



Insensitive Munitions Technology Development

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Abstract. The concept of Insensitive Munitions, or IM, is not new; the U.S. Department of Defense (DoD) has been working to improve the safety of munitions since their inception. The first NATO standard on IM, STANAG 4439: Policy for Introduction and Assessment of IM, was published for ratification in 1995 and was ratified in 1998. U.S. Congress passed the „Insensitive Munitions law” in 2001 that specifically requires „The Secretary of Defense [to] ensure, to the extent practicable, that insensitive munitions under deployment or procurement are safe throughout development and fielding when subject to unplanned stimuli”. These unplanned stimuli take the form of rapid or slow heating events, such as a fuel fire on a vehicle or aircraft, or an adjacent fire in a vehicle or storage magazine; impact by fragment or bullets due to shrapnel from nearby explosions or small arms fire from combat or terrorist events; sympathetic reaction due to the detonation of adjacent munitions; and shaped charge jet attack from rocket-propelled grenade or similar weapons used by enemy and friendly forces. In 2007, U.S. DoD focused its efforts on developing joint solutions through a centrally managed IM technology program: the Joint IM Technology Program (JIMTP). There have been numerous JIMTP IM technology development successes and transitions to munition systems. The U.S. DoD will continue to develop new munitions to meet increased performance requirements to respond to various threats and enable lethality overmatch in any scenario.

Using today's available technology to obtain higher performance typically translates to a worse IM response. As a result, the U.S. DoD will continue to develop IM technology in order to assure safety and reduced vulnerability while improving munitions performance.

Keywords: Insensitive Munitions, Explosives, Safety

1. INTRODUCTION

Late in the afternoon on July 10, 1926, lightning struck a tree overhanging a magazine that housed TNT, starting a series of explosions at the U.S. Naval Powder Depot at Picatinny Arsenal. 670,000 pounds of explosives detonated in Storehouse No. 8 and the largest explosion came from Storehouse No. 9, which held 1.6 million pounds of explosives. Everything within 3 000 feet of the site was demolished. Shock waves followed the explosion, uprooting trees, blowing out windows and twisting cars into heaps of metal (Fig. 1). Over an approximate three-day period, several million pounds of explosives were detonated, 19 people were killed and 38 injured. The damage was estimated at more than \$1.25 million. Congress approved the arsenal's rebuilding, spending nearly \$3 million on rehabilitation in the mid-1930s and another \$15 million by 1945. After the full-scale Congressional investigation, The Department of Defense Explosives Safety Board (DDESB), formerly called the Armed Forces Explosives Safety Board, was established in 1928 by the Seventieth Congress.



Fig. 1. Aftermath (left) and craters produced by the 1926 explosion at Picatinny Arsenal, N.J.

Late in the morning on June 29, 1967, the USS Forrester, the U.S. Navy's first „supercarrier”, was positioned off of Vietnam preparing to conduct bombing runs, when a Zuni rocket was accidentally launched from one aircraft, shooting right through the fuel tank of another aircraft. It did not explode, but it did set off a large fuel fire (Fig. 2).

The heat of the fire exploded a bomb on the flight deck approximately ninety seconds after the fire began, and a second bomb exploded a few seconds later. These explosions severely damaged the carrier and killed several sailors on the flight deck. The fuel tanks of several other planes ruptured, adding to the intensity of the blaze. The exploding bombs created several holes in the flight deck, allowing fire and smoke to spread into the interior of the ship. Forrestal's crew feverishly battled and eventually extinguished the fire. It took over twenty-four hours to extinguish the fires that spread below the flight deck. The losses caused by this incident were high. One hundred thirty-four sailors were killed by the fire, and 161 more were injured. Over twenty aircraft were lost. The damage forced Forrestal to suspend combat operations and conduct temporary repairs in the Philippines before returning to the US for permanent repair. Repairs to the ship cost approximately \$72 million, and took approximately two years to complete.



