20057 - Novel Slow Cook-off Test Method to Replicate Worst Case for Munitions Containing Internal Fuel
Blazek

There exist munitions containing internal fuel. Some of these types of munitions may contain one or more energetic warheads. Historically, during an event such as Slow Cook-Off (SCO), one but not all of the energetic components may react causing dispersal and ignition of the internal fuel. Depending on the violence of such an event, the remaining energetic components may remain situated within the newly formed fuel fire. Some munitions may have sufficient violence to project the remaining components clear of the fuel fire. However, this function occurs in an unpredictable and non-repeatable manner. In essence, a munition in one test event may project the remaining components clear, but in a subsequent identical test event leave the remaining components within the fuel fire. Components exposed to a fuel fire following or during exposure to a SCO environment have exhibited much more severe reactions than when subjected to the standard Fast Cook-Off test. Furthermore, a first reaction with sufficient violence to project components clear of a fire typically fails to comply with standardized response levels, and the necessary changes made to reduce the first reaction increase the likelihood of exposing the remaining components to the fuel fire.

For many programs, testing an All-Up-Round (AUR) is so expensive that testing an AUR enough times to replicate the worst case event proves unpractical. Therefore efforts are being pursued to develop a practical method to replicate such a worst case test event consistently, while minimizing cost, to enable development of engineering solutions. Such a method required a test which replicated both the standard SCO environment as well as the fuel fire intrinsic to the system response, in order to assess the remaining system components.

A method was developed to consistently test munition component(s) to SCO incorporating the intrinsic fuel fire. This method enabled successful engineering design development of a component level solution, which was demonstrated in tests replicating the system level response. This method was deemed useful in assessing design improvements of the remaining component(s) undergoing a worst case system level response environment in such a manner as to provide consistency between numerous test events. In order to achieve consistent replication, certain system components were replaced with representative mechanisms, which allowed consistency as well as significant cost savings. As a result, this method satisfactorily replicated the worst case AUR system SCO response, including the intrinsic fuel fire, with significant cost savings.

20059 - A New IMI Systems Less Sensitive Brisant Explosive Composition
Strul-Yudkiewicz

Recently, IMI Systems has completed the qualification process for a new less sensitive brisant explosive composition, named CLX-881. This HMX based explosive is analogous to PBXN-110.

This composition was developed for applications where RDX based compositions could not meet the performance requirements. This compsition is less sensitive and intended for applications in IM munitions.

The qualification process was process was performed according to IDF test protocol, based uopn STANAG 4170.

The presentation will contain elaboration on various tests performed for this composition.

20063 - US Navy Insensitive Munitions (IM) Munitions Reaction Evaluation Board (MREB)
Tomasello

In August 2017, the Naval Ordnance Safety and Security Activity (NOSSA) issued NOSSA Instruction (NOSSAINST 8010.1A, Munitions Reaction Evaluation Board. This instruction is an update to the original NOSSAINST 8010.1 of July 2009 which created the US Navy unified board for scoring IM, Hazard Classification (HC) and safety tests. The guidance provided by this instruction ensures consistent evaluation of ordnance hazard assessment test plans and scoring technical performance (i.e., test/no-test and reaction level) of hazard testing in support of IM compliance, HC and Weapon System Explosive Safety Review Board (WSESRB) review processes for munitions. NOSSAINST 8010.1A clarifies and updates the operating philosophy of the MREB including: Leadership, Membership, Meetings, Authority and Responsibility and Documentation for the Board. This paper describes the background of formation of the unified Navy board and reviews the applicability of the instruction and provides highlights from the instruction.

20069 - Influence of concentration, type and particle size of fillers on the dynamic mechanical behaviour of elastomeric HTPB binder

Bohn

Recently, it was found that the second peak of the loss factor curve determined by DMA of HTPB bonded composite propellants and high explosives can change significantly in intensity and shape with composition. Composite propellants with AP connected via bonding agents to the binder matrix can show a pronounced second peak, whereas HMX and RDX produce a weaker peak and with high content, it can appear as shoulder only attached to the first peak at lower temperatures. The second peak is much more sensitive to ageing and to de-wetting. This means interaction between filler and matrix influence the appearance of the peak. These interaction play also a role in sensitiveness, if the bonding between particles and binder is not good. Therefore, a more detailed investigation was started to elucidate the influences of fillers on the loss factor curve. Polyurethane binders made from polyol HTPB and isocyanate IPDI were filled with 20, 40 and 60 mass-% of ammonium perchlorate (AP), aluminum (Al) or RDX, using fine and coarse particles. For obtaining the cured elastomer, a special turning device constructed and manufactured at Fraunhofer ICT was installed inside the curing oven in order to avoid sedimentation of the fillers during curing. The cured composites were characterized by DMA in torsion mode from -100°C to +70°C, and the quality of distribution of fillers was evaluated by X-ray micro-tomography, which showed homogenous distribution of the filler particles in the samples. The part of loss factor tan? at lower temperatures originates from the glass-rubber transition of the binder parts, which are unrestricted in mobility, defined so as comparison for the second broader peak at the high temperature side, which is caused by binder parts restricted in mobility. The temperatures at each maximum are called Tg_unr and Tg_res, respectively. The results are: AP and RDX cause more changes in intensity of the first main peak in tan? than Al particles. The maximum temperature Tg_unr is nearly not changed by any of the fillers. The changes in tan? intensity determined from baseline corrected loss factor curves and modelled by EMG (exponentially modified Gauss) distributions indicate that Al has a stronger interaction with HTPB binder than AP and RDX particles. The particle sizes of AP and RDX and their shapes effect the viscoelastic properties. Increasing content of AP and RDX increase the storage modulus G’ and somewhat the loss modulus G’’, but as a whole tan? intensity is lowered in the main peak.

Keywords: filler effects on loss factor; DMA loss factor modelling; HTPB-IPDI binder; filler AP, Al, RDX

20074 - Characterization of MTNP (1-methyl-3,4,5-trinitro-1,2-pyrazole)
Samuels

The Ordnance Environmental Program (OEP) from RDECOM has recently funded synthesis efforts evaluating new green synthesis routes to produce both RDX and TNT replacements. MTNP (1-methyl-3,4,5-trinitro-1,2-pyrazole) is a low melting energetic compound. Recently, MTNP has shown promise in terms of a relatively simple synthesis route. ARDEC has characterized this compound from lab scale batches for safety testing.

Thermo-chemical codes such as Cheetah and Jaguar were used to predict the Gurney energy for this high energy material. MTNP was reported in literature using pyrazole, chloro pyrazole and Methyl Pyrazole as starting materials. Our approach involves commercially available 3-Nitropyrazole as starting compound and its synthetic transformation to MTNP.

Small scale safety testing was completed, including impact, friction and electrostatic discharge testing. The crystal density was determined by pycnometry and the thermal stability was accessed via DSC, isothermal weight loss, and vacuum thermal stability (<2 cc gas/48hrs at 100°C). MTNP has proven to be compatible with most energetics and metals. This paper will discuss the synthesis, thermal, sensitivity and analytical results of pure MTNP.

20077 - Evaluation of Composition B using Nano-Energetics
Samuels

This paper will discuss the preparation, shock sensitivity and thermal stability of Nano-energetics-based Composition B (N-Comp B) consisting of nano-crystalline RDX and TNT. The formulation was prepared by pressing Comp B molding powder that was produced by spray drying an acetone solution of RDX and TNT. The nanostructure of N-Comp B was characterized by focused ion beam-scanning electron microscopy (FIB-SEM) and the shock sensitivity was evaluated using small scale gap test (SSGT). The characterization of the nanostructure shows that the majority of the voids inside the formulation are in the nanoscale range but have a large quantity. Reduction in shock sensitivity was observed in SSGT test and is attributed to the elimination of large voids, and yet the quantity of smaller voids seems to have limited this sensitivity decrease. Thermal cycling, which was used to evaluate the thermal stability of N-Comp B, induced significant structural change, i.e., the increase of both void size and the crystal size, causing an increase in sensitivity.

20080 - Slow Heating Testing Survey and Historical Events Review
Baker

This report describes the results of an international review of the STANAG 4382 Slow Heating, Munitions Test Procedures, as well a review of heating rates and durations associated with actual fire events. The purpose of the slow heating test is to assess the reaction, if any, of munitions and weapon systems to a gradually increasing thermal environment. To perform the review, MSIAC created a questionnaire in conjunction with the custodian of this STANAG, the United States, and sent it to subject matter experts including test centers in most of the AC/326 nations. Moreover, an analysis of similar standards has been done in order to achieve more consistency in the recommendations. From a NATO point of view, the requirements for the slow heating test are defined within three documents: STANAG 4439, STANAG 4382 and AOP-39. The test 7 (h) from the "UN – Manual of Tests and Criteria" specifies a slow cook-off test for the classification into hazard division 1.6. The questionnaire questions deal with the test purpose, test procedure, heating rate, actual events, oven design, oven standardization, temperature preconditioning, energetics melting, reaction temperature, test item restraints, test item orientation, instrumentation, and number of tests. This report provides an analysis of the answers received, summarizes best practice and provides some recommendations to potentially support an amendment of STANAG 4382. The recommendations include:

• Develop a group consensus as to the intent of the test and document it.

• Query all of the MSIAC nations to provide information on actual event durations and rates.

• Based on consensus test intent and supporting data, develop a consensus as to changing rate or leaving the rate unchanged.

• Clarify the minimum number of required thermocouples and thermocouple positioning.

• Observations of events inside the oven.

• Develop and provide a best practice oven design examples for different types and scales of test items.

• Characterize the heating equipment and perform calibration testing.

• Provide a best practices example test configuration.

• Remove redundancies or contradictions between the STANAG 4382 and AOP-39.

This study was an efficient way to identify recommendations to further improve the STANAG 4382. These recommendations are being discussed within the NATO AC/326 SG/B Slow Heating Custodial Working Group (SH CWG). The working group has already reviewed the review results and is currently drafting updates to STANAG 4382 NATO documentation, which includes the technical content of the STANAG that is being migrated into a new AOP 4382.

20081 - Gap Test Calculations and Correlations
Baker

The Munitions Safety Information and Analysis Center (MSIAC) has developed a number of safety related computational tools, including NEWGATES (New Excel Worksheets on GAp TESts) [1] which is a large data base and computational tool for gap test data. NEWGATES currently contains information about 10 gap tests (dimensions, scope, principles); pressure calibration curves; time calibration curves; shock curvature calibration curves; 1455 gap test results; and over 250 Hugoniots. Reported gap test pressures represent the shock pressure in the attenuator material just before it shocks the energetic material being tested. As the shock pressure is reduced as it passes through the attenuator, a pressure calibration curve is required [2,3]. Donor-produced shock pressures are sustained at higher levels for longer distances as either the test diameter or confinement is increased. This makes the calibration curve highly test dependent. NEWGATES includes pressure calibration curves for the various gap tests based on test results, numerical simulations and analytical calculations. NEWGATES can also calculate the shock pressure transmitted in the tested energetic using the attenuator material Hugoniot and tested energetic unreacted Hugoniot. As the unreacted Hugoniot of most tested energetics is not available NEWGATES includes an analytical module that estimates the unreacted Hugoniot of a material using a rule of mixtures approximation [4,5]. The unreacted Hugoniot approximation requires the material density, the composition and the Hugoniots of its ingredients. The unreacted Hugoniot calculation includes porosity effects of a mixture at less than the theoretical maximum density [6]. The required input data are the mass percentages of the different ingredients, the density of the composition and the pressure range for the Hugoniot calculation. Up to 5 ingredients can be used to calculate the Hugoniot mixture. Most recently, NEWGATES has been modified to include a critical diameter estimation calculation. In order to reduce the cost, time and risks involved in the conception of an explosive, researchers have often tried to determine ways to predict the sensitivity properties of an explosive. We have conducted studies investigating laboratory test characteristics correlations. The properties investigated include the Held criterion, the weight percentage of RDX, the composition density, the composition, the Gurney energy, the Rotter impact test and the detonation state properties. A correlation between the Large Scale Gap Test from the Naval Ordnance Laboratory (NOL LSGT) and the critical diameter has been found. Weaker correlations with the explosive density, the composition and the Held criterion have also been found. The Gurney energy, the Figure of Insensitiveness of the Rotter Impact test and detonation performances characteristics do not provide any correlation relationship with the gap test results or critical diameter. The result is that NEWGATES now provides several ways to estimate laboratory sensitivity properties knowing other properties.

1. P.F. Peron, “NEWGATES Version 1.10 User Guide”, NATO MSIAC Report L-148 Edition 3, November 2011.

2. A.L.Bowman, S.C.Sommer and J.H.Fu, “Calibration curves for four standard gap tests”, Report LA-11763-MS (1990)

3. “Gap tests and how they grow”, D. Price, 22nd DDESB Seminar, pp.365-380 (1986)

4. R.R. Bernecker, "The Calculation of Unreacted Hugoniots. I. TNT, RDX, and their Mixtures," JANNAF Propulsion Systems Hazards Subcommittee Meeting, CPIA Publication 582, Vol. I, April 1992, p. 285.

5. R.R. Boade, ”Compression of Porous Copper by Shock Waves”, J. App. Phys.. 39,5693-5702 (1968).

6. A. Milne, A. Longbottom and J. Millet, "On the Unreacted Hugoniot of Three Plastic Bonded Explosives", Propellants, Explosives, Pyrotechnics, Vol. 32, n° 1, pp 68-72 (2007).

20082 - Gun Launch and Setback Actuators
Baker

There is currently no agreed standard methodology for assessing the suitability of explosives for gun launch or for the determination of acceptance criteria for explosive fill defects. Laboratory setback activator testing has been used as an assessment tool for investigating the suitability of explosives for gun launch. Unfortunately, laboratory setback activator testing is not standardized and large variations exist in activator design, function and results between different laboratories. However, it is the only currently available tool for assessing an explosives safety and suitability to launch-induced setback forces. This paper is a review of gun launch setback and laboratory setback activator testing and results. Observations indicate that actual gun launch setback ignitions cannot be clearly correlated with the results of ignition sensitiveness results from laboratory setback activator tests. The laboratory setback activator tests normally indicate ignitions at much higher setback loadings than are believed to be produced in actual gun launched projectiles. Additionally, the defects in actual projectiles appear to be very different than the laboratory tests. Both ignitability and explosiveness are considered in assessing an explosive's resistance to launch-induced explosion. Ignitability is defined as the tendency for ignition to be induced. Explosiveness is defined as the reaction violence once ignition is induced. Explosives are often not rejected on the basis of exhibiting high ignition sensitiveness in the activators unless the reaction violence levels are also high. The activators may be limited in their ability to appropriately measure explosiveness since they commonly generate considerably shorter pressure pulses than that produced in the launch environment. This could inhibit violent reaction for explosives which do not burn rapidly either because insufficient surface area is produced during cavity collapse or because of relatively slow chemical kinetics. In the controversy between brittle and soft explosives, ignition sensitiveness results are biased towards the strong brittle materials, often observed for melt pour explosives. Clearly, the laboratory setback actuator approach tells only part of the story, as the testing may not reflect all the ways in which the mechanical properties influence potential stimulus amplification mechanisms. In spite of all this, the activator, remains the currently only available tool for assessing an explosives resistance to launch-induced premature explosions and it is recommended that the munitions community should work toward developing an understanding of the ignition phenomena and laboratory setback activator technology as part of a process development for defining physically based acceptable defect criteria.

20083 - Insensitive Munitions Explosive Ordnance Disposal Challenges
Pope

Development of appropriate procedures for the disposal of explosive ordnance are mandated by NATO STANAG 2143 (AEODP-10). As a result of Insensitive Munitions (IM) development, many munitions are being introduced with increasingly less shock sensitive energetics with increased critical diameters. This poses problems for Explosive Ordnance Disposal (EOD) operations in conducting a successful Render Safe Procedure (RSP). Traditional EOD methods for disposal consist of a number of tried and trusted techniques used singly or sometimes in combination such as, shock initiation by donor charge, directed energy attack (e.g. shaped charge, EFP), thermal initiation charge and projectile attack. In addition EOD operations sometimes require a non-detonating response (Type IV to Type V IM response). As the newer IM rounds are designed to have reduced sensitiveness to these types of stimulus this presents a new challenge for EOD.

As an example, the shaped charge jet velocity versus the jet tip particle diameter required to produce explosive initiation is now well-known as “Held’s criteria” [Held 1996, Lapebie 2006, Lapebie 2010, Peron 2010]. In order to have an idea of typical Held criteria values produced as a function of shaped charge warhead size, typical jet diameters were plotted from available data of fairly standard shaped charges [Blouin 1993, Baker 2010, Arnold 2015]. For fairly standard shaped charges, a linear jet tip region diameter to shaped charge warhead explosive diameter resulted. Patel and Voisin have shown that Held criteria values correlate fairly well with explosive critical diameters required for detonation [Voisin 2016]. Using these relationships, an analysis of required shaped charge warhead size to defeat munitions with various explosive fills was conducted. The results indicate that typical 35mm to 100mm diameter shaped charges are predicted to initiate a large range of munitions. Smaller diameter designs would require a very high jet tip velocity and careful design, whereas a 100mm charge would be very conservative. A reasonable 50mm design should be able to initiate a broad range of traditional high explosives. However, the introduction of less sensitive explosives with larger critical diameter explosives require larger shaped charge warheads. In particular, very large shaped charge warheads between 370 and 700 mm diameters are predicted to be required in order to initiate munitions with critical diameters in the 60 to 70 mm region.

