IM Testing and Assessments

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ABSTRACT:

The introduction of new technology to enable munitions and weapon systems to reduce their vulnerability to safety-related hazards and hostile threats requires a means to ensure the suitability and effectiveness of this technology. Verification by means of large scale testing is necessary to achieve this end. Test requirements have been established and agreed upon by the international community for this process. This chapter will provide a detailed description of this testing and how to interpret the test results. The test results are used as part of an overall assessment to determine an IM signature for a munition and for suitability to be designated as an "insensitive munition." Unique national policies require different methodologies used by three NATO nations. These assessment methodologies will be discussed and compared for the IM assessment process.

1. IM TESTING – WHY, WHAT AND HOW

By now, you've heard the story of the origin of insensitive munitions and the urgent need to minimize the inherent dangers and hazards associated with the transport, handling, storage and deployment of munitions used by our warfighters. These dangers exist in both friendly and hostile environments. We strive to remake our weapons and populate our inventories with items that can be labeled "insensitive munitions." We do this to save lives, to protect our assets, both weapons and weapon system platforms, and to preserve or maintain our operational warfighting capability. IM testing may be a strict requirement now in many NATO nations, but it's a means to an end – a measuring stick to ensure improved weapon safety and decreased risk for the occurrence of unplanned hazardous events.

1.1 IM Testing as a Subset of System Safety Testing

The primary purpose of full-scale IM testing is to establish the response of a munition to unplanned stimuli when tested under specified conditions. This information can then be used to determine compliance with national IM policies. There are additional reasons for conducting full-scale IM testing which make an important contribution to the safety assessment of a munition. These are mentioned in a Best Practice Guide[1] (published in the UK in 2005) and are summarized below.

- IM testing provides a measure of the munition's response to each hazard or threat and enables an assessment to be made of the likely ***collateral damage*** from the munition's reaction, which can be used to evaluate the ***risk*** posed by the response of the munition.
- IM testing results can evaluate or determine the need for appropriate mitigation and risk reduction measures.

1 "IM Testing – A Guide to Best Practice", Issue 1.0, August 2005. Document released by the UK's IM Assessment Panel, DOSG, Abbey Wood, UK

- Other purposes of full-scale IM testing include: evaluating the effectiveness of external mitigation concepts such as packaging and barriers; and establishing the IM characteristics of specific design concepts during development and technology demonstrator programs.

The UK's Best Practice Guide continues with these important distinctions.

- IM testing differs from all other ordnance and munitions safety testing in that the pass criterion for each test most often involves a violent response.
- For all other safety testing, the pass criterion is that there should be no explosive response and the munition is expected to remain safe, either for use or for disposal.
- For IM testing, the reaction of the munition under test may range from full detonation to no reaction but also may include responses with varying degrees of severity between these extremes. The difficulty in full-scale IM assessment is in determining which level of response occurred.
- Analysis of IM testing often requires differentiating between the intervening categories of the IM response levels and requires specific evidence, generally of a quantitative nature, which must be evaluated by expert assessors.
- The results of the IM Assessment process define the ***IM signature*** for a munition.

1.2 Evolution of Large Scale IM Testing

Large scale system safety testing conducted 50 years ago in the US became the foundation of our present day IM test standards. In 1964 a system safety directive, WR-50, was established by the US Navy[2] to record warhead vulnerability characteristics and certain safety-related characteristics. These included fast and slow cook-off information and bullet impact response. No pass/fail criteria were identified but the resulting response to the thermal or impact stimuli was to be recorded as well as the time-to-reaction for the thermal events as an aid to the firefighters. As the IM program was later formally established in the US, so too were the IM test requirements. The US Navy took the lead in the formulation of these requirements, which eventually became joint service requirements within the US. IM acceptance was achieved throughout the international community and the test requirements soon followed with the help of NATO. The following list highlights the evolution of large scale IM testing[3].

- **1964** – NAVSEA established warhead vulnerability test requirements in WR-50.(FCO, SCO, BI)
- **1977 –** MIL-STD-1648 established requirements for ordnance exposed to aircraft fuel fire. (precursor to FCO test as STANAG 4240)
- **1982 –** WR-50 published as MIL-STD-2105.
- **1984 –** OPNAV established IM policy and program. NAVSEA directed to develop, publish, and maintain technical requirements.
- **1985 –** NAVSEA published IM technical requirements in NAVSEAINST 8010.5. (FCO, SCO, MBI, FI, SD)
- **1991 –** IM technical Requirements included in MIL-STD-2105A (Navy).
- **1994 –** MIL-STD-2105B becomes Joint Service Requirements document.