Fig. 2. Fires and explosions on the USS Forrestal

On the morning of July 11, 1991, a defective heater in a M992 ammunition carrier loaded with 155 mm artillery shells caught on fire at Camp Doha near Kuwait City. Unit members tried unsuccessfully to extinguish the fire before being ordered to evacuate. This evacuation was underway when the burning M992 exploded, scattering artillery submunitions (bomblets) over nearby combat-loaded vehicles and ammunition stocks. This set off an hours-long series of blasts and fires that devastated vehicles and equipment and scattered unexploded ordnance (UXOs) and debris over much of the remainder of the camp (Fig. 3). The fires died down enough by mid-afternoon to allow a preliminary damage assessment. There were no fatalities; however, 49 US soldiers were injured, two seriously. The post-blast destruction was overwhelming. One hundred and two vehicles were damaged or destroyed, including four M1A1 tanks and numerous other combat vehicles. More than two dozen buildings sustained damage as well. An estimated \$14 million in munitions had been damaged or destroyed.



Fig. 3. Camp Doha explosions and aftermath

These are some of the most dramatic examples of what can happen when weapons systems with „sensitive” munitions exposed to threat caused by external stimuli. There are scores of other examples in US History, such as the Port Chicago in 1944, S.S. Grandcamp in 1947, Camp Doha, Kuwait in 1991, and many others. So has the US DoD learned from history? Yes, so that we are not doomed to repeat it.

These incidents have caused a major shift in military thinking on how the US DoD should be prepared for these types of events, including changing fire protection systems and procedures, how it handles and stores munitions, and how weapon systems are designed and built. All four services have made incremental improvements to de-sensitize munitions to prevent unintended initiation. The Joint Insensitive Munitions Technology Program (JIMTP) seeks to build on these improvements for increased protection of the warfighter and further sustainment of the mission.

2. INSENSITIVE MUNITIONS REQUIRED BY US LAW

On December 12, 2001, the US Congress recognized the need for Insensitive Munitions and codified it into law, requiring that „The Secretary of Defense shall ensure, to the extent practicable, that munitions under development or procurement are safe throughout development and fielding when subjected to unplanned stimuli” [2]. This gave the Office of the Secretary of Defense (OSD) the impetus to institutionalize an Insensitive Munitions program that the Department of Defense (DoD) had been working on since the Forrestal incident. OSD created a dynamic, highly coordinated Insensitive Munitions Program through a series of directives and policy memorandums that is administered at the highest levels of the Department. As part of this, „(...) The Services (were required to) support and fund the ...Insensitive Munitions Science and Technology enhancement” [3], „The OSD required acquisition officials to assess all of their weapons systems according to test standards standardized by the Joint Requirement Oversight Council (JROC)” [4], and document these assessments in an Insensitive Munitions Plan of Action and

Milestones (POA&Ms) for all munitions and Insensitive Munitions technology development efforts. In other words, the OSD put a high priority on developing safe, insensitive munitions early in their lifecycle, and funded the JIMTP to create new technologies that enable weapon systems to meet these goals.

3. JOINT INSENSITIVE MUNITIONS TECHNOLOGY PROGRAM

Since its inception in 2007, 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 partnership has been extremely fruitful in the pooling of knowledge from U.S. scientists and engineers. As an example, the primary candidate explosive fill for the insensitive 500-pound general purpose bomb was developed under JIMTP leadership. The fill was developed at an Army laboratory, specifically ARDEC, tested at a Navy facility, the Naval Surface Warfare Center, and supplied by industry, BAE-managed Holston Army Ammunition Plant, with project management by Air Force personnel at Eglin Air Force Base. IM technology development can include changes in the packaging, non-energetic parts, the energetic fills within the munitions, and other novel approaches. The JIMTP provides Insensitive Munitions technologies with an end goal of being transitioned to the Army, Navy, Marine Corps and Air Force munition systems. The JIMTP invests mostly 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. In the DoD munitions portfolio there were 772 non-compliant munitions identified for procurement in FY2011/2012. 141 of these munitions were identified as a priority by the PEOs. Of these, approximately 124 have components that are targeted for improvement by the JIMTP.

