

Insensitive Munitions – Design Principles and Technology Developments

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Abstract: The concept of Insensitive Munitions was developed more than 40 years ago. The challenge for the munition designer was to produce munitions that gave the required performance but did not respond violently when subject to accidents or enemy action. Given that munitions contain metastable energetic materials which are by design able to release large quantities of energy in very short time-

frames, coupled with the other constraints of reliability, service life, environmental impact, ease of disposal and cost it is easy to understand that this was and to some extent still is a major challenge. This paper provides a brief summary of the key technologies developed over the last 40 years and provides a set of design principles to facilitate the IM design process.

Keywords: Insensitive Munitions · Explosive ordnance · Munitions · Design · Safety

1 Introduction

Insensitive Munitions are defined as munitions which reliably fulfil their performance, readiness and operational requirements on demand and which minimize the probability of inadvertent initiation and severity of subsequent collateral damage to weapon platforms, logistic systems and personnel when subjected to selected accidental and combat threats [1].

The development of Insensitive Munitions can be traced back to the early 1970s [2]. The initial drive was to mitigate the response to thermal threats such as fuel fires. As the concept progressed, impact and blast threats were also included.

The challenges in developing munition designs that are compliant or near compliant with the NATO requirements, whilst also meeting the other key requirements such as performance, cost etc. have been significant. Overcoming these challenges has largely been a question of developing new technology, such as new energetic molecules, new explosives, and new materials.

This paper aims to provide an overview of the IM design principles as well as the key developments in IM design technology over the last 30 years.

2 IM Design

From an IM design perspective, munitions can be considered as consisting of three key elements, the energetic material, the casing or architecture, and the packaging (if present). Whilst the response of the munitions to the various IM threats (e.g. bullet impact, fast heating) will to a greater extent depend upon the energetic material, the architecture, and packaging can also have a significant effect.

2.1 Energetic Materials

In a vast majority of cases, energetic material formulations used in munitions are compositions rather than single compounds. However the contribution of the explosive component plays a key part in the response of the energetic material formulation.

2.1.1 Explosive Molecules

The sensitivity to accidental stimuli and response of an explosive formulation depends upon the chemical composition and structure as well as its physical characteristics (e.g. morphology).

Selection of explosives that have inherently lower sensitivity to shock and/or thermal decomposition will reduce the vulnerability of the resulting formulation. Although there has been a significant amount of effort directed towards developing predictive models for the sensitivity of energetic materials, there is much reliance on semi-empirical and empirical models in the down selection process for potential candidate replacements. Examples of technology advancements in this area, together with references to relevant examples are shown in Table 1.

As noted previously the physical characteristics can also affect the sensitivity to accidental stimuli. Reducing particle size has been shown to significantly reduce the shock sensitivity [3]. The manufacturing process can also have an

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Table 1. Energetic material technologies.

Technology type	Example technologies
Replacement energetic material	2,4-Dinitroanisole (DNAN) 3-Nitro-1,2,4-triazol-5-one (NTO) [6] 1,3,5-Triamino-2,4,6-trinitrobenzene (TATB) [7] 1,1-Diamino-2,2-dinitroethene (DADNE) N-Aminocarbonyl-guaninidium dinitramide (GUDN) [8] Diethylene glycol dinitrate (DEGDN) Phase Stabilized Ammonium Nitrate (PSAN) 2,6-Diamino-3,5-dinitropyrazine-1-oxide (ANZPO) RS-RDX
Physical modification	Micronized RDX/HMX/NTD

Table 2. Explosive formulation technologies.

Technology type	Example technologies
Rubbery binders	Plasticized HTPB, HTPE [10], Polyacrylate elastomers
Energy partitioning	Partial replacement of ammonium perchlorate with BTTN/PSAN [7]

effect on the shock sensitivity; this has been observed most notably with Reduced Sensitivity RDX [4]. The phenomenon of RS-RDX has yet to be fully understood, recent efforts coordinated by the NATO Munition Safety Information Analysis Centre (MSIAC) were unable to establish a mechanism for the reduced sensitivity [5].