2 Beauregard, Raymond, "History of the US Navy's IM Program", 24 January 2005

3 Blashill, Stuart, technical paper, "Concerns About Trends in Insensitive Munitions Testing", Proceedings from the 2006 Insensitive Munitions & Energetic Materials Technology Symposium, Bristol, UK, October 2006.

- **1995 –** NATO established IM policy and technical requirements.
- **2003 –** US incorporates NATO technical requirements in MIL-STD-2105C. (test requirement by individual STANAGs)
- **Present –** IM technical requirements amended as per NATO agreement and Joint Service coordination (US).

1.3 IM test requirements & descriptions

IM hazards and threats are either thermal events or shock and impact events. Six unique tests have been developed to represent these IM events. These tests are summarized in Figure 1.

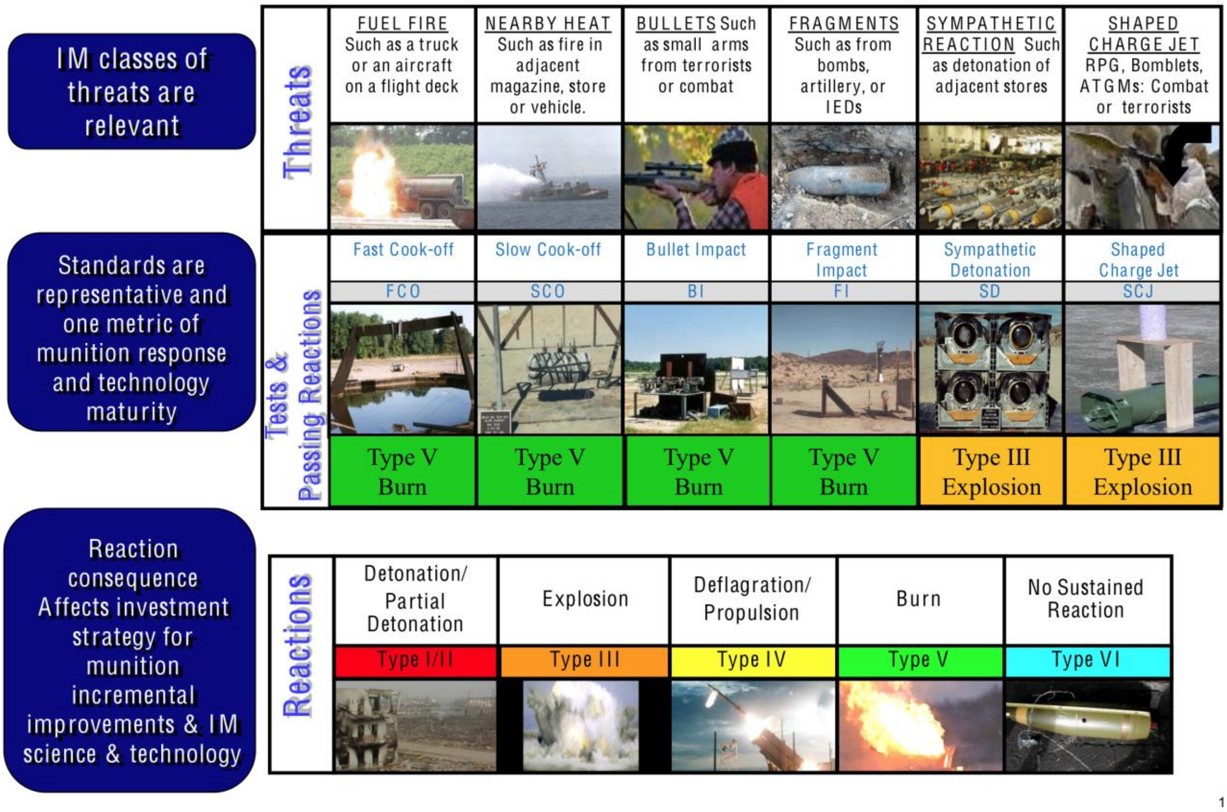

Figure 1: Summary of IM Technical Requirements

There are two over-arching documents that provide guidance for IM testing. STANAG 4439, *Policy For Introduction And Assessment Of Insensitive Munitions*[4] cites all of the STANAGs that set forth the requirements and provide guidance for the individual IM tests. Additional critical information is provided in AOP-39, *Guidance On The Assessment And Development Of Insensitive Munitions*[5]. This document includes test requirements, test protocols, a list of the response descriptors and an assessment methodology for the IM