Complex problems are best solved by breaking them down into smaller pieces. In JIMTP, this is accomplished by dividing the program into five Munitions Area Technology Groups (MATGs):

- MATG I – High Performance Rocket Propulsion
- MATG II – Minimum Signature Rocket Propulsion
- MATG III – Blast-Fragmenting Warheads
- MATG IV – Anti-Armor Warheads
- MATG V – Large Caliber Gun Propulsion.

These five groupings are the highest priorities for developing Insensitive Munition-compliant weapon systems. The MATGs are formal groups that have one chairperson and two to three co-chairpersons that include representatives from all the major service laboratories. MATGs are tasked with:

- 1) coordinating, establishing, and maintaining five-year technology development plans and roadmaps,
- 2) coordinating biannual meetings to review technical and programmatic details of each funded and proposed efforts,
- 3) developing and submitting Technology Transition Agreements in coordination with appropriate PEOs for insertion in their Insensitive Munitions Strategic Plans, and
- 4) interfacing with other MATGs and Insensitive Munitions science and technology projects as appropriate.

The JIMTP Technical Advisory Committee (TAC) (consisting of senior DoD and DoE laboratory representatives and senior Munitions PEO representatives) provides oversight, policy, direction and priorities of the JIMTP during its annual meeting. Over the last 5 years, each of the MATGs has worked with the acquisition community to develop roadmaps for insertion of technology into weapon systems. These roadmaps take into account 5, 10, and 15 year goals that focus the program on incremental and substantial improvements to reactions to potential threats. As one would expect, the short-term goals focus on easier to accomplish tasks, where the longer-term goals require substantial investment in new and novel technologies.

4. THREATS, TESTS AND REACTIONS

Insensitive Munitions are defined as munitions that reliably fulfill their performance, readiness and operational requirements on demand, and that minimize the probability of inadvertent initiation and severity of subsequent collateral damage to weapon platforms, logistic systems and personnel when subjected to unplanned stimuli.

Munitions are considered insensitive munition compliant when they have met the passing criteria for each of the threats as defined by the JROC. Munitions need to be tested according to the Joint Insensitive Munitions Test Standards [7], and the reaction of the munition during the test needs to be evaluated by service-specific Insensitive Munitions boards. Figure 4 summarizes each of these.

In the case of the USS Forrester, most of the initial damage was caused by bombs „cooking-off” from the burning fuel that was spilled on the deck. Cook-off is caused by raising some portion of the energetic fill – either the fuze, booster or the main explosive fill – to exceed its decomposition temperature. If the fuze is in place, the higher temperature will build up pressure within the bomb, causing a more violent reaction.

In order to make bombs safer, several improvements can be made, including using a fill with a higher decomposition temperature, insulating the bomb, and allowing the bomb to vent excess pressure. Technologies for insulating the bomb have been in place for decades. This is usually accomplished with an intumescent coating that has char that expands when exposed to fire. The expanded char can provide several minutes of additional time before the bomb cooks-off. Bomb venting can be accomplished at the fuze end of the bomb by adding a thread liner sleeve that melts below the decomposition temperature. After it melts, the pressure from inside of the bomb expands and pushes the fuze out. This, in combination with new explosive fills, can result in a bomb simply burning like fuel, rather than detonating in a fire.

Other threats, such as impacts from bullets and fragments or sympathetic detonation can be handled through internal liners or external packaging that protects the bomb right up to the point of loading it on an aircraft. Shaped jet charge is by far the most difficult threat to defeat because of the high temperatures and velocity of the shaped jet.

