Insensitive Munitions – US Problems and Solutions

Kenneth J. Graham, President and Chief Technical Officer
Judson Consulting Service, Warrenton, VA
USA

kjgraham@erols.com

ABSTRACT

This paper describes some of the problems in implementing insensitive munitions requirements in the United States, and solutions that have been applied. Mr. Graham has worked in this area for over 43 years, and the views expressed are his own. All information is unclassified and releasable to the public.

1.0 INTRODUCTION

The phrase "Insensitive Munitions" seems to be incongruous. "Munitions" implies weapons that are sensitive to their boosters or igniters; while "Insensitive" implies that the weapons aren't. So to start out, some definitions are in order.

- Munition – An assembled ordnance item that contains explosive material(s) and is configured to accomplish its intended mission.
- Insensitive munition – Munitions which reliably fulfil (specified) performance, readiness and operational requirements on demand, but which minimize the probability of inadvertent initiation and violence of subsequent collateral damage to the weapon platform (including personnel) when subjected to unplanned stimuli.
- Burning – The least violent type of explosive event. The energetic material ignites and burns, non-propulsively. The case may open, melt or weaken sufficiently to rupture nonviolently, allowing mild release of combustion gases. Debris stays mainly within the area of the fire. The debris is not expected to cause fatal wounds to personnel or to be a hazardous fragment beyond 50 ft.
- Hazardous fragment – For personnel, a hazardous fragment is a piece of the reacting weapon, weapons system or container having an impact energy of 58 ft-lb [79 J] or greater.
- Deflagration – Reaction driven by thermal conduction in an energetic material. For solids and liquids, no utilization of atmospheric oxygen is required. The reaction wave is subsonic in the energetic formulation and the reaction products flow in a direction opposite to the reaction front.
- Detonation – Chemical reaction induced by a compression wave and driven by the expansion wave in the products. A shock wave is formed that propagates at a steady velocity if the formulation is above its critical diameter. The velocity of the shock wave in the explosive (detonation velocity) is supersonic, and the reaction products travel in the direction of the shock wave.
- Critical diameter – The diameter of a long, unconfined right circular cylinder of energetic formulation that just sustains a steady detonation. Propagation of detonation fails below critical diameter.

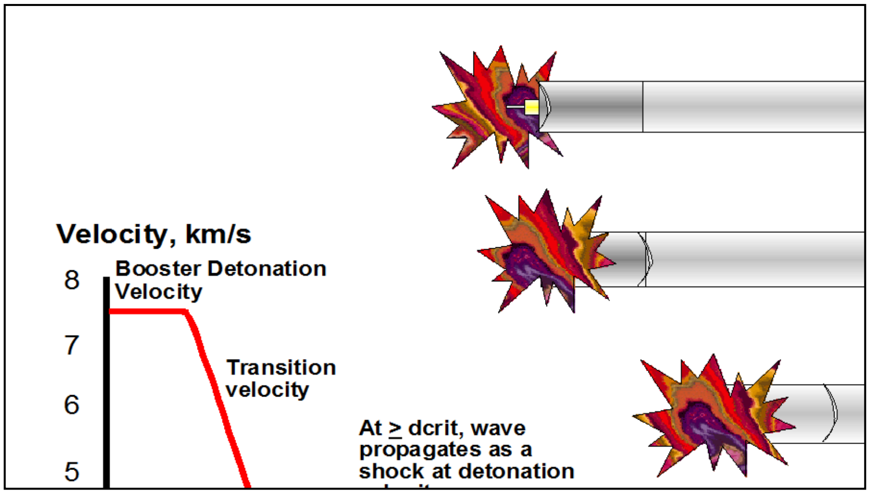
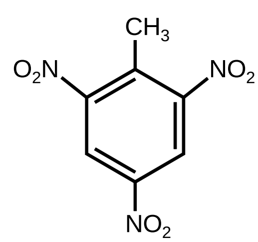


Figure 1. Cylindrical Critical Diameter Test.

- Sympathetic reaction – The detonation of a munition or an explosive charge induced by the detonation of another like munition or explosive charge.
- Explosive - Substances or mixtures of substances which are capable of undergoing exothermic chemical reaction at extremely fast rates to produce gaseous and/or condensed reaction products at high pressure and temperature.
  - Detonation reactions take place in microseconds
  - Energy release rates are ~ 4000 J/g
  - Power level of energy conversion is ~5×10^9 W/cm^2 at detonation front. (For comparison, the total US electrical generating capacity (in 1960) was 3×10^{11} W.)

Some reference explosive molecules include TNT, RDX and HMX. Figure 1 gives some typical values for the detonation of TNT, while Figure 2 shows some properties for the much higher performance explosive HMX.

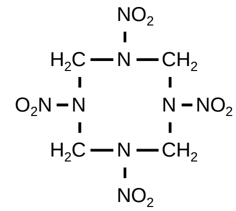
Parameter	Value (SI)	Value (English)
Detonation Pressure	21 GPa (210 kbar)	> 3,000,000 psi
Detonation Velocity	6.93 km/s	> 4.3 miles/s
Detonation Temperature	~ 3000K	~5000°F



2,4,6-trinitrotoluene (TNT)

Figure 2. Detonation properties of TNT.