4 STANAG 4439, Edition X, "Policy For Introduction And Assessment Of Insensitive Munitions", March 2010

5 AOP-39, Edition 3, "Guidance On The Assessment And Development Of Insensitive Munitions", March 2010

Signature. Examples of a simplified and a detailed test protocol are given in Figures 2 and 3, respectively. The response descriptor and assessment methodology topics will be discussed later in this chapter. A synopsis of the individual IM tests is provided in the following paragraphs.

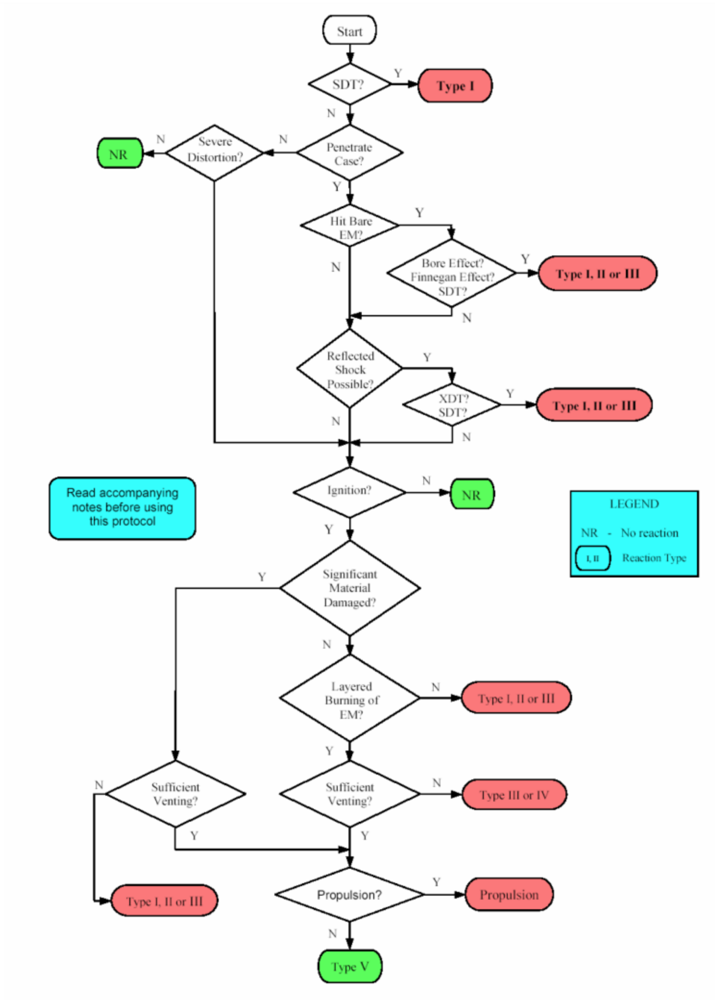

Figure 2: Simplified Hazard Protocol for Bullet and Fragment Impact Tests.

