Concerns About Trends in Insensitive Munitions Testing

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Introduction

As a member of the U.S. Naval Air Systems Command (NAVAIR) Ordnance Hazards Evaluation Board (OHEB) which evaluates Insensitive Munitions (IM) test results and provides official ratings on the severity of the reactions, I have become concerned with the current state of IM testing. Since I only have limited knowledge of the IM testing and test results evaluation processes in the other U.S. military services or in other nations, please accept these concerns as applying only to the U.S. Navy unless you can see similar issues in your own operations.

I have been working in Insensitive Munitions since 1985 and conducted many of the early IM tests on rocket motors, including work on mitigation devices and in international cooperative programs. I am currently the Director for Energetics Technology for the NAVAIR Weapons and Energetics Department at China Lake, and I believe I can speak on the subject of IM, and my concerns, with some authority. These concerns include the lack of a universal application of the term “Insensitive Munitions”, the paucity of data on reaction severity for a weapon system received by the warfighter and firefighter, the subjective definitions for the reaction types, the deviation from standardized IM tests based upon Threat Hazard Assessments (THAs) as permitted by the current standards and the low level of understanding on the part of the warfighter and firefighter on exactly what all the information he does receive really means. I am very concerned that we will have too many weapons that are designated as IM but which will have a very real probability of killing people and destroying assets when subjected to real-world conditions.

What makes a weapon IM?

Both STANAG 4439 and MIL-STD-2105C define Insensitive Munitions as “munitions which reliably fulfill (specified) performance, readiness and operational requirements on demand, but which minimize the probability of inadvertent initiation and severity of subsequent collateral damage to the weapon platforms, logistic systems and personnel when subjected to unplanned stimuli.” In other words, the weapon must meet all other requirements, but only has to minimize the hazards from IM. Indeed, STANAG 4439 and AOP-39 refer to the passing reaction types for each test as goals, implying they are not hard requirements. But, in the U.S. Navy, though we have the same words and the same standards, the effective meaning of IM is “passing all the tests”. This is quite different. In the Navy, if a weapon system is designated as IM the warfighter, firefighter or rescue worker may assume that it will be difficult to ignite when subjected to an unplanned stimulus and will do nothing more than burn benignly if it did. However, that weapon may well have been designed and developed to merely minimize the hazards, which is a good first step, but it could readily ignite and might actually detonate or explode. This could be deadly.

What data are provided?

STANAG 4439 requires that the nation developing the munition needs to collate and provide the results of IM and other assessments including a munition threat analysis, explosive characterization tests, sub-scale generic testing and the full-scale IM tests. AOP-39 suggests using the data sheets called out in the relevant test STANAGs to present the data which should include the information shown in Table I.

Table I. Information Required in IM Data Sheets

- Characterization data
- Details on test stimuli used
- Modelling techniques used
- Test vehicle specifications
- Measured explosive responses with confidence levels
- Details of reactions and responses to standardized tests

AOP-39 goes on to suggest providing a “signature table” such as the example shown in Figure 1. However, the document notes that this should be “read in conjunction with the detailed data”. I would certainly agree with that statement. While all the data noted in Table I could be quite a bit, the information provided in a signature table could be more dangerous than no data at all and really no better than what those that need this information – the warfighters, firefighters and rescue workers – are provided today which is usually nothing more than the hazard classification of the weapon and the IM test reaction types.

Type of Response								
No Reaction								
V	o	o	o		o		o	
IV								
III				o		o		
II								
I								
	FH	SH	BI	SR	FI	SCJ	Spall	Other

Figure 1. Signature Table Example

IM reaction definitions

The levels of response to the various IM stimuli are defined officially in AOP-39. In the U.S., they are also provided in MIL-STD-2105C. These should be the same, but they are not. In addition, I believe the current definitions are confusing, vague and far too subjective. It is my belief, based on my experiences in the OHEB, that many reactions ruled to have been at one level of violence, could easily have been ruled something else depending on the body making the ruling, the personnel actually present that day, and the manner in which the data is presented. This could also present a future hazard to a warfighter, firefighter or rescue worker if he is expecting a Type V reaction and the weapon explodes. In the paragraphs below I will present the current major differences between the two documents and some of the key words in the definitions that guide the various boards to their decisions. The definitions from AOP-39 are presented with the italicized words in parentheses indicating how MIL-STD-2105C differs. The underlined words and phrases are the key elements of the definition and are discussed in the paragraph immediately below the definition.