This paper will look to assess the effect of reduced sensitiveness energetic materials on EOD RSPs and make proposals and recommendations on considerations in planning and conduct of EOD operations.

Arnold W., Rottenkolber E., Hartmann T., “Challenging v^2d”, 2015 Insensitive Munitions & Energetic Materials Technology Symposium, Rome, Italy, 18 – 21 May, 2015.

Baker E. et al., “Rocket Propelled Grenade Shaped Charge Initiation Test Configuration for IM Threat Testing”, IM Technology Gaps Workshop, The Hague, Netherlands, 20-24 June 2010.

Held M., “Initierung von Sprengstoffen, ein Vielschictigen Problem der Detonationsphysik”, Explo-sivstoff, Vol. 5, pp. 2-17, 1968 (Translated by Lawrence Livermore National Laboratory as Ref. 02973, 1980).

Lapebie E., Peugeot F., “TEMPER: a Toolbox for Engineering Models to Predict Explosive Reac-tions”, session 8B, Modelling & Testing (Part 3), 2006 Insensitive Munitions & Energetic Materials Technology Symposium, Bristol, U.K., 24-28 April, 2006.

Lapebie, E., Vigie H., Peron P.-F., “Using TEMPER’s Genetic Algorithm and MSIAC Databases to fit SDT Model Parameters”, paper 10442, ibid., 2010.

Peron P.-F., “MSIAC IM Databases: An Efficient Toolbox to Assess IM Signature”, 2010 Insensitive Munitions & Energetic Materials Technology Symposium, Munich, Germany, 11-14 October, 2010.

Voisin M., “Critical Diameter Correlations”, MSIAC Report L-202, September 2016.

20111 - Effect of microstructure control on the reaction characteristics in Al/Ni reactive powder
Jung

Abstract (Poster Session)

A microstructure and reaction characteristics that appear in Al/Ni reactive powders and the correlation between those were investigated. 3 types of Al/Ni reactive powders, that are clearly distinguishable in terms of microstructure, were prepared by using 3 kinds of milling processes (i.e. turbula mixing, attrition milling, planetary milling). The Al/Ni powder prepared by using turbula mixer shows that the shape and grain size are maintained from initial state of raw Al and Ni powder. In contrast, the Al/Ni powder prepared by using attrition mill shows that the shape was distorted and grain size largely decreased from raw material. And the powder prepared by using planetary mill was completely deformed from the initial state of raw material and represents a new type of microstructure (i.e. nano-lamella structure). In terms of interface state, these 3 types of powders are also clearly different according to observation of transmission electron microscopy. To compare the reaction initiation temperature of these powders, differential scanning calorimetry analysis was performed. As a result, the reaction initiation temperature varies more than 350 oC according to the changes in microstructure. In order to compare reaction rate, thermal explosion phenomena of the 3 types of powder were also observed by high speed camera at a condition of 10,000 fps (frame per seconds). And it represents that the reaction rate also varies greatly depending on the microstructure of the powders. These results represent that reaction characteristics of reactive powder can be tailored by controlling the microstructure of reactive powder.

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Keywords: reactive materials, mechanical alloying, nano-lamella, Al-Ni reactive powder, self propagating reaction

20112 - Review and Update of STANAG 4496 Fragment Impact, Munitions Test Procedure
Jacq

The custodial working group for STANAG 4496, Fragment Impact, Munitions Test Procedure is developing an updated Allied Ordnance Publication (AOP) that will replace STANAG 4496 which was ratified in 2006. The STANAG 4496 edition 1 is dated and needs improvements in order to greater standardize the threat hazard assessment, and to be in step with the current measurement capabilities.

Two Custodial Working Group meetings have been held: DGA Missiles Testing, Bordeaux, France 24 – 25 January, 2017, Kromhout Kazerne, Utrecht, Netherlands 10 – 11 April 2017. These meetings aimed at clarifying and introducing new requirements and recommendations in order to improve the test procedure.

An AOP is being written that will update the new test specifications, including the aim point selection, the accuracy requirement, and the orientation of the fragment at impact. An historical overview on the fragment will also be added.

Moreover, test facilities developed at DGA Missiles Testing (France) in order to be in compliance with the new AOP 4496 ed A will be presented.

20113 - Investigation of the Hugh James Criteria using Estimated Parameters
Sweitzer

The ability to predict the response of an energetic device to IM stimulus is one of the major focus areas within the IM community [1]. Several methodologies have been proposed and used for this purpose, including direct calculation via reactive burn models [2-8], analytic criteria such as Held's V2D criteria [9-13], and semi-empirical techniques such as the Hugh James (HJ) criteria [14-16]. A method was recently presented that leverages the HJ criteria with estimated parameters combined with the ALE3D hydrocode [17]. Statistical models are used to predict reaction threshold. Extensive validation of the model was not performed, but would be useful in determining the viability of the approach. If sufficiently validated, the approach can provide a means to estimate the impact sensitivity of energetics that are not thoroughly characterized in reactive flow models. In this paper, this methodology is examined in detail by applying it to a well-characterized explosive.

The basis for the methodology is in threshold statistics, as detailed by Hrousis, et al [19]. Energetic materials are often characterized in terms of '50% go/no-go' thresholds [20], underscoring the inherent variability in material response. These concepts were initially applied to an explosive for which HJ parameters were not readily available (LX-14), but a large body of Fragment Impact (FI) test [21] data was. Values for the missing parameters were 'guessed' by substituting parameters from a similar explosive. The initiation threshold was developed by applying the 'guess' parameters to the existing data, and extrapolated forward through a Binary Logistic Regression (BLR) model [22].

To test this methodology, the UF-TATB parameters from Hrousis, et al, were used in place of test data. The mean and variance of the ignition threshold were calculated using the QMU method and applied to a BLR model. Model variations were then simulated to test the predictive capability of the method.

20114 - Life Cycle Demilitarization Considerations for IM Development
Mescavage

The Product Manager for Demilitarization was established under PEO Ammunition as part of the Single Manager for Conventional Ammunition function to provide focused management of the demilitarization of conventional ammunition from across the Services. As the final phase of the life cycle, demilitarization comprises a significant portion of a product's life cycle costs and presents numerous liabilities to the Department of Defense, as well as potential opportunities to the munitions development community. Demilitarization also accomplishes important Warfighter enhancement through streamlined munition logistic storage and supply chain functions. Design decisions made early in development of a conventional ammunition item constrain options during demil and either positively or adversely impact cost, efficiency, safety, recycle potential, and environmental aspects of demil operations. Consideration of demil impacts during design – or "design for demil" (DFD) – should be done as an integral part of a systems engineering approach and is also DoD level policy. Along with Demilitarization, sustainment of a weapon systems is a crucial life cycle consideration. The industrial base's end to end production, handling, waste management and storage are greatly impacted by new IM materials and must be handled properly in accordance with environmental policy. The current environment of constrained resources makes it all the more compelling to ensure a holistic approach is taken during early development that incorporates life cycle perspective.

Insensitive Munitions in particular present unique challenges to demilitarization operations but also potential opportunities to create efficiencies that reach across the life cycle to effect proactive reduction of long term sustainment costs. Several examples illustrate this point. During testing of existing processes for melt out of IMX-101 from the new M1123 projectile it was discovered that existing demilitarization equipment could not adequately remove the explosive fill due to the melt dynamics of the IM explosive. This will result in increased end of life cycle cost due to the need for prototype equipment development followed by capital investment to modify existing equipment across multiple Army depots. Cast cured IM fills in general cannot be demilitarized using the traditional demil method of melt out, precluding the ability to recover energetics for reuse as has historically been the case. This will result in loss of recovered value and the need for additional expense in the production of new energetic material where recovered material is no longer available. As a rule, demil infrastructure does not currently exist for plasticized cast cured type fills. High pressure water washout has been explored, but not fully proven out. Where it does work, it produces a material containing non-energetic components, some of which are heavily regulated and result in environmental risk during the disposal process, particularly when open burning is used. In addition, high pressure water washout produces contaminated liquid waste streams containing new contaminants that must be addressed. These complications result in less efficient and more costly demil processes requiring significant capital investment in new demil facilities across multiple depots to meet the new requirement cast cured fills are imposing on end of life demil operations. On a brighter note, signs of early demil consideration are appearing in IM energetics research and development. Innovative methods are currently being investigated to provide for quick and easy disillusion of new energetic fills with the application of a reactant material. One particular program is looking at development of a potential demil method concurrent with the development of the new IM energetic fill during very early research. Upfront considerations of demilitarization needs during IM development such as this will ensure the sustainment elements will help reduce the installations ‘burden of ownership’ and ensure that new capabilities will continue to support Army combat readiness. At the least, the need for new demil equipment can be identified early enough that it can be programed, planned, and prepared by the time IM stocks reach their end of life and require demilitarization.

This paper will discuss DFD principles as well as DoD level DFD policy and implementing guidance. It will identify some of the challenges unique to the IM community and provide guidelines for mitigating life cycle risks. It will also discuss opportunities in the form of design recommendations that can create reductions in life cycle cost and a variety of positive life cycle impacts.

20115 - Innovative Nitrogen-doped Boron Propellants
Manning

The U.S. Army has a need for more powerful propellants with balanced/stoichiometric amounts of fuel and oxidant to provide an advantage to its warfighters. In addition to improved power, balanced propellants have reduced blast force and secondary flash, an important advantage in terms of signature for the soldiers. However, balanced propellants lead to accelerated wear and erosion of gun barrels due to the higher flame temperature. Ceramic additives in the propellant can theoretically prevent barrel

deterioration by coating the inside of barrels, but implementation of composite propellants with conventional ceramics (i.e. alumina) has not resulted in improved wear and erosion resistance to date. Due to challenges with dispersing the particles in the propellant, and due to incomplete sublimation, propellant and ceramic composites that produce regenerative wear-resistant coatings have not been effectively demonstrated. Boron nitride (in the form of crystalline hexagonal BN or amorphous (BN) has the ideal properties of a propellant additive. Boron nitride can form a lubricating coating on barrel walls. Further, boron can dope steel, which drastically improves its strength and wear resistance. However, to form a thin coating that reduces abrasion, boron nitride must be in the form of a nano-particle, and must be evenly dispersed in the propellant. Further, the production of nano-scale boron nitride must be economical for implementation in advanced propellant composites. These materials can be dispersed in propellants to form a stable composite. During propellant firing the additive will either form hexagonal boron nitride, which can provide a protective coating and lubricating barrier on the inside of the barrel walls, or oxidize to form boron oxide. Boron oxide could also coat the barrel, or dope the steel with boron. Additionally, because of its low molecular weight, boron nitride oxidation could help to lower the propellant flame temperature.

In this paper, updated results from propellant characterization testing of boron nitride nano-composite propellants will be presented. This will include vacuum thermal stability, closed bomb and erosion testing. Detailed characterization of the boron nitride incorporated into gun propellant formulations before and after firing will be shown by methods including electron microscopy and x-ray photoelectron spectroscopy. This promising boron nitride additive shows the ability to improve wear and erosion resistance, without any destabilizing affects to the propellant. Potential applications could include longer barrel life for large diameter fire arms, and rocket propellants with reduced nozzle erosion rates.

20117 - Analysis of Temperature Profiles of Chemical Reaction upon Impact of Reactive Materials
Cho

We analyzed temperature profiles of chemical reaction upon high speed impact of reactive materials. A two color pyrometer, which included high speed camera, spectral splitter, and band pass filters, was utilized to measure transient temperature profiles during and after reactive metal samples impacted into steel plate with velocity of 1600m/sec. The spatial temperature distribution was analyzed from the ratio of spectral radiances at two different wavelength in infrared zone, i.e. 700 and 900 nm. The measured temperatures were calibrated with black body source. Two different types of metal samples, namely aluminum and nickel, were employed to understand reaction behavior upon the impact of samples in ambient condition. According to our experiments, the Ni sample appeared to react with ambient air much less than the Al sample did.

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Keywords:reactive materials, Pyrometer, spectral radiances

20118 - Advancing the Propane Fast Cookoff Burner and Testing
Washburn

Propane burners have already been shown to produce the temperature and heat flux requirements to replicate the thermal environment of a liquid-pool-fire fast cookoff test. Ordnance items tested for fast cookoff in both propane burners and liquid pool fires have shown to have comparable reactions in the test. Further design work was done on the propane burner to allow it to be used to test larger ordnance items. The fuel delivery system to the larger burner was optimized and calibration showed that it produced a uniform flame that met the thermal requirements. It was then used to test a 500 lb bomb which was also tested in a liquid pool fire. The results of the testing are compared and demonstrate the ability to test large ordnance items in the propane burners. Additional testing was performed on an ammunition can containing a large number of energetic items. This test demonstrated that the multiple reactions that occur in such a test do not damage the burner or cause the test to change. The results from this test were very similar to the results from an identical test that was performed in a liquid pool fire. These test results continue to show that propane burners are safer, less expensive, and more environmentally friendly compared to the liquid pool fire for conducting fast cookoff tests.

20119 - GrIMEx (Green IM Explosive): Development of Novel IM Comp B Replacements Based on Green TNT and RDX Replacements
Price

Comp B is an explosive formulation consisting of TNT, RDX and wax and has been used for many years in bomb fills, grenades and anti-personnel mines. Although Comp B has performed well over the years, the environmental impact of the formulation warrants concern. With the recent development of IMX-101 and IMX-104, invented by BAE Systems Ordnance Systems' scientists, IM replacements for TNT and Comp B were created. However, although IMX-104 is considered and accepted to be a Comp B replacement, some performance data of IMX-104 indicates it is lower than that of Comp B. There is a need for IM melt-pour formulations with performance equivalent to or above Comp B while retaining the IM properties of the IMX family of explosive formulations and also containing non-toxic and environmentally-benign ingredients produced through synthetic methods of low environmental impact. This project combines the capabilities of the US Army Public Health Command and BAE Systems, Ordnance Systems Inc and is funded by the DoD's Strategic Environmental Research and Development Program or SERDP.

The objective of this project is to address the following: 1) Develop environmentally acceptable synthesis methods to scale-up environmentally sustainable, insensitive secondary explosives as alternatives to cyclotrimethylenetrinitramine (RDX), 2, 4, 6-trinitrotoluene (TNT), and ammonium perchlorate (AP); and 2) Develop novel formulations utilizing the alternative materials to replace Composition B (Comp B).

This paper describes the synthesis of all the ingredients including justifications and rationale for evaluating these materials, technical challenges encountered with the synthesis and scale-up efforts, development of DNP- and TNBA-based formulations, and analytical results.

20121 - VALIDATING EXPERIMENTS FOR VULNERABILITY CALCULATIONS OF MUNITIONS AND LESSONS LEARNED

Scholtes

ABSTRACT

For ship vulnerability and survivability calculations, TNO developed a toolbox to estimate the probability of a violent event on a ship (or other platform), when the munition bunker is hit by e.g. a bullet or fragments from a missile attack. To obtain the proper statistical output, several millions of calculations are needed to obtain a reliable estimate. Because millions of different scenarios have to be calculated, hydrocode calculations cannot be used for this type of application, but a fast and good engineering solutions is needed. At this moment the Haskins and Cook-model is used for this purpose.

To obtain a better estimate for covered explosives and munitions, TNO has developed a new model which is a combination of the shock wave model at high pressure, as described by Haskins and Cook, in combination with the expanding shock wave model of Green. This combined model gives a better fit with the experimental values for munitions response calculations, using the same critical energy fluence values for covered as well as for bare explosives. Also, several series of experiments with shells and warheads have been performed firstly, to investigate the vulnerability of munitions in storage conditions and secondly to validate and toolbox calculation results.

In this paper the theory is explained and results of the calculations for bare and covered explosives and stored munitions will be presented and compared with the experimental results. Also, interesting results and lessons learned from the munitions test series will be presented.

20122 - Outgassing Pad for Cook-Off Mitigation in Warheads
Garfield

An effort, funded through the Joint Insensitive Munitions Technology Program (JIMTP), is being conducted to look at the addition of several Insensitive Munitions (IM) technologies to improve the reaction of warheads to Slow Cook-Off (SCO) and Fast Cook-Off (FCO). In addition to evaluating the potential improvements in IM response, the new system will also be assessed for its ability to maintain performance and minimize environmental concerns.

The primary technology being implemented to achieve this IM objective is the strategic application of an Outgassing Agent (OA). The OA will be placed at the forward end of the warhead, to eject the entire explosive charge prior to ignition. This should allow the explosive to burn totally unconfined, thus producing a Type V reaction. In addition to the application of the OA in the nose of the warhead, this approach also relies on the implementation of a thermally releasable end closure on the warhead. The aft releasing mechanism would release prior to the decomposition of the outgassing agent. After the thermally releasable baseplate becomes significantly weakened or entirely released, the decomposition of the OA should produce gases that push the explosive billet from the warhead case.