Threats	FUEL FIRE Such as a truck or an aircraft on a flight deck	NEARBY HEAT Such as fire in adjacent magazine, store or vehicle.	BULLETS Such as small arms from terrorists or combat	FRAGMENTS Such as from bombs, artillery, or IEDs	SYMPATHETIC REACTION Such as detonation of adjacent stores	SHAPED CHARGE JET RPG, Bomblets, ATGMs: Combat or terrorists
						
Tests	Fast Cook-off FCO	Slow Cook-off SCO	Bullet Impact BI	Fragment Impact FI	Sympathetic Detonation SD	Shaped Charge Jet SCJ
						
Reactions	Detonation/ Partial Detonation	Explosion	Deflagration/ Propulsion	Burn	No Sustained Reaction	
	Type III	Type III	Type IV	Type V	Type VI	
						

Fig. 4. Summary of IM threats, tests and responses

5. IMX-101 REPLACES TNT IN THE M795

The JIMTP provided support to Product Manager (PM) Combat Ammunition Systems (CAS) to develop the M795 155 mm projectile (Fig. 5). This is the first munition that has passing reactions to all Insensitive Munitions tests, including the Shaped Jet Charge. The main contributor to this improvement is the change of the energetic fill from Trinitrotoluene (TNT) to Insensitive Munitions Explosive 101 (IMX-101). This is the first JIMTP technology to be fielded – several thousand of the projectiles are scheduled to be deployed over the next few years, eventually completely replacing the existing system. Both the Army and Marine Corps will benefit from the new IMX-101 formula, slated to replace traditional TNT in large-caliber projectiles like the 155 mm high-explosive.

One example of this is the reaction of the M795 to the slow cook-off test. During a slow cook-off test, the IMX-101 loaded projectile is exposed to high temperatures over an extended period. Instead of blowing up like the traditional explosive fill (TNT), the IMX-101 simply melted and expanded out of the top of the munition as seen in Figure 6.

The improved M795 is scheduled for delivery to deployed Army and Marine Corps units. Numerous tests have proven that IMX-101 is a safer alternative to TNT in the Army and Marine Corps' existing large-caliber projectiles, especially during transportation, storage and loading. While the material cost for IMX-101 is higher than TNT, the price will fall as the Army produces more quantities in coming years. However, the real cost savings will come with the improved logistics of the new explosive, which will cost a significant amount less than the Army currently pays to transport and store TNT [9].



Fig. 5. Army Soldiers and Marines will use the new IMX-101 filled M795



Fig. 6. Slow cook-off result of an IMX-101 filled M795

6. SUCCESS: LIVES SAVED

Afghanistan, September 12th, 2009. A Mine Resistant Ambush Protected (MRAP) Vehicle with a patrol from the Army's 10th Mountain Division was hit by a very powerful Improvised Explosive Device (IED). The IED ruptured the vehicle's hull and fuel tank, which engulfed the vehicle interior in flames-to include sixteen M768 60 mm mortar cartridges that were carried inside the cabin with the seven-man crew. Although several soldiers were seriously injured in the ambush, all survived. The survival of the crew has been credited to the Insensitive Munitions features of the M768 cartridges.

The M768 incorporates several Insensitive Munitions features, including new energetic materials in the fuze and shell body. It also contains a plastic fuze adaptor that melts in an accidental fire, allowing the fuze to separate from the cartridge. This relieves internal pressure and prevents detonation of the explosive fill. After the MRAP had stopped burning, the wreckage was examined and all of the mortar shell bodies were intact, proving that none of them had gone "high order" in the fire (Fig. 7). Also lying in the wreckage were the remains of the fuzes that had separated from the cartridges as designed. Separation of the fuze allowed the Picatinny Arsenal Explosive 21 (PAX-21) explosive fill to burn rather than explode.

The M768 cartridge, Full Materiel Released in 2006, is one of the early success stories in a larger Insensitive Munitions Strategic Plan that PEO Ammo is implementing to develop and produce safer ammunition throughout its portfolio. The PEO's Project Managers have instituted POA&Ms for improving Insensitive Munitions characteristics for their assigned munitions through improvements in packaging, explosive fills, propellants, and fuzes for all calibers, up to and including 155 mm.

Although the M768 was not a JIMTP program, it is a great example of how Insensitive Munitions improvements can save lives. The JIMTP and PM CAS are teaming again to improve the M768 even more to protect the munition (and the warfighter) against other threats. This will be done by changing the fill from the first-generation insensitive explosive, PAX-21, to an even less sensitive composition, IMX-104.