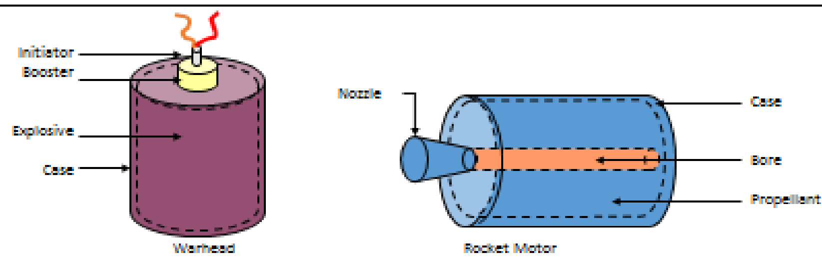
Parameter	Value (SI)
Detonation Pressure	39.5 GPa (395 kbar)
Detonation Velocity	9.1 km/s



1,3,5,7-tetranitro-1,3,5,7-tetraaza-Cyclooctane, (HMX)

Figure 3. Detonation properties of HMX.

There are numerous potential hazards associated with munitions. They are sensitive to thermal and shock or impact stimuli, with potential responses ranging from none to very severe combinations of reactions. Figure 4 illustrates.



Stimuli	Some Potential Responses	
• Impact & Shock – Drop – Bullets – Fragments – Shaped-charge jets	• None • Ignition • Burning • Propulsion • Explosion	• Blast – Shockwaves – Overpressure • Fragments – Small, high-speed
• Thermal – Fires – Slow heating – Hot spall fragments	• Detonation • Heat – Radiant – Hot gases – Plasma	– Large, lower speed • Combinations of the above

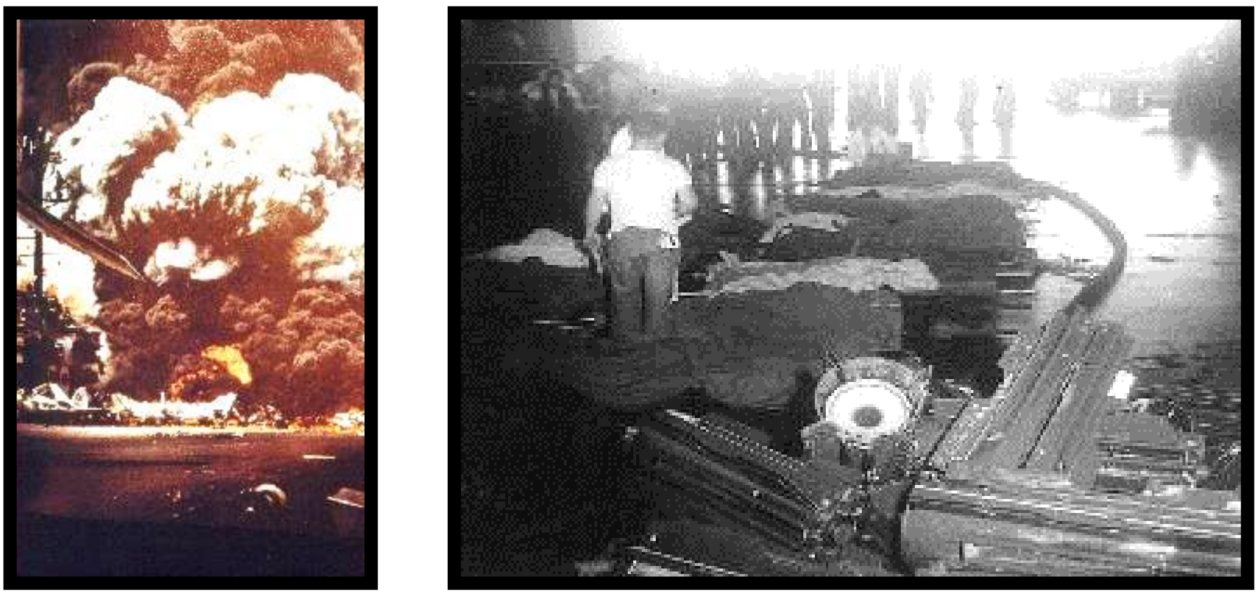
Figure 4. Potential Hazards from Munitions

2.0 US PROBLEMS. HISTORICAL DRIVERS TO REDUCE MUNITIONS SENSITIVITIES – OR – OUR OWN WEAPONS ARE KILLING US!

In order to fulfil their missions, the US services need to have functional personnel and materiel. A way to accomplish this is to have munitions that do not react violently to inadvertent threats, destroying personnel and materiel. In particular, fire is a significant threat. A few examples of what drove the US to implement insensitive munitions research and development follow.

2.1 US Navy

The US Navy experienced several inadvertent violent reactions of munitions aboard ship, causing loss of life and major materiel damage. Estimates for three shipboard accidents approached 2 billion dollars and loss of functionality. An example is the USS Forrestal incident. A ZUNI rocket was fired accidentally from an aircraft being readied for a mission on July 29, 1967. The rocket screamed across the flight deck, struck another aircraft and ignited a fuel fire (Figure 5(a). The initial fire could have been contained, but 90 seconds after the fire started a bomb detonated, killing or seriously wounding most of the fire fighters. The detonation ruptured the flight deck, and burning fuel spilled into the lower levels of the ship (Figure 5(b). Bombs, warheads, and rocket motors exploded with varying degrees of intensity in the fire, killing 134 and wounding 161 men. Twenty-one aircraft were destroyed.