Currently several small scale controlled volume tests have been conducted to identify a suitable OA with an appropriate decomposition temperature, rate, and quantity of gas production. Additionally, several Outgassing Small Scale Cook-off Bomb (OSSCB) tests have been conducted to verify the function of the OA, geometry, and container. A steel cylinder with the OA in the nose and loaded with approximately one (1) pound of explosive, was heated at the SCO heating rate (6°F/hr.). All OSSCB tests conducted demonstrated that the outgassing agent was capable of expelling the explosive prior to ignition, allowing the billet to burn unconfined. These passing reactions indicate that this technology is a viable solution for improving IM warhead performance. Evaluation of the OA in a weapon system with a significant increase in explosive quantity is scheduled for testing in FY18.

20123 - Modernization and Capabilities of the Lawrence Livermore National Laboratory Pilot Facility for Remotely Controlled Energetic Materials Synthesis

Zuckerman

Lawrence Livermore National Laboratory has invested in the modernization of their synthesis pilot facility for the kilo-scale preparation of energetic materials and precursors. This capability will serve to accelerate the research and development progression toward new energetic materials as well as for the optimization of processes for existing conventional materials. The first two planned campaigns for the facility will include the nitration of 2,6-diaminopyrazine-N-oxide (DAPO) to 2,6-diamino-3,5-dinitropyrazine-N-oxide (LLM-105), and the amination of 1,3,5-trichloro-2,4,6-trinitrobenzene to TATB. The presentation will focus on the design and agile capabilities of the pilot facility, the transition from all glass vessels to the new two-story integrated skid with glass-lined carbon steel reactors, and the efforts to provide optimal operator safety by utilizing a custom Wonderware® platform for reagent additions and the majority of process manipulations.

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20126 - An Investigation into a Proper Heating Rate for Slow Cook-off Testing
Hubble

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Slow cook-off (SCO) testing is performed on munitions to simulate accident scenarios in which a munition is slowly heated over an extended period of time. This can result when a fire occurs but is separated from the munition by some barrier such as the walls of a magazine. If the munition cooks off, the reaction can be severe because much of the energetic material is at an elevated temperature when the cook-off occurs. SCO testing is therefore necessary to help developers improve the response of munitions to this type of thermal threat and ensure that any reaction that occurs is as mild as possible.

Historically, SCO testing has been performed by heating the munition in an oven at a constant rate of 3.3°C/hr until a reaction occurs. Recently, however, the validity of this heating rate has been disputed and it has been argued that it is too slow to represent a realistic threat scenario. While many agree that the heating rate should be increased, there has been no real consensus on what the new rate should be. This investigation was performed to help determine what heating rates are possible for munitions and to help select a more appropriate heating rate for future SCO testing. This was done by examining historical accidents, reviewing existing analysis, and modelling possible threat scenarios. In the course of this analysis, no data was found or generated which supports a rate as slow as 3.3°C/hr and it is concluded that a heating rate of approximately 15-25°C/hr is more appropriate and better represents real-world threats to munitions.

20127 - CRASH-P and X-ray Laboratory Scale Slow Cook-off Tests to Quantify the Reaction Violence of High Performance Rocket Propellants

Essel

Full-scale slow cook-off (SCO) tests for high performance rocket propellants (HPPs) are very expensive and difficult to schedule in a timely manner. While a variety of sub-scale SCO tests exist, they often do not confine the sample in a similar manner to a full-scale test and they do not quantify the violence of the SCO reaction. Generally, the sample container is visually inspected after reaction and a qualitative reaction violence score is assigned. This degree of resolution is often not enough for a HPP formulator to determine if a propellant ingredient change affects the reaction violence of the sample. Two laboratory tests have been developed to address these needs. The first test is the Combustion Rate Analysis of a Slowly Heated Propellant (CRASH-P) test in which HPP samples up to 100 grams confined in a miniature polyether ether ketone (PEEK) rocket motor are slowly heated in a pressure sealed closed bomb until they ignite and the blast pressure is captured by dynamic piezoelectric pressure sensors. The temperature at ignition, peak blast pressure, and the blast pressurization rate are all quantified for each test. The second test is a dual axis X-ray test developed at Los Alamos National Laboratory (LANL) in which a HPP sample is slowly heated until SCO reaction. One x-ray axis takes quasistatic images of any HPP changes before ignition. The other x-ray axis is a high speed dynamic axis that captures images of the HPP while it is undergoing its exothermic SCO reaction. The x-ray test investigates and quantifies sample volume expansion, density changes, and how quickly the SCO reaction causes the HPP container to deform. Standard ammonium perchlorate (AP) based HPP formulations with rubberized binders were investigated. Formulation modifications were made that included using alternative oxidizer supplementation, different types of binders, different and varying amounts of polymer plasticizer, and other variables to determine if the tests could quantify a difference in the material behavior under a SCO environment. The lab-scale results were then compared to the full-scale results (if available) for validation.

20131 - Critical Diameter and Gap Tests for Hazard Classification of Solid Propellants and Motors
Romo

Critical diameter and gap tests have been used to determine the transportation and storage hazard classification of solid propellants and motors. A team of researchers at the Naval Air Warfare Center Weapons Division (NAWCWD) has been working on an extensive literature review summarizing the use and evolution of both the critical diameter and gap tests through the years. The information presented here is a status report on the progress of the literature review document.

The propellant formulations have changed through history. Fluctuation in critical diameters came with formulation changes. Double-base (nitrocellulose and nitroglycerine) propellants, common in World War II and the early 1950s, had relatively small critical diameters that were easy to determine. Composite propellants containing ammonium perchlorate (AP), aluminum (Al), and binder replaced many of the double base propellants in the 1950s and 1960s. These composite propellants had critical diameters measured in multiple feet [1]. The diameter of solid propellant motors has increased markedly since. With changes in formulations came changes in hazard classification methods. The Naval Ordnance Laboratory Large Scale Gap Test (NOL LSGT) with its 1.44 inch sample size was commonly used. However, programs quit measuring the critical diameters for composite propellants because the actual diameters of the final configurations were so large, although the NOL LSGT was still used. The 1970s focused on increasing performance. The addition of nitramines increased the performance of the propellants and decreased their critical diameters. The combination of small critical diameters and large motor diameters required larger gap tests than the NOL LSGT. The Super Large Scale Gap Test (SLSGT) was proposed as an alternate test to be used for large rocket motors [2]. The SLSGT presented in the 1998 TB-700 [2] was later modified on January 8, 2002 [3].

This document focuses on a brief history of propellants, as well as the critical diameter and gap tests used for their hazard classification. It also discusses how the hazard classification methodologies and standards have evolved with changes in propellant compositions. Moreover, this document discusses the three current options of alternate tests presented in the 2012 TB-700 [3] used to hazard classify propellants and motors. The strengths and weaknesses of these three tests are also studied, as well as the proposed changes to improve the ability to hazard classify propellants and motors.

References

1. Irwin, O.R., Poark, G.L., and Salzman, P.K., Large Solid-Propellant Boosters Explosive Hazards Study Program (Project SOPHY), Aerojet-General Corp., Downey, CA, 24 Nov. 1965, 328 pp, DTIC AD0476517

2. Department of Defense (DoD) Ammunition and Explosivs Hazard Classification Procedures Joint Technical Bulletin TB 700-2/NAVSEAINST 8020.8B/TO 11A-1-47/DLAR 8220.1; 5 January 1998

3. Wright, William. Changes to Alternate Test Procedures for Solid Propellant Rocket Motors. Department of Defense Explosives Safety Board Memorandum DDESB-KT. Alexandria, VA. 8 January 2002.

20132 - Loading Density and Vent Area Ratio Effects on the Structural Response of Reinforced Concrete Structures Storing HD 1.3 Gun Propellant
Romo

Seven fire-initiated experiments involving M1 gun propellant were performed at the Naval Air Warfare Center Weapons Division (NAWCWD) to help address concerns regarding the storage and transportation of Hazard Divisions (HD) 1.3 materials. The results of these experiments have been presented in the documents Combustion of Hazard Division 1.3 M1 Gun Propellant in a Reinforced Concrete Structure [1], and Combustion of Hazard Division 1.3 M1 Gun Propellant in a Reinforced Concrete Structure Part 2. Tests 5 Through 7 [2]. This paper compares the results obtained for three tests which structures failed due to over pressurization: Test 4, Test 6, and Test 7. The difference and similitudes among tests set ups will help determine relationships between vent area ratio, loading density, structural composition and response, as well as their effects on thermal, pressure, and fragmentation hazards.

The three tests being compared here contained the same energetic material, 7-perforation M1 Gun Propellant. The M1 pellets had a 4.77-mm outer diameter and a 10.765-mm length. These pellets had seven perforations (7P), each with a 0.451-mm diameter. The combustion of the propellant in these test arrangements created choked flow, which caused the rapid pressurization of the structure and its failure.

Comparisons are made between Test 4 versus Test 6, and Test 6 versus Test 7. Tests 4 and 6 compare the response of different structural compositions exposed to the same thermal stimuli under similar circumstances, vent area ratios, and loading densities. Tests 6 and 7 compare two similar structures with equal vent area ratios loaded at different densities. The analysis and comparisons presented in this paper focus on the importance of the relationship between venting and loading density, and how it could be used to prevent structural failure.

References

1. Naval Air Warfare Center Weapons Division. Combustion of Hazard Division 1.3 M1 Gun Propellant in a Reinforced Concrete Structure, by A. D. Farmer, K. P. Ford, J. Covino, T. L. Boggs, and A. I. Atwood. China Lake, CA, NAWCWD, August 2015. (NAWCWD TM 8742, publication UNCLASSIFIED.)

2. Naval Air Warfare Center Weapons Division. Combustion of Hazard Division 1.3 M1 Gun Propellant in a Reinforced Concrete Structure. Part 2. Tests 5 Through 7, by A. D. Farmer, K. P. Ford, J. Covino, et al. China Lake, California, NAWCWD, June 2017. (NAWCWD TM 8764, publication UNCLASSIFIED.)

20133 - Small scale assessment of LOVA Thermoplastic elastomer (TPE) propellants for Large Calibre Gun Systems

Sowden

BAE Systems Land (UK) has been developing new gun propellant formulations over a number of years at their Research and Development facility in South Wales, UK. LOVA TPE propellants have formed a large part of this development, concentrating on reducing IM response, which has achieved noticeable step change in this area.

The small scale assessment of LOVA TPE propellants has been conducted on a variety of formulations over a number of different development programmes. These assessments include EMTAP, stability, compatibility, physical & chemical analysis, small scale IM, ballistic and ageing, testing in accordance with the relevant STANAG or AOP. This paper will review these assessments, bringing the results together to give a comprehensive overview of how these types of propellants perform on the small scale.

As part of the review of the current data available we have proposed the question; are the existing tests relevant for assessments for LOVA TPE based propellants?

20134 - Initial steps towards large scale production of UK LOVA Thermoplastic Elastomer (TPE) propellants

Sowden

BAE Systems Land (UK) has been developing new gun propellant formulations over a number of years at their Research and Development facility in South Wales, UK. LOVA TPE propellants have formed a large part of this development, concentrating on reducing IM response, which has achieved noticeable step change in this area.

With renewed interest to establish this technology for the next generation of UK propelling charges work has started to move the technology from development scale to production scale with our propellant partner. Small but significant steps have now been taken towards achieving this goal. This paper will present an overview of this work and the assessment results of the propellants produced in the larger batch sizes paving the way towards achieving production scale manufacture of LOVA TPE propellants.

20135 - The Unknown Detonation Transition (XDT) Mechanisms Associated with Damaged Rocket Propellant Impacting a Surface: Understanding and Applications to IM
Neidert

In the literature, XDT is labeled unknown as the exact detonation initiation mechanisms are not well understood or agreed upon in the community. This has resulted in the term being used for several detonation initiation mechanisms that may or may not be directly related. One of these mechanisms is associated with a re-compaction and rarefaction of propellant that is in the process of being damaged via impact and appears to very stochastic in nature. Another mechanism is associated with the impact/compaction of a damaged propellant debris cloud against a rigid surface – a process that has relatively defined limits of when it will occur. This effort focuses on the latter of the two XDT mechanisms. To investigate the properties of a damaged debris cloud, a NATO STANNAG frag was impacted against a variety of test setups and high speed cinematography, flash X-ray, and Digital Image Correlation were employed. High fidelity modeling efforts were also applied to provide further understanding of this XDT mechanism. Results indicate that there are clearly defined XDT upper and lower thresholds that are dependent on fragment velocity and distance between the propellant sample and the rigid surface that the propellant debris cloud impacts. These upper and lower thresholds will shift, depending on other testing parameters (propellant thickness, type of rigid surface). The lower threshold appears to be a result of increasing porosity (increasing sensitivity) of the propellant debris cloud, while the upper limit appears to be a result of the porosity becoming so high such that a detonation cannot be propagated back through the debris cloud to the main propellant charge.

20136 - Subscale Testing to Predict Full-Scale Response to Fragment Impact in Solid Propellants
Neidert

Flat panel and cylindrical subscale testing has been developed and demonstrated to help determine detonation thresholds (both SDT and XDT) in minimum signature propellants when exposed to fragment impact. Results will be provided showing guidance which are encouraging toward future early screening in concert with gap testing

20137 - MSIAC workshop 2018: Improved Explosives and Munitions Risk Management
van der Voort

The management of explosives and munitions risks is a broad area which is covered by many policy documents. These documents are based on a combination of best practice and underpinning technical and scientific knowledge. MSIAC is organising a workshop with the aim to exploit our improved understanding of munitions vulnerability and consequences to deliver improvements in munitions risk management.

The workshop will bring together stakeholders from the Hazard Classification (HC), Insensitive Munitions (IM), and explosives storage safety communities to develop a coordinated and optimised approach to managing explosives and munitions risk. A secondary aim of the workshop is to initiate changes that will help realise the benefits of IM, particularly during transportation and storage to improve safety and help safeguard military capability in hazardous operating environments.

The workshop will seek to achieve the following goals:

1.Support the IM and HC harmonization initiative

a.Identify how response descriptors can be introduced in HC testing

b.Identify whether there's a need for revised definition of Hazard Divisions (HD)

2.Develop improved methods for explosives and munitions risk management

a.Exploit results from small- and full-scale testing

b.Manage risk with sufficient detail and granularity

c.Enable benefits of IM to be realized

d.Enable more efficient management of munitions presenting greatest hazard

3.Recommend implementation of improved methods in explosives and munitions safety risk standards

a.Ensuring they reflect the changing nature of the munitions stockpile

b.Balancing complexity versus ease of user application

This paper presents how MSIAC plans to achieve these goals. MSIAC also seeks support of the community to participate in the workshop and comment on the proposals in this paper.

20138 - Qualification and Energetic Materials Challenges
Andrews

Since 1991 MSIAC, and its predecessor NIMIC (NATO Insensitive Munitions Information Center), have contributed towards knowledge exchange between its members by organizing technical workshops, compiling software tools and writing technical reports.

During the same period dramatic cost increases associated with larger-scale testing (Insensitive Munitions & Performance), in conjunction with the decrease in costs for computational resources and their widespread availability, have resulted in significantly increased use of modeling and simulation to augment experimental capability. Discussions and output from many MSIAC workshops such as the 2014 Shaped Charge Jet and 2016 Science of Cook Off have highlighted the increase in, reliance on, and availability of, models to aid the energetics community. Numerous models exist, ranging from those used in the design of shock initiation of warheads such as the MSIAC TEMPER tool, to those used to assess the safety of energetic materials through the calculation of critical temperature of ignition.

Complex models require high-fidelity, well-posed experiments, that serve to not only produce precise, repeatable results, but are also set up in such a way as to isolate specific parameters needed in building the model. Many models require experimentally derived data but relatively few materials have been fully characterized. This statement of data gaps between modelers and experimentalists has been echoed by the energetics community at almost every engagement with MSIAC.

As part of energetic material qualification, this paper will review recent discussions with respect to the required parameters for modeling energetic materials, the methodology required in acquiring these parameters, the current processes that demand experimentation, and what is still needed to bridge the gap between the modeling, experimental and safety communities. Comments will also refer to the Energetic Materials Compendium (EMC) as a source of information and to a recent MSIAC review of energetic material manufacturers.

20139 - Correlation of Response for Munitions Containing RDX/TNT: Bullet Impact and EMTAP Tube Testing Results
Cheese

Variability of response in full scale munition hazard testing is problematic: relying on the result of the usual one or two tests can lead to false confidence. This paper explores whether a correlation can be found between the frequencies of response in charge scale and full scale tests; any such correlation would increase confidence in both the efficacy of design solutions, Hazard Division assignment and risk assessment throughout the munition lifecycle. Repeated tests on some UK munitions have given results encompassing both burning and detonation; this variability is also observed in charge scale testing for both thermal and internal ignition (DDT) tests such as those we have reported at recent IMEMTS for a variety of explosive formulations.