Propulsion: A reaction whereby adequate force is produced to <u>impart flight</u> to the test item (*in its <u>least restrained configuration</u> as determined by the life cycle analysis*).

In this case, MIL-STD-2105C provides additional information that could change how a board interprets the result. The AOP-39 definition could allow considerable restraint on the test item to prevent a propulsive reaction.

No reaction: A non-explosive event in which there is no perceptible reaction of the energetic material to the applied stimulus.

There is no definition for “no reaction” in MIL-STD-2105C.

Type I: The most violent type of explosive event. A supersonic decomposition reaction (detonation) propagates through the energetic material to produce an <u>intense shock in the surrounding medium</u> (e.g. air or water) and a very rapid <u>plastic deformation</u> of metallic cases followed by extensive fragmentation. <u>All energetic materials will be consumed</u>. The effects will include <u>large ground craters</u> for munitions on or close to the ground, <u>perforation, plastic deformation or fragmentation</u> (*holing/plastic flow damage / fragmentation*) of adjacent metal plates, and <u>blast overpressure damage</u> to nearby structures.

As can be seen, there is very little difference between the definition of a Type I reaction in AOP-39 and that in MIL-STD-2105C, merely a rewording for clarity. And, this is the least confusing or controversial of any of the definitions. In most cases a detonation reaction is obvious because the shock wave can be observed and the plastic deformation of the case is evident. However, it’s not clear if all the effects noted need to be present for it to be ruled a Type I reaction, or merely one effect. In many of the detonations that the OHEB has seen, many have not produced a large ground crater, but have produced damage to witness plates and considerable blast overpressure. If the amount of energetic material in the test item is small, there would not be a large ground crater or even blast overpressure damage. On indicator of a Type I reaction that seems to be missing from the definition is fragment size. In a detonation, the case fragments are usually very small and because of this much of the case material is never recovered. The small fragment size is included in the Type II definition.

Type II – The second most violent type of explosive event. Some but not all the energetic material reacts as in a Type I response (*detonation*). An intense shock occurs (*is formed*); a part (*some*) of the case is broken into small fragments; a ground crater can be produced, the adjacent metal plates can be damaged as in a Type I response (*detonation*) and there will be blast overpressure damage to nearby structures. A Type II response (*partial detonation*) can also produce large case fragments as in a violent pressure rupture (brittle fracture). The amount of damage, relative to a Type I response, depends on the portion of the material that detonates.

In my years on the OHEB, I have seen few reactions ruled as Type II. The primary indicator is the presence of unreacted energetic material and two size sets for metallic cases. However, since the energetic material that doesn't detonate will often then burn, that's not always apparent. The other issue is fragment size – what does "large" mean? In a Type III reaction, the case fragments can often be very small and numerous, particularly for a rocket motor.

Type III – The third most violent type of explosive event. Ignition and rapid burning of the confined energetic material build up high local pressures leading to violent pressure rupture of the confining structure. Metal cases are fragmented (brittle fracture) into large pieces that are often thrown long distances. The unreacted and/or burning energetic material is also scattered (thrown) about. Air shocks are produced that can cause damage to nearby structures. Fire and smoke hazards will exist. The blast and high velocity fragments can cause minor ground craters and damage (breakup, tearing, gouging) to adjacent metal plates. Blast overpressures *(pressures)* are lower than for Type I or Type II responses (*a detonation*).

This definition can be confusing. The violent pressure rupture can usually be observed and heard. However, how much more violent than a Type IV reaction does it need to be? What are large pieces? The OHEB has ruled many reactions as Type III that had very small pieces. This is particularly true for rocket motors which have thin, brittle cases. How far do fragments need to be thrown before they are considered long distances? In a Type IV reaction, unreacted and burning energetic material is also thrown about. How intense an air shock must be produced? Since pressure or overpressure levels for Type I and Type II reactions are not defined, how can a board judge that a Type III reaction is lower?