2.1.2 Explosive Formulations

As noted above, the energetic material formulation consists of energetic compounds held together with binder materials. In some cases there will be other ingredients to enhance the performance (e.g. aluminium, ballistic modifiers) or provide adequate service life (e.g. stabilizers, antioxidants). The nature of these ingredients, in particular the binder, can significantly affect the response of the formulation. Binders that can reduce the propensity of the energetic material to shatter, thereby reducing the available burning surface, will reduce the resulting IM response. Binders

that retain sufficient integrity under thermal threats can prevent the explosive molecules from clumping together and increasing the likelihood of an adverse response. Binder systems based on hydroxyl terminated polybutadiene (HTPB) have excellent mechanical properties over the typical service temperature ranges and consequently have seen widespread use across a range of systems including general purpose (GP) bombs, penetrator bombs, air launched missile warheads, rocket motors, and torpedoes.

In some cases direct replacement can incur a loss in performance in the final formulation; however this can usually be compensated for by reducing the inert fraction by either adjusting the ratio of ingredients or by partial replacement of inert components with more energetic ones.

In recent years, the US has developed formulations based on DNAN and NTO to replace TNT and Composition B (RDX/TNT) for gun launched applications. DNAN melts at a similar temperature as TNT, so these formulations can be processed using the same manufacturing plant. The resulting munitions achieved near full IM compliance [9].

Examples of technology advancements in this area are shown in Table 2.

2.2 Munition Architecture

From an IM perspective, the munition architecture covers the casing of the energetic material and the charge design.

2.2.1 Casing

Casing, by definition, will provide a degree of confinement. Should the energetic material ignite as a result of a particular threat/stimulus, confinement can prevent combustion gases from escaping quickly enough thereby resulting in a build-up of pressure. This build up pressure could result

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Table 3. Case venting technologies.

Technology type		Example technologies
Passive	Fusible/combustible parts	Meltable plugs Meltable fuze adaptors Meltable covers/panels Bonded casing (composite cases, steel strip laminate cases) Combustible cases
	Weakened parts	Stress risers Shear pins
Active	Case cutters	Thermally initiated venting systems
	Controlled ignition ^{a)}	Subsystems containing energetics with a lower temperature of ignition than the main charge.

a) This can be combined with passive venting technology.

in a thermal runaway reaction leading to a violent deflagration or even a detonation. A key technique to mitigate this is to provide appropriately sized vent paths for the combustion gases. These need to be designed such that they do not reduce performance or affect the integrity of any environmental sealing. Vent paths can be either passive or active. Passive venting involves fusible parts or parts that give way under pressure, whilst active venting uses energetic materials to create vent paths. The key technologies are summarized in Table 3.

Many of these technologies have transitioned into in-service munitions, for example the use of meltable parts in the 155mm M795-IM Artillery Shell, Paveway IV GP Bomb, BLU-111C/B GP Bomb, 120 mm IM HE-T, and Stormshadow missile and bonded cases in Aster 30, Brimstone DMB, and VT-1 missiles.

2.2.2 Charge Design

In addition to the contribution of any casing, the charge design can have an effect on the munition response. For example, charges that are below the critical diameter will not detonate when subjected to high shocks. This technology has the potential to be incorporated into rocket propellants for some applications.

2.3 Packaging

The final element of IM design is packaging. When exposed to a particular IM threat, packaging can affect the response in several different ways; by confinement (in a similar way to munition casing); by the spatial distribution of several munitions in one container or by affecting the energy input in the munition.

2.3.1 Confinement

As for casing, mitigation of confinement can be achieved by providing suitable vent paths. Similar technologies have

been developed for packaging, e.g. meltable venting panels in the 155 mm MACS and 120 mm tank ammunition [11,12].

2.3.2 Spatial Distribution

The relative location of munitions within a packaging container can have a dramatic effect on the IM response. For example adjacent warheads could propagate sympathetically or energetic components could initiate a violent response in other nearby subsystems. Technologies developed to mitigate these effects include displacing the warheads to avoid the diagonal propagation effect [13,14], displacing the rocket motor away from the explosive charges [15] and orienting the munitions in a nose to tail arrangement within the container.

2.3.3 Energy Input

Reducing the energy input into the packaged munition can reduce the response to IM threats. There are three types of energy input that need to be considered, mechanical, shock, and thermal. Reducing mechanical energy input requires the use of barrier materials that either directly intercept and retard the impactor or deflect the impactor away from the munitions. These have been used in such applications as Bangalore Torpedo [16], AGM-158 JASSM [17], AGM-114 Hellfire [18], and Apache [19].