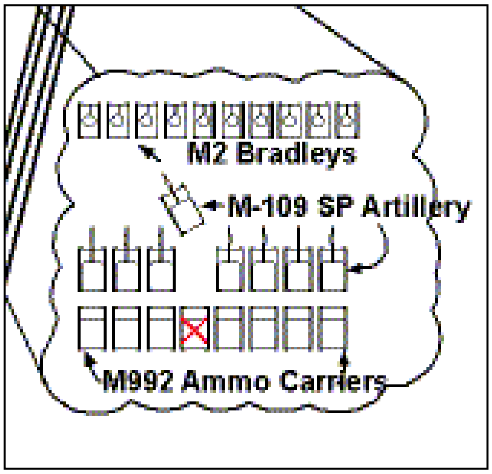


(a) **(b)**

Figures 5. (a) Raging fuel fire on Forrestal deck; (b) Hole in carrier deck after bomb detonated in fast cookoff.

2.2 US Army

The US Army experienced the inadvertent violent reaction of munitions due to fire, causing loss of life and major materiel damage at Camp Do-Ha (Black Horse Camp) in Kuwait. 56 persons were killed and damage estimates were over 50 million dollars, again resulting in loss of functionality. The first incident occurred on 11 July 1991. Defective heater in ammunition carrier started a massive fire (Figures 6(a) and 6(b)). 53 soldiers died in fast cookoff of 155mm Howitzer shells and other munitions. The second incident occurred on 24 July 1991, where 3 more soldiers were killed clearing the site. It is of note that more tanks were destroyed in the accident than in the war (14 M1-A1's).



(a) (b)

Figures 6. (a) Location of ammo carrier with defective heater; (b) Overview of damage following fire.

2.3 US Air Force

Though not an adverse munition reaction to a threat, in a related situation, the sensitivity of Tritonal-loaded bombs became an issue for storage in Germany. The Air Force needed to store a large number of hazard class 1.1 (mass detonating) bombs in an area that was surrounded by civilian population, but the number of bombs that could be stored was severely limited by the required quantity-distance requirements. They chose to develop a new insensitive bomb fill for MK-82 bombs that gave the munitions a hazard classification of 1.6 (Extremely Insensitive Articles). The change in quantity distance requirements was dramatically affected, allowing many more bombs to be stored in the same area. Figure 7 illustrates.

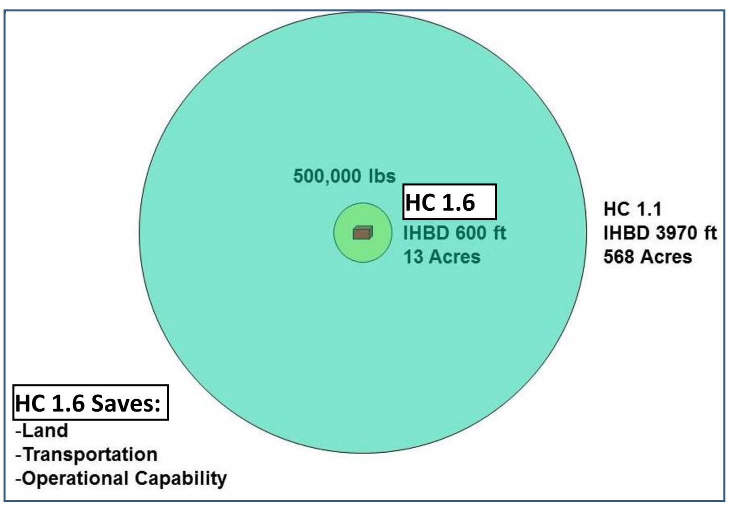


Figure 7. Dramatic reduction in inhabited building Q-D by changing from HC 1.1 Tritonal to insensitive HC 1.6 PBX explosive.

2.4 SOLUTIONS

With the disastrous incidents with our own munitions reacting violently to unplanned stimuli, it was clear something had to be done. The US Navy led the way. In 1984, the Navy's IM program was established. Collaboration with experts in the field of energetics was key. The Navy established the Insensitive Munitions Advanced Development program that included key government and industry technical personnel helping to understand threat stimuli and modes of reaction; and the sensitivities of energetic ingredients and formulations. Life-cycle based threat hazard assessment of weapons was implemented. Working groups assessed the potential sensitivities of munitions and prepared priority lists. Military Standards were promulgated and generic IM tests were developed and continually refined addressing shock and impact as well as thermal threats. Weapons were subjected to the IM tests and impartially scored to assess the current state of the art and to identify problems and areas for potential fixes. These were tabulated in 1985 in the first Technology Status Chart (figure 8). You will note the large amount of red indicating detonation and yellow indicating deflagration as the mode of reaction.