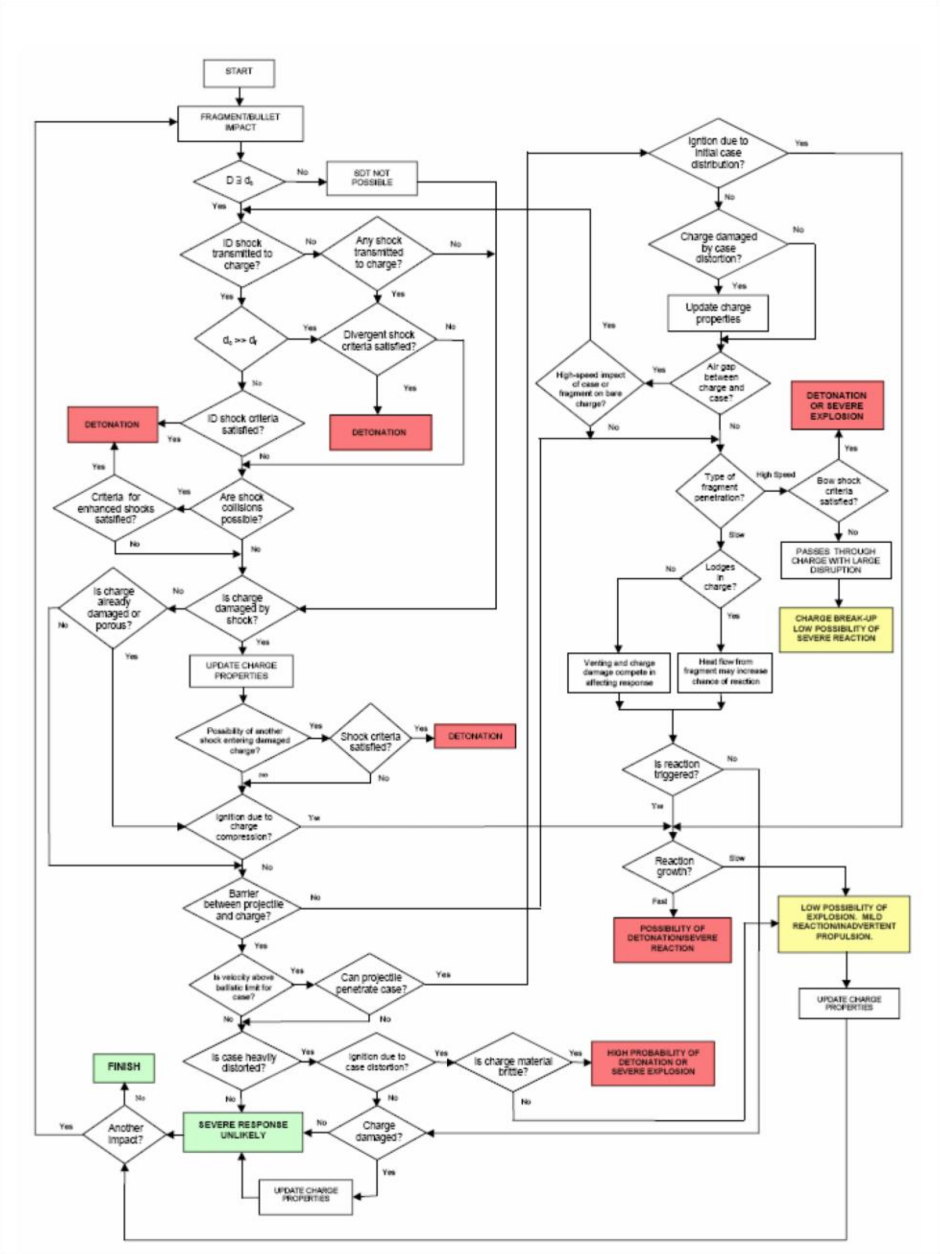

Figure 3: Detailed Hazard Protocol for Bullet and Fragment Impact Tests.

Fast Cook-off Testing: The requirement to test for a fast heating hazard comes from the ignition of liquid fuel fires such as burning aircraft fuel on a flight deck or burning diesel fuel from a truck as a result of a transportation accident. These types of incidents thus require exposure of the test item configuration to heat fluxes generated within the incandescent flame envelope of a large liquid hydrocarbon fuel fire.

STANAG 4240[6] provides guidance and procedures for fuel fire tests. Extensive test details are given in this STANAG. However, a summary of the test requirements taken from this STANAG is given below:

> "The test consists of engulfing the munition in a fuel fire and recording its reaction as a function of time. The munition is placed one meter above the burning fuel and the test is terminated upon completion of the reaction of the munition. In the standard liquid fuel/external fire test, the test specimen is surrounded by fuel rich flames from a large open hearth containing liquid fuel. The large horizontal dimensions of the hearth ensure that the flames are fuel rich and hence heat transfer to the test specimen is approximately 90% radiative. The fuel fire tests are designed only to simulate the most intense heating conditions likely to be created in a hydrocarbon fuel fire. They do not, however, simulate a particular in-service or accident scenario.
>
> The test item must be to the full production standard, although non-explosive sections of the item need only be geometrically and thermally representative. For all-up rounds that contain more than one major energetic component (such as rocket motors and warheads), the energetic components may be tested either individually or as an all-up round. Where it is determined that only packaged items will be exposed to accidental liquid fuel fires in the service environments (including storage, transport and processing), tests should be conducted with the test item in the packaged configuration."