Reducing shock energy can be achieved by using porous barriers or laminates. The latter dissipates the shock via a complex process involving a combination of void space collapse, particulate frictional resistance, shockwave scattering, choked flow, and interaction within the particulate turbulent flow fields. Laminates can reduce the transmitted shock through impedance mismatching of the laminated layers. These technologies have been used in such applications as AGM-84 SLAM-ER, AGM-154 JSOW [20].

Reducing thermal energy inputs can be achieved by using thermal barriers to reduce the heat flow. Technolo-

Review

I. J. Powell

gies such as aramid/ceramic fiber impregnated blankets have been developed for such applications [21]. The use of ceramics can also provide a degree of resistance to bullet/fragment impact.

2.4 IM Design Principles

The development of technologies to reduce the vulnerability of munitions systems to meet the goal of full IM compliance has focused on three key areas; energetics, munition architecture, and packaging.

IM compliance of any munition includes compliance with the sympathetic reaction requirements. IM compliance is therefore a systems attribute, where the individual munition is a single part. In deriving a set of design principles for IM compliance, it is convenient to consider the realization of an IM threat (or event sequence) in four phases:

- (i) The IM threat.
- (ii) The energetic material response.
- (iii) The subsystem response.
- (iv) The final system response.

The IM threat can be any of the six defined in STANAG 4439 (fast/slow heating, bullet/fragment impact, sympathetic reaction and shaped charge jet impact).

The energetic material response is the direct response to the IM threat, i.e. burning, detonation etc.

The subsystem response is the response of a munition subsystem or an individual munition. This includes any outputs such as heat, shock, fragments etc.

The system response is the response of the overall system, which includes packaged/stacked munitions, i.e. the final IM signature.

The first three of these phases can be used to generate a set of design principles for IM, which are centered around, reducing the follow-on effects as the event sequence progresses. The fourth phase represents the final IM signature, which is a product of the responses in the preceding phases. The three principles can be expressed as follows:

- (1) Reduce the IM threat.
- (2) Reduce the energetic material response.
- (3) Reduce the subsystem response.

A summary of these principles and the key approaches used is shown in Table 4.

3 Future Direction

IM compliance is now a key element in the design of new munitions. In many cases there are existing solutions that can be adapted; however there are still significant gaps in technology for some type threats and munition types. In

Table 4. IM design principles and approaches.

IM design principles	Key approaches
Reduce the IM threat	Barrier materials in the casing and/or packaging
Reduce the energetic material response	Reduced vulnerability energetic compounds or formulations
Reduce the subsystem response	Venting Charge design Spatial distribution Barrier materials in the packaging

particular high performance and reduced smoke rocket motors and large caliber gun propellants are only able to achieve a moderate degree of IM compliance [22]. The continuing development of novel energetic molecules has the potential to improve IM compliance in these areas.

4 Conclusions

Since the initial development of the IM concept some 40 years ago, there has been significant progress in the development of technologies to reduce the response of munitions when exposed to unplanned stimuli. Whilst the ultimate goal of full IM compliance has only been achieved for a handful of munitions systems, the incorporation of these technologies in fielded munitions has provided a safer environment for those handling and storing such munitions.

Designing munitions for IM compliance is best achieved by adopting a systems approach. The set of three design principles highlighted in this paper provide overarching guidance to facilitate the goal of IM compliance.

References

- [1] NATO STANAG 4439, *Policy for Introduction and Assessment of Insensitive Munitions*, Edition 3, **2010**.
- [2] R. Beauregard, *History of the US Navy Insensitive Munitions Program*, July **2004**, <http://www.insensitivemunitions.org/>.
- [3] H. Moulard, J. Kury, A. Delclos, The Effect of RDX Particle Size on the Shock Sensitivity of Cast PBX Formulations, *8th Detonation Symposium*, Albuquerque, NM, USA, July 15–19, **1985**, p. 903–913.
- [4] A. Freche, J. Aviles, L. Donnio, C. Spyckerelle, Insensitive RDX (I-RDX), *Insensitive Munitions and Energetic Materials Technology Symposium*, San Antonio, TX, USA, November 27–30, **2000**.
- [5] R. Doherty, D. Watt, Relationship Between RDX Properties and Sensitivity, *Propellants Explos. Pyrotech.* **2008**, 33, 4–13.
- [6] R. Mesil, R. Aumasson, Field Artillery Ammunition 155 mm HE LU-211-IM With Significant IM/MURAT Performance, *7th Parari Australian Explosives Ordnance Symposium*, Melbourne, Australia, **2005**.
- [7] C. Songy, G. Eck, P. Chabin, D. Struye, I. Lebrun, Qualification of a New IM Composition and First Evaluation in 90 mm HESH-T Ammunition, *Insensitive Munitions and Energetic Materials Technology Symposium*, Rome, Italy, May 18–21, **2015**.

