficiency, at 99.8% (repeated the following year and finding 99.999%), while the 67-mm shaped charge at the back only produced a detonation efficiency of 74.3%. The 67-mm shaped charge may have missed the explosive in the round. This method, using an 84-mm shaped charge, is, as far as we are concerned, the best way of disposing of UXO's of those rounds in the field, but if the booster can be targeted, a smaller shaped charge can be used to obtain a good efficiency detonation.

Other results have also shown similar trends [3]. The use of plastic explosives (or TNT) in blocks, outside of explosive shells, will meet limitations with very insensitive explosives (and propellants). It seems obvious now that shock-insensitive explosives would resist better to a shock through a metal wall coming from a plastic explosive. We believe that we are already there with the current IM explosives. And it is imperative that those new methods are developed to reduce or eliminate any future accumulation of contaminants in the training ranges.

DRDC - Valcartier Research Center has already started working on those new EOD methods for IM. The shaped charge approach was presented in the paper. In addition, here are some of the ideas that have been explored or are being explored:

- An optimal shaped charge for EOD. This tool is being developed with the objective of being tailored for EOD operations, and not necessarily for penetration of metal.

- Cutting charges for very insensitive explosives. When C-4 fails, when shaped charges would have to be monstrous in order to be efficient, a two-step process may be used, especially for tank and artillery rounds. The first step is to separate the fuse from the shell using a cutting charge. The main explosive and/or the booster explosive now become exposed. The second step is to place plastic explosives to initiate the charge from the booster well. Given the high detonation efficiency for high-order of IM rounds, this could work well to reduce the contamination.

- Thermite torches or any other device to initiate a burning reaction. Explosives burn well, and burning is often a rather clean process that at least does not generate large amounts of explosives residues.

- Modifications to the IM formulations to optimize the detonation efficiency while preserving the IM character. Tests have just been performed to that effect and the results will be known in the following months.

- High-power lasers. Tests have been performed using high-power lasers on IM rounds and the results are very promising. This will be the topic of another paper at a future meeting.

Conclusion

Different ways of destroying UXO's containing an IM explosive based on DNAN and NTO have been explored. The results showed that, in that case, the attack using C-4 blocks on the side of the round were not efficient (detonation efficiency of 72-84 %) and created large amounts of explosive residues. An optimal way of applying the C-4 was tested, but reached a detonation efficiency of 97%, which could be problematic for some ranges. An EOD method using shaped charges was tested. It was found that, if the shaped charge is precise enough, attacking the booster with a shaped charge can produce 99% efficiency of detonation using a 33-mm shaped charge. However, the best results were found using an 84-mm shaped charge aimed at the back of the round, in the base plate, perpendicular to the axis of the round, so that the jet would run all the way to the front through the explosive.

Those results indicate that, even if visually a high-order reaction appeared to have been created in an EOD operation, in practice it may still spread significant amounts of explosive on the ground. This was not the case with conventional rounds filled in Composition B. The results also indicate that new EOD methods for IM rounds need to be developed, that may not involve the traditional application of plastic explosives. It would be wise to couple deposition rate tests with the development of these new EOD methods for IM, to ascertain the success of the operation.

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