Slow Cook-off Testing: The requirement to test for a slow increase in the thermal environment such as a fire in an adjacent magazine, store or vehicle. These types of incidents require exposure to a gradually increasing thermal environment at a rate of 6° F/hr.

STANAG 4382[7] provides guidance and procedures for Slow Heating (slow cook-off) tests. Extensive test details are given in this STANAG. However, a summary of the test requirements taken from this STANAG is given below:

> "The objective of the Slow Heating test is the assessment of the reaction and time to reaction, if any, of a munition when subjected to a slow heating environment. In Slow Heating tests, a substantial part of the explosive material may reach hazardous temperatures before ignition occurs. Subsequent events are likely to be more violent than those that occur in Fast Heating tests.
>
> The test item must be to the full production standard, although non-explosive sections of the item need only be geometrically and thermally representative. For all-up rounds that contain more than one major energetic component (such as rocket motors and warheads), the energetic components may be tested either individually or as an all-up round.
>
> The test is usually performed by placing the test item in a disposable oven and heating the item with circulating heated air. The test facility shall be capable of increasing the air temperature at the prescribed rate throughout the anticipated temperature range and maintaining a reasonably uniform temperature in the air around the test item. The oven should be constructed so as to provide the least possible confinement for any reactions that occur and it should have a window to permit video coverage. Temperature as a function of time should be recorded at multiple positions.

6 STANAG 4240, Edition 2, "Liquid Fuel / External Fire, Munition Test Procedures," April 2003

7 STANAG 4382, Edition 2, "Slow Heating, Munition Test Procedures," April 2003

> Using the facility, test set-up, and instrumentation specified in the test plan, subject the test item to gradually increasing temperatures at a rate of 6° F/hour, until a reaction occurs, and record its reaction as a function of time and temperature."

Bullet Impact Testing: The requirement to test for bullet impact threat from small arms during terrorists or combat events. These events require the test item to be impacted by a three-round burst of 0.50 caliber AP projectiles.

STANAG 4241[8] provides guidance and procedures for Bullet Impact tests. Extensive test details are given in this STANAG. However, a summary of the test requirements taken from this STANAG is given below:

> "It is necessary to assess the likely response of munitions that may be exposed to deliberate bullet/projectile attacks. These can occur in peacetime as the result of saboteur activity or in wartime as a consequence of enemy action. Munitions that are stowed in unsheltered stores, magazines or launchers are considered to be particularly vulnerable. The bullet impact test can only represent a particular set of conditions since it Is not possible to test to the wide range of attack weapons, sizes of fragments, strike velocities or angles of attack which may occur in the real world.
>
> The test item shall normally be positioned with Its longest axis horizontal on a suitable stand at a height to facilitate ease of testing. If necessary, the item may be strapped or restrained by other means to prevent it from becoming propulsive, but such restraint is not to interfere with instrumentation nor significantly affect the ability of the warhead or motor case to rupture or fragment.
>
> Two tests are required, one aiming at the largest explosive component, and the other aimed at the most shock-sensitive explosive component (excluding the booster). The target area shall be a 5cm circle. For bullet impacts, a range of approximately 20-30m to the target (sufficient for bullet stabilization) is acceptable. The impact velocity must be adjusted to 850 +/- 20 mps and the rate of fire shall be equivalent to 600 +/-50 rounds/minute."

Fragment Impact Testing: The requirement to test for a shaped charge jet threat comes from combat or terrorist events where bombs, artillery shells or IEDs are detonated. These types of events thus require the test item to be subjected to the effects of a high-velocity impact of a calibrated fragment representative of a bomb or artillery fragment.