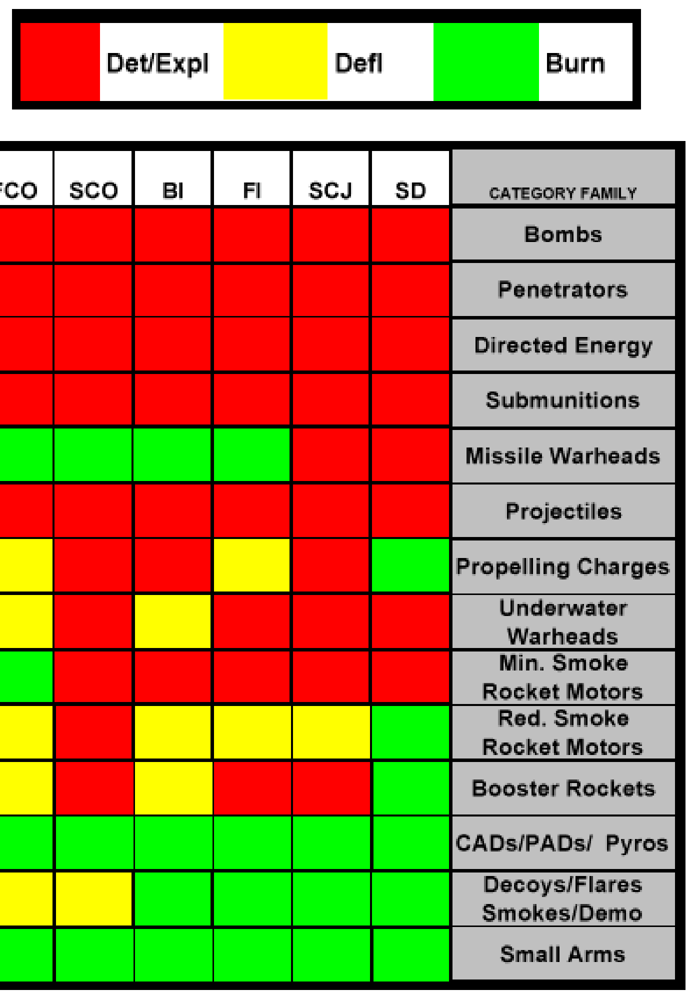


Figure 8. IM Technology Status chart 1985 [1]

This work expanded to the other services (1987 Joint MOA on IM). The problem was where to store the baseline IM test data, energetics information, and test results with mitigation applied. The Navy developed a first generation IM database where the records and reports were physically stored and then incorporated in searchable electronic database. The US allies were also implementing IM testing and improvements to their weapons systems. It soon became apparent that an international information center was needed and in 1991 the NATO IM Information Center (NIMIC) opened in Brussels, Belgium. The database function was transferred to NIMIC, and IM information made available to member NATO allies. NIMIC hosted numerous international workshops on various aspects of IM, and published the results in their databases. In 1995 NATO released policy and technical requirements for insensitive munitions. In 1996, IM requirements were promulgated as part of the US acquisition policy in DoD 5000.2-R. and later as US public law (Figure 9).

"The Secretary of Defense shall ensure, <u>to the extent practicable</u>, that munitions under development or procurement are <u>safe throughout development and fielding</u> when subjected to <u>unplanned stimuli</u>."

Figure 9. United States Code, Title 10, Chapter 141, Section 2389, ensuring safety regarding insensitive munitions [2].

Over the years, there were many successes in reducing the severity of responses to IM threat stimuli. Many of the results have been published in unclassified symposia such as the US National Defence Industrial Association (NDIA) Insensitive Munitions and Energetic Materials Symposium. In 2000, the second IM Technology Status chart was released, showing that reduced sensitivity to IM threats was indeed achievable (figure 10). The 1985 initial assessment is also shown for comparison. Notice the considerable movement from red to yellow and green responses. This trend continues today, albeit the problems seem more and more difficult.

The takeaway from this discussion is as follows:

- Implement a formal insensitive munitions program and fund it
- Collaborate with military, government and industry personnel
- Adopt international standards for testing
- Utilize existing resources such as NATO's MSIAC and international IM symposia

