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Insensitive Munitions Maturity — A Systems Perspective

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Catastrophic events aboard US aircraft carriers in the 1960's and 70's highlighted the need for new approaches in the design and deployment of weapons to prevent future military disasters. Weapon insensitivity to hazardous stimuli was recognized then, as it is widely so today, as an imperative safety measure for our military forces. The goal of transforming our weapon inventories into insensitive munitions was put in place in the 1980's. Great strides have been made in the decades since then but the goal of a complete IM inventory is largely unfulfilled.

This paper will describe the state-of-the-art of IM technology as a point of departure and will discuss the challenges that are ahead in the pursuit of total IM compliance. These challenges, which focus on system-level IM solutions, will not only address technology shortfalls, but will also examine how we evaluate and assess IM-ness. Many of our processes are examined here, from our evaluation techniques to our assessment standards, and all are part of the system-level IM process. The focus question for this paper can be stated in simple terms: *Insensitive Munitions — are we there yet ?*

INTRODUCTION

Insensitive munitions has been with us now for more than two decades, a full generation. It has become institutionalized within the US Department of Defense. There has been significant progress in advancing technology that supports the IM mission during that time. But how we approach IM, from setting requirements, to incorporating new technology and assessing the results of these actions is changing. This paper will examine these IM issues with respect to how well the goals have been met during the past 20 years and what lies ahead for the next generation, the next 20+ years. Technology challenges, some old and some new, will be discussed for the way ahead. This discussion will focus on a top-level, weapon system perspective.

SYSTEM LEVEL IM

IM in the new world order. In the current view of our national warfighting capabilities, insensitive munitions are pervasive throughout the DoD. IM is everywhere. What do I mean by this? The US Navy took the lead many years ago in recognizing the need to improve shipboard safety to save lives and preserve costly military assets. It was recognized that although the weapons of war are dangerous to handle, store or use in hostile environments, improvements must be made. These improvements focused on such things as replacing the old TNT-based explosives, but also on improving weapon component design and even logistic handling procedures. That was 1970's and 1980's thinking. But it was more widespread than that. IM slowly became institutionalized throughout DoD as a requirement for all of the services. Its also mandated by public law[(1)]. How we go about accomplishing this, making weapons compliant with all IM requirements identified in the US MIL-STD-2105 and now the accompanying international agreements (STANAGS) is a major challenge for all of the services.

Although most of the investments in new technology for IM were centered primarily on energetic materials, explosives and propellants, that is no longer the case. IM solutions are now aimed more often at "fixing" the whole weapon system, from munition subsystem and components, to weapon launchers, magazines, launch platforms and vehicles. How we protect, handle, store and deploy our weapon systems is extremely important in today's world of joint operations among the services, including opportunities for international cooperation. We must pay particular attention to how we integrate new technology. New advances in S&T must be an integral part of these future system-level IM solutions.

Examples of system-level solutions. Two recent examples highlighted this notion of integrated technologies to solve IM deficiencies. The JASSM and SLAM-ER missiles were developed in the US in the late 1990's with a strong emphasis on incorporating appropriate technology to enable them to meet the IM requirements. Both used relatively new main charge explosive formulations. Both used novel concepts to permit venting of combustion products for the case and for the fuze booster during cook-offs. And both used improved shielding for ballistic protection during stowage and transport. These are examples of integrating IM technologies that rely on more than just replacing the energetic materials. Fortunately, the effectiveness of these IM designs has not been demonstrated during real world IM events. But what about platform related events? Will these IM compliant weapons remain as safe as advertised during a major event in a shipboard magazine or on a flight deck? The whole warfighting *system* must be adequately protected to ensure that all of its weapons are not vulnerable to accidental or hostile IM events.

IM TECHNOLOGY

The development of new technology to enable weapons, new and old, to become *insensitive munitions* is a continuing process, a battle, so to speak, being waged on many fronts. To have a better understanding of the state-of-the-art, let's look at where we started with IM and what's been achieved since then.