STANAG 4496[9] provides guidance and procedures for Fragment Impact tests. Extensive test details are given in this STANAG. However, a summary of the test requirements taken from this STANAG is given below:

> "The intent of this test is to expose a munition to the effects of a fragment impact to determine the reaction of the munition and to provide an indication of the effectiveness of safety barriers or other devices used to limit the severity of the fragment impact. The fragment to be fired at the test item must be a right circular cylinder with a conical tipped nose with a mass of 18.6 grams (specific details provided in the STANAG). Two test procedures are identified for this test: a standard procedure where the fragment impact velocity is 8300 +/- 300 fps; or an alternate procedure where the fragment impact velocity is 6000 +/- 200 fps (if deemed credible by a threat hazard analysis). The point of impact of the fragment will be chosen in order to generate the worst reaction: one test is conducted with impact in the center of the largest presented area of energetic material or component and the second in the most shock sensitive region."

[8] STANAG 4241, Edition 2, "*Bullet Impact, Munition Test Procedures*," April 2003

[9] STANAG 4496, Edition 3, "*Fragment Impact, Munition Test Procedures*," March 2010

Sympathetic Reaction Testing: The requirement for this test is to determine if a sympathetic reaction response results when a detonation of an adjacent munition occurs as a result of an accident or hostile event.

STANAG 4396[10] provides guidance and procedures for Sympathetic Reaction tests. Extensive test details are given in this STANAG. However, a summary of the test requirements taken from this STANAG is given below:

> “The purpose of this test to: subject one or more acceptor munitions to the effects of the worst case credible reaction of an identical donor munition, in the in-service situation assessed to be the most likely to result in sympathetic reaction; determine the sympathetic reaction sensitivity of munitions; and provide an indication of the effectiveness of safety barriers or other devices used to separate either single, packaged, or multiple packages of munitions. The test is generally not required for IM if the item will not detonate.
>
> The test items should be in their storage/transport configuration, but in the smallest configuration (smallest individual package) offered. The test items (donor and acceptors) must be to the full production standard, although non-explosive sections of the items need only be geometrically and thermally representative.
>
> In the case of a storage stack, the donor munition should be surrounded by the acceptor munitions, with similar but inert munitions providing the outer containment. Where protection devices are used with the objective of reducing the likelihood of sympathetic reaction, they shall be included in the test configuration.
>
> Two tests shall be performed – one with confinement and one without. Any confinement should represent that of a typical storage confinement.”

Shaped Charge Jet Impact Testing: The requirement to test for a shaped charge jet threat comes from combat or terrorist events where rocket propelled grenades, land mines, airborne bomblets or guided weapons are deployed. These types of events thus require the test item to be subjected to a direct hit from a representative shaped charge jet.

STANAG 4526[11] provides guidance and procedures for the Shaped Charge Jet Impact test. Extensive test details are given in this STANAG. However, a summary of the test requirements taken from this STANAG is given below:

> "This test consists of subjecting the test item, in either its logistical or tactical configuration, or both, as stated in the approved test plan, to the impact of a jet from a shaped charge. Applicable shielding should be included.
>
> The test is most appropriate for systems containing materials having a detonation failure diameter significantly larger than the jet diameter. Systems containing materials with small failure diameters, including most warheads, will normally fail this test. Consider this when determining whether or not to conduct the test. I other data indicate that the test Item is very unlikely to pass the test, do not waste resources by conducting a test whose result is known in advance. The test may also be unnecessary If it can be reliably shown that the detonation failure diameter of the energetic material Is larger than the diameter of the munition (so that a detonation cannot be sustained), and if the threat hazard assessment Indicates that reactions less severe than Type I or Type II are not a concern.

10 STANAG 4396, Edition 2, “Sympathetic Reaction, Munition Test Procedures,” April 2003

11 STANAG 4526, Edition 1, “Shaped Charge Jet Impact, Munition Test Procedures,” October 2002

The test item must be to the full production standard, although non-explosive sections of the item need only be geometrically and thermally representative. For all-up rounds that contain more than one major energetic component (such as rocket motors and warheads), the energetic components may be tested either individually or as an all-up round. The item may be either packaged or unpackaged.”

The IM Signature: There have been several references above to an IM Signature. The results of the tests described above are the roadmap to the IM Signature. AOP-39 describes in detail how to arrange this information in a table to visually present an IM Signature for a weapon. This is presented in Tables 1 and 2 below. Another variation on this topic is the grouping of several munitions in the color-coded format (often referred to as a "stoplight chart"). A notional example of a stoplight chart is presented in Figure 4.