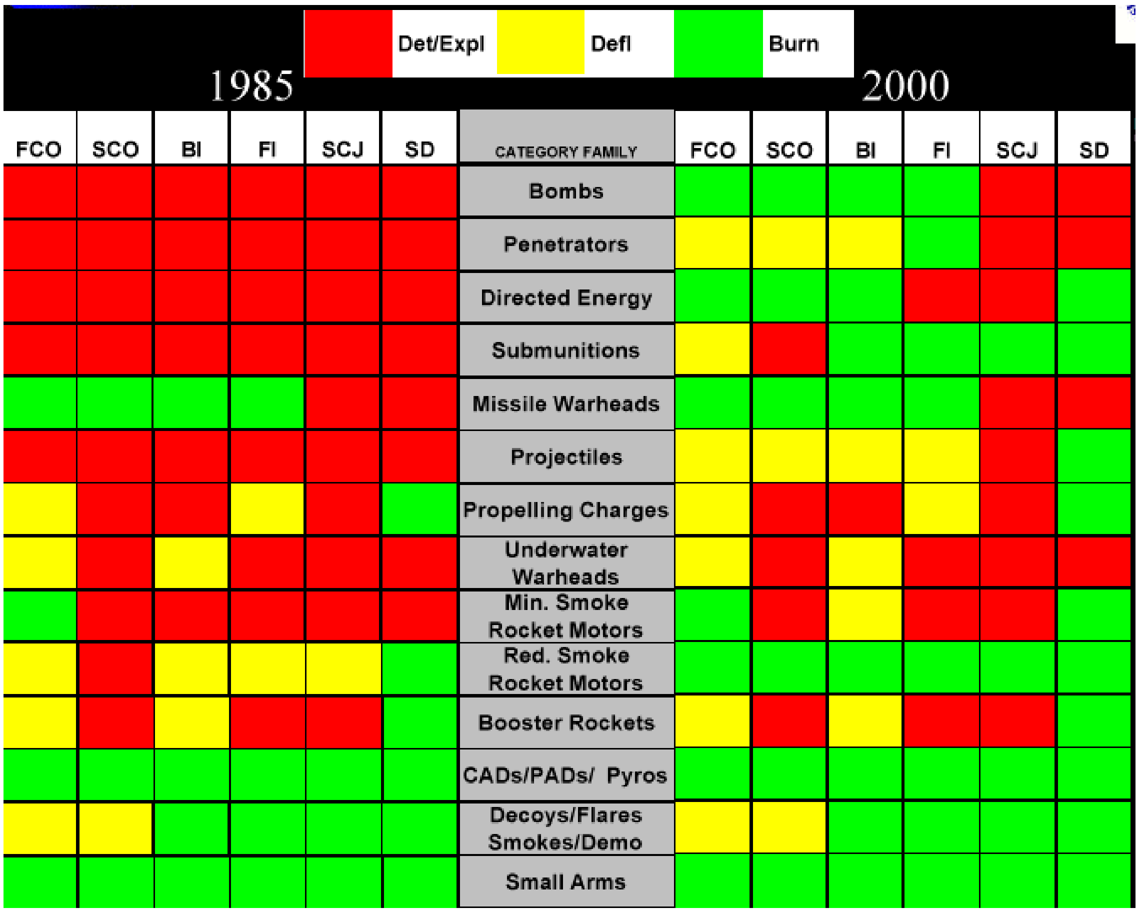


Figure 10. Reduction of IM responses following implementation of IM program.

3.0 THE "SIMPLIFIED" IM PATHWAY

What drives the development of an IM munition system? And who does what? In the simplest sense, the pathway to a fielded IM system follows the pathway shown in Figure 11, below. In this paper we discuss some of the problems the US faces and some solutions to those problems.

3.1 Where do requirements come from?

As shown in Figure 11, there are several sources for requesting production of IM systems. One is the upgrade of legacy munitions that do not meet the IM requirements. The services have prioritized lists of legacy weapons and may choose to improve top priority weapons. Another pathway is new requirements from the field. Mission requirements change as new threats appear, and new, improved weapons are needed. Program offices generally handle and fund these requests, typically to government laboratories.