Historical perspective. Most of us are aware of the disastrous carrier incidents in the US Navy that occurred in the 1960's and 1970's. The establishment of new safety policies and new technology programs to support the implementation of these policies soon followed. The vast majority of the RDT&E investments in the 1980's centered on developing new energetic materials as the principle, if not the only, IM solution. A very ambitious goal of a complete IM inventory for the Navy by 1995 was never realized.

The magnitude and scope of the problem far exceeded our anticipated ability to respond with new technology in a cost efficient and effective manner.

In the early years IM was viewed as a safety issue, as it should be. Improved safety involves *risk management* — that of reducing accident frequency and the consequences of accidents when they occur. In an IM sense risk management has an even broader application since IM events can occur as a result of both accidents and hostile actions. We still must strive to minimize the level of reaction violence as much as possible to effectively reduce, and maybe eventually, eliminate the risks associated with putting insensitive munitions into service use.

How much have we accomplished in improving the IM state-of-the-art in the last 20 years? Dr. Rich Bowen gave a 15 year snapshot in time historical perspective a few years ago at the IM/EM Technology Symposium(2). He showed that dramatic improvements have been made for many types of weapon categories for the six major IM requirements. The *then & now* comparison is still relatively the same for the 20 year time horizon. Although the number of improvements are shown to be significant, there are many deficiencies that remain. No single weapon category is *fully IM compliant*.

IM technology state-of-the-art. How mature is the technology that's available to make our weapon systems insensitive? When we examine the state-of-the-art just for energetic materials, we can see that we've come a long way in 20 years. Several new, less sensitive explosive molecules have been developed and their processing procedures have been improved. Dozens of new explosive formulations have been introduced into various types of weapons for many unique and widely differing applications. Although new formulations continue to be developed and the ingredients continue to be tweaked (such as the reduced sensitivity RDX currently under evaluation internationally), these energetic materials are relatively mature. On a scale of 1 to 10, with 10 being the most mature, they would probably be rated an 8 or 9. Twenty years of dedicated resource investments in this area have reaped many benefits.

This is not true for propellant development. LOVA propellants were developed in the 1970's and 1980's to improve safety and IM risks and were a marked improvement for gun applications. More recently, HTPE and HTCE propellants used with many types of oxidizers have been shown to be effective IM improvements for some solid rocket motor applications. However, many more unresolved technology mysteries remain for the propulsion community. To put things into perspective, all large solid rocket motors are IM *non-compliant*. Without exception, their continued service use relies on the renewal of IM waivers. To further exacerbate the situation, some future propulsion systems are even considering the use of liquid fuels, an area that has, for the most part, not been addressed by the IM community. One would then logically conclude that, overall, propulsion formulations would be given a much lower rating on the hypothetical maturity scale, a 5 or 6 rating.

As mentioned earlier, system-level IM must not rely on new energetic materials alone. There have been technical advancements in many other areas over the years.

Several types of venting systems have been designed, successfully demonstrated and incorporated into both ordnance and propulsion systems to mitigate the hazards associated with thermal events. Many new materials, combinations of new and exotic materials and novel shielding or barrier mechanisms have been employed to mitigate shock and fragment hazard effects. Are there new, more effective materials on the horizon that can be used as IM solutions? Probably so.

System-level IM must also consider weapon logistics — how we handle, store and transport weapons. New procedures continue to be implemented that help reduce the susceptibility to IM hazards. Logistics, however, is an area that's subject to continuous evolution not only as new weapons emerge, but also when new launchers, handling systems and even platforms are designed and deployed. The design tools, test methods and assessment methodologies used by the IM community are becoming critically important. They are becoming more robust but these are still areas that are ripe for growth. Modeling and simulation tools, for example, would at best be categorized with a maturity level of 4 or 5.