- [8] J. Dahlberg, B. Gustafsson, GUDN Propellants and the UNIFLEX 2 IM Modular Charge System, *Insensitive Munitions and Energetic Materials Technology Symposium*, Miami, FL, USA, October 15–17, **2007**.
- [9] K. Lee, W. Balas-Hummers, R. DiStasio, C. Patel, P. Samuels, Qualification Testing of the Insensitive TNT Replacement Explosive IMX-101, M795, *Insensitive Munitions and Energetic Materials Technology Symposium*, Munich, Germany, October 11–14, **2010**.
- [10] I. Powell, D. Watt, A Review of the Use of HTPE in Rocket Motor Propellants, *7th Parari Australian Explosives Ordnance Symposium*, Melbourne, Australia, **2005**.
- [11] B. Ingold, Insensitive Munitions Analysis for 120 mm Tank Ammunition, *Insensitive Munitions and Energetic Materials Technology Symposium*, San Antonio, TX, USA, November 27–30, **2000**.
- [12] P. Lu, D. Armour, J. Rutkowski, P. Hui, Consideration of Insensitive Munitions Requirements in Modular Artillery Charge System (MACS) Development, *Insensitive Munitions and Energetic Materials Technology Symposium*, Tampa, FL, USA, November 29–30, **1999**.
- [13] C. Annereau, S. Lecume, Analytical Model for Predicting Sympathetic Detonation, *Insensitive Munitions and Energetic Materials Technology Symposium*, San Diego, CA, USA, November 16–19, **1998**.
- [14] P. Blanc, B. Mahe, B. Nouguez, P. Salle, CBEMS 250: A Fully IM Multipurpose Bomb, *Insensitive Munitions and Energetic Materials Technology Symposium*, Orlando, FL, USA, March 10–13, **2003**.
- [15] T. Wright, R. Miller, J. O'Driscoll, M. Pellon, B. Walsh, Anti-Personnel Obstacle Breaching System – An IM Compliant System, *Insensitive Munitions and Energetic Materials Technology Symposium*, Bordeaux, France, October 8–11, **2001**.
- [16] C. Young, Bangalore Torpedo Development, *Insensitive Munitions and Energetic Materials Technology Symposium*, Munich, Germany, October 11–14, **2010**.
- [17] S. Lobdell, Insensitive Munitions Support for Joint Air-to-Surface Standoff Missile, *Insensitive Munitions and Energetic Materials Technology Symposium*, San Diego, CA, USA, November 16–19, **1998**.
- [18] E. Farrell, IM Packaging Technology to Address Sympathetic Detonation and Fast Cookoff, *Insensitive Munitions Technology Symposium*, San Diego, CA, USA, March 18–21, **1996**.
- [19] P. Chabin, S. Lecume, P. Sallé, Sympathetic Detonation Test on Apache AP Missile, *Insensitive Munitions & Energetic Materials Technology Symposium*, Bordeaux, France, October 8–11, **2001**.
- [20] L. Kandell, E. Cykowski, Pumice Technology – Pumice as a Sympathetic Detonation Barrier, *44th Annual Fuze Conference*, April 11–14, **2000**.
- [21] T. Mulkern, G. Gibbons, A. Canami, Development of a Flame and Fragment Resistant Blanket to Protect Stored Munitions, *29th DoD Explosives Safety Seminar*, July 18–20, **2000**.
- [22] M. Becker, IM State of the Art, *Insensitive Munitions and Energetic Materials Technology Symposium*, San Diego, CA, USA, **2013**.

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