Here we present and compare the results of internal ignition testing of RDX/TNT at the charge scale (10 repetitions) with repeated full scale STANAG 4241 Bullet Impact tests on munitions containing that formulation, including 81 mm mortar bombs (47), 105 mm (11) and 155mm (13) shell. We find no linear correlation between test item size and frequency of violent response, although the tube test results are generally the most violent and the mortar bombs least violent. We make recommendations as to how this information can be exploited in munition design process and in risk assessment.

20140 - Reaction Mechanisms for Rocket Motors
Collet

Rocket motors are designed to propel payloads to their final destination by ejecting hot gases through a nozzle. The gases are produced by combustion of fuel and oxidizers, which can be separated (hybrid combustion) or mixed with each other (gun propellant, propellant grain). However, when a rocket motor and therefore, its propelling charge, is subjected to an accidental threat, it may cause a non-nominal decomposition behavior. Depending on the solicitation, its intensity and its duration, the reaction type may range from combustion to detonation with corresponding level of damages in the surrounding environment.

New generations of propellants may contain high energy constituents such as nitramines or energetic polymeric binders in order to attain higher or more tightly controlled burning performance. These new ingredients usually lead to a greater sensitivity to mechanical stimuli and also to smaller critical diameters. Hence, the propellant's ability to detonate may be increased, which is a major concern for new insensitive munitions. More specifically for propellant grains, some geometrical aspects of the motor design also have to be taken into account, as they may lead to unexpected shockwave concentrations and to violent reactions.

This presentation consists of an overview of possible reaction mechanisms for a rocket motor propellant under dynamic mechanical loading such as fragment or bullet impact, and how those mechanisms have evolved with the most recent advanced propelling charges.

Finally, we will focus on mitigation techniques recently developed by the community and especially designed to mitigate the reaction level of rocket motors subjected to high energy mechanical solicitations.

20141 - Mitigation Technologies for Propulsion Applications
Collet

During the last decades, strong efforts have been made by the IM community to decrease the reaction level of ammunition when submitted to standard test scenarios such as fast and slow heating, bullet and fragment impacts, sympathetic reaction and shaped charge jet impacts. To do so, numerous studies were conducted to identify the reaction mechanisms occurring within the ammunition and, in a second step, to decrease the reaction level of the tested ammunition.

As a consequence, many mitigation systems were developed and studied to achieve these goals: decrease the solicitation applied to the tested item, prevent any violent reaction of the tested item, or, if a violent reaction is unpredictable or impossible to avoid, decrease its effects in the surrounding environment.

A review of mitigation techniques available for rocket motors was completed last year within an MSIAC intern project. A massive number of documents were analyzed, sorted and released to the community through a limited MSIAC document, L-199. Five mitigation technology families were identified for rocket motors: venting devices, active mitigation, intumescent coatings, case composition and packaging barrier arrangement. This presentation aims to share the major outputs of this study with the IM community, describing the principle of each technology family, giving some relevant examples, and pointing out the advantages and drawbacks within each family.

20145 - PROPERTY-PROCESSING IMPLICATIONS IN ADDITIVE MANUFACTURED MATERIALS FOR MUNITIONS
Babcock

Additive manufacturing offers many opportunities in the munition design space to tailor bulk properties (for example spatially-variant composition and density) with intent to subsequently affect macro behavior through changes in stress/strain profiles, variable burn rate, fracture progression, and other parameters.

With the introduction of any novel processing and manufacturing technology, new and very different material properties, flaws, and defects are also introduced. Historically this was seen with the introduction of welding in the early 20th century and subsequent understanding of heat affected zones and inclusions, drastically changed the science of fracture and fatigue. The introduction of lamellar and fiber-reinforced composites in the 1950s created entirely new fracture, fatigue, creep, and crack-growth phenomenologies. The advent of microelectronics expanded materials science into new realms with layered micro- and nano-metallic films, deposition techniques, and incorporation of metals, semiconductors, and plastics, which introduced even more material failure mechanisms, flaws, and defect creation.

MSIAC is reviewing the types of materials currently being used in additive manufacturing (AM) technology, the resultant material properties achieved, and the main issues that will face munitions science in utilizing these AM-created materials. This presentation will provide the key issues, a comparison of the materials possible, and assistance for practitioners who plan to employ AM in munitions. Published reports have already illustrated novel pin-cushion shaped flaws in AM metals and plastics that will significantly impact the ease of crack formation and propagation, independent of the material’s stress intensity factor. Additionally, many AM processes appear highly prone to creation of micro- and macro-voids during material build-up dependent on rate of travel/deposition, input heat intensity, etc. This could have a significant effect on bulk sensitivity in energetic materials.

20146 - AGE-RELATED MECHANICAL DAMAGE AND AGEING OF MUNITION MATERIALS
Babcock

A textbook definition of engineering material degradation is the gradual alteration of relevant material properties caused by routine exposure to service conditions. Ageing is a common thread in the study of munition materials and assessing weapon systems for safety and suitability for service. Service conditions can expose munitions to simple environmental factors such as humidity and temperature excursions, or more complex exposure to vibration, radiation, and chemicals, as well as a myriad of combinations of these. Changes in one material property are accompanied by changes in other material properties, which if not properly anticipated can be disastrous.

This presentation will provide highlights of an MSIAC report which collects the most common age-induced degradation mechanisms, as they pertain to the most common materials applied to munition systems. The information contained in the report will provide the requisite guidance that experienced practitioners may use to bound and inform their examination of their own systems.

20147 - Stopping km/s blunt fragments and limiting shock lensing with a new advanced energy absorbing composite
Tear

We are developing a lightweight ceramic/polymer composite for km/s fragment resistance. It uses a fundamentally new physical process for energy absorption that complements the conventional forms of energy dissipation of fracture and plastic deformation. This composite comes into its own against very high impact velocities, being able to provide protection in shock regimes where conventional materials like kevlar and steel can be considered incompressible fluids with zero protection capabilities.

This material can be used in rocket motor casings for increased IM compliance. It can absorb and dissipate energy extremely quickly (of the order of 100kJ/m2/?s). Crucially it limits shock lensing effects, augmenting current capabilities against blast and shaped fragments. The energy dissipation mechanism propagates at 7km/s inside the material and activates with minimal (<2%) overall strain of the structure. The design of the composite is flexible enough to be optimised for a range of projectile threats and velocities.

In practical terms, the composite has the same density as aluminium and is made from abundant raw materials. It can also be made transparent, enabling applications beyond rocket motor casings into protective blast windows.

We present here experimental verification of our fundamental energy absorbing process through plate impact experiments, taking measurements by interferometry (PDV) and high-speed videography. We demonstrate that this process does provide a significant decrease in projectile velocity at 800m/s impact speed. We present an equal weight comparison of performance against fragment simulating projectiles (FSPs) between our composite, aluminium and steel

20149 - MSIAC – Highlights and Future Priorities
Sharp

The NATO Munitions Safety Information Analysis Center (MSIAC) is a multinational collaboration that collects, stores, and analyses technical information related to Munitions Safety (MS) and Insensitive Munitions (IM). MSIAC supports its member nations through a variety of products and services. In addition to a core responsibility of addressing technical questions related to Munitions Safety posed by nations, MSIAC has a diverse programme of work aimed at developing and sharing the related underpinning scientific knowledge. This is then applied to support policy implementation and development related to munition safety. Some examples of current activities are given in this paper.

The paper also presents a plan of proposed workshops and technical meetings. Using input from the nations, MSIAC has developed the plan to ensure that the member nations' needs are addressed in the coming years. The paper provides brief descriptions of the topics and planned dates over the next six years.

20150 - Heavyweight Torpedo warhead – IM assessment

Chaffois

Thanks to its stealth, range and fire power, the F21 heavyweight torpedo gives client navies an unrivalled tactical advantage over all threat. Exploiting a range of innovations and advances in torpedo technology, a single F21 can knock out any surface combatant or submarine. The high energy density primary battery offers both high maximum speed and extended range while the new-generation acoustic head guarantees improved search efficiency from very shallow to deep waters. Fully digitalized technologies result in improved signal processing and enhanced overall performance.

The F21 complies fully with the demanding safety requirements applicable to nuclear-powered submarines. Regarding to the warhead insensitivity, this high requirement level is reached because the ammunition embeds live improved IM components such as an RDX/Al/AP cast cure substance for the main charge and dedicated thermal igniter formulation. Moreover, its specific internal rubber based Thermal Protection gives some additional surviving characteristics against thermal threat such as external fire.

IM assessment was performed according to a rigorous process. This paper will describe the design principles and focus on results obtained against full scale tests such as shaped charge test.

20151 - Influence of ageing on the properties of IHE
Radies

In the last decades operation areas of NATO partners have drastically changed. The time of a long-term storage of the ammunition in air-conditioned bunker arrangements to immediately before use is not always guaranteed. In actual fact the ammunition is often stored in hot regions and in provisional rooms or containers under dubious conditions. In some cases the ammunition may even be exposed to direct sun radiation without any protection. Accordingly, ammunition may experience extreme weather conditions and temperature loads. To assess the possible impact of extreme climate conditions on the ammunition - especially on the explosive charge -, lab scale samples of explosive charges were artificially aged and afterwards different comparative investigations were performed with stressed and unstressed samples. Investigations were carried out with respect to the mechanical properties, the shore A hardness, friction and impact sensitivity and thermal properties of the explosives. Additionally, GAP tests were performed.

The presentation reports the results of these investigations.

20152 - Increased impulse of solventless extruded double base rocket propellant by addition of high explosives RDX and FOX-7.

Tunestål

The extruded double base (EDB) propellant has been used and produced for more than a century. The composition of the propellants has basically remained the same throughout the history and only in recent years new development has been necessary due to environmental and health regulations.

The limitation of EDB rocket motor propellants compared to composite based rocket motor propellants is the limited specific impulse. In order to close this gap Eurenco Bofors has developed “triple-base rocket motor propellants”. This is achieved by adding amounts of RDX and FOX-7 into the double-base formulations. This is done without any use of plastic binders and the propellant grains remain smokeless. With this concept propellant compositions with a specific impulse of up to 2350 Ns/kg has been produced.

The development in the high explosive production which has opened up for these tests has been process to produce small particle size RDX and FOX-7. Both the RDX and FOX-7 has been precipitated and not milled, the particle size of the RDX is about 4 µm and for the FOX-7 the particle size is about 12 µm. There are also qualities with milled FOX-7 but these has not yet been evaluated for this purpose. These small size RDX crystals are of propellant grade. The FOX-7 is still a little bit too large to be classified as propellant grade. The precipitated FOX-7 quality has been developed recently and the batch used was produced in 2016. The RDX quality has been used in Eurenco Bofors for many years in propellant production, similar size is used for the NL007 (LOVA) production.

The addition of RDX into double base gun propellants is known to decrease the burn rate of the propellant. This is explained by a decreased reaction rate in the fizz zone, due to it becoming fuel rich when RDX is added to the composition. This is also confirmed in the current study where the burn rate is decreased over the entire pressure range. The effect of adding RDX seems to diminish with content. From 0 to 10% RDX-content the burn rate is reduced by 2% per percent of RDX but only 1% per percent of RDX with higher content.

When performing the same experiments with the addition of FOX-7 however the burn rate is not altered. The experiments has been performed with 5% of FOX-7 and 15% of FOX-7. A difference between the behavior of FOX-7 and RDX is also seen in DSC analysis, the RDX has a melting which is not present in the FOX-7. The FOX-7 has a pure decomposition at 250 °C. It should also be noted that the DSC results are vastly different when using sealed cruicible compared to open, especially for FOX-7.

What also can be noticed from the experiments is that the effect of the ballistic modifiers is not affected. The curvature of the burn rate is similar in all experiments.

This study has shown that the specific impulse of an EDB propellant can be increased by the addition of high explosive molecules of RDX or FOX-7. The addition of RDX is known to reduce the burn rate and this is confirmed by the study, on the other hand the study shows that addition of FOX-7 does not reduce the burn rate. This is an interesting result since it means you could alter the specific impulse without significantly altering other ballistic parameters.

The current EDB composition studied did not have any mesa-effect which might affect the analysis. Further experiments with FOX-7 have been performed to verify the behavior also for other EDB rocket propellant compositions.

20153 - QUALIFICATION OF MALLEABLE PLASTIC EXPLOSIVE HEXOMAX AND ITS APPLICATION IN A FLEXIBLE LINEAR SHAPED CHARGE SYSTEM

Songy

Based on his know-how on cast-cure compositions, EURENCO developed several years ago a new generation of malleable plastic explosive blocks, called Hexomax. Since 2014 the product has further been improved to meet the highest levels of requirements of Armies in term of performances, safety and malleability, and the French Army qualified Hexomax in 2016.

Thanks to its constant properties on the large range of temperatures recognized by the French Forces, Hexomax has been recently qualified by the French Army in the system Supraflex, a flexible linear shaped charge, designed and supplied by SUPRAMECA. Moreover, the preliminary test results, performed with Hexomax blocks combined with the specifically designed logistical box, demonstrated that a type V reaction against the sympathetic reaction is achievable.

This paper will present available results in term of characteristics, performances and vulnerability of this improved Hexomax in tactical and logistical configurations.

20154 - Sheet-metal Ammunition Packing Tray for Mitigation of Secondary Cook-off of Medium-caliber Ammunition
Little

Bullet and Fragment Impact Insensitive Munitions (IM) testing against unlinked, medium-caliber ammunition packaged in ammunition cans with high-density polyethylene (HDPE) packing trays has demonstrated a secondary hazard distinct from the rounds' initial reaction to impact. Specifically, the trays show a tendency to catch fire as a result of the impact and initial reaction of the ammunition. This fire begins a sustained series of secondary cook-offs of projectiles and cartridge cases that lasts until either the available fuel is expended or the contents of the ammunition can have been ejected due to the force of secondary reactions.

This hazard has been witnessed in two types of ammunition, with two more due for demonstration testing in Q1 FY18. Any munitions packaged in similar trays may be vulnerable to this phenomenon. Secondary reactions often continue long after the initial impact with no obvious visual indication that combustion is taking place until a reaction occurs.

Replacement of these trays with a nonflammable alternative would mitigate this safety hazard. Preliminary testing of prototype Sheet-metal Ammunition Packing Trays has demonstrated favorable results in this regard while not worsening the initial IM response. Currently, design refinements are underway to improve manufacturability of these trays. Once these refinements are complete, the trays are expected to meet all necessary packaging requirements (cost, weight, performance) while mitigating the secondary cook-off hazard.

20155 - New NTO workshop and associated product characterizations
Delage

NTO was produced for more than 20 years in the EURENCO Sorgues plant. However in 2016, the existing workshop was redesigned and rebuilt, to allow a continuous way of production and increase control on the process safety and improve the final product quality.

This paper will firstly describe the different steps of the NTO manufacturing showing some specific process improvements put in place in the workshop.

Then will be presented the results of all the characterizations done at the granular scale on different classes of NTO (Class 2, 3, 4) but also and the specific quality NTO CF which has a granular size distribution and an apparent density designed for IM melt cast applications.

All the results obtained during this study allow our product to be qualified by the French MoD.

The new NTO has then been also tested and checked in two IM compositions, one plastic bonded explosive B2214B and one for a pressed application P16945. The results obtained confirm that the main characteristics in performance, safety and vulnerability of this two IM products are kept with using of our NTO.

20156 - NATO Working Group on Insensitive Munitions and Hazard Classification Requirements, Assessment and Hazard Frequency.
Cheese

AC/326 Main Group (MG) approved the creation of a Working Group (WG) to review and look at the opportunities, challenges and benefits of integration of NATO policy and guidance on Insensitive Munitions (IM), Hazard Classification (HC) and Hazard Frequency Analysis (HFA). Mr B Knoblett (US) and Mr P Cheese (UK) were appointed to lead the WG, with support from MSIAC.

This paper will present the WG's current progress towards this, expose the WG's thinking, our draft policy document structure and contents. The NATO WG are seeking wider comment, engagement and comment from the IM and HC community to support what is an ambitious and challenging proposal: to standardize, harmonize and streamline the NATO approaches to IM, HC and Hazard Frequency Analysis.

Background:

At the spring 2015 meetings of AC/326 SG/B&C and MG, the US put forward proposals to begin work on harmonizing the NATO IM and HC policies and processes. In fall 2015 AC/326 Main Group approved the creation of the WG to progress these issues. The purpose was to examine the potential for integration of Insensitive Munitions and Hazard Classification policy and procedures recrafting the related policy documents. Further developing this to the point where NATO's new standardized HC assignment procedure for Class 1 Explosives in military are submitted to the UN as a update for the current UN Test Series 7 (TS7).

Aim: To standardize, harmonise and streamline IM and HC policy on requirements and assessment and enshrine this in UN international policy to establish this as a legislated approach

- Reaffirming and clarifying the purposes of the IM and HC policy;
- Building on IM and HC methodology to improve hazard frequency analysis for unplanned stimuli;
- Developing a single guidance document for delivering these.