IM Compliance — The Holy Grail. Our end goal is to field only *insensitive munitions* in the future battlefield, both at sea and ashore. Are we there yet? Have we achieved the sought after *IM utopia* given that we've had 20+ years and a multi-million dollar resource investment? Examine the notional curve shown in Figure 1. We clearly haven't straight-lined the curve, but how far up the knee in the curve have we progressed? When we examine the technology state-of-the-art that's been previously described, its obvious that there's much that can and should be done in the years ahead.

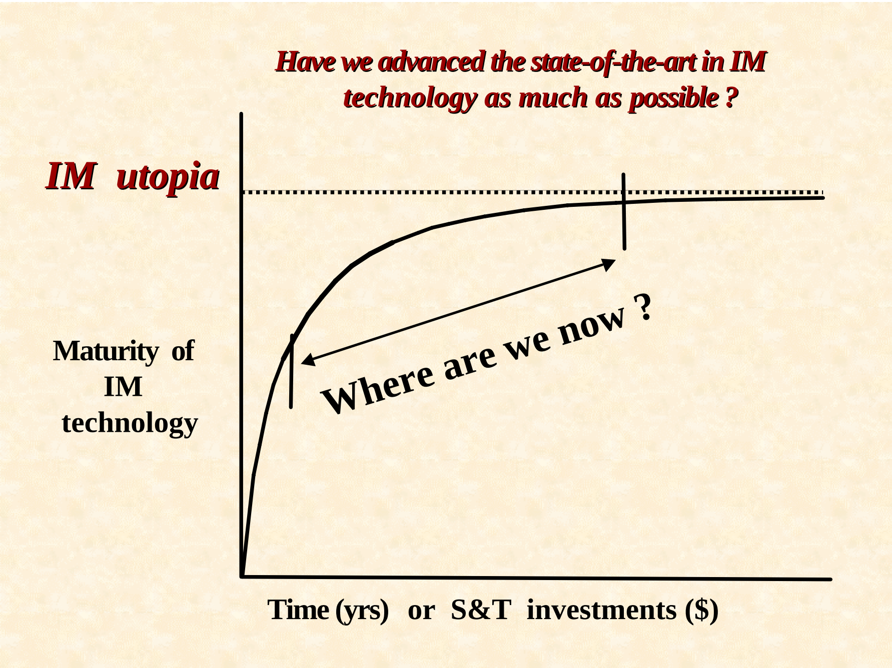

Figure 1. Advancement of IM Technology — Are we there yet?

IM SIGNATURES AND ASSESSMENTS

When we attempt to certify a weapon for IM compliance a series of tests are conducted to determine its IM characteristics. The results are often looked at as a measure of the weapon's IM-ness. In the US these results are often shown in a "stoplight chart" format where passing tests are shown in green, very bad test failures (Type I detonation) in red and just plain bad (Types II, II or IV) test failures in yellow. AOP-39 specifies a graphical representation of the test results to indicate an IM signature or IM-ness of an item. It is what it is. In either case, the IM characteristics are assessed and the item is either accepted, rejected or granted a waiver for service use. That's the universal IM assessment process. But let's look further into the long established requirements, their consequences and their associated risks, especially in light of the IM state-of-the-art discussed earlier.

Reaction comparison & consequences. In recent years many things have been taken for granted with respect to acceptability of some IM reactions. Look at one of the most serious and often most challenging IM issues, that of preventing mass detonation reactions. Sympathetic reaction events are most often characterized as a chain reaction of *detonations* among several weapons. Our aim is to lessen the severity of the initial reaction to prevent its propagation among its neighbors. A very challenging issue indeed. But what if an initial reaction is *only* a Type III explosion? Does it propagate? It's certainly a violent reaction which can project large, lethal fragments at high velocities and can produce relatively high shock pressures to neighboring munitions. Yet, this is deemed an acceptable sympathetic reaction response. This may be acceptable for widely separated munitions stowed in low density in an ammunition storage area. But what about a very densely populated weapon magazine on a naval vessel? Will a Type III explosion reaction propagate or transition to detonation reactions that result in the near equivalent damage caused by an initial propagating detonation reaction? We really don't have an answer for this.