Type IV – The fourth most violent type of explosive event. Ignition and burning of the confined energetic materials lead to nonviolent pressure release as a result of a low strength case or venting through the case walls (*closures*) *(*outlet gap, initiation capsule, etc.(*loading port/fuze wells, etc.*)). The case may rupture but does not fragment; orifice (*closure*) covers may be expelled and unburnt or burning energetic material may be scattered about and spread the fire. Pressure releases may propel (*propulsion might launch*) an unsecured test item causing an additional hazard. No blast effect or significant fragmentation damage to the surroundings, only heat and smoke damage from the burning energetic material.

This definition is also confusing. Many discussions have occurred during an OHEB meeting where the debate was on Type IV versus Type V or Type III. Sometimes even Type II gets thrown into the mix. How nonviolent does the pressure release have to be? With a metallic case, this is usually not an issue as the case fragments can be observed launching from the test item. However, for a composite case, those fragments aren't visible. Many OHEB decisions have hinged on what the pressure release sounded like. For a rocket motor, it's very difficult for a high strength case to rupture and not produce some fragments. The OHEB has ruled many reactions as Type IV when case or container fragments have been found many meters away. Indeed, some have been classified as Type V when the fragments have been confined to within 15 meters. Determining if a test item could be propulsive is never easy. So much depends on how it's been constrained. With the way the items are constrained at China Lake (hanging from an A-frame for most of the tests), propulsion can usually be seen as the test item will shift in one direction upon reaction. However, if it's more securely restrained (many test items have the head end butted up against a restraint to prevent movement) a propulsive reaction many not be obvious.

Type V – The least violent type of explosive event. The energetic material ignites and burns non propulsively. The case may split up non-violently; it may melt or weaken sufficiently to allow slow release of combustion gases; the case covers may be dislodged by the internal pressure. (*The case may open, melt or weaken sufficiently to rupture nonviolently, allowing mild release of combustion gases.*) Debris stays in the area of the fire although covers may be thrown up to 15 meters. This debris is unlikely to cause fatal wounds to personnel. (*Debris stays mainly within the area of the fire. This debris is not expected to cause fatal wounds to personnel or be a hazardous fragment beyond 15 m.*)

This reaction is usually obvious as the OHEB leans heavily on the requirement to have no hazardous fragments beyond 15 meters. However, what is a non-violent split of the case? With a large amount of propellant, a rocket motor produces gas very quickly and the case split can seem anything but non-violent. However, we usually rule it a Type V reaction if there are no fragments beyond 15 meters, even if there is a large fireball and burning debris raining down. With 1300 pounds of propellant, there is never a slow release of combustion gases. On the other hand, a very small rocket motor could burst its case very violently and still seem to release the gases slowly.

In the previous paragraphs, I have noted some of the issues with the definitions. AOP-39 does provide some further interpretation, though this additional material is often not used. For example, for a Type IV reaction, it states that the case won't fragment into more than three parts and the pressure is less than 50 mbar at 15 meters. This sounds like it should help. However, for a rocket motor, you can easily have more than three parts for even a Type V reaction as the end closures can both come off, the arming firing device and igniter can dislodge, fragments could be formed from the impact of the bullet or impinging fragment, and the nozzle retention ring could fly away. And, if it's a composite case, there could literally be thousands of separate fibers. For a Type V reaction, AOP-39 offers that the pressure should be under 50 mbar at five meters, there should be no fragment over 79 joules or over 150 grams beyond 15 meters and the heat flow should be less than 4 kW/ m^2 at 15 meters. How do you determine if the fragment had a velocity that equated to over 79 joules? The 150 grams is easier, but has rarely been used in the OHEB. And, no test that I've ever seen has measured the heat flow. Indeed, many OHEB rulings of Type V reactions undoubtedly had a heat flow greater than that indicated.