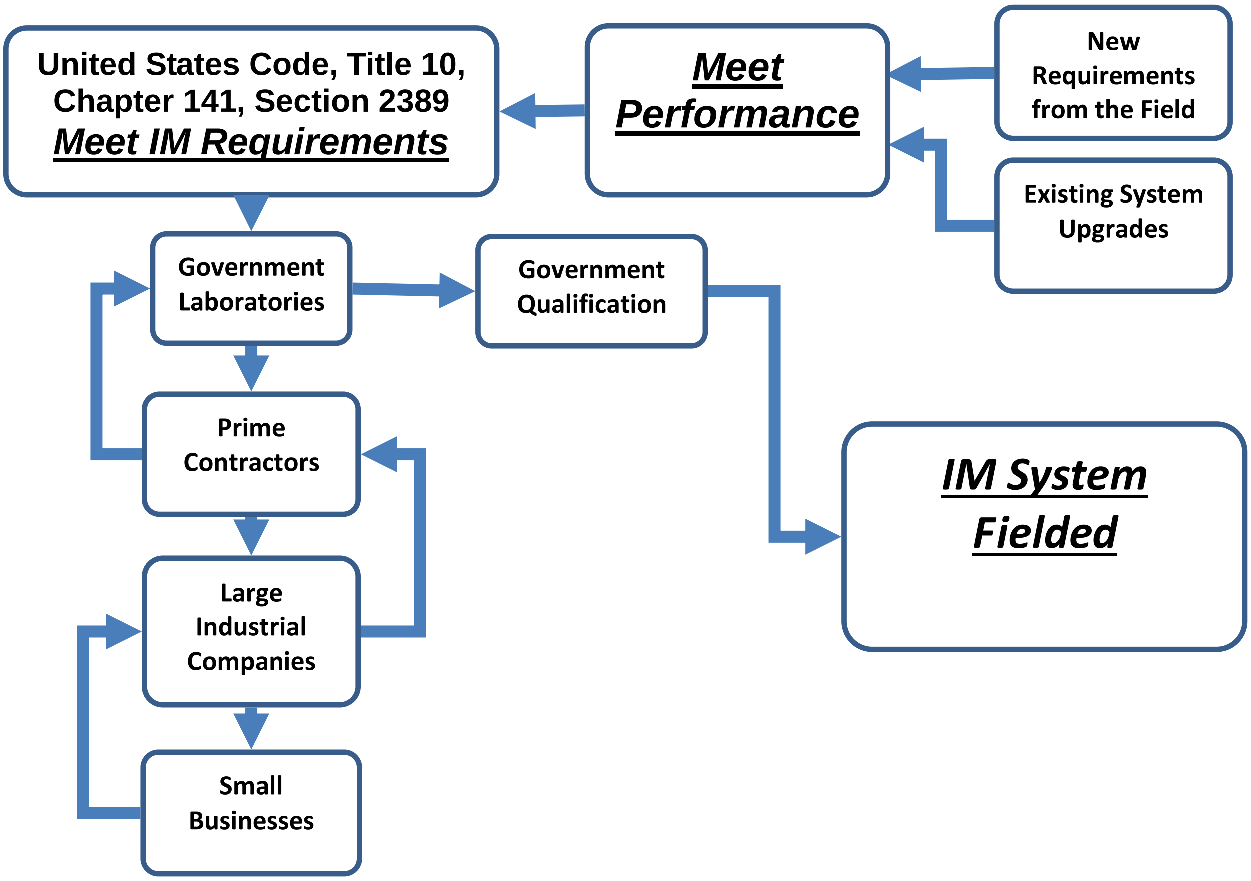


Figure 11. Simplified IM Pathway

3.2. What are the primary requirements?

In virtually all new weapons developments, whether upgrades or those with new missions, **performance** is the primary driver. Systems must meet the performance goals. However, US public law specifies 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."** In general these are opposing requirements.

4.0 PROBLEMS AND SOLUTIONS

Munition systems can be sensitive to various threat stimuli leading to adverse reactions that can injure or kill personnel, damage materiel, and severely impact operations. IM deals with the response of **systems** (munitions) in the all-up-round (AUR) or major subsystem configuration, whether that be in the logistical or tactical environment. System design features such as the placement of the igniter, propellant and warhead explosive selection, case material, and the launch container design are important in preventing "cheap kills" on valuable assets. **There is not one simple solution**. Combinations of system components are required for the mitigation of violent reactions. **IM is a system issue and addressing IM requires system solutions**.

4.1 Provide more performance while making system more insensitive

Problem: For new or weapons upgrades, the requirement from the services is "give me more performance but also make it insensitive. In general these are opposite constraints. For example, to get more performance one may increase the concentration of higher performance energetic ingredients, while making it more insensitive points toward using less of these energetic ingredients.

Potential Solutions: Several potential solutions can contribute to reduced system sensitivity. Energetic ingredients such as crystalline nitramines can be processed to remove crystalline defects whether by recrystallization or grinding reducing hot spots that increase shock sensitivity. More energetic solids can then be used to increase performance.

Another method that may be available is to partition the energy between the energetic solids and the binder by using an energetic binder system. With the reduced energetic solids content, sensitivity is decreased while total energy may be increased.

For rocket motors, performance can be increased by lightening the system and increasing the operating pressure. Here, replacement of metal cases with composites is of value. Composites can be stronger than metal cases, are lighter, and can provide IM benefits in both impact and thermal threats due to their failure modes.

To improve the "IM-ness" of a system, mitigation methods and devices are important. A partial list of passive and active mitigation methods is shown in Table 1. Note that passive methods are preferred and active methods carry a number of restrictions. Also note, that for best performance and IM value and potentially lowest weight impact, mitigation techniques should be part of the initial design and not a strap-on as an afterthought.

Passive	Active
Preferential Insulation Treatment	Thermally Initiated Vent System (TIVS)
Memory Metal Alloys and Bimetallics	Explosive Bolts
Bore Mitigants	Impact Switches
Pulse Motor	Thermal Switches
Composite Cases	Case Bar Cutter
Slotted Cases	External Thermite Case Penetrator
Case Embrittlement Concepts	Internal Thermite Case Penetrator
Hybrid Cases	Explosive Case Separator
Steel Strip Laminate Cases	Multihazard Threat Mitigation System
Metal Matrix Composite Cases	
Roll Bonded Cases	
Shear Vent Patch Strip	
Packaging	
Shock absorbing materials	

Table 1. Some Passive and Active Mitigation Techniques for Rocket Motors

4.2. Incomplete lifecycle analysis

Problem: Ignoring part of the system lifecycle can lead to imperfect IM solutions. While one or more threats may predominate in the field, ignorance of storage and transportation aspect of the lifecycle can lead to poor munition responses.

Solution: A good IM system solution requires that the whole lifecycle be considered. Then, a lifecycle-based hazard assessment can be performed to assess threats and focus on the best, total system solutions. Using risk analysis techniques, the total system risk can be quantified. This analysis couples system safety and risk analysis techniques and includes the contribution from each threat type, in each stage of the lifecycle, and includes platform damage potential. It is developed using IM databases, historical experience and engineering analysis to determine the probability of risk. The methodology can be implemented on a desktop computer to become a design aid to evaluate alternate mitigation features; and assist in management decisions.