Another equally serious concern should be with the lower level IM response, a Type V burning reaction. For many years this has been, and continues to be, the ultimate IM goal. Let the munition take a hit or cook away but please don't go BOOM! Just burn, and burn, and burn! This to the chagrin of firefighters throughout the world. Burning reactions can often produce violent results. Compare the results from a high explosive detonation and a propellant burn in a large confined structure, Figure 2. Both events cause a violent pressure rupture of the confining structure! The acceptability of burning reactions can vary to a great degree. An unconfined burn in an open ammunition storage area with a very limited number of neighboring munitions present and with firefighters safely distant may be acceptable. An enclosed shipboard magazine that contains many large tactical rocket motors (1,000's of lbs of rocket propellant) may represent an entirely different scenario. An initial burning reaction may spread very rapidly, overwhelming any potential fire suppression system or human firefighting capability. A mass conflagration such as this, if large enough, could render the vessel terminally, rather than temporarily, inoperable. The future goals of IM must strive to at least limit the extent of a burning reaction and seek to eliminate it altogether. This will be a very challenging future endeavor.

Structural failure from HE ***detonation*** Structural failure from propellant ***burn***

Figure 2. Comparison of results from detonation and burning reactions

IM testing. A final word on IM testing may be in order here as well. The discussion above concerns *life-cycle* implications of IM reaction assessments. But what about the required IM qualification testing. Do the test methods identified in AOP-39 and its associated STANAGs reflect life-cycle conditions for potential IM hazards? Generally so, but one can always argue for THA results to override the general test specifications. But the test methods can be improved to better reflect life-cycle conditions.

A prime example is the test requirement for potential sympathetic reaction hazards. Donor warheads are required to be initiated in the "design mode." This is an extremely unlikely event, more so than accidents or combat threat events for the initiation of the first item in a potential propagation situation. I repeat, external threats are a more likely occurrence and could result in a more or less hazardous situation. A high speed fragment or a shaped charge jet could asymmetrically initiate an unprotected munition. This would result in mass and velocity focused fragmentation projected at neighboring munitions. Conversely, a well shielded munition might defeat a threat fragment or bullet and prevent the initiation of a donor munition with no subsequent sympathetic reaction event occurring. The bottom line here is that a credible THA must be the determining factor (not an option) in identifying the appropriate, albeit most likely, means of initiation for sympathetic reaction testing. Life-cycle factors must override the apparent arbitrary selection of test procedures such as design mode initiation.

New IM goal. Less violent reactions *are* the answer to IM events but how far do we need to go. Type IV, Type V or … Type VI? The ultimate IM response is the *No Reaction* cited in AOP-39 and achievable only in very rare instances right now. But this should become a serious goal for the next 20+ years. This will *not* be easy — the technical challenges are daunting! But are the current IM standards good enough to allow for the most desirable consequences? Probably not. Let's not be complacent with our current IM requirements in the years ahead.

Risks associated with non-compliance. As mentioned earlier, the concept of converting our weapon stockpiles to fully compliant IM is a safety concern and a way to mitigate the risk of exposing our warfighters to unwanted hazards. When we accept the continued use of items that are not fully IM compliant, then risk, safety, operational, cost and other issues arise. Our ability to conduct sustained, continuous operations in a hostile environment can be improved significantly when IM compliant inventories are deployed(3). Are increased risks acceptable, even on an interim basis? Maybe so, but each munition and its unique circumstances must be assessed individually. At the very least a safety and operational risk assessment should be made for any item that's deemed less than fully IM compliant. This risk tolerance should then be the true measure of IM-ness and suitability for service use.

TECHNOLOGY CHALLENGES FOR THE WAY AHEAD

S&T challenges for improved IM. The S&T community that broadly supports all new IM technology initiatives will have many new and continuing challenges in the years ahead. Work has begun to address some of these issues but other issues remain for future investigation. First, let's look at our in-service weapons, many of which may be IM-compliant or nearly so. They often have long shelf lives, 10-20 years in some instances. Surveillance of these weapons, especially components that contain energetic materials, has traditionally been conducted to assess safety and functionality for continued use. Can any change due to aging (i.e., chemical decomposition) be linked to a change in IM characteristics — the response to IM hazards? A recent MSIAC Workshop(4) focused on the effects of aging on IM characteristics and highlighted this topic as a technology challenge for future generations.