However, the main problem with this additional information is that it's not clear how it should be applied. If one of the measurements or observations indicates a Type V reaction, but another indicates a Type III, should it be rated a Type III for the worst case, or should the results be averaged to a Type IV?

It's my understanding that a revision of AOP-39 is in progress. Hopefully, many of these definition issues can be cleared up. Today, there is considerable debate among the OHEB members about the reaction level. That's good. However, in the end, the ruling is usually based upon the experience of the more senior members, myself included. That may not be good.

Here is an example of the problem. I'm providing the data for a slow cookoff test of a certain item, called DT1-410, which was a warhead with simulants for other missile components in a canister,. Table II is a description of the events from the start of the test until the reaction. The mist referred to in the description was from liquid fuel which was part of the test item. A non-standard heating rate was used, but it was in accordance with an approved Threat Hazard Assessment (THA). Figure 2 is a map of the debris. Table III is a description of the debris. There were two pressure "gages". They were what is known a Bikini Gages, consisting of holes of various sizes in a metal plate that are covered by aluminum foil. They indicate the level of pressure by which size hole, if any, has the foil ruptured. In this test, Bikini Gage 1 was 50 feet from the centerline of the test item, 45° forward and to the left. Only the largest hole was affected, with a 1¾- by 2-inch tear shaped roughly like a triangle. Bikini gage 2 was also 50 feet from the centerline, but 45° aft and to the right of the test item. Its largest hole had a 2-inch long tear, the next largest hole had a ½ by ½-inch square hole, and the third largest hole had a 1/8-inch diameter hole. However, in the test report the test manager indicated that he believes the ruptures were from debris hitting the foil rather than from overpressure and estimated the pressure to be under 1 psi. The witness plate had no damage. Unfortunately, in this paper you will not be able to see or hear the reaction, but you can get a fairly good idea of what it looked and sounded like from the description. How would you have ruled?

Table II. SCO Test DT1-410 Description.

Time, hr:min:s	Temperature, °F	Description of Event
00:00:00	65	Oven air temperature was ramped from 65 to 80°F in 30 minutes.
00:30:00	80	Oven air temperature ramping at 40°F per hour began.

08:30:00	400	Oven air temperature reached 400°F and was held at that level.
19:53:20	400	A reaction, accompanied by a loud roaring booming sound, occurred; and material was seen spraying and dispersing in all directions. Flames were seen near the forward end of the setup. While much of the material emanating from the oven appeared to be in a mist form, larger objects were also being dispelled. Burning of the disbursing material initiated from the forward end of the setup and progressed rapidly through the material being dispelled forming a large fireball. Its intensity eventually caused a "wash out" of the video cameras.
19:53:22	N/A	The video cameras' visibility was restored. Remnants of a fireball, whose size was larger than that of the video viewing area, were observed and debris were seen falling to the ground. After the fireball subsided, flames from the burning material, with their intensity decreasing with time, were seen in and around the site. The greatest intensity occurred in and near the fuel retainer vessel.
20:00:00	N/A	The intensity of burning had decreased significantly.