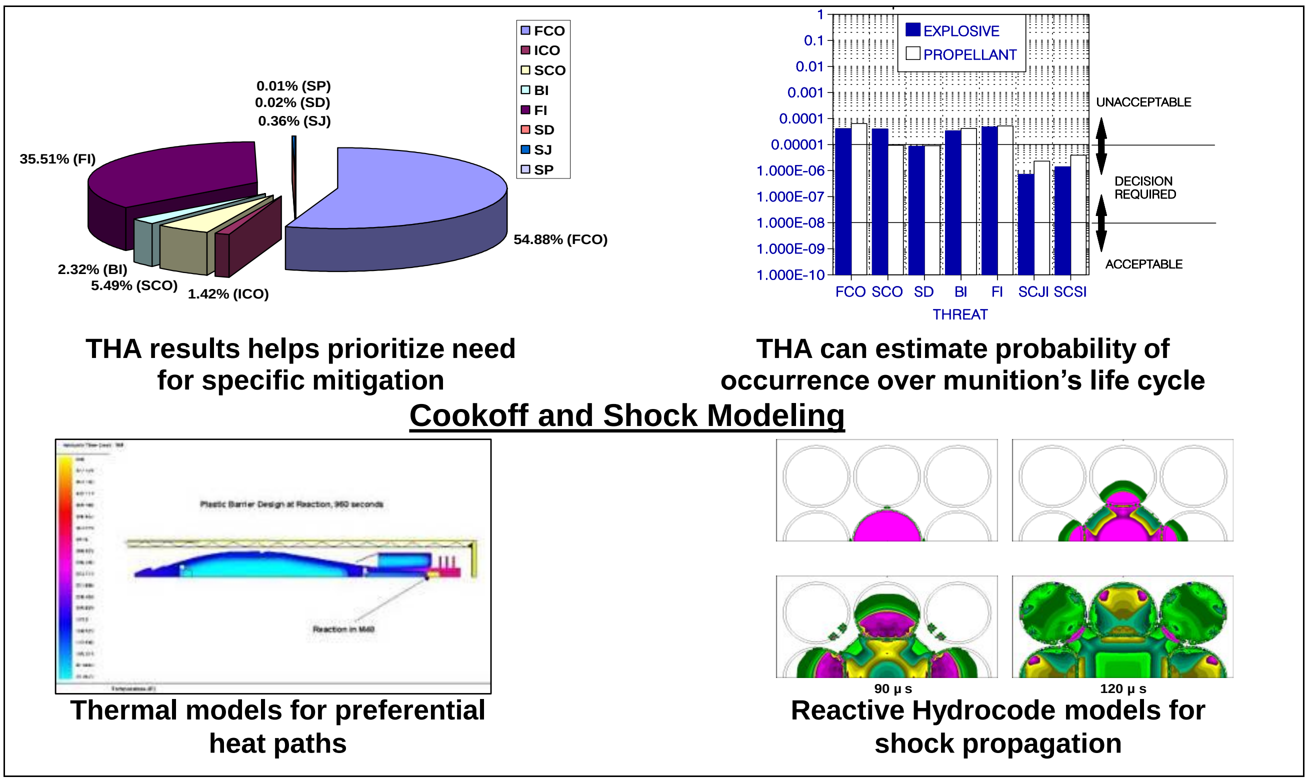


Figure 12. Lifecycle-based threat hazard assessment utilizes risk assessment methodology. Thermal and shock modeling show critical features needing mitigation.

There is a perception that IM solutions cost too much. There is pressure to keep costs low. A complete lifecycle hazard assessment should also include a cost-benefit analysis. There is the distinct probability that the overall munition system costs may actually be reduced, because there may be only the need for a reduced number of weapons if they are insensitive to unplanned stimuli.

4.3. Problem: Lack of Coordination of Service IM Programs

Early on, the US Navy led the way toward solving IM problems. But each service had service-unique problems such as different types of munitions and different environments for similar munitions. The Navy had bombs, missiles, and underwater munitions; the Air Force had bombs and aircraft-borne missiles; and the Army had artillery and man-portable missiles among others. What was needed was collaboration and "jointness".

Solutions: A first big step to improved coordination was the 1987 Joint Memorandum of Agreement on Insensitive Munitions. This was followed by DoD acquisition policy 5000.2-R and later public law USC Title 10 Chapter 141, Section 2389 making IM US policy. A major step in coordination was the implementation of the OSD-sponsored Joint Insensitive Munitions Technical Panel (JIMTP).

THE JIMTP is a DoD 6.2/6.3 program that develops and mature technologies for improving munition response to combat and accident hazards. Technical thrusts are in 5 major areas: (1) High performance rocket propulsion; (2) Minimum signature rocket propulsion; (3) Blast and fragmentation warheads; (4) Anti-armor warheads; and (5) Large-caliber gun propulsion. JIMTP established 5, 10, and 15 year goals for each of the five areas, and established quantitative metrics to assess progress on their funded programs. A key element is the requirement for a technology transition agreement (TTA) with the respective program office stating that the IM solutions developed will be implemented into munitions. There are a number of IM successes and transitions to the field are occurring. Publicly released recent successes include an insensitive high-performance reduced smoke propellant for AMRAAM; DAAF booster explosive; PBXC-135 main charge explosive fill for HELLFIRE/JAVELIN; improved case technologies and new mitigation techniques [3]. In addition, the US Air Force and the US Navy now share bomb fills.