Scope: Consolidating current policy and guidance, pulling together relevant elements from the documents listed below for inclusion in a revised document structure and where necessary improving correcting and adding content:

- STANAG 4439 (AOP-39 and SRD)
- STANAG 4170 (AOP-7)
- STANAG 4240 (AOP 4240 in ratification)
- STANAG 4241 (AOP 4241 in ratification)
- STANAG 4382 (AOP 4382 in ratification)
- STANAG 4496 (AOP 4496 in ratification)
- STANAG 4396 (AOP 4396 in ratification)
- STANAG 4123 (AASTP-3)

The work programme has currently delivered:

- A draft new document structure detailing IM and HC requirements (including situation specific risk across the lifecycle environmental profile)
- Developed joint guidance on testing and assessment
- Developed a methodology for hazard frequency analysis for situation specific risk across lifecycle environmental profile
- Undertaken a review of evidence to support assessments
  - Identified and addressed harmonization issues (including tests)
  - Developed protocols for HC 1.1, 1.2, 1.3, 1.4 and 1.6 assignment
  - Review and develop (where necessary) default
- Standardised rationales for assigning HC and IM

Many of the contradictions and problems that have emerged as a consequence of the organic and separate development of IM and HC policies have been identified, and some specific suggestions made about how TS7 and the assignment of Hazard Division might benefit from application of the wider evidence base used for assessment of IM signature. These proposals have been well received by many members of the IM & HC communities with useful comment and feedback.

The current issues that require further work and involvement from the wider community are:

- Explosive substance tests to inform HC (drawing from AOP-7 established qualification tests)
- Evidence to support the whole body of evidence approach to support IM assessment and HC assignment
- Completeness of the current draft policy

A programme has to be developed to progress this proposal to the UN ECOSOC Sub-Committee consisting of:

- Review and draft proposals to make changes to UN manual of tests and criteria (UN TS7).
- Ensuring relevant civil authority involvement to reduce implementation risk

20157 - Development of a CONUS Manufacturing Capability for FOX-7
Sleadd

1,1-diamino-2,2-dinitroethene, or FOX-7, is an insensitive energetic material originally developed by FOI Sweden. Theoretical thermochemical calculations indicate that FOX-7 should exhibit nearly equivalent performance with that of RDX, while being considerably less sensitive to unplanned stimuli. Much like TATB, FOX-7 contains amino and nitro groups which can participate in intra and intermolecular hydrogen bonding. This phenomenon is believed to provide both materials with their unusual stability.

FOX-7 has been evaluated in both propellant and explosive applications with very promising results. As such, a domestic source of FOX-7 is highly desirable since the only current commercial supplier is the European conglomerate, Eurenco.

As part of a JIMTP program, NSWC IHEODTD has been tasked with developing a domestic manufacturing capability for FOX-7, as well as providing the four classes of material currently available from Eurenco. FOX-7 has been synthesized at NSWC IHEODTD at the 5, 20, 100 gram, and kilogram scales, and there is currently an active SOP for the manufacture of FOX-7 at the multi-kilogram scale with yields typically in the 65-70% range. We have also produced all four classes/particle size distributions of FOX-7; Class 1 (20-40 µm), Class 2 (50-100 µm), Class 3 (100-200 µm) and Class 4 (250-350 µm) via recrystallization, and have produced Class 1 and Class 4 at the multi-kilogram scale.

This paper will discuss the process development for the synthesis and recrystallization of FOX-7, as well as exhaustive characterization of the products. An evaluation of the scalability and affordability will also be provided.

20159 - DEVELOPMENT AND SUCCESSSFUL DEMONSTRATION OF A LIGHTWEIGHT, PARTICLE IMPACT MITIGATION SLEEVE (PIMS) WITH SPECIFIED HARDNESS AND PERFORATION FEATURES

Pudlak

To date, Particle Impact Mitigation Sleeves (PIMS) have been developed and successfully demonstrated to mitigate the Insensitive Munitions (IM) Fragment Impact FI threat at 8300fps for several munitions systems, however, the major challenge has been to transition a design that meets the system requirements (e.g. cube, weight, handling). This paper discusses the development and demonstration of a new lightweight solution, incorporating several technologies that leverage vehicle ballistic protection design features. Lightweight, Hardened, Perforated, (PIMS) developed by the Joint IM Technology Program (JIMTP) poses a significant opportunity for weight reduction and superior performance in comparison to previous PIMS designs. The PIMS material is treated to a specified hardness which provides sufficient fragment break-up and dispersion, which allows for a reduction in weight of approximately 25% - 50% compared to the untreated material, and the perforated feature provides an additional 44% - 63% reduction in weight. This paper provides design considerations and test result analyses.

20161 - Filling the Gap between the Initiation Behavior of Shaped Charge Jets and Fragments
Arnold

Motivation

During more than a decade of studying initiation phenomenology numerous papers at previous IMEMTS and other symposia ([1] - [10]) were published. Most of them dealt with the hypervelocity impact initiation of plastic bonded high explosive charges by shaped charge jets (SCJ) and a few ones reported results in the ordnance velocity impact regime with STANAG projectiles [10] and explosively formed projectiles (EFP) [2]. A recent finding of our inves-tigations of charge jet (SCJ) attacks suggests that the critical stimulus $S = v^2 d$ (v = SCJ / projectile velocity; d = SCJ / projectile diameter) for the initiation of a munition can no longer be seen as a constant (S ? const.) Also, known equations, e.g. Jacobs-Roslund, are not capable to describe low velocity and hypervelocity impacts with the same parameter set.

Therefore a new initiation model is needed taking these findings into account [10]. On the way to such a new model further investigation were necessary trying to make a link be-tween the initiations phenomenology of shaped charge jet impacts in the hypervelocity regime and of projectile impacts in the lower velocity regime. The situation of today is that a larger number of experimental results is available in the hypervelocity regime of the SCJs and only a few ones in the lower velocity regime of STANAG / EFP projectiles. In the present work therefore a series of trials were planned and conducted to close the data gap in the low velocity regime.

Experimental Trials and Numerical Simulations

Firing tests with the STANAG projectile and modifications of it were planned and car-ried out. A powder gun was used to accelerate the projectiles which were mounted in a sabot. While making the above mentioned transition from SCJ towards STANAG projectile impacts several changes of initiation phenomena were expected. Therefore this transition will be explained step-by-step starting from a continuous copper jet and ending up with the standard steel STANAG projectile with L/D = 1 [10]. The individual steps include the

- continuous Cu liner SCJ
- particulated Cu liner SCJ
- modified STANAG projectile: elongated (L/D > 1) and material changed to Cu

- modified STANAG projectile made of steel but elongated (L/D > 1)
- standard steel STANAG projectile (L/D = 1)

Each individual situation has been investigated carefully either by experimental tests or by comprehensive numerical simulations, or both. All of the tests were done using a fixed charge design here called the “standard” and meant to model a typical practical configuration.

Finally, the new investigations will be used to complete our understanding of the ini-tiation phenomenology found and explained in the referenced publications ([1] to [10]). These will be partly revisited trying to explain the physics behind based on both, experimental results and numerical simulations applying reactive material models (HVRB) [7]. All results and findings will be presented in this paper.

References

[1] W. Arnold, E. Rottenkolber, “Sensitivity of High Explosives against Shaped Charge Jets”, Insensitive Munitions & Energetic Materials (IMEMTS) 2007, Miami, USA

[2] W. Arnold, “High Explosive Initiation by High Velocity Pojectile Impact”, HVIS 2010, Freiburg, GE

[3] W. Arnold, M. Graswald, “Shaped Charge Jet Initiation of High Explosives equipped with an Explosive Train”, IMEMTS 2010, Munich, GE

[4] W. Arnold, E. Rottenkolber, “Shaped Charge Jet Initiation Phenomena of Plastic Bonded High Ex-plosives”, IMEMTS 2012, Las Vegas, USA

[5] W. Arnold, E. Rottenkolber, “High Explosive Initiation Behavior by Shaped Charge Jet Impacts”, Hypervelocity Impact Symposium HVIS 2012, Baltimore, USA

[6] W. Arnold, E. Rottenkolber, “Significant Charge Parameters influencing the Shaped Charge Jet Initiation”, IMEMTS 2013, San Diego, USA

[7] W. Arnold, E. Rottenkolber, T. Hartmann, “Analysis of Shock and Jet Initiation Tests of High Explosives”, 19th Int. Symposium on Detonation ISD 2014, San Francisco, USA

[8] W. Arnold, E. Rottenkolber, T. Hartmann, “Challenging v^2d ”, IMEMTS 2015, Rome, IT

[9] W. Arnold, E. Rottenkolber, T. Hartmann, “Testing and Modeling the Initiation of In-sensitive Explosives by Projectile Impact”, 11th EUROPYRO International Seminar 2015, Toulouse, France

[10] W. Arnold, T. Hartmann, E. Rottenkolber, “Towards a Unified Initiation Model”, IMEMTS 2016, Nashville, USA

[11] STANAG 4496 (Edition 1), “Fragment Impact, Munitions Test Procedure”, 2006

20163 - Impacts of REACh, ITAR and other regulations on Energetic Materials Sustainability
Eck

EURENCO has for many years been producing a complete range of high explosives as well as the compositions based thereof.

Most of these compositions require the implementation of solvents or various components such as polymers, plasticizers, catalysts, bonding agents. In recent years, the availability of some of these components has become more and more critical because of European or US regulations.

Thus EURENCO has identified the chemical components considered as critical in its production process. Some of them have been or will be banned by REACh regulation, the other products are subject to exportation limitations (ITAR and EAR) or sometimes by producers themselves which are reluctant to provide products for military application.

This paper will present the work performed by EURENCO in order:

-To find new suppliers and/or to replace the chemical component by equivalent compounds

-To qualify the compositions based on these new components if necessary

20164 - New Polycarbonate-Based Thermoplastic Polyurethane Binder for HMX Based Explosives
Robertson

Plastic bonded explosive formulations comprised of HMX are commonly used in high value, high precision weapons platforms that consequentially leave relativity small asymmetrical payload volumes remaining for the explosive charge. Thermoset polyurethanes have been studied extensively as binders for these explosive charges. We chose to examine thermoplastic polyurethanes (TPUs) based on the processing advantages they promise, leading to their application in several established high explosive formulations. For example, aromatic polyester based thermoplastic polyurethanes under the trade name Estanes® have been used in several DOE explosives, including LX-14 (95.5% HMX and 4.4% Estane). Because of the attractive properties of TPUs and the availability of new commercially available polycarbonate polyurethane systems, we have undertaken a study of new HMX-based formulations using new TPUs, mainly derived from polycarbonates. To our knowledge there have been no reported energetic material formulations using polycarbonate-based polyurethanes.

The polymers and multiple HMX formulations utilizing the polycarbonate-based thermoplastic polyurethanes (PC TPU) have been produced and characterized. Commercially available polymers have been characterized by differential scanning calorimetry for glass and melt transition temperatures. Formulations comprised of 95% HMX and 5% binder with different polymers were produced and characterized for processing feasibility, small scale sensitivity, pressing density, softening temperature, and thermal expansion. Based on these experiments we found that the isocyanate used to produce the polycarbonate polyurethane is important and believe aliphatic polyurethanes are a viable alternative to traditional thermoset polyurethane in explosive formulations.

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

20166 - Particle size and surface area effects on the initiation of Diaminoazoxyfurazan (DAAF)
Francois

Diaminoazoxyfurazan (DAAF) is an explosive studied and valued for its low sensitivity to common insults. In friction and impact, it is as insensitive as TATB. It has another side too: shock sensitivity when the shock is strong. We have studied the effects of surface area, particle size and porosity on initiation from an Exploding Foil Initiator (EFI) and found it makes an excellent detonator. This particle size/ surface area study has investigated nano-DAAF, produced by ARDEC, with favorable results. The voltage requirements for initiation using both a rigid chip slapper and a flexible blue-light will be compared and discussed.

The shock sensitivity of DAAF is being used in formulations with 3-nitro-1,2,4-triazole-5-one (NTO) to reduce the critical diameter. NTO is a well-studied, high energy molecule with a large critical diameter (25.4 mm). NTO is a component in many Insensitive Munition (IM) fills. DAAF is an Insensitive High Explosive (IHE) candidate. A combination of these two outlier materials was explored to obtain unique explosive power in an all IHE system. Particle size and surface area knowledge could be a novel method of enhancing critical diameter in these formulations.

20171 - Melt-pour explosive formulation development featuring TNBA
Fung

Melt-pour explosives such as TNT and Composition B had been used as main explosive fill for multiple end items such as mortar, artillery, general purpose bomb, grenades and demolition stores. While these legacy melt-pour explosives have high detonation performance, their responses to accidental stimuli such as shock, thermal and impact are no longer acceptable from the Insensitive Munitions compliance standpoint. A new generation of melt-pour explosives such as IMX-101 and IMX-104 had been introduced to address the IM deficiency of TNT and Composition B respectively. While these IM melt-pour explosives offered significant improvement in IM responses over the legacy products, a drop in detonation performance was subsequently observed.

In order to address the shortfall in detonation performance, scientists at BAE Systems had conducted research activities to evaluate alternate melt-pour ingredients. One of the ingredients evaluated is 2,4,6-Trinitro-3-bromoanisole (TNBA).

The synthesis of TNBA had been developed by BAE Systems several years ago and it is considered as a robust synthesis process which generates high purity end product. This process had been demonstrated in full scale production at HSAAP and TNBA is readily available.

Formulation efforts were conducted to evaluate TNBA as a potential high performance melt ingredient. Several melt-pour explosive formulation candidates featuring TNBA had been prepared and will be evaluated in terms of shock sensitivity and performance in comparison with legacy melt-pour explosives such as Composition B and IMX formulations.

This paper details the preliminary evaluation of TNBA melt-pour explosive formulations from the IM and performance standpoint, and the feasibility of using TNBA as a potential high performance melt ingredient.

20172 - MDNT: IM Melt-Phase Energetic Binder
Abbassi

As the push for Insensitive Munition (IM) compliancy in munition systems continues, the maturity of DNAN-based High Explosive (HE) solutions have contributed to significant improvements over their legacy counterparts. However, a technology gap still exists as the output of the DNAN-based IM HE formulations limits their ability to meet the lethality requirements of several munition systems. A need continues to exist for a higher output melt-phase IM HE capable of meeting lethality requirements of several families of systems such as small critical diameter items, HE mortars, and extended range artillery requiring a reduction in payload.

A promising high-output melt-phase energetic binder that has been evaluated in recent years is 1-methyl-3,5-dinitro-1,2,4-triazole (MDNT). In screening tests MDNT was demonstrated to have detonation velocity similar to that of Composition B, while simultaneously having shock sensitivity rivaling IMX-104. Follow-on testing confirmed the performance output of MDNT, and additional shock sensitivity testing illustrated very promising trends.

Pushing the envelope for high-output formulations capable of being utilized in shaped charge applications, formulations with HMX demonstrated exceptional performance; comparable to PBXN-9 and approaching LX-14. Characterization and demonstrations included a side-by-side comparison to LX-14 in testing utilizing a 3.2” Generic Shaped Charge Testing Unit (GSTCU). Testing included Fragment Impact (FI) mitigation testing and penetration testing of a copper liner through steel.

20174 - ROBUST ENHANCED BLAST EXPLOSIVE MANUFACTURING AT HOLSTON ARMY AMMUNITION PLANT

Fung

Enhanced Blast (EB) explosives offer performance characteristics of both aluminized and non-aluminized formulations for target defeat. The incorporation of aluminum powder achieves high shock overpressure for longer duration than non-aluminized compositions. The composition of the formulations represents ingredient ratios that balance the detonation velocity and the total mechanical energy. This results in desirable metal pushing capability as well as high blast energy. EB explosives are typically selected for multi-purpose warheads in shoulder-launch weapons.

While there were multiple ways to manufacture these EB explosives such as granulation via slurry coating, extrusion through a Twin Screw Extruder (TSE) or physical mixing with high shear planetary mixer, BAE SYSTEMS Ordnance Systems Inc. (OSI) had been focusing exclusively with the aqueous slurry coating technique, which is considered by far the most efficient and cost-effectively way to manufacture EB explosives. It is also most suited for the existing infrastructure at our facility at Holston Army Ammunition Plant (HSAAP), without any need for major investment in new equipment.

Starting in the laboratory, the aqueous slurry coating processes were developed and refined for EB explosives such as PAX-3, PAX-30, PBXIH-18 (Aluminized HMX based EB explosive) and PAX-42 (Aluminized RDX based EB explosive), understanding the interaction between various processing parameters while maximizing product yield.

After extensive effort in laboratory process development, PAX-3 and PBXIH-18 had been selected for full production manufacturing using the 500 gallon coating vessel. To date, over 4,000 lbs. of PAX-3 and 1,500 lbs. of PBXIH-18 had been successfully manufactured over multiple campaigns using the aqueous slurry coating process. Additionally, new coating vessels have been installed and commissioned at our R&D Pilot Facility; these coating vessels will allow us to further optimize the aqueous slurry coating process for EB explosive in larger scale.

This paper details the process development, production manufacturing and future process improvement of EB explosives at HSAAP.

20179 - Characterization of LX-14 FEM / PBXN-9 FEM High Energy Explosives
Alexander

LX-14 and PBXN-9 are high energy explosives containing significant amount of HMX. This high nitramine content is desirable for defeat of hardened, bunkered or armored targets found in current theaters of conflict. Weapon platforms such as Javelin, TOW and HELLFIRE are maintains in the weapon inventories that utilize these types of explosive compounds. However, the high explosive content renders these weapons vulnerable to battlefield hazards outside the control of the warfighter.