Color Coding	IM Compliance	
Green	IM requirement fulfilled.	Pass (P)
Yellow	IM requirement not fulfilled - one response level difference between the assessed response level and the IM requirement	Fail (F)
Red	IM requirement not fulfilled - two or more response levels difference between the assessed response level and the IM requirement	Fail (F)
White	Not Assessed (N/A)	Not Assessed

Table 1: IM Signature Color Coding

		FH (FCO)	SH (SCO)	BI	FI	SR	SCJI
Configuration 1		Type V	Type V	Type VI	Type IV	N/A	Type III
Configuration 2		Type III	Type IV	Type IV	N/A	N/A	Type I
Configuration 3	Warhead	Type III	N/A	Type VI	Type V Main Charge Type III Booster	Pass	Fail
Configuration 3	Rocket Motor	Type IV	Type V	Type V 0.50 AP Type IV 7.62 ball	N/A	N/A	(Pass)
Configuration 3	AUR	(Type I)	Type V	Type IV	Type III	Pass	Fail

( ) = assessed by analysis

Table 2: Example of IM Signature with Response Type + Color Coding

List of Munitions	FCO	SCO	BI	FI	SR	SCJ
Small caliber artillery ammunition	(III/IV)	III	V	III	(P)	UKN
Large caliber artillery ammunition	(V)	(IV)	(V)	(III)	(F)	(F)
Small guided missile warhead	IV	III	IV	I	F	(F)
Small guided missile rocket motor	IV	I	I	III	P	F
Large guided missile warhead	V	I	III	I	F	(F)
Large guided missile rocket motor	(V)	(III)	(V)	(V)	(P)	(F)
Small free-fall bomb	IV	III	IV	I	F	F
Large free-fall bomb	IV	III	V	IV	P	F
Air-launched rocket warhead	III	I	III	I	F	F
Surface launched torpedo	(IV)	(IV)	(V)	(IV)	(P)	(P)
Pyrotechnic device XYZ	IV	IV	(IV)	(IV)	(P)	(P)
High velocity penetrator warhead	(V)	(V)	(IV)	(IV)	(P)	(P)

Figure 4: IM Signature Summary – Multiple Munitions (hypothetical example of a stoplight chart).

2. IM TESTING – A PROCESS EVOLUTION

Test Plan Development: As described earlier, all IM testing specifically intended for IM qualification purposes must be conducted in accordance with the requirements set forth in STANAG 4439 and AOP-39. Individual plans may then be written to describe the details of each test but a comprehensive Test Plan that documents all of the test activities of an IM test program must be written. The Test Plan is normally submitted to a national review authority for review and approval BEFORE the commencement of any testing. This is to ensure that all required procedures are correctly in place and any proposed test deviations (from standard requirements) are appropriately approved.

How much testing is required for any acceptable IM test program? The requirement documents stipulate that each test be conducted only two times. Is this really enough? Two tests, even if producing the same result, are certainly NOT statistically significant to ensure continued success. We'll never really be sure if risk is *totally* mitigated. In most instances, the expense of additional tests and the cost of the test items can be an intolerable burden for a weapon development program. Single or double success for a test event does give an *indication* with limited assurance of risk mitigation and will continue to be the acceptable test standard.

In the early days of IM testing the test items were tested "bare," that is, separate from any adjoining weapon components, logistic container or launching system items such as canisters. However, testing that is intended to replicate "real world" conditions must be reflected in the configurations of the test items. For example, in the US the JROC mandated joint IM Test Standards[12] that specified the configurations necessary for each test. Either logistical or tactical configurations, defined below, were required for final IM tests. The JROC requirements are shown in Figure 5.

> **Logistical Configuration (Storage, Shipping, or Transportation):** The logistical configuration is intended to be synonymous with the packaged configuration in which the munition is stored, shipped, or transported. In the event that a munition has different storage, shipping, or transportation configurations, multiple configurations or at least the configuration expected to result in the reaction providing the maximum credible event will be tested.