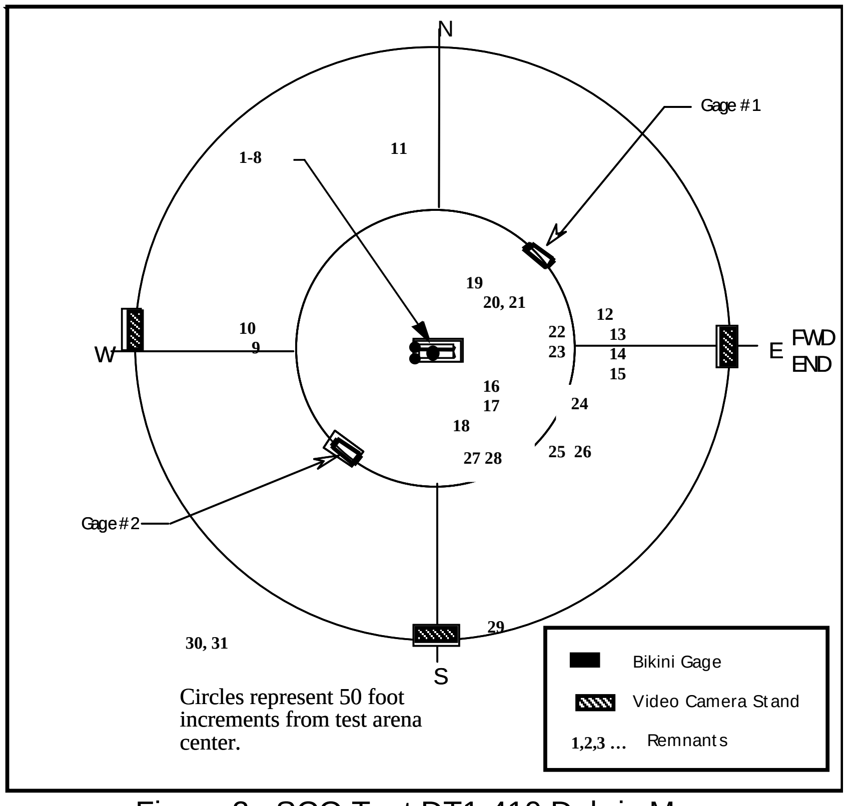

Figure 2. SCO Test DT1-410 Debris Map

Table III. SCO Test DT1-410 Debris Description

	Description	Size, inches	Weight, pounds	Location or Feet From Arena Center
1	Section of warhead case (empty), attached to piece of canister	24.75 × 18	920	At center
2	Section of empty warhead case with fuzewell and dummy fuze	40 × 18	142	At center
3	Piece of nose cone	17.5 × 9	4.06	At center
4	Piece of nose cone	8 × 6.25	2.13	At center
5	Launcher guide pad	6.25 ×y 6	4.44	At center
6	Launcher guide pad	6.25 × 6	4.92	At center
7	Aft mass simulator	20 .5 × 13	4.19	At center
8	Piece of melted aluminum	11 × 7	3.0	At center
9	Piece of nose cone	12.5 × 10.25	2.78	60
10	Piece of canister	9.5 × 6.0	3.08	64
11	Piece of nose cone	45 × 22	10	66
12	End seal for canister	24.75 × 24.74	3.14	66
13	Piece of nose cone	17.5 × 11	2.69	70
14	Piece of nose cone	19 × 14	3.0	70
15	Piece of nose cone	7.25 × 5.25	0.54	70
16	Piece of nose cone	8.5 × 3	1.12	16
17	Piece of nose cone	13 × 11	1.72	18
18	Piece of nose cone	20.5 × 6	6.09	18
19	Piece of nose cone	7.5 × 3.5	0.23	20
20	Piece of nose cone	9.5 × 4.75	0.35	20
21	Piece of nose cone	3.75 × 3.0	0.10	20
22	Piece of nose cone	5.75 × 3.75	0.13	43
23	Piece of rubber liner	6.15 × 4.0	0.116	41
24	Piece of nose cone	4.5 × 2.0	0.10	57
25	Piece of nose cone	5.75 × 3.0	0.05	57
26	Piece of nose cone	11.45 × 3.5	0.48	63
27	Piece of nose cone	3.25 × 3.5	0.08	47
28	Piece of nose cone	4 × 2.75	0.68	45
29	Piece of nose cone	7 × 3.25	0.15	100

30	Piece of canister	26 × 8	3.25	Approx. 110 feet
31	Piece of canister	10.25 × 8	1.37	Approx. 110 feet
32	Numerous pieces of explosives	Various sizes	48.18	Within a radius of 335 feet

Though there were numerous fragments, the OHEB ruled this was a Type IV reaction as the main part of the test item, the warhead case, remained in the center of the test arena and was only in two pieces.