BAE Systems and the U.S. Army Research and Development Engineering Command (ARDEC) have begun to assess the characteristics of the new reduced sensitivity explosives LX-14 and PBXN-9 contained Fluid energy Milled (FEM) nitramines. These FEM containing explosives began in 2014, as a preliminary internal research and development (IRAD) effort by BAE Systems to determine if shock sensitivity could be reduced by utilizing FEM HMX in standard explosive compositions.

Previously reported explosive characterization has shown the LX-14 FEM and PBXN-9 FEM maintain explosive performance as measured by VOD and pressure, while reducing the overall NOL LSGT card values. These types of explosives may allow for a reduction in IM response severity, in existing weapon platforms to increase the safety factor for the warfighter.

This paper will discuss recent characterization of the explosive performance, mechanical properties and any preliminary IM data collected.

20180 - Synthesis, Formulation, and Testing of 3,4-DNP
Morris

Explosive formulations are an integral component to the performance and safety of weapon systems, especially to the Army's Future Combat Systems efforts. Research focused on explosive materials and formulations that provide baseline/enhanced energetic performance while offering improved sensitivity is critical to the continued mission success and safety of the U. S. Warfighter. Historically, TNT has been the primary melt cast binder for melt pour formulations. However, due to sensitivity, stability and exudation issues, replacements for TNT have long been of interest. Recently, 2,4-dinitroanisole (DNAN) has found widespread use as a TNT replacement. Although DNAN has slightly lower explosive performance than TNT it is considerably less sensitive to external stimuli. Even though DNAN offers many advantages as a melt cast binder, relative to TNT, ideal “next generation” candidates would offer further improvements in explosive performance and sensitivity over existing melt cast binders.

As such, BAE Systems and ARDEC have partnered to further develop the chemistry and measure the explosive performance of the melt-pour explosive ingredient 3,4-dinitropyrazole (DNP). Initial performance testing of DNP has shown it to have greater energy performance than Composition B, while significantly less sensitive to impact, friction, ESD, and shock.

The objective of the current research effort was to scale-up the melt-pour ingredient DNP to the pilot-plant scale and test the performance and shock sensitivity of the material in order to demonstrate its utility as a high-energy melt-pour within IM-compliant explosive formulations. In addition, the toxicity and potential dermal sensitivity issues of DNP were further evaluated. The end state of this project will provide knowledge of the performance and shock sensitivity of DNP as a neat and formulated material. Included in this effort was the formulation of DNP with other high energy materials to meet ARMY IM and lethality goals.

20181 - Improving knowledge of tactical rocket motor response under Insensitive Munition threats: BI, FI and FH Tests results of the research program
Bonhomme

End of 2008, French rocket motors manufacturers Roxel and Arianegroup began a research program under French MOD funding.

Main objectives of the program were:

- Identifying the best compromise for tactical rocket motor architecture including use of mitigation device

- Analysis of the stimuli representativeness and IM test results interpretation following STANAG 4439

- Knowledge of a tactical rocket motor IM characteristics evolution according to ageing

Modelling of tests and response prediction are also major concerns for IM response but they are not including in this research program.

This paper summaries the rocket motor manufacturers' approach of the overall program to reach these objectives and presents the IM test campaign which has begun end of 2010.

Finally, the paper gives information on tests which have been performed.

The first part of the program was to establish a database containing effective IM rocket motor technology and mitigation devices technology. This database had been filled with previous existing French IM tests.

The test plan that has been built taking into account the lack of information coming out from the database, combined with the IM stimuli analysis.

As it is known that mitigations devices may be needed to reach fully IM compliant rocket motor, some mitigation devices will be tested at full scale during the program. Main characteristics and expected efficiency are also briefly presented.

This test plan considered more than 40 (forty) IM tests including test on operational rocket motor to evaluate ageing effect.

In 2010, more than 20 prototype rocket motors and 12 mock-ups have been manufactured, including 2 inert rocket motors devoted to liquid fuel test evaluation. The overall test campaign was performed until 2015 at French MOD facility.

Series of bullet impact tests and fragment impact test were performed. The results are presented and analysed.

Then, a Fast heating tests campaign was conducted. These tests confirmed the interest and the efficiency of a venting system to aim a type V.

20182 - Additive Manufacturing for Net Shape Munitions
Chelluri

Operational and tactical challenges of the Armed Forces require the ability to respond rapidly using a broad spectrum of lethal and non-lethal weapons. The advanced munition technology efforts that will be described here focus on processing of various shapes from powders through an Additive Manufacturing (AM) process – Dynamic Magnetic Compaction (DMC). DMC enables net shape forming of different shapes from powders. This powder compaction method uses pulse magnetic fields of millisecond duration to yield desirable shape, density/strength for specific device characteristics. No special powders are required for AM-DMC processing and powders of different morphology and sizes ranging from nano to micron are processable. The compaction method, when combined with powder co-filling process, enables the selective use of different materials in a single device configuration as needed for specific functionality. Such weapons have the potential to be lightweight, compact and offer higher performance characteristics. The process is also highly consistent and repeatable yielding superior reliability. Further, since no solvents are used during processing the technology is environmentally friendly. Description of the AM-DMC process will be presented along with examples of the shapes that can be fabricated with different materials.

20183 - Fragment Impact Testing of the XM25
Al-Shehab

The XM25 Counter Defilade Target Engagement (CDTE) is a shoulder-fired weapon system that will provide Infantry Soldiers with an improved capability to engage exposed / personnel targets. Cartridges currently available for use are the XM1083 High Explosive Airburst (HEAB) and XM1081 Target Practice (TP). Formal baseline IM tests of the packaged configuration show that the XM25 HEAB cartridges react violently to fragment impact (FI). This is consistent with modeling predictions that the first impacted round should react violently, although the induced shock strength for small caliber items is particularly sensitive to fragment obliquity and hit location error, and the fragment likely breaks up as it perforates the container. The models also predict significant mechanical insult to adjacent rounds should one detonate, both in FI and Sympathetic Reaction (SR) scenarios. This is consistent with engineering level SR tests performed for packaged rounds which indicate violent reactions for adjacent and diagonally adjacent acceptor rounds. Several Fragment Impact mitigation strategies are discussed and continuum modeling is used to predict their effectiveness. FI testing of the TP cartridges (inert warhead, live propellant) were conducted to assess the propulsion's contribution to the reaction violence. While responses to the TP tests were generally benign, in all these tests the lid was repeatedly thrown a significant distance from the test stand. Containers with inert simulants were tested against FI threats to determine the debris throw expected from the fragment momentum alone, and the results compared with high-rate continuum modeling. It was determined that the small arms propellant used in both rounds was, by itself, able to project hazardous debris under fragment attack.

20188 - IM Plans and JIMTP Future in the United States
Di Stasio

Purpose – The Purpose of the Joint Insensitive Munitions Technology Program (JIMTP) is to provide a science and technology base to support the Secretary of Defense in ensuring that munitions under development or procurement are safe throughout their lifecycle, when subjected to unplanned stimuli, to the maximum extent practicable. Since its inception, the JIMTP has utilized the expertise of the entire weapon system community, including DoD, Department of Energy (DOE), and private industry to develop enabling technologies for new weapon systems, or for improving existing weapon systems. This can include changes in the packaging, non-energetic components, the energetic fills within the munitions, and other novel approaches. The JIMTP provides Insensitive Munitions technologies with an end goal of transitioning them to Army, Navy, Marine Corps, Air Force, Missile Defense Agency, and Special Operations Command munition systems. The program invests exclusively in applied technology/research and advanced technology development, with the understanding that Insensitive Munitions is not an independent requirement, but part of an overall desired capability of an entire weapon system. The JIMTP utilizes the service Program Executive Office's (PEO) Insensitive Munitions strategic plans to determine technical needs and shape priorities. The JIMTP focus has been on safety and survivability for many years. The success over those years and dynamic requirements from customers has dictated a required refocus of the portfolio and funded efforts.

Success Stories - The following are a few examples that show relevance as well as return on investment JIMTP Program Office:

•	Advancement of IM Research and Understanding (BA2)

o	Rocket propellants that self-extinguish or lose structural integrity

o	Novel rocket motor designs that incorporate new reactive case materials and venting

o	Shock-dissipating coating of explosive crystals using advanced manufacturing

o	Spray drying of explosives and Resonant mixing

o	Use of microwaves to sensitize booster explosives and primers on-demand

o	Fundamental understanding and predictive technologies of slow cook off properties of gun propellants

o	New binders for energy partitioning/use of less sensitive materials

o	Synthesis of next-generation insensitive explosives

o	Development of new small-scale IM testing and Modeling & Simulation that save money in formulation development

•	Task 15-3-36 IM Javelin Propulsion

o Improved IM performance under Fragment Impact (FI) and Slow Cookoff (SCO) stimuli without degrading system performance

o Meets other system requirements

? Survives environments

? Form factor

• Task 13-3-26 Improved SR Response for the 1000lb GP Bomb

o Utilize a fill that has a balance of large critical diameter, low shock sensitivity, and robust auxiliary booster that reliably initiates the fill from the nose or tail

o Compatible with current fuzes

o Loadable with existing industrial base and equipment

o Less expensive than existing explosive fill

JIMTP Technology Gaps – As the JIMTP continues to mature, the program office along with the Services, update their priorities and identify technology gaps. These gaps will be the program's focus. New JIMTP Goals will be briefed. The goals for each Munitions Area Technology Group have been updated in 2017 to include performance metrics to remain aligned with the changing customer requirements.

Summary – Since its inception, the JIMTP Program has been making munitions safer for the warfighter as well as in some cases, making the munitions more lethal while making them less sensitive during storage and transportation. This allows the warfighter to have world dominating munitions while gaining survivability. As indicated above, there are still many technology gaps that will be addressed moving forward.

20228 - Synthesis Development of Novel Energetic Ingredients
Headrick

There is a constant need for the development of processes to generate new or little-known energetic ingredients for both explosive and propellant applications. Often, it is also realized that a material can be developed for an initial, certain purpose but after characterization, is better suited for other means. As such, scientists at BAE Systems have remained dedicated to furthering the state of the art of explosive and propellant ingredients by developing and optimizing synthesis routes for either new or little-known energetic materials. Over the course of several years, some materials have been developed for which the optimal use of these materials has been identified. The purpose of the following paper is to highlight the properties of various energetic materials in an effort to inspire a discussion within the energetics community about future uses for these interesting and potentially valuable energetic compounds. A few examples of the materials to be discussed are DNGU, TNABN, HK-56, TNTCs and TNBI.

20233 - Qualification of Explosives Formulations Manufacturers and Ingredient Manufacturers for US Navy Use
Kenyon

The Naval Surface Warfare Center (NSWC) Indian Head Explosive Ordnance Disposal Technology Division (IHEODTD) is designated by NAVSEA Instruction 8020.11A the US Navy high explosives in-service engineering agent (ISEA). We are also tasked to ensure high explosives specified for loading into munitions for fleet use have been Final (Type) Qualified and chair the configuration control board for US Navy explosives. This includes review and coordinating concurrence for disposition of qualification of manufacturers, process changes and changes of ingredient manufacturers. We are adding QPLs to Navy explosive specifications to list qualified manufacturers. Manufacturers or program offices will have to pay for qualification.

This discussion will review the assessments necessary to qualify changes to manufacturers, manufacturing processes and ingredient manufactures. For the US Navy these changes require qualification of the explosive formulation to ensure it will perform in an ordnance system as it was when Final (Type) Qualified. To do this the US Navy requires limited qualification testing in accordance with NAVSEA Instruction 8020.5C to show the explosive formulation maintains the same characteristics as when

it was Qualified. The specific assessments are selected based on the change to the explosive material and determine whether it possess properties which make it safe and suitable for consideration for use in its intended role. For example:

• A change of the manufacturer using current accepted technology requires limited assessment compared to introduction of new technology which may alter sensitivity and thus impact safety, reliability or performance of the ordnance.

• Use of currently qualified manufacturers of ingredients may be “grandfathered in” if we have necessary data.

• Qualifying new ingredient manufacturers requires 6 month aging for ingredients that impact the aging characteristics of an explosive formulation.

20241 - Effect of Insensitive HE on Shaped Charge Jets
Arnold

A few decades ago, shaped charges were typically filled with TNT-bonded explosives. Already at that time, it was tried to measure the roughness of the detonation front resulting from the inhomogeneity of the explosive ([1]) and the question was raised if this roughness has an impact on the performance of a shaped charge jet. However, experiments showed that the influence was only marginal (e.g. [2]) and only little further attention was given to the topic.

The question re-emerged when the classical TNT bonded explosives were replaced by plastic bonded explosives (PBX) to make the charges more insensitive [3]. While the TNT binder was detonable and thus causing the detonation front to proceed with approximately the same velocity in the explosive and in the binder, this is not the case with the inert plastic binder. Consequently, the roughness of the detonation front is increased.

At the same time, the developers of shape charges are striving for higher performance by the application of higher density liner materials and / or non-constant thickness liners – both measures at least partly decreasing the liner thickness and thus making the shaped charges (theoretically) more sensitive towards a rough detonation front.

Facing these trends, the detonation front roughness became an issue again and an experimental program was launched to investigate its effects on the liner material and to quantify its influence on a shaped charge jet.

Three batches of the TDW PBX KS32 (HMX/HTPB 85/15) with different distributions of the HMX grain size were manufactured:

- standard: bimodal with mean grain sizes of 30 µm (fine mode) and 500 µm (coarse mode),
- coarse: unimodal with mean grain size 500 µm, and
- fine: unimodal with mean grain size 30 µm.

These different explosives were then investigated in two test series. In the first series, the explosives were cast onto confined and extended copper plates and detonated. Additionally, one test with a machined charge surface was conducted. For each test, the roughness of the copper surface, i.e. the indentations caused by the detonation front, was evaluated and compared to the other HE batches.

For the second test series, specially designed shaped charges were manufactured and filled with the different HE batches. The charges were fired in front of a double FXR and evaluated with respect to tip velocity, jet breakup, jet length and particle drift allowing a quantitative comparison of the influence of the grain size distribution and the detonation front roughness, respectively.

The presented paper describes the test charges and setups and provides a detailed description of the experimental results as well as their implication on shaped charge design.

References

[1] M. Held, “Roughness of the Detonation Front”, TDW-Report TDW-TN-AG41-134, 1984

[2] P. Chanteret, A. Becuwe, A. Kerdraon, “A Study of the Influence of HE Grain Size on Shaped Charge Jet Fragmentation”, Proc. 13th Int. Symp. on Ballistics, Stockholm, Sweden, 1992

[3] I. Plaksin, R. Guirguis, L. Rodrigues, R. Mendes, S. Plaksin, E. Fernandes, C. Ferreira, „Effects of Meso-Scale Perturbations in the Detonation Reaction Zone on Shaped Charge Liner Response“, Proc. 28th Int. Symp. on Ballistics, Atlanta, GA, USA, 2014

20245 - IM Characteristics of Large Diameter Extruded Double Base Rocket Motors with Composite Cases

Bellotte

This paper gives an overview of the Insensitive Munitions (IM) characteristics of extruded double base (EDB) propellant grains when utilized in large diameter rocket motors with wound composite motor cases. These characteristics include the card-gap values of the base propellants as well as the performance under standard IM test conditions such as fragment impact and cookoff testing.

In the pursuit of practical, cost-effective solutions for min-smoke large diameter tactical solid rocket motors, EDB propellants have largely been discounted due to perceived performance issues and historical IM testing with metal case rocket motors. However, work using cast propellant systems as well as advances in extruded propellant technology have closed the historical performance gap. In tandem, the inclusion of composite motor case technology, has shown marked improvements in IM performance of classic metal case EDB motors.

Work in large diameter tactical EDB motors for the purposes of developing IM propulsion systems is explored. Performance comparisons are provided for the purposes of design trade space exploration and technology advances for EDB propellants are presented.

20249 - U.S. Navy Insensitive Munitions Handbook
Ward

The Naval Ordnance Safety & Security Activity (NOSSA) is developing a "U.S. Navy Insensitive Munitions Handbook" as a comprehensive source of information tailored for the Navy Insensitive Munitions (IM) community, specifically for the Munitions Program Offices that are required to develop and conduct IM Programs for their munitions. The paper is intended as an advance introduction to the Handbook and provides summary discussions of handbook contents, such as: (a) Selected history of the IM Program, (b) Navy IM policy and guidance, (c) The Navy IM development process, (d) The Joint IM Strategic Planning (IMSP)/Plans of Action and Milestones (POA&Ms) process, (e) Selected IM research projects, (f) Threat Hazard Assessments, (g) IM qualification, and (h) IM compliance. The IM research projects and the relevant points of contact are based on information from the FY17/18 IMSP/POA&Ms and documentation from technology programs with IM related efforts such as the Joint Munitions Program (JMP), Joint IM Technology Program (JIMTP), IM Advanced Development (IMAD) Program, and IM Technology Transition Program (IMTTP). The 2017 information is included in the Handbook to provide recent examples of the extent of IM research and collaboration that is indicative of the range of possibilities for future areas for IM research and development. Upon completion of the Handbook, NOSSA plans are to issue and maintain the Handbook on its secure website.