[12] "*Standardization of IM Tests and Passing Criteria*, " JROCM 235-06 Memo 2006, US Joint Requirements Oversight Council

Operational Configuration: The operational configuration is intended to be synonymous with the tactical configuration in which a munition is ready to be employed as in an All-Up-Round (AUR) in a bare state. In the case where a munition is not removed from its packaging and shipping container prior to employment, the logistical configuration testing should be replicated where standardized testing specifies any operational configuration tests.

	Threat	Passing Criteria	Comments	STANAG
FCO 	Liquid Fuel Fire (e.g., truck or an aircraft on a flight deck)	Type V (Burning)	Stimulus: rapid heating Required for HC	4240
SCO 	Slow Heating 3.3 °C/Hr (e.g., fire in adjacent magazine, store or vehicle)	Type V (Burning)	Stimulus: slow heating Heating rate study needed Required for reduced HC	4382
BI 	.50 Cal M2AP 3 round burst (e.g., small arms from terrorists or combat)	Type V (Burning)	Stimulus: low level kinetic impact More severe threats exist. Consider other threats Required for reduced HC	4241
FI 	18.6 gram fragment 8300 +/- 300 fps (e.g., bombs, artillery, or IEDs)	Type V (Burning)	Stimulus: shock, mechanical & thermal damage Artillery fragments slower but some KE & EFP threats more severe	4496
SD 	Detonation of a single donor (detonation of adjacent stores)	Type III (Explosion)	Stimulus: output of adjacent munition Does not address mixed stores & multiple donors Required for HC	4396
SCJ 	81-mm Precision shaped charge (e.g., RPG, Bomblets, ATGMs: Combat or terrorists)	Type III (Explosion)	Stimulus: shock & mechanical damage More severe threats exist but acceptable test standard	4526

Figure 5: Standardized IM Tests and Passing Criteria

A final thought on test planning. It should be noted that the guiding documents permit deviations from the specified test requirements if a threat hazard analysis indicates that an alternative threat scenario is more likely for an IM event. An alternate test procedure such as a slow heating rate or a threat fragment striking velocity could be deemed more appropriate. However, the US mandate for IM testing is clear – thoughtful consideration has been given to the test standards for both IM and hazard classification. The testing shall be conducted, using the configuration described above, *without* deviation. THA-based test deviations will only be allowed with rare exceptions in the US.

IM Test Data: Long ago, safety trials, yes, even the rudimentary IM tests were conducted with minimal instrumentation. Evidence of success or failure relied on a single query: "*to boom or not to boom – that is the question!*" We must be more discerning than relying on a simple yes/no outcome. An IM event can result in varying degrees of goodness (or badness). This outcome must be characterized to the greatest degree possible. AOP-39 lists 6 response types to characterize the outcome of IM and hazard classification testing. Each test event presents an opportunity to gather evidence to enable subject matter experts to assess the event and determine the response type.

Photo coverage is a must: before/after still shots as well as extensive video coverage (near/far field, high speed or real time, internal to the test item if possible); witness panels to record collateral damage; blast overpressure data; and most importantly, debris collection (number of pieces, size and shape, origin, and spatial distribution). The totality of the evidence obtained from an IM test will enable a proper assessment of the test outcome. Most IM tests do NOT end up on the ends of the IM spectrum (boom or not boom), but may fall in one of the intermediate categories. It is important to arrive at the right conclusion. The evidence gathered, both debris and recorded information, will enable this process to be completed in a thorough and thoughtful manner.

Test Requirement Evolution: This chapter would be incomplete without a discussion of how the test requirements have changed since the 1980's. Some archival test data reveal testing conducted based on requirements that differ from present day standards. Likewise, future requirements may evolve into entirely new ones. Several examples can illustrate this.

Fragment impact testing has long been a topic of discussion within the IM community. Size, shape, velocity and how to project the fragment were the driving issues. The earliest requirement stated that multiple half-inch square mild steel cubes be projected at the test item with 3-5 hits recorded with a striking velocity of 8300 fps. This was intended to represent the hazardous fragments projected from the detonation of a general-purpose bomb. Test procedures used in the 1980's and 90's often relied on explosively projecting the fragments, that is, detonating a large block of explosive (Comp B) with a mat of preformed fragments on the front face of the charge. The number of fragment hits and the orientation (flat or edge on) