

University of Wales Trinity Saint David

Group Project Portfolio

ACDA5022 Work-Based Group Project Assignment

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Contents

Introduction	2
Project Direction.....	2
Cratering Kit Redesign	4
Speaking to Subject Matter Experts (SME)	4
Other Group Work.....	4
The Presentation.....	5
MTDS Introduction.....	5
Manufacturing	5
Surveillance and Life Extension.....	6
Disposal.....	7
Individual Feedback	7
References.....	10
Appendix A – CBRN Communications	11
Appendix B – Group Presentation	12

Introduction

As part of the ACDA5022 Work-Based Group Project module, the author, along with three others (referred to by their initials: JS, WN, RG), was assigned a project. This report outlines the activities performed by the group members individually and collectively, as well as the project deliverable, which was a presentation to the lecturing staff.

The project objectives included [1]:

- Comparing the performance of TAW-EX 2022 with existing formulations.
- Obtaining safety data.
- Proposing a design for the cratering kit
- Recommending a production route.
- Describing the Manufacturing to Target or Disposal Sequence (MTDS)
- Proposing packaging.
- Suggesting a series of trials to prove the device meets MTDS requirements.

The system addressed in this project is the Charge, Demolition Rapid Crater Kit Mk2, referred to as the cratering kit. The purpose of this kit is to rapidly create craters that can block important strategic points such as airport runways and critical roads [2].

The cratering kit comprises several elements. It includes cratering charges (bag charges), which are blocks of high explosive (HE) in bags that are intended to create craters when placed into the ground and detonated. For maximum effect, the bag charges need to be placed into the ground, which may require digging a hole with a shovel. For hard ground, the kit contains a shaped charge to create a small directional hole. The kit also includes means of initiation for both types of munition; however, this is out of scope for this project and won't be discussed.

The overall aim of the group project was to improve the Insensitive Munition (IM) compliance of the cratering kit. IM tests are the NATO standard for assessing the energetic response of an Ordnance, Munitions, or Explosives (OME) article to various external stimuli. This includes fast heating to simulate aircraft or vehicle fuel fires; slow heating to simulate storage in shipping containers or fires in adjacent magazines; bullet impact to simulate small arms attack; fragment impact to simulate fragmenting munition attack; sympathetic reaction to adjacent explosions to simulate events occurring within the same magazine; shaped charge jet impact to simulate attack by shaped charge weapons [3]. The response of the OME article is graded from Type I (detonation) to Type VI (no reaction) [4].

Project Direction

The first step taken by the group was to understand the tasks that needed to be completed for the project. From the requirements provided, the following list of tasks was produced:

1. Introduction and background
2. User requirements document (URD)
3. Overview of current composition (TNT/RDX)
4. Explosive qualification
 - a. Chemical testing (STANAG)
 - b. Hazard testing (EMTAP)
 - c. IM testing (small scale)
 - d. Artificial aging

5. Comparison between new and old compositions
6. Redesign (if performance is not adequate) or retain design depending on the performance of the new composition.
7. System qualification: assign groups for different testing.
 - a. Artificial aging
 - b. Vibration
 - c. Diurnal cycling
 - d. Thermal shocks
 - e. Environmental testing (e.g. water ingress, salt spray)
 - f. Electromagnetic charge (EMC) tests
 - g. IM (full suite)
8. Packaging redesign – Not needed if munition doesn't require redesign.
 - a. Vibration
 - b. Diurnal cycling
 - c. Environmental testing
 - d. Drop test.
 - e. Bonfire test
 - f. Spigot.
9. Manufacturing
 - a. RAM mixing
 - b. General process overview including hardware.
10. Disposal (approved method is open detonation)
 - a. Briefly mention other disposal methods (be careful of scope creep!!)
11. Summary, recap, and conclusion

The tasks above were produced by the author with help from JS. The structure of these tasks follows the standard development structure for new OME items containing energetics. First, the energetic materials must undergo testing and qualification, a process known as Explosive Qualification. These tests provide data that indicates whether a material is suitable for the applications in which it may be used. Then a System Qualification must be done where the OME item is tested to ensure that the munition design is suitable for all relevant applications. Packaging must be considered for transport between manufacturing sites, transport out to theatres, and transport in the field. The munition must be protected in all scenarios; however, other criteria are relevant at each stage such as portability when in theatre. Important considerations when designing a munition are how to manufacture items, how change across their service lives will be monitored, and how they can be safely disposed of at the end of life. Several group tasks were specified to ensure that the presentation would flow logically and coherently.

Once the presentation structure was established, it was divided among the group members so that each person would be responsible for a specific section. The author and JS split the tasks up into self-contained sections. A meeting was held on the 5th of February 2024 to discuss who would be responsible for each section. The explosive qualification section (green) was assigned to WN; the system qualification section (blue) was assigned to JS, the transportation testing section (gold) was assigned to RG, and the MTDS section (purple) was assigned to the author. General tasks were to be collectively completed by the group once all individual sections had been completed.

Cratering Kit Redesign

A second meeting was held on the 6th of February to discuss the new design for the cratering kit. The project's scope was limited to making the shaped charge and the bag charges IM compliant. Any detonator cord, digging equipment, or boosters were not considered.

Within industry, there is a reluctance to completely redesign OME items due to the complexity and cost of the qualification work required to ensure new products function correctly and safely under various conditions. Similarly, the group decided to make minimal changes to the design while also meeting the new requirements by using different explosive compositions while keeping the same design. To do this, more IM compliant energetics must be found that have similar performance characteristics as the current compositions. Without this, a sacrifice in performance would need to be accepted by the end user as a worse-performing composition may make the cratering kit ineffective for its role.

IM threats are greatest to the cratering kit while in the field. Having significant packaging for the cratering kit could improve the IM response by providing better protection to OME articles but it would be impractical as these kits would need to be carried by soldiers or on vehicles where other combat equipment must be stored. Therefore, the group decided that the current packaging would be kept and would not be changed to improve the IM response of the cratering kit.

As the transportation section of the presentation was no longer significant, RG instead refocused their efforts on generating a detailed user requirements list which could inform the rest of the design activity. They also conducted a design review of the critical elements of the current design and a hazard analysis.

The author's section initially only referred to the manufacturing and disposal of the new munitions. This was expanded to include surveillance and life extension programmes that would inevitably be a critical element to the lifecycle management of the munition.

Speaking to Subject Matter Experts (SME)

When assessing the suitability of new energetics, the current energetics must first be understood. To facilitate this WN reached out to CBRNergetics – the business that currently manufactures the rapid cratering kit mk2. Communication from WN about CBRNergetics's responses is included in Appendix A.

The shaped charge contains 11 kg of Composition B (60:40 RDX/TNT with 1% wax). This was chosen by CBRNergetics because it met the requirements they were given, was transportable, and was also the most affordable solution. Composition B does not meet the criteria for an insensitive munition under STANAG 4439.

The bag charge contains 15 kg of Hexatonal Flake (40:40:20 RDX/TNT/powdered aluminium). This composition was chosen because of its long impulse and high heat of explosion which makes it more able to displace soil. It hasn't been qualified against STANAG 4439.

Other Group Work

Between the initial work and the final presentation, several team meetings were conducted:

- On the 11th of March 2024, a design review was held between the group and lecturing staff. Feedback from the design review was that progress was good and meeting the expectation for the project.
- On the 21st of May 2024, an online meeting was held where the individual progress made by each group member was discussed. This informed a discussion of how to make individual sections fit well together to produce a coherent presentation.
- Between the 3rd and 5th of June 2024, a series of meetings were held in person. The new explosive compositions were agreed upon at these meetings, and work on the presentation began.
- Between the 5th and 7th of June 2024, individual sections were completed and compiled into the final presentation.

The presentation was delivered to lecturing staff on the 7th of June 2024.

The Presentation

Appendix B contains the final group presentation. The author produced slides 38-53.

Pertinent to the author's section, IMX-104 was selected for use in the shaped charge due to IM properties and similar performance to composition B. To replace the Hexatonal, TB I200 was selected due to its affordability, improved IM performance, and long impulse.

MTDS Introduction

The author first introduced a summary of what the MTDS is and its components (slides 38-39). MTDS considerations are critical factors at the design phase as they will have a major effect on the success of any product. For example, if a product meets all requirements but is impractical to manufacture then it will likely cost significantly more and smaller inventories might have to be accepted by the end user as sufficient items cannot be produced.

Lifecycle duration must be considered to allow enough time for manufacture, a reasonable time items can be kept safely by the end user, and enough time to dispose of the item before it becomes unsafe. Knowing this, longer-life materials can be used, and in-service surveillance and life extension programmes can be anticipated by designing the item so that it can be disassembled to give access to its energetics.

Item design must also consider how a product can be disposed of so that there isn't a situation where safety is compromised to get rid of surplus or out of life assets.

Manufacturing

The second topic the author covered was manufacturing (slides 40-44). The melt-casting process was decided to be the most appropriate method of manufacture for both IMX-104 and TB I200. This is because the average melting temperature of IMX-104 and TB I200 is 94.5 °C [5] and 80.4 °C [6] respectively. This is significantly below the autoignition temperatures of these energetics – IMX-104 auto ignites at approximately 205 °C and TB I200 auto ignites at approximately 470 °C.

The first step in melt-casting is to melt the energetic material. This is typically done at just above the melting temperature to minimise energy input and increase safety [7]. Heating is done gradually to avoid creating hotspots and reduce the risk of accidental detonation. Any equipment used must be chemically compatible (unreactive) with the energetic composition. Compositions will generally be stirred during the melting process to prevent localised overheating.

Once the energetic material is fully melted it is poured into a mould. That mould can be a casing such as the body of the shaped charge. Alternatively, energetics can be cast into removable moulds - the cratering charge can be manufactured in this way. Once the pouring is complete, the mould should be vibrated to remove air bubbles and ensure a uniform fill. The energetic materials are then cooled gradually to not induce cracking or other structural issues. Gradual cooling can be done by leaving the mould in an ambient atmosphere, however, to ensure quality standards are met and cool-down cycles are consistent other mechanisms such as temperature regulated water baths are used.

Following casting, a quality inspection is done to ensure the OME article is to standard. This will generally include a visual inspection and a radiographic inspection.

Surveillance and Life Extension

The next topic discussed by the author was in-service surveillance and life extension (SALE) (slides 45-50). SALE programmes are a critical element of MTDS as they validate the results obtained during qualification, provide evidence that assets are safe to use at the time of testing, and can demonstrate that the service life of assets can be safely extended.

Typically, SALE programmes are conducted by the original manufacturer at the request of the end user. The value of the asset largely determines how many assets are sent for SALE, with a minimum quantity of three assets required for a SALE programme. The initial activities always include an inspection of packaging, a visual inspection of the assets, leak tests to ensure no moisture ingress, and radiography. These tests provide insight into the general condition of the assets and determine whether it is safe to proceed.

For life extension programmes, assets will then undergo artificial ageing, with thermal ageing being the most suitable method. This involves conditioning the asset at high temperatures to accelerate the rate of chemical reactions within the energetic materials.

Assets involved in a SALE programme will follow one of two pathways: functional testing or Breakdown, Testing, and Criticality Analysis (BTCA). A minimum of two assets will be assigned to functional testing, as the item must be operated at either temperature extreme. Successful functioning of the items at each temperature extreme provides confidence that in-service items are suitable for use across the whole temperature range. The functional test itself must closely simulate how the items will be used in-service. For a cratering kit, the shaped charge could be used to create a hole for the cratering charges, which can then be used to create a crater. It is likely that as much data as possible will be gathered from these tests to compare to items from the same batch that were tested fresh (immediately after manufacture).

The remaining asset(s) are assigned to BTCA. This involves the disassembly or deep strip of the assets to access energetic materials or critical structural elements. A series of laboratory tests can then be performed to investigate how the materials and bond lines have changed over the asset's lifecycle. Tests typically involve chemical tests to determine whether the materials are chemically the same as at manufacture, hazard tests to assess whether the materials have become more sensitive due to being in service, and mechanical testing to ensure all materials are still mechanically suitable after being in service.

As SALE programmes are typically conducted by the manufacturer, who is usually also the design authority, any unusual features that are found can be thoroughly investigated. Additional testing may be performed, original records can be consulted, and technical knowledge can be leveraged to provide information on the unusual feature.

Disposal

The final topic the author discussed was the disposal of assets (slides 51-52). Several disposal methods are available, and their suitability depends on access to the energetic material, availability of equipment, and the type of energetic material.

Chemical neutralisation can be used when the energetic material can be reacted with another substance to neutralise it. However, this method is unlikely to be suitable for IMX-104 and TB I200. Hydrolysis is only effective for energetics that can be dissolved in water, such as nitrate esters, and thus is not applicable for IMX-104 and TB I200. Bioremediation may be applicable for IMX-104 and TB I200, as it involves the breakdown of energetics by microorganisms. The remaining waste can then potentially be disposed of as non-energetic waste.

More common methods of energetics disposal include incineration, open burning, and open detonation. Incineration occurs within a contained space, where the energetics are heated to the point where they burn without progressing to detonation. When designing a munition with incineration in mind, it is important to consider how close the explosion temperature is to the burning temperature and whether the material in its designed configuration can burn without detonating. It is unclear whether IMX-104 and TB I200, in the roles of shaped charge main filling and cratering charge respectively, could safely be disposed of through incineration.

Open burning and open detonation are methods that aim to detonate the munition being disposed of and thereby consume its energetic material. Open burning achieves this by igniting the munition and allowing a deflagration to detonation transition (DDT) to occur. By contrast, open detonation aims to sympathetically detonate the munition through a shock to detonation transition (SDT). Since both IMX-104 and TB I200 are IM compositions, they may require longer exposure to a flame to ignite or greater shock to cause a sympathetic detonation. Provided the right equipment is available, both open burning and open detonation are suitable methods for disposing of the IM components of the rapid cratering kit.

Individual Feedback

The individual feedback provided by lecturing staff following the group presentation can be seen in Figure 1.

Peter

Carrier and Filler, not all melted.

Cooling critical. Why?

What shape is the bag charge? How do you get it?

Could you cast it from PBX.

What tests are you going to do in the life cycle extension. What do you do in BTCA.

Sensitiveness testing? Why do we do sensitiveness testing?

How do you judge the sensitiveness of the bluk?

You've got melt cast? Would you open burn in situ OR melt cast.

Figure 1: Individual feedback provided to the author.

Carrier and Filler, not all melted.

The composition TB 1200 contains powdered aluminium. The melting temperature of powdered aluminium is significantly higher than TNT and the desensitising agent that make up the remainder of the composition. If this is not considered during the melt-casting process, the powdered aluminium could settle in a clump and negatively affect the performance of the charge. To address this, the composition must be stirred after being melted and prior to being poured. Thus, when the cooling process starts, the powdered aluminium will be equally dispersed throughout the composition.

Cooling critical. Why?

This has been partially addressed within the section 'The Presentation: Manufacturing'. The cooling rate is critical as it is the primary means of controlling crystal size and shape. Crystal size and shape have a direct impact on the sensitivity of the composition – long and narrow crystals are far more sensitive to impact and thus the safety of the composition is reduced.

What shape is the bag charge? How do you get it?

The bag charge appears to be a cuboid shape. This can be achieved by melt-casting into a mould that is that shape.

Could you cast it from PBX?

The author is unsure whether PBX compositions were investigated for this project. If a PBX composition were suitable for this application, it would likely not be melt-casted but would instead be made through pressing or extrusion. This is because the binders used in PBXs often have significantly different melting temperatures to the explosive material being used.

What tests are you going to do in the life cycle extension? What do you do in BTCA? Sensitiveness testing? Why do we do sensitiveness testing? How do you judge the sensitiveness of the bulk.

This has been partially addressed within the section 'The Presentation: Surveillance and Life Extension'. Tests generally fall into three categories: chemical, mechanical, and hazard testing. Chemical tests might include looking at the migration of explosive species into liners and bond lines or the depletion of stabilisers (if applicable). Mechanical tests may include tensile testing within materials, Dynamic Thermal Mechanical Analysis (DMTA) that provides information on the mechanical behaviour of the material at different temperatures, Differential Scanning Calorimetry (DSC) that provides insight into where the glass transition temperature of the sample is or pull tests that give the strength of bond lines. Hazard/sensitiveness testing may include the Rotter Impact test and temperature of ignition test that provide information on the Figure of Insensitiveness (F of I) and Temperature of Ignition (T of I) respectively.

Sensitiveness testing provides important benchmark data that has a bearing on the handling of energetic materials. Knowing a material is relatively sensitive can allow for safer processes to be developed and for people to be better protected while doing them. Additional precautions might be taken in the design of munitions containing more sensitive energetics. Sensitiveness is the product of many factors and thus cannot accurately be predicted – thus the value produced from fresh testing is only useful as a comparator. To clarify this statement, tested sensitiveness values do not account for sensitisers that may be encountered in field conditions such as grit which increases friction sensitivity.

You've got melt cast. Would you open burn in situ OR melt cast?

Re-melting the explosive filling could allow for it to be separated from its hardware and the hardware could be retained. However, the explosive fill would still require disposal as it couldn't be reused due to chemical changes in composition such as degradation products being more prevalent. Re-melting energetic compositions at end of life could be unsafe as the condition of the munition is unknown, and the behaviour of aged compositions differs with the specific age they have.

Remelting charges as part of the disposal process would require the charges be sent to a facility where this could happen. This would either be a dedicated facility which would require significant investment, or it would be an existing manufacturing line. The latter option would carry significant risk as any event would put the line out of operation. There would also be an increased risk of cross-contamination between aged energetics and fresh energetics.

By contrast, open burning and open detonation can be done with minimal setup and at low cost. It can also be done anywhere, as opposed to specific facilities. Thus, it is appropriate at factories, storage sites, and in theatre.

References

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- [3] "Insensitive Munitions," in *JSP 520 Part 2 Vol 11*, 2015, p. 6.
- [4] "POLICY FOR INTRODUCTION AND ASSESSMENT OF INSENSITIVE MUNITIONS (IM)," in *AOP-39 Edition D Version 1*, NATO STANDARDIZATION OFFICE (NSO), 2018, pp. I-2, I-3.
- [5] D. Price and A. Carrillo, "Large Scale Manufacture of Granular IMX-104 Melt Pour Explosives," *NDIA Insensitive Munitions & Energetic Materials Technology Symposium*, 2013.
- [6] T. Gilloux, Bulot Stephane, C. Coulouarn and E. Thomas, "New low cost melt-cast composition for IM mortar ammunition".
- [7] M. J. Margolin and E. A. Skettini, "Ammunition Loading Techniques," *Explosives Development Section Feltman reseach and Engineering Laboratories Picatinny Arsenal*, 1966.

Appendix A – CBRN Communications

The below is communication from WN on the 13th of March 2024 detailing the responses he'd received from CBRN concerning the Rapid Cratering Kit Mk2.

noakesy. 03/13/2024 5:24 PM

yoo... got a reply from a contact at CBRN who produce the Rapid Cratering Kit Mk2 after I asked him to suggest any possible improvements... this was what he had to say... Will

The RCK Mk2 was refined by me.

The filling of Comp B with RDX/Wax booster and crater bags of Hexatonal flake were optimised to maximum effect.

Other mixes were tried but did not produce the strong penetration of the pilot charge nor the slow cratering effect of hexatonal flake.

We made additions to the Hexatonal in wet form. I am unable to give that info away.

The optimisation of effect went through a long gestation, but 11kg of Comp B over a 60 degree copper cone is difficult to beat in affordable terms.

It meets my requirement and is transportable.

Now in service with NATO so any changes would be futile.

Any good?

no real improvements suggested but confirms the spec for the main shaped charged and that the crater bags are hexatonal (which seems to be HMX/TNT/aluminium)

seems like the current 'optimised' spec is based on low cost... so we would probably get the most to talk about if we re-designed as an IM and put it across as a higher cost option

ill do some looking into the sensitivity of hexatonal and Comp B and find some similar performing alternatives with better IM application

noakesy. 03/13/2024 6:35 PM

some more info as well...

Re: Composition of Hexatonal Yes

But the mix is absolutely critical as is the form

The original data pack called for cast Hx

By experiment we could that is not optimum as better intimate contact is required

It was quite a long test period as so many combinations of mix and form were tried

Our product was optimised and found to be the most effective.

We did not find IM material satisfactory for the purpose of this application

Rapid Cratering Capability Design review and recommendations for a replacement capability to the Mk II rapid cratering kit	Basic User Requirements - Easily Transported - Needs to work in all conditions - Safe – to use, transport, store etc. - Quick to deploy - Foolproof to operate - Cheap	Mk2 - Generated from interviews with Stakeholders																																																																																																																																	
Expanded System Requirements - Easy to transport - Some external dimensions as previous kit for ease of storage/transport for compatibility with current storage and transport solutions. - Preferably Shaped charge, separate electrical detonator, firing cable and initiator, and separate follow through charges. - Similar Weight or lighter for same reasons. - Safety - IM response - Exhibit Type V or better for Fast Heating, Slow Heating, Bullet Impact and Fragment Impact and Type III reaction or better for Symptomatic Reaction. Response to Shaped charge preferably IV or better. - Safe initiation - Should be initiated with standard shock tube detonator system - Should be operable in any climate, but focus is on Desert/Hot Climates. - Unlikely to be used in Arctic environments but cold environments - Use climatic categories (A-E) as per standard - Must remain safe to transport by fixed and rotary wing transport (all platforms) as well as by tracked and wheeled transport, with little to no degradation to effects. - Requires tests for Vibration - KNO important for rotary wing deployment (potentially 30 KHz exposure) - Can be readily repaired to "fit" a hole in the ground - Ease of use – for use by trained service personnel, but in potentially stressful or time sensitive situations. - Similar price to current solution.	Design Review - Critical Functional Components determined through FMEA and user interviews - Pilot Charge (shaped charge) - Uniform/inconsistent grain size, and a homogeneous mix in craters bag charges is critical for reliable initiation and full combustion of energetic material. - Liner for main fill and good quality control on filling process - to ensure intimate contact between fill and liner during throughout varying temperatures - Material for casing should have low coefficient for thermal expansion and good quality control for interfaces with main fill. - Apex angle of shaped charge is critical to achieve optimal penetration with chosen composition - wider shape is recommended to produce required depth at reduced weight. - Liner material critical to ensure good formation of liquid jet within standoff distance. - Cratering charges - Long impulse, gas generating composition needed to expel sufficient ground to form crater	Hazard Analysis/Safety - Critical Safety Features - Detonators – Vulnerable to ESD and EMF – To be transported and carried separately to main effect/booster/bag charges. - Cratering bag mix must be consistent to minimise unspent explosive material remaining in crater or expulsion of uncombusted energetic material.																																																																																																																																	
EXPLOSIVE COMPOSITIONS	CURRENT COMPOSITIONS Shaped Charge (HRS1) Penetration of ground Charge length: 114mm GO-AD RDX/TNT +1% Wax Cratering Charge (HRS1) For displacement of soil Hexagonal "flake" RDX c.40%, TNT c.40%, Aluminium, powdered c.20% HEXAGONAL FLAKE RDX c.40%, TNT c.40%, Aluminium, powdered c.20% + "additions in wet form" Long impulse and high heat optimised for soil displacement (f. alike to Torpede but on land) [Grain/particle size, homogeneity of mixture] and intimate contact is critical as is the form – Robert Gilliam, CRNergetics	CURRENT COMPOSITIONS COMPOSITION B - GO-AD RDX/TNT +1% Wax - High detonation pressure for brisance and penetration [2] "60 degree cone angle with this charge was difficult to beat in affordable terms" – Robert Gilliam, CRNergetics HEXAGONAL FLAKE - RDX c.40%, TNT c.40%, Aluminium, powdered c.20% + "additions in wet form" - Long impulse and high heat optimised for soil displacement (f. alike to Torpede but on land) [Grain/particle size, homogeneity of mixture] and intimate contact is critical as is the form – Robert Gilliam, CRNergetics																																																																																																																																	
CURRENT (Mk.2) ISSUES INSENSITIVE MUNITIONS - Comp-B does not meet the criteria for an insensitive munition under STANAG 4439 - Hexagonal flake appears not to have been qualified against STANAG 4439, but, based on its composition, would not meet the required criteria THERMAL DEGRADATION - TNT has a relatively low melting point (79°C), meaning that both Comp-B and Hexagonal flake are susceptible to partial melt at high temperatures - Can lead to uneven distribution of RDX particles and anisotropic detonation properties [1]	INSENSITIVE MUNITIONS In insensitive Munitions concept was introduced following various incidents involving in-service munitions in response to a range of stimuli STANAG 4439 details the required tests and criteria for classification of materials as insensitive munitions The material must meet a minimum reaction threshold for each of the relevant stimuli [3]	INSENSITIVE MUNITIONS <table border="1"> <thead> <tr> <th rowspan="2">Test procedure</th> <th colspan="2">France</th> <th colspan="2">NATO</th> <th colspan="2">UK</th> <th colspan="2">USA</th> <th rowspan="2">Type I</th> <th rowspan="2">Detonation</th> </tr> <tr> <th>DGA BURAY</th> <th>STANAG 4439</th> <th>STANAG 4439</th> <th>STANAG 4439</th> <th>STANAG 4439</th> <th>STANAG 4439</th> <th>STANAG 4439</th> <th>STANAG 4439</th> </tr> </thead> <tbody> <tr> <td>Fast cook-off</td> <td>V</td> <td>V</td> <td>V</td> <td>V</td> <td>V</td> <td>V</td> <td>V</td> <td>V</td> <td>Type II</td> <td>Partial Detonation</td> </tr> <tr> <td>Slow cook-off</td> <td>IV</td> <td>V</td> <td>V</td> <td>V</td> <td>V</td> <td>V</td> <td>V</td> <td>V</td> <td>Type III</td> <td>Explosion</td> </tr> <tr> <td>Bullet impact</td> <td>III</td> <td>II</td> <td>V</td> <td>V</td> <td>V</td> <td>V</td> <td>V</td> <td>V</td> <td>Type IV</td> <td>Deflagration</td> </tr> <tr> <td>Fragmentation, detonation</td> <td>III</td> <td>II</td> <td>V</td> <td>V</td> <td>V</td> <td>V</td> <td>V</td> <td>V</td> <td>Type V</td> <td>Burning</td> </tr> <tr> <td>Fragment impact (light)</td> <td>III</td> <td>II</td> <td>V</td> <td>V</td> <td>V</td> <td>V</td> <td>V</td> <td>V</td> <td>No Reaction</td> <td></td> </tr> <tr> <td>Fragment impact (heavy)</td> <td>III</td> <td>II</td> <td>V</td> <td>V</td> <td>V</td> <td>V</td> <td>V</td> <td>V</td> <td></td> <td></td> </tr> <tr> <td>Shaped charge attack</td> <td>III</td> <td>II</td> <td>V</td> <td>V</td> <td>V</td> <td>V</td> <td>V</td> <td>V</td> <td></td> <td></td> </tr> <tr> <td>Shrapnel impact</td> <td>III</td> <td>II</td> <td>V</td> <td>V</td> <td>V</td> <td>V</td> <td>V</td> <td>V</td> <td></td> <td></td> </tr> <tr> <td>Drop</td> <td>NPT</td> <td>NPT</td> <td>NPT</td> <td>NPT</td> <td>NPT</td> <td>NPT</td> <td>NPT</td> <td>NPT</td> <td></td> <td></td> </tr> <tr> <td>Electrostatic discharge</td> <td>NPT</td> <td>NPT</td> <td>NPT</td> <td>NPT</td> <td>NPT</td> <td>NPT</td> <td>NPT</td> <td>NPT</td> <td></td> <td></td> </tr> </tbody> </table> Both images: [3]	Test procedure	France		NATO		UK		USA		Type I	Detonation	DGA BURAY	STANAG 4439	STANAG 4439	STANAG 4439	STANAG 4439	STANAG 4439	STANAG 4439	STANAG 4439	Fast cook-off	V	V	V	V	V	V	V	V	Type II	Partial Detonation	Slow cook-off	IV	V	V	V	V	V	V	V	Type III	Explosion	Bullet impact	III	II	V	V	V	V	V	V	Type IV	Deflagration	Fragmentation, detonation	III	II	V	V	V	V	V	V	Type V	Burning	Fragment impact (light)	III	II	V	V	V	V	V	V	No Reaction		Fragment impact (heavy)	III	II	V	V	V	V	V	V			Shaped charge attack	III	II	V	V	V	V	V	V			Shrapnel impact	III	II	V	V	V	V	V	V			Drop	NPT	NPT	NPT	NPT	NPT	NPT	NPT	NPT			Electrostatic discharge	NPT	NPT	NPT	NPT	NPT	NPT	NPT	NPT		
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CANDIDATE MATERIALS FOR Mk.3 Shaped Charge - TAW-EX-2022 is a novel explosive formulation, put forward by Dave Holley - Data sheet supplied shows good properties but the formulation is complex - Not yet qualified as an IM and with a figure of insensitiveness of 60, lower than pure RDX, it seems unlikely to be suitable for this classification (at least when unpacked). - Other options, further through the development phase are available...	CANDIDATE MATERIALS FOR Mk.3 Table 1: Comparison of candidate materials for Mk.3. The table lists various materials and their properties, including sensitivity, stability, and performance metrics. It compares different formulations and their suitability for use in insensitive munitions.	CANDIDATE MATERIALS FOR Mk.3 Shaped Charge - The IMX series is a group of formulations developed by BAE for use in insensitive munitions - IMX-101 has begun to replace TNT in shell fillings. As a composition however it has a large critical diameter (>60mm), potentially rendering it unsuitable in this shaped charge. - IMX-104 touted as best replacement for Comp-B based formulations and has also been qualified as IM. - This formulation is close an exact match for power of detonation and TNT equivalence to Comp-B, and has a smaller critical diameter of 20mm, making it suitable for use in smaller charges such as this example - Melting point 94-5C, providing better stability than Comp-B in hot environments [6, 7, 8]																																																																																																																																	
CANDIDATE MATERIALS FOR Mk.3 Cratering Charge - Development and literature of insensitive aluminized formulations is very limited - However, a very recent development by Thales shows significant promise - TB-1200 has been qualified as an IM, and is based on Trinitrol (aluminized TNT) with the addition of a soluble desensitizer, 2-naphthol - The formulation is 80-85% TNT, 2-6% 2-naphthol, and 15-20% aluminium, with this ratio range providing best compromise between IM response and performance - Critical diameter of 10mm when unfired would allow for detonation of the formulation as a flake form without booster charge - Furthermore, with the low cost and high availability of TNT, using this formulation creates a significant cost saving compared to the IMX explosives and also RDX [9]	REFERENCES [1] D. N. S. ... [2] A. ... [3] ... [4] ... [5] ... [6] ... [7] ... [8] ... [9] ...	- Sequential Environmental Trials (SET) is a series of tests a munition must undergo to demonstrate it is Safe and Suitable for Service (S3) - Safe and suitable for service - The requirements needed to demonstrate that the inherent risks from Ordnance																																																																																																																																	