4.4. Legacy explosive fills

Problem: There are still some TNT-based explosives in the inventory. Melt-cast TNT-based explosives have many issues including poor castings, cracking and voids, increased shock sensitivity, and pink water pollution. Pink water pollution is associated with load, assemble and pack operations or with the demilitarization of munitions involving contact with finished explosives. Residual waste water from water wash-out has been pumped into lagoons where contaminants include TNT, RDX, 2,4-DNT, 2,6-DNT, 1,2-DNB, 1,3,5-TNB and nitrobenzene, all of which contaminate ground water [4].

Solution: The services need to eliminate TNT and TNT-based explosives like the melt-cast explosive Tritonal, and replace them with less sensitive melt-cast or plastic-bonded explosives. Explosive wash-out water should not be pumped into lagoons but rather destroyed in furnaces. Plastic-bonded explosives (PBX) are mechanically compliant, cushioning the high-energy solids in a rubbery binder system. Examples of PBX's include the Navy PBXN-109 and the Air Force AFX-757.

5.0. CONTINUING PROBLEMS THAT NEED SOLUTIONS

Despite all of the improvements developed over the last 25+ years, some components of munitions systems remain sensitive to some of the IM threats. For example, minimum smoke propellants for the most part still contain nitrate esters, nitramines, and heavy metal burning rate modifiers, leading to enhanced sensitivity to shock and impact. Work is proceeding on burning rate modifiers that are not heavy metal based and show some promise. Improved launcher materials and the use of bore mitigants may offer some benefits.

For high-performance rocket motors using ammonium perchlorate (AP) as the primary oxidizer, there is an increasing awareness of the potential for AP contamination of ground water. Health care officials are regulating and monitoring this compound as an environmental hazard [5,6]. The environmental protection agency is considering a standard of 1 part per billion in groundwater, the equivalent of one grain of salt in an Olympic sized swimming pool! Clearly, alternate oxidizers are needed. Some include ammonium nitrate (AN) which is stable, cheap, and a high gas producer, but has a slower burning rate than perchlorate and is hydroscopic (absorbs moisture from the air over time); and ammonium dintramide (ADN), a high-energy oxidizer that is more environmentally friendly and may function in non-urethane/isocyanate binder systems. Performance improvement and sensitivities to IM threats in rocket motors remains to be verified.

Modeling and simulation provides great value in that some properties can be computed, potentially reducing testing costs. However, hurdles remain. For one, there is still a lack of calibration data from tests. For example, the tests required for shock and impact such as run distance to detonation as a function of input pressure (Pop Plot) and Hugoniot relations are expensive and time-consuming. It is difficult to find funding for generation of calibration data. Further, though we have a suite of high-powered shock and thermal models (ALE-3D; CTH; Mesa; many others), **none are able (yet) to predict the violence of reaction**. This is a continuing work in progress, and OSD has assigned the responsibility for this effort to the US National Laboratories.

Testing is required to prove munition insensitivity to the IM threats, and to provide model calibrations. There are very few large test sites available for all-up round testing. Most belong to the government laboratories. Component testing is more the norm, but remember, IM **requires system solutions** for all up munition systems.

6.0. CONCLUSIONS

There have some horrific incidents that stimulated the need for less sensitive, insensitive munitions. The danger of fire is ever present and bullet and fragment impacts are present, in particular in the battlefield. A relative new threat is the improvised explosive device (IED) that can be blast/fragmenting devices or a shaped charge. To prevent or minimize adverse reactions of our own munitions, we must make our munitions systems less sensitive, through formulation, case, transport container, and mitigation devices and materials.

We have learned that tough viscoelastic materials can be less vulnerable to thermal and mechanical stimuli. They reduce fissuring and can be energy-absorbing. Energy partitioning between the fuel and the oxidizer can result in less violent reactions. The use of endothermic binders, energetic plasticizers, and alternate oxidizers can provide IM benefits. Many of the failure modes of rocket motors have been characterized such as bore spall and delamination of the propellant from the container. Container design and novel materials can reduce the prospect of sympathetic detonation, either by configuration or material selection. Rocket motor and warhead designs have been developed that can reduce confinement and reduce hazardous fragments. The use of composite materials is increasing as are novel solutions for venting.

There is not one universal solution to making insensitive munitions. Decisions should be based on a lifecycle-based hazard assessment for the all up round or major subsystem. For optimum results, system solutions should be started early in the design phase where possible. **Achieving IM munitions is possible and is proven**.

7.0. REFERENCES:

[1] Bowen, Richard E, Insensitive Munitions, a Technology Forecast, 1999 NDIA IM/EM Meeting,

[2] United States Code, Title 10, Chapter 141, Section 2389. Ensuring safety regarding insensitive munitions.

[3] Gonzalez, JIMTP, http://www.dtic.mil/ndia/2012munitions/JoseGonzalez.pdf

[4] TNT-based explosives, http://www.frtr.gov/matrix2/section2/2_10_3.html

[5] AP Pollution, *http://www.freedrinkingwater.com/water-contamination-perchlorate-faq.htm*

[6] AP Pollution, www.serdp.org/content/view/pdf/4918