<u>IM testing in accordance with approved THAs</u>
MIL-STD-2105B and previous versions required that the IM tests be conducted in certain ways with variation allowed if supported by an approved THA. The standard tests included a slow cookoff (slow heating) test at 3^{o}C per hour until reaction, a fragment impact test with a “Fragmat” that would throw a specified number of fragments or a single fragment at 2530 meters per second, and a bullet impact test using three 50-caliber bullets. Variations to this were rare, though they were occasionally done. This is really no different today with STANAG 4439 and MIL-STD-2105C, though some of the standard tests have changed. Everyone agreed that the standard tests had little “reality”, but provided a comparison between the tests. And, the tests were very hard to pass.

Today, the programs have increasingly embraced the alternate tests. They have rigorous THAs which indicate the most likely threats, and the tests are conducted replicating these threats. The argument is that these tests are closer to the “real world”. However, there is no longer a ready comparison between the tests. One other consequence is that more test results are ruled as “passing”. There is no intent on my part to indicate that anyone is “gaming” the process. Rather, they are strictly following the approved procedures. However, the result will be the same. We will have accidents were people will be unnecessarily killed or injured.

Some of the alternative tests that have been permitted due to the THA have been different slow cookoff heating rates, barriers for bullet and fragment impact to replicate ship structures, different caliber bullets, and lower velocity bullets and fragments. In each case, the test approximated the most likely threat to the weapon system. The one thing to remember is that the STANAGs only require a limited number of tests, usually two, and usually with the same threat. I know that a more thorough test series is done in some nations, but in the U.S. Navy, the standards are normally strictly followed.

One example of the problem was what started my quest to make people more aware of the IM testing issues. One program asked the OHEB to rule on the reaction level of a bullet impact test on a warhead. The THA had indicated that the most likely bullet threat was a single 7.62- by 51-mm NATO full metal jacket round at 2300 fps. Two tests using that round were conducted. The tests were conducted perfectly. In each instance, the OHEB ruled that the item passed the test – there was no reaction at all. However, in both tests, the bullet did not penetrate the warhead case! The part that is worrisome is that we don't know what would happen if the caliber was increased to the point where it did penetrate. While that round may have been the most likely threat, it was certainly not the most dangerous possible threat. We cannot control what bullets are shot at that warhead. It's unrealistic to conduct the test in only one way for what is essentially a stochastic process.

Do they really understand?

What do the warfighters and firefighters really know about the weapons and their IM reactions. As indicated throughout this paper, not enough. They usually only know the reaction type. Other required information may be available, but it's not specifically provided, used or understood. They certainly do not know how the weapon was tested, and it's doubtful that they really know what the reaction types really mean to them.

Recommendations

First, the definition of an Insensitive Munition needs to be consistently applied throughout the world. Second, the definitions need to be reworked and not as subjective. As noted earlier, hopefully the changes coming to STANAG 4439 and AOP-39 will correct this problem. Third, if the testing is really going to be "real world", then more than a couple of tests should be required. The range of threats needs to be evaluated, not just the most likely. Finally, we need to provide training and information to our warfighters, firefighters and rescue workers. They need to understand the definitions and they need to have at their ready disposal all the data required by STANAG 4439 and AOP-39. The purpose of insensitive munitions is not to pass the tests – it's to save lives and protect our assets.

References

AOP-39	Guidance on the Development, Assessment and Testing of Insensitive Munitions
MIL-STD-2105B	Hazard Assessment Tests for Non-Nuclear Munitions
MIL-STD-2105C	Hazard Assessment Tests for Non-Nuclear Munitions
STANAG 4240	Liquid Fuel/External Fire, Munition Test Procedures
STANAG 4241	Bullet Impact, Munition Test Procedures
STANAG 4382	Slow Heating, Munition Test Procedures
STANAG 4396	Sympathetic Reaction, Munition Test Procedures
STANAG 4439	Policy for Introduction, Assessment and Testing for Insensitive Munitions
STANAG 4496	Fragment Impact, Munition Test Procedure
8020, Ser478000D/2439	Ordnance Hazards Evaluation Board (OHEB) Meeting Minutes of 21 April 2005; 28 Apr 05
8020, Ser478000D/3454	Ordnance Hazards Evaluation Board (OHEB) Meeting Minutes of 26 May 2005; 20 Jun 05