References

- AOP-15 Allied Ordnance Publication (AOP) 15: The process for assessing safety and suitability for service of munitions
- DEF STAN O0-035, Part 1, Chapter 2-01: Sets out the process for developing a Sequential Environmental Trials (SET) programme.
- DEF STAN O0-035, Part 3, Sets out the fail-back tests that can be used in the SET
- AOP-63: Non-destructive and destructive testing
- Other documents of relevance:
 - AOP-46 - The Scientific Basis for the Whole Life Assessment of Munitions
 - AASP-Q1 - Allied Ammunition Safety and Suitability for Service Assessment Testing Publication - Guidance

Pete Down

*Manufacture to Target
or Disposal Sequence
(MTDS)*

Overview

-  The Manufacture to Target or Disposal Sequence (MTDS) is a framework to understand the lifecycle of a munition.
-  The MTDS includes manufacture, in-service support, use of munition, and disposal of munition.

*MTDS:
Manufacturing*



Explosive Selection

IMX 104

NTO/RDX/DNAN - for use in shaped charge.

TB I200

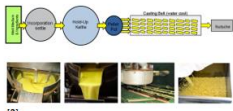
TNT/Al/2-Naphtol - for use in bag charge.

Shaped Charge - Case

- Shaped charge cases are made from steel billets.



Shaped
Charge Fill



- Average melting temperature of IMX 104 is 94.5 °C [4].
- Temperature during melt casting tends to be between 1 °C and 9 °C above melting temperature [5].

Bag Charge Fill

The melting temperature of TB I200 is 80.4 °C [6].



MTDS: In-Service Surveillance and Life Extension



In-Service Testing

- In-service testing is critical to validate the data gathered at qualification.

Distinctions and Definitions

- | | |
|-----------------------|---|
| Surveillance | In-service testing to ensure the munitions are in a suitable condition.
Can be used as evidence to support current lifecycle duration. |
| Life Extension | In-service testing to extend the lifecycle duration of munitions. |

Typical Programme Outline

- Receipt Inspection
- Leak test (shaped charge)
- Radiography (shaped charge, bag charge)
- Functional testing
- Breakdown, test, and criticality analysis (BTCA)

Functional Testing

- Functional testing is the normal initiation of the munitions at temperature extremes to investigate the change in certain parameters over asset lifecycle.
- Usually, two shaped charges will be tested, one at each temperature extreme. Two bag charges will undergo the same testing.
- Data gathered includes blast pressure over time and the confirmation of

Test	Temperature	Shaped Charge 1	Shaped Charge 2	Bag Charge 1	Bag Charge 2
Detonation	Hot	X		X	
Detonation	Cold		X		X

Breakdown, Testing, and Criticality Analysis (BTCA)

Test	Purpose
Dynamic Mechanical Thermal Analysis (DMTA)	Determine material mechanical properties across range of temperatures.
Differential Scanning Calorimetry (DSC)	Investigate mechanical and thermal properties, such as melting temperature.
Tensile testing	Investigate mechanical properties.
Figure of Insensitiveness (Fol)	Hazard analysis
Figure of Friction (Fof)	Hazard analysis
Temperature of Ignition (Toi)	Hazard analysis

- The purpose of BTCA is to assess the condition of energetic materials after natural ageing.
- The shaped charge requires disassembly for BTCA.
- The charges may be sectioned to inspect crystal structure changes.

*MTDS:
Disposal*



Disposal Methods

- Munitions that have not been used during their service life have a disposal period lasting for a few years within which they must be disposed of.

Method	Description
Open burning/detonation	Energetics are placed in an open area and ignited to either burn or function the munition.
Incineration	Energetics are thermally degraded within a large incinerator. Fumes are captured.
Chemical neutralisation	React the energetic material with another chemical to neutralise it.
Hydrolysis	Energetics are dissolved in water and broken down by hydrolysis process. This is most effective with nitrate esters.
Bioremediation	The use of microorganisms to breakdown and neutralise energetic material.

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