20258 - Cost of Propane Fast Cook-Off Testing
Yagla

The cost of fast cook-off testing with propane has been obtained by careful tracking of expenses over a significant number of tests. These costs are compared to liquid fuel fire testing. The costs consist of nonrecurring costs, the costs directly attributable to a given test, and recurring costs of damage repair, maintenance, and environmental compliance. The nonrecurring costs are design, siting, materials, chamber fabrication, fuel distribution systems, fabrication, and calibration. The costs attributable to given test are mainly planning, construction of test stands, instrumentation, field crews, fuel, data analysis, and reporting. Recurring costs of damage repair, maintenance of the cook off facility including fuel equipment, and environmental compliance are itemized.

These costs have been compared to the corresponding costs of liquid fuel fire testing. The cost of testing with propane is shown to be significantly less than with liquid fuels.

The total cost breakdowns are shown in tables. Once the costs were itemized over several years and a significant number of tests, the propane test could be compared with liquid fuel test. The costs of environmental impacts were not calculated. The total cost of the propane fast cook-off test was found to be $25,886 compared to $36,791 for the liquid fuel test.

The paper explains the development of the cost model, and cost of each item, and how the costs were obtained.

20259 - Fast Cook Off Modeling and Simulation
Yagla

Modeling with experimental confirmation was the subject of our IMEMTS paper and poster presented in Nashville in 2016. We showed a very accurate time to reaction for a rocket booster motor in 25 x 25 inch square missile launcher canister made out of a carbon fiber composite material. A reaction time of 14 minutes was predicted before the test. The test showed the reaction to occur at 14 minutes. Since that time the computer simulation was run for a 21 inch diameter second stage rocket motor in an open fire. The prediction before the test was 244 seconds to reaction, the test showed 225 seconds minutes to reaction. Calculations were then carried out for a very complicated third stage rocket motor with a composite case. The predicted time was 260 seconds the experimental time was 240 seconds.

Recently, we had an opportunity to model a fast cook of test of 110 rounds of 30 mm gun ammunition contained in an ammo can with a thermal protection system. We did not have accurate Arrhenius reaction rate chemistry data, so we used a generic value for nitrocellulose / nitroglycerin propellant from a French paper and computed a reaction time of 163 seconds , compared to 150 seconds from the experiment. We made no changes in the input or property data to converge the model on the experimental time.

In this problem each cartridge case was modeled with its own propellant and primer. The thermal protection system consisted of fiberboard panels around the inner surface of the can. There also was a wide strip of canvas wound back and forth in the can separating the layers of cartridges. Having modeled the time to reaction, and realizing the model is likely to be predicting the evolution of decomposition products accurately, we are ready to start work on predicting the violence of the reactions. Results from the models will help our understanding of fast cook off and lead to safer weapons.

20260 - Fast Cook of Simulated Rocket Motors with Intumescent Paint
Yagla

Intumescent paint is sometimes used to extend the time to reaction. The paint swells and chars in the fire. The swelling puts more thickness of material between the fire and the rocket motor chamber, reducing the heat flux and delaying the reaction. Experiments were conducted to determine the time history of thermal penetration into a simulated motor in a propane fire and compare to a motor without the paint. The first set of tests was to select the best paint. Two types of paint were applied to simulated test units and compared by testing in a radiant chamber. The best paint was then applied then to two identical rocket motor chamber segments. One was put in a liquid fuel fire, the other a propane fire. The results were……….

This is a work in progress and will be completed well before the symposium. The down-select test units were built, instrumented, insulated, and filled with simulated propellant. They were then painted to achieve a 25 mil thickness, cured, and are now ready to test in a radiant chamber:

20261 - The DOTC Enterprise – Helping You Accelerate Technologies to the Field
Wilson

With the enactment of the National Defense Authorization Acts for FY1994 and FY2016, Congress provided the Department of Defense with a tremendously powerful acquisition tool designed to spur innovation across the defense contractor community and attract new innovative companies to carry out prototype projects using "other transactions". Other transactions (OT) offer a streamlined and highly collaborative process between Government, industry, and academia and today is a vital tool that reduces barriers to attract new companies to the DoD market and accelerates the transition of new technologies to the Warfighter.

Since its creation in 2002, the Department of Defense Ordnance Technology Consortium (DOTC) enterprise has realized unprecedented double digit growth and has cumulatively awarded 950 DOTC initiatives for over $3.07 Billion. This past GFY2017 alone set growth records by issuing 192 awards totaling $781 Million. The National Armaments Consortium (NAC) continues to grow significantly and offers access to a powerful 560+ member consortia consisting of the most innovative large and small defense contractors, academia, and emerging new companies that offer innovative commercial solutions for defense requirements.

The DOTC Enterprise is a strategic acquisition program that accelerates the fielding of insensitive munitions and energetic materials technologies to the Warfighter. Since 2010, the DOTC and the NAC has directly supported the Joint Insensitive Munitions technology Program (JIMTP) and has provides access to a robust Science and Technology (S&T) community through the execution of the DOTC annual requirements plan and awards lifecycle processes. In this current GFY alone, the DOTC Enterprise is actively supporting 80+ Energetic Materials and JIMTP related initiatives totaling over $195M.

The DOTC Enterprise is interwoven with the performance advances of IM/EM technologies the realization of these technological benefits. The DOTC Enterprise is a continued "gold standard" for OT use across all the major DoD agencies working in tandem with one of OSD's identified Center of Excellences for OT's, ACC-NJ. The combination of the DOTC Program Office, the NAC, and ACC-NJ bring DoD agencies the most powerful mechanism for technology prototype development and transitioning success to the field. This engaging brief will share DOTC Enterprise success stories related to the IM/EM community, show tangible examples of streamlined acquisition processes, and will empower the audience to leverage the DOTC Enterprise for their future IM/EM prototype projects.

20262 - Radiant Chamber for Fast Cook of Testing and Simulation
Yagla

Two radiant chambers were built and tested. They provide a uniform radiation field for testing small items with incident radiant heat fluxes up to 90 kW/square meter. They have been calibrated with thermocouple rakes and cylindrical steel calorimeters. The radiation fields are unexpectedly uniform and have axial and circumferential uniformity. The chambers use eight 250 Watt cylindrical halogen bulbs. The bulbs are enclosed in inexpensive work light housings readily available at home centers. A variac has been used to control the heat flux. Since fast cook heating of test items is 90% radiative, the chambers provide good tests for many items.

They have been used to test instruments before putting them in large fuel fires. They have also been used to obtain highly controlled laboratory data for development of computer simulations, explaining experimental data from equipment being tested during development, and converging computer simulations when there was uncertainty in material property data.

Calibration data are presented along with results from testing a 7-inch (180 mm) rocket motor chamber with insulation and simulated propellant. Temperature versus time data was recorded by fifteen thermocouples to measure the heat flow along each of five thermal paths from the outer surface of the motor, through the insulation, and into the propellant. The data were used to resolve problems caused by uncertainty in property data for the motor chamber and insulation in a finite element model of a restrained firing of a missile in a shipboard launcher.

20263 - IM Technology for Stryker Tank Munitions
Eng

ABSTRACT

IM Technology for Stryker Tank Munitions

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The 105-mm tank rounds for the Stryker Mobile Gun System are not expected to meet the insensitive munition requirements for slow cook-off and fragment impact threats due to the confinement of a large amount of propellant inside a crimped steel cartridge case. A research and development effort has been funded by the Joint Insensitive Munitions Technology Program (JIMTP) to develop a foamed celluloid combustible cartridge case (FCCCC) to serve as a vented case and replace the existing steel case. This cartridge case venting solution could mitigate the slow cook-off response by preventing pressure and temperature build-up inside the cartridge case leading to a violent reaction of the propulsion system and mitigate the fragment impact response by eliminating the steel debris cloud generated from the steel cartridge case. The precursor bead material used for foamed celluloid cases can be manufactured at low cost by conventional propellant manufacturing processes. The cellular structure of the foamed celluloid allows the case to absorb energy and provides good mechanical strength. Preliminary modeling and simulation results indicate that the FCCCC should be able to survive the Striker's autoloader and transportation rough handling requirements, while also meeting ballistic performance requirements at ambient conditions. Developmental testing is being planned to validate and calibrate the models as well as to demonstrate that the FCCCC has the potential to survive actual rough handling and meet the current requirements for ballistic performance and post-fire residue.

20264 - Insensitive Minimum Smoke Propellants
Deschner

In close collaboration, FFI and Nammo have developed a family of minimum smoke composite propellants based on nitramines (RDX or HMX), glycidyl azide polymer (GAP) binder and low-risk nitratoethylnitramine (NENA) energetic plasticizers. The propellants contain tailored bonding agent systems and lead-free burn rate modifiers and are compliant with upcoming environmental regulations.

Recently, we have successfully scaled up one of our GAP-nitramine propellants to ton-scale production and qualified it for application in the Lightweight Multirole Missile (LMM) boost motor. The LMM is developed by Thales UK as a precision lightweight weapon for light platforms to counter the modern and emerging threats of land, sea and air targets. As the LMM boost motor is the first munition incorporating a GAP-nitramine propellant in the UK inventory, a full type qualification, including several IM tests, has been performed by Nammo, Cranfield University and by the COTEC Weapons Testing Facility.

In order to achieve good IM properties, reduced sensitivity nitramines and the low sensitive NENA plasticizer are incorporated into the propellant. However, small scale fragment impact testing (EMTAP test no. 36) of the LMM propellant formulation revealed high explosiveness. Hence, to further reduce sensitivity and increase safety during production, storage, transport and use, some or all of the nitramine has to be replaced by other low sensitive energetic fillers like FOX-7 or ammonium nitrate.

FOX-7 has an explosive performance similar to RDX. Nevertheless, it is inherently less sensitive than RDX and HMX which allows for a safer handling of the material. On the downside, the current price of FOX-7 is high. This is mainly caused by the absence of demand as HTPB/AP-based rocket propellants are still the workhorse for the rocket industry.

In order to evaluate the impact of FOX-7 on mechanical and ballistic properties as well as sensitivity for the family of minimum smoke GAP-propellants at Nammo, we have prepared, characterized and tested several propellant formulations. Strain and strength of the propellant is reduced compared to pure nitramine/GAP-propellant while the modulus is increased. However, tensile testing at -40°C indicate a better low temperature behavior of the GAP/FOX-7 propellant compared to purely nitramine/GAP-propellant. Burn rates are reduced and pressure exponents increased by incorporation of FOX-7.

20265 - Historical Review of Fragment Impact Standardization
Hunt

This report describes the results of a review of the history and development of NATO STANAG 4496 Fragment Impact Munitions Test Procedures related to the origin of the threat fragment characteristics and requirements that were first cited in the initial edition of STANAG 4496. The review was performed by completing a literature search of historical papers and documents surrounding the original development for the STANAG. The purpose of the fragment impact test is to assess the reaction, if any, of munitions and weapon systems to impact by a high velocity fragment. The review discusses the technical rationale behind the following aspects of the STANAG requirements: (1) Fragment size (2) Fragment shape, both a discussion of the effect of yaw at impact as well as a discussion of the merit of various designs and shape factors (3) Multiple fragments and (4) Fragment velocity. This study was used to inform the NATO AC/326 SG/B Fragment Impact Custodial Working Group (FI CWG). The working group has already reviewed the review results and drafted updates to NATO STANAG 4496, the technical content of which will be migrated into a new AOP 4496. A version of this study will be included in Annex A of the new AOP.

20266 - An Approach to Predict the Cook-off Response of Confined and Vented Full Scale Munitions Based on Small Scale Tests

Moussa

Historical data (USS Oriskany 1966, USS Forestall 1967, USS Enterprise 1969 and USS Nimitz 1981) suggest that accidents involving energetic materials and munitions can lead to large scale damage during regular military operations. This has prompted the DOD and DOE to develop Insensitive Munitions (IM) that are safe under normal conditions, but can be activated on-demand. However, the explosive formulations being evaluated as IMs can undergo cook-off when exposed to heat. Controlled venting has been proposed as a safety method to reduce the violence of cook-off. Cook-off response is commonly studied using full scale tests that are time and resource intensive.

We have recently developed an approach to predict the cook-off response of confined and vented full scale munitions based on small scale testing and analysis. This approach consists of the following steps: (1) Measure the thermal degradation rates of confined and vented explosive versus temperature through small scale tests (2 g of explosive per test), (2) Measure the bun rates of pristine, heated and thermally degraded explosive through strand burner studies on ~3 g of explosive per test, (3) Develop a fast running cook-off model that combines the key findings from the above two steps. Included in this model are algorithms for thermal degradation kinetics versus temperature and venting (from step 1) and the burn rate as a function of temperature, pressure, extent of thermal degradation and venting (step 2), and (4) Validate the model by comparing its predictions of wall temperatures at ignition (and pressure-time histories) at various heating rates to measurements in small scale cook-off tests (~2 g of explosive per test).

Following is a summary of key findings from the implementation of the above approach for PBXN-111:

* The rate of thermal degradation rate depends on temperature and confinement. For example, the mass loss of confined PBXN-111 due to thermal degradation increases from 0.74%in 32.6 hours at 151.8°C to 13.2% in 5.8 hours at 175.7°C. The initial thermal degradation rates of confined and vented PBXN-111 are almost identical, but the reaction accelerates much more rapidly in confined systems at later times.

* The burn rate of PBXN-111 is almost independent of temperature, pressure and time up to 2000 psig, but it increases marginally (up to 7.5 times) with the extent of thermal degradation. Above 2000 psig, the burn front of thermally degraded PBXN-111 undergoes acceleration, and for severely degraded PBXN-111, the acceleration can be >4 orders of magnitude higher that in moderately degraded material.

*	The wall temperature required for ignition increases with heating rate.

The thermal degradation, burn rate and cook-off tests that we conducted with PBXN-111 are discussed in detail in this paper along with the test data, data analysis and model development.We find that tracking the pressure evolution (while ignored by others) is critical to proper modelling of slow cook-off.

20267 - INSENSITIVE MUNITIONS INDUSTRY CONTRIBUTION FOR NEW STANAG - AOP EDITION OF THE SLOW HEATING TEST

Guengant

Currently, various works are conducted by National experts from AC 326 in the aim to design a new edition of STANAG - AOP 4382. These works have been encouraged by the MSIAC survey of the Slow Heating tests and the MSIAC Science of Cook-off workshop. Thus, IMEMG proposes feed-back coming from European Insensitive Munitions Industry about the Slow Heating trials requirements. IMEMG is the European Organisation that brings together the twenty-two leading armament manufacturing groups working with IM technologies. It aims to express the viewpoint of the European armament industry with regards to relevant transnational regulations and requirements. This paper presents the analysis carried out by the Hazard Assessment & Classification Expert Working Group of IMEMG. It has been focused on similar topics to the MSIAC survey: test standards (IM & UN), heating rate value and its relevance, temperature preconditioning, oven & heating system design, test item restraints and orientation, reaction temperature definition, minimum instrumentation requirements, etc. In addition, it appears that the Response Descriptors seem to be almost unchanged in the next AOP 39 edition still carrying the 20 Joules criterion for fragment projection. These requirements are still questionable for the Type V response requirement for the slow heating test. If we consider that the slow heating threat can only be achieved in an enclosed oven (the whole process requesting at least 30 hours), is the actual criterion stipulating that the energy of any fragments produced should not exceed 20 Joules at 15 meters range still relevant? Indeed, such propelled fragments cannot even penetrate 2 mm thick aluminium sheets, in which case a type IV reaction requirement seems to be more appropriate. This paper will present the European IM industry proposals concerning current discussions for the forthcoming updates of relevant STANAG - AOP 4382.

20268 - An Explosive Fragment Projector for IM testing
Eliash

Fragment Attack (FA) testing, as described is STANAG 4496, calls for a specific fragment shape, material and velocity. Usually this is achieved by accelerating a fragment in a long barrel, powder or light gas gun. This method requires a heavy infrastructure, binding FA tests to stationary facilities. At Rafael, the need for a mobile FA test apparatus had led us in the past to use specially designed Explosively Formed Projectiles (EFP) as substitutes for the STANAG fragment. We called this method Modified Fragment Impact or MFI. In this method the EFP had the needed mass and velocity but was hemispherical in shape and was made of Copper rather than steel. Another advantage of this method, besides being portable, was its accuracy both in velocity and in aim.

The objective of the presented work is to develop a new explosive charge and test set-up that will have the advantages of our EFP test method while projecting a fragment in the velocity, shape, mass and material as required by the STANAG. The design process includes both hydrocode modeling and characterization of the performance through testing of selected designs.

20269 - Thermal modeling of fast cook-offs
Graswald

Being fully compliant to Insensitive Munitions requirements is of utmost importance for today's and future munitions. The IM approach as defined in AOP-39 is typically conducted by using insensitive plastic-bonded high explosives and assessing IM states and mitigation technologies on warhead system, munition, and, if necessary, munition packing level. Among other IM hazards listed in STANAG 4439, thermal stimuli through fast cook-off heating are usually of particular interest for large warheads and bombs, since they may strongly drive the warhead system design and shall be evaluated at the earliest opportunity.