Fig. 7. Interior view of the MRAP vehicle after the fire (left) and unexploded shell bodies from M768 cartridges (right)

7. ROCKET AND MISSILE WARHEADS

JIMTP is also working to improve the IM properties of the TOW 2B and Tomahawk Missiles in the project „Anti-Armor Warhead IM Technology Integrated Demonstration and Transition”, led by Nausheen Al-Shehab, from ARDEC, Energetics, Warheads, and Manufacturing Technology Directorate at Picatinny Arsenal, N.J. This effort focuses on improving the warhead response to impact, sympathetic reaction, and cook-off threats.

The team is composed of scientists and engineers from ARDEC, Naval Air Warfare Center at China Lake, AMRDEC, Naval Postgraduate School, Program Manager Air-280, PM CCWS, and industry partners (General Dynamics-Ordnance and Tactical Systems, Dynetics and CGI Federal) that have worked to integrate, demonstrate, and eventually transition multiple IM technologies into new anti-armor warhead designs that increase operational survivability of the munition.

For the TOW 2B warhead, the primary areas of focus are cook-off (both fast and slow) and impact (both bullet and fragment) through multiple shotlines; while sympathetic detonation and fragment impact are the primary and secondary focus areas for the Tomahawk warhead. JIMTP is developing a TOW 2B warhead that utilizes proven venting technology and a particle impact mitigation sleeve to improve the IM response while still meeting the performance requirements.

PIMS aids in reducing the shock transmitted to the explosive by distributing the shockwave over a larger area and reduces the shock as it passes through the material. JIMTP has successfully demonstrated the TOW 2B warhead to pass the initial fragment impact tests at high and low velocities using a composite PIMS (Fig. 8). JIMTP has also shown that venting technology successfully mitigates the fast cook-off threat. Integrating these technologies is not simple. It requires significant design, analysis, and test and evaluation, to ensure an improvement in one IM aspect does not negatively impact the performance or reaction in another IM threat aspect. Modeling and simulation was used extensively to evaluate the various PIMS designs, by determining the pressure reduction within the explosive as a result of using the PIMS increased shock protection. This design tool has enabled the review and revision of the PIMS liner thickness and optimization prior to testing. Modeling and simulation was also used to predict the result of the Tomahawk warhead responses to a sympathetic reaction threat. The modeling results lead to the selection of a new PIMS technology and insensitive main fill explosive to be pursued to reduce the response to a sympathetic detonation.

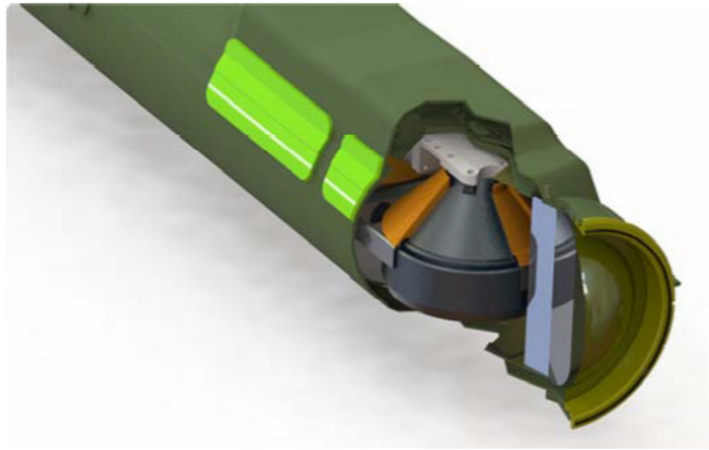


Fig. 8. TOW 2B IM prototype munition with incorporated PIMS

8. INSENSITIVE MINIMUM SMOKE MISSILE PROPELLANTS

Another example of JIMTP work is being conducted at the U.S. Army Aviation and Missile Research, Development and Engineering Center at Redstone Arsenal, Ala. Rob Esslinger, from the Weapons Development and Integration Directorate there, leads the Tactical Minimum Smoke Phase I IM Demonstration project. Esslinger is aiming to develop and demonstrate rocket motors for air-to-ground missile systems that are less sensitive to fragment impact and slow cook-off threats.

Throughout the last six years, Esslinger's team from AMRDEC, Redstone Arsenal Test Center, and the Naval Air Warfare Center at China Lake have joined with industry partners ATK and Aerojet-Rocketdyne and the Joint Attack Munition System Program Management offices to research various rocket motor configurations, seeking to improve the threat responses. Using several venting technologies and rocket motor formulations in composite and metal rocket motor cases, the team has successfully demonstrated that various formulations and venting configurations combined with composite motorcases enable the rocket motor designs to pass the initial fragment impact and slow cook-off tests.

The team has conducted rocket motor test firings on articles that have undergone temperature and shock extremes to simulate the environments of the real world, such as transportation and handling, captive carriage loads, and thermal shock resulting from altitude fluctuations. These tests prove that the performance of IM rocket motors can match or exceed those of the currently fielded motors. The work was initially focused on air-to-ground missiles, but it has also gained the interest of the Close Combat Weapon Systems Project Office for application on the tube-launched, optically-tracked, wireless guided, Javelin and Griffin missile systems (Fig. 9). With CCWS support, JIMTP has provided additional funding to have the team conduct testing that will serve as risk reduction efforts for the transition of technologies to system development efforts and planned product improvements.

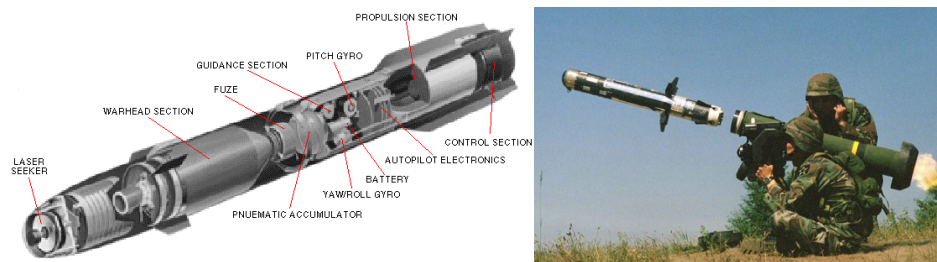


Fig. 9. JIMTP is developing new IM minimum smoke propellants appropriate for missiles such as the Hellfire (left) and Javelin (right)

The specific technologies of interest are a low-cost composite motor case, less shock-sensitive propellant, and cook-off venting devices. While it sounds simple to have two programs interested in similar technologies under development, each has their own unique challenges. The differences in motor diameter, propellant mass, and performance parameters, such as the presence of a launch motor in the ground launched systems and flight weight considerations for the air launched systems, resulted in significant propellant formulation tailoring and careful attention to the venting considerations in order to provide solutions to the two very different operating regimes.

The leveraging of funds and assets between the JAMS and CCWS Program Management offices and the JIMTP led project has resulted in real financial savings for each organization.

9. CONCLUSION: A LOT OF CHALLENGES REMAIN

The US munition inventory continues to see improvements in the responses to unplanned stimuli. Successful projects such as the M795 and M768 demonstrate both the feasibility and benefits of having IM systems. These systems provide increased safety, operational efficiencies, and logistical advantages for the warfighter. While continued progress is desired, complex and challenging problems remain for the foreseeable future as systems attempt to address some of the more difficult threats. A comprehensive and coordinated approach: identifying technology gaps in the IM Strategic Plans, providing innovative technical solutions in the JIMTP, transitioning through the Program Managers, and integrating the technologies with the contractors, are all required if these demanding challenges are to be met. The munition community has worked very diligently and been very successful in providing solutions to the IM threats. Continued success is needed if all munitions are to defeat all IM threats. While the ultimate goal is to have a fully IM compliant inventory, it is important to remember that with each incremental Insensitive Munition improvement, a safer weapon is being placed in the hands of the warfighter.

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