Do we really understand the extent of all of the hazards associated with an IM event? Weapon reactions obviously propagate. This occurs for detonations, but what about explosions? Do these "less violent" reactions also propagate? They still can have very serious consequences. It might happen. And what about chain reaction events resulting from the combined effects of IM hazards — a fire (cook-off) causing a munition case rupture that projects fragments to other munitions which may or may not cause still other events (deflagration, explosion or worse)? Our most desirable reaction in IM events is often burning. Even this can lead to an unwanted result. Imagine a ship magazine that takes multiple hits during combat and its IM-compliant munitions burns and overwhelms its firefighting capability. The ship could lose all warfighting capability as a minimum or at worst be lost altogether. Has the goal of IM been achieved? The technology challenge here is to strive for a *no reaction* response in the decades ahead.

The final major technology challenge involves the tools that enable the IM community to design and evaluate new technology and to assess potential solutions to improve safety and mitigate the risks associated with IM hazards. Many of the enabling tools involve our ability to accurately predict the onset of reactions and to determine a level of reaction violence. These tools are very immature at the present time but with our collective resources applied here, we should one day be able to fully develop this capability. This technology challenge is an evolving far term goal.

New IM hazards & threats. We live in an ever-changing world which also means that the threats to our munitions can and will change. Will we see new unplanned stimuli (i.e., IM hazards)? The nature of warfare is changing — new threat weapons are being introduced, tactics employed in hostile environments are changing and weapon interoperability among multi-national forces is becoming more important. The need to prevent collateral damage resulting from both hostile and accidental IM events will be heightened as public awareness of fatal incidents is propagated by the media.

The original IM hazards (circa 1980) were simply defined as heat (fire), shock (blast overpressure) and impact (bullets and fragments). In the past, very little attention has been paid to the very difficult threats like shaped charge jets. This is a very real threat, especially in the global war on terror now (see Figure 3), one that's an emerging IM challenge for the vast majority of our weapons. Will there be other threats in the future — unplanned stimuli such as electromagnetic pulses, chemical contamination, and radiation among others — that the next generation will encounter? The entire IM process must continue to evolve to meet these future demands.

Figure 3. Shaped Charge Jets are the most challenging IM threats

The way ahead. Several changes should occur in the world of IM over the next 20 years, especially with respect to the development of new technology and how this technology is implemented to produce a safer environment for the warfighters. New energetic materials could be developed that should result in Hazard Class 1.2.3 munitions, as well as new shielding materials to mitigate the effects of shock and impact events. The design tools, specifically a major leap forward in a dedicated M&S capability focused on IM issues, will also be needed in the next decade. These changes, however, will only help to meet the current IM standards.

To be truly effective in achieving the overall IM objectives we must seriously consider raising the bar. The ultimate IM standard must be one in which the munition response is nil — strive for a *No Reaction* response. This can be an appropriate response in many, but realistically not all weapon applications. Projecting fragments, large or small, and igniting fires are in most cases an improvement over what we had decades earlier, but their consequences are still not the most desirable.

The emphasis of our future investments in IM technology should increase in the S&T arena. Although there has been work in this area in the past, prior work has concentrated on the demonstration, development and the implementation of quick-fix solutions to existing munitions and their upgrades. Investigate areas associated with IM related *phenomenology* to discover *how and why* munitions respond to various stimuli and how we can change their response. Finally, all of these areas must be included when determining the most appropriate and effective IM solution — energetic materials, components and subsystems, the entire weapon system and even the weapon platforms such as the ships, planes or land-based vehicles that transport and deliver the weapons. This total systems approach is essential to incorporating Insensitive Munitions and creating a safe environment for our future warfighters.

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