A simplified approach applies a transient FE model in ANSYS with a typical flame temperature profile that allows predicting temperatures and times during a fast cook-off. Such investigations are used to evaluate critical components or apply potential mitigation measures such as additional coatings on the casing.

In a new approach, a reaction kinetic model originally developed for modeling self-heating of explosive charges at slow cook-offs and implemented into COMSOL is adapted for fast cook-off simulations. Differential scanning calorimetry (DSC) tests of small explosive samples at fast heating rates provide input data required. Self-heating of the explosive charge is modeled with AKTS thermokinetics software fitted to such experimentally determined heating curves. This data is eventually implemented into COMSOL simulating fast cook-off behavior of full-scale warheads. This results in an accurate prediction of spatial temperature profiles as well as reaction times and temperatures verified with experimental data.

20271 - MICROFLUIDIC SYNTHESIS OF ENERGETIC MATERIALS
Scavuzzo

Microfluidic synthesis is the use of microliter scale flow reactors to manipulate reactive liquids or solutions to produce chemical transformations. Microfluidic synthesis processes have some advantages over traditional batch processes, particularly when producing energetic molecules. For example, microfluidic reactors contain only microliters of reactive solution, which greatly reduce risks associated with large volumes of energetic material. Further, because of the high surface area-to-bulk ratio in microfluidic reactors, heat is efficiently transferred away from the system. This is of particular importance

for the synthesis of energetic molecules where exothermic nitrations and oxidations are common. The simplicity of microfluidic reactors also allows for easy scale-up and automation for remotely controlled processes. The present work deals with the design and fabrication of a microfluidic reactor used to produce energetic molecules. A nitrated precursor for an energetic polymer was chosen as the target molecule. The synthetic process contains two steps where organic molecule X1 is first nitrated to produce

NO2-X1. In the second step, NO2-X1 undergoes an exothermic rearrangement to give the final product, NO2-X2. Each step was performed and optimized individually on the microfluidic reactor. The optimized conditions were then used to perform the two steps in series on a single reactor.

20273 - Explosive Ordnance Disposal (EOD) of Insensitive Munitions: Challenges and Solutions
Brousseau

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 NTO, 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 have to 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 on the ground. During those tests, many different disposal methods were explored, i.e. one or many blocks of 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. 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 low-order reactions. Our efforts to find or create 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.

20274 - New generation Influence Mine classified as 1.6N
Granqvist

New generation Influence Mine classified as 1.6N

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A new underwater Influence Mine, BLOCKER, is a cost effective Influence Mine equipped with advanced sensor systems, customer programmable algorithms/parameters and Insensitive Munitions Plastic Bonded Explosives, exercise systems and an impressive total energy output equivalent of over 1000 kg of TNT. This Mine fulfils all the IM requirements, it has no mass explosion hazard and therefore hazard classification does not make justice to this system. During the last years after completing the extensive testing, the work to reclassify the Underwater Influence Mine to 1.6N has started in Finland.

Abstract

The BLOCKER is manufactured by OY FORCIT AB in Finland. Explosives in this product are plastic bonded explosives FOXIT (main charge) and FPX R1 (booster). Both of these explosives are widely tested and qualified.

The main charge FOXIT is tested according to UN Recommendations on the Transport of Dangerous Goods, Manual of Test and Criteria and qualification is performed by Finnish Defence Forces Research Agency. Based on the tests, FOXIT meets the requirements of EIS-material (Extremely Insensitive Substance).

Qualification for the explosive in the booster FPX R1 has been performed by both Swedish Defence Forces and Finnish Defence Forces. Sensitivity and quality tests for the booster explosive FPX R1 have been performed at Finnsh Defence Forces research Agency (FDRA). Swedish Defence Materiel

Adminstration's FSD 0214 standard test methods for booster explosives were used as test guidelines. Underwater Influence Mine, BLOCKER system and its main charge (FOXIT) and booster (FPX R1) combination have proven to be insensitive enough to be classified to class 1.6N.

Current transport classification for the Underwater Influence Mine, BLOCKER is UN 0137 1.1D. The aim is to get international transport classification in hazard division 1.6 and compatibility group N under the UN 0486.

In addition to STANAG IM tests, the UN Tests 7 (g) - 7(k) have been conducted to the whole Underwater Influence Mine (Article) and series 3, 5 and 7 (a) – 7(f) tests have been made to the FOXIT (Substance). According to tests performed by FDRA, the Underwater Influence Mine is not too dangerous to transport (the Manual of Tests and Criteria, Series 4) and it is thermally stable (the Manual of Tests and Criteria, Series 3). The Underwater Influence Mine passes all the test series 7 tests, and therefore Underwater Influence Mine could be assigned to division 1.6. Tests results will be presented in this presentation.

The technical information of Underwater Influence Mine, test results (FOXIT) from UN Test series 3, 5 and 7, other performed tests and FPX R1 (qualification tests according to FSD 0214 and AOP-7) will be presented in this presentation.

The concept have been discussed with the Finnish Safety and Chemicals Agency and also with the Finnish Transport Safety Agency. The Sub-Committee of Experts on the Transport of Dangerous Goods (Committee of Experts on the Transport of Dangerous Goods and on the Globally Harmonized System of Classification and Labelling of Chemicals) had this topic on their agenda during their meeting in Geneva November 2017. There were an international consensus that provided that all the tests required will be performed acceptably, the classification to 1.6N should be possible. The work continues and by the summer 2018 the new classification is expected to be valid.

20275 - Passing Sympathetic Reaction Responses in 500 and 1,000-lb General Purpose Bombs with AFX-770

Crouse

The search for a means to pass Sympathetic Reaction (SR) in General Purpose (GP) bombs for Insensitive Munitions (IM) compliance has led to the investigation of alternative explosive fills to reduce the sensitivity of the weapon without compromising its performance. Threshold criteria necessary for achieving a passing response with respect to SR vary with warhead size and pallet configurations, however, modelling and simulations results along with historical data indicate that candidate IM compliant explosive fills for GP bombs must have a Super Large Scale Gap Test (SLSGT) threshold pressure greater than 55 kbar and a critical diameter greater than two inches. After a comprehensive examination of all Air Force and Navy GP bomb formulations the insensitive explosive, AFX-770, was selected by the Air Force Research Laboratory, Munitions Directorate, Energetic Materials Branch (AFRL/RWME) as a candidate fill to improve the response to SR in both the 500-lb and 1,000-lb GP bomb variants.

AFX-770 is a RDX-based, large critical diameter, insensitive, non-ideal, cast-cure explosive formulation. The formulation was originally developed in the early 1990's as a potential IM compliant replacement for Tritanol in the 500-lb GP bomb and successfully achieved passing scores in SR, Bullet Impact (BI), Fast Cook-off (FCO), and Slow Cook-off (SCO) full-scale tests. AFX-770 was reformulated in 2013 to improve the SR performance in the 1,000-lb GP bomb. The modern variant of AFX-770 demonstrated an SLSGT threshold pressure equal to 62 kbar and a critical diameter greater than 4.0 inches. Full-scale arena testing with AFX-770 verified that the formulation was capable of meeting the performance requirements for both the 500-lb and 1,000-lb GP bomb variants.

In 2015, AFRL/RWME partnered with Aerojet-Rocketdyne to demonstrate a passing response to SR in the 500-lb GP bomb. In 2017, under the support of the Joint Insensitive Munitions Technology Program (JIMTP), AFRL/RWME again partnered with Aerojet-Rocketdyne to extend this success to the 1,000-lb GP bomb using a modern variant of the insensitive explosive formulation AFX-770. Results from both SR tests, in addition to initiation testing and sub-scale testing will be presented.

20276 - PBXN-5 Mechanical Characterization and Proposed Constitutive Model
Peairs

PBXN-5 samples have been mechanically characterized at 3 different temperatures (-54°C, 22°C, 71°C) over strain rates from 0.001 s-1 to 1200 s-1. Quasi-static testing included unconfined compression, confined compression, and brazil tests. High rate testing was performed in an unconfined compression configuration with a Split Hopkinson Pressure Bar. The data collected in the unconfined compression testing agrees well with other quasi-static data collected by previous authors. To the author's knowledge, the confined compression and Brazilian test data is the first of its kind for PBXN-5.

The data collected under this effort was used to fit a constitutive model proposed for use in the design of hard target penetrating fuzes. The proposed model fit will be discussed and the results will be compared with the collected data

20279 - Scaling of Fast Cook Off Fires
Yagla

Data from a number of fast cook off fires were compared to see if simple geometrical (replica) scaling could be applied for comparing the fires. This has importance to the design of test fires, as the size of the fire is very important when considering the effects of test item blockage and wind. It is also important to the design of especially large fires for long items such as missiles. It may be possible to construct modular fires that use basic building blocks to create fires that conform to the objects under test. These could minimize the amount of fuel and time to conduct the test.

The linear dimensions of the fires were divided by the half-width (or radius for round fires) of the pan to nondimensionalize the spacial variables. Then the fire temperature fields were overlain to assess the differences. Additional data points from various fires were then included in the fields to gain even more insight as to how broadly the method can be used. Both liquid fuel and propane fires were considered. Data from a small fire with a two to one aspect ratio were also compared to a data from a large fire with a significant aspect ratio, and square fires.

20282 - INSENSITIVE MUNITIONS (IM) GUN PROPELLANT OPTIMIZATION EFFORTS FOR MEDIUM CALIBER APPLICATION

Liberatore-Moretti

The development of gun propellant formulations that meet both insensitive munition (IM) and performance requirements is an important goal in the energetic materials community. The focus on decreasing the shock sensitivity of the propellant must be carefully weighed with the need to maintain or increase muzzle velocity. A novel or modified formulation is subjected to a variety of tests, such as compatibility, strand critical diameter, bed critical diameter, closed bomb, thermochemical calculations, and interior ballistic calculations, to ensure that both requirements are met. Further examination includes mechanical properties and friction, impact, and electrostatic discharge (ESD) testing. An experimental base grain Formulation A was characterized via the aforementioned methods to obtain sensitivity and performance data; the results showed that the muzzle velocity requirement had not yet been met with conventional propellant grain dimensions. Two burn rate modifier (BRM) compounds were subsequently added separately to the formulation in portions smaller than five percent, and these two Formulations B and C were evaluated in similar fashion. The strand critical diameter test results indicated that Formulation B outperformed A and C, and the bed critical diameter test results showed that all three Formulations exceeded the diameter of the medium caliber cartridge case. The mechanical properties of Formulations A and C were similar to each other when comparing SEM images and stress-strain plots, with Formulation B appearing more brittle at ambient and cold temperatures. The closed bomb test results suggested that Formulations A and C outperformed Formulation B. All three Formulations were similar in friction, impact and ESD sensitivities, with Formulation B being the least impact sensitive. Interior ballistic calculations revealed that all three Formulations would need to be manufactured with tiny grain dimensions (for example, an outer diameter of less than one millimeter) to meet muzzle velocity requirements; Formulation B would require the smallest dimensions. The characterization data from both burn rate modifier formulations were compared to the base grain formulation, and Formulation B was removed from contention. The two remaining Formulations A and C were then submitted for scale-up to assess feasibility of grain production, and also to perform further bed critical diameter testing. One formulation was then downselected and prepared for further IM study and optimization.

20289 - Manufacturing of PAX-3 High Explosive
Swaszek

The manufacturing methods and processing controls of explosives play an important role in maintaining the quality of explosive formulations. ARDEC has developed the explosive formulation PAX-3 which has been scaled up utilizing a twin screw extrusion mixing method. This is a continuous process in which a two part mixture is fed into the extruder using high shear mixing to produce PAX-3. Currently, ARDEC is also pursuing the development and scale up of PAX-3 in a single batch 500 gallon slurry coating process. Efforts for qualification of the explosives often require a significant amount of time to run all the required testing. ARDEC is evaluating the material to assess its safety and maintaining similar sensitivity & performance characteristics for saving time and cost. PAX-3 is an explosive formulation that is of interest to the ARMY for use in gun launch munitions and grenades. PAX-3 shows improved shock and IM response as compared with traditional explosive fills. The material is being evaluated to determine any changes in sensitivity, long-term aging, and performance characteristics according to AOP-7.

20290 - Electronic properties and Hirshfeld surface analysis of insensitive high energy density material Dihydroxylammonium 5,5'-bistetrazole-1,1'-diolate under compression
Abraham

The art of designing novel energetic materials that can exhibit high performance together with reasonable sensitivity to external stimuli remains as a challenging issue. The recently synthesized Dihydroxylammonium 5,5'-bistetrazole-1,1'-diolate (TKX-50) is a future high energetic material because of its high performance, low toxicity and insensitivity towards external stimuli[1]. The calculated detonation velocity of TKX-50 (D = 9.69 km/s) is found to be higher than some of the traditional explosives such as CL-20 (D = 9.45 km/s), b-HMX (D = 9.22 km/s) and RDX (D = 8.98 km/s). Its impact and friction sensitivities (IS = 20 J, FS = 120 N) are lower than that of CL-20, b-HMX and RDX [1]. The promising features of TKX-50 allowed the scientific community to study the underlying mechanisms governing the properties in this crystal. In the present work, the first principles calculations were performed via the Vienna ab-initio simulation package (VASP)[2] using projector augmented wave (PAW) method. To account the long-range dispersion interactions, we used DFT-D2 method developed by Grimme. The Tran-Blaha modified Becke-Johnson (TB-mBJ) method is employed to predict the accurate band gap values. Hirshfeld surface calculations were performed using CrystalExplorer 3.1 for analyzing the intermolecular interactions in a molecular crystal.

The influence of external pressure on the electronic properties can affect the structure and properties of energetic materials. The TB-mBJ band structure along high symmetry directions is as follows: Z (0.0, 0.0, 0.5) ? ? (0.0, 0.0, 0.0) ? Y (0.0, 0.5, 0.0) ? A (-0.5, 0.5, 0.0) ? B (-0.5, 0.0, 0.0) ? D (-0.5, 0.0, 0.5) ? E (-0.5, 0.5, 0.5) ? C (0.0, 0.5, 0.5). The obtained band structure indicates that TKX-50 is an indirect band gap insulator along C-B direction with a band gap of 4.018 eV and is found to decrease monotonically with increasing pressure. The tendency of band gap lowering as a function of pressure is consistent with the widely used energetic materials such as RDX [3] and TATB [4]. At a pressure of 20 GPa, the band gap is decreased by 0.21 eV. This pressure induced reduction in the magnitude of band gap is lower than that of HMX and nitromethane [5]. From partial density of states, the top of the valence band is mainly due to 2p states of oxygen (O1) and nitrogen (N1, N3) atoms. It can be expected that the former makes more significant contributions to the valence bands than the latter. This shows that O1 atoms act as active centers and chemical reactions are more possible to happen. While the conduction band minimum is dominated by p states of C, N1, N2 and N4 atoms and very less contribution arises from p states of O1 atoms. As pressure increases, the bands of TKX- 50 tend to shift towards lower energy region.

Hirshfeld surface analysis is a novel approach for exploring the nature of intermolecular interactions with in the crystal. The corresponding 2D fingerprint plots highlights both the close contacts between particular atom types and also the area where the contacts are week. The structure of TKX-50 has strong hydrogen bonding interactions and the strength of these bonds can be mapped onto the Hirshfeld surface using normalized contact distance (dnorm), which is visualized in red-white-blue color scheme. The interaction between O-H part of cation and oxygen atoms of anion are shown as dark red spots in the dnorm surfaces, indicating O-H…O as a strong hydrogen bonding in TKX-50. The largest percentage of TKX-50 molecule is due to N…H/H…N and O…H/H…O contacts (~70%), which is in accord with the aforementioned hydrogen bonding networks as the primary intermolecular interactions and also responsible for the low sensitivity of TKX-50. As pressure increases, the structure of fingerprint has been compressed and drawn towards the origin due to shortening of longer intermolecular contacts, which is related to the decrease of de (the distance from the point to the nearest atom outside to the surface) value at elevated pressures (0 GPa = 1.52 Å; 30 GPa = 1.28 Å). Further, the orange and red points in the fingerprint plots of 30 GPa indicate the closest contacts in this crystal structure. By closely examining the molecular geometry of TKX-50, the average distance between intermolecular H…A contacts at 0 GPa (2.06 Å) and 30 GPa (1.97 Å) is found to be less than the sum of the van der Waals radii of H and N/O (~2.7), which represents the strengthening of hydrogen bond due to shortening of intermolecular H…A contact distance under pressure. These attractive features of TKX-50 highlights the importance of hydrogen bonded interaction in the design of advanced energetic materials.

References:

1. N. Fisher et. al., J. Mater. Chem., 2012, 22, 20418.

2. G. Kresse and J. Furthmuller, Phys. Rev. B, 1996, 54, 11169.

3. Q. Wu et al., Can. J. Chem., 2013, 91, 968.

4. Q. Wu et al., RSC Adv., 2014, 4, 53149.

5. W. Zhu et al., Theor Chem Acc., 2009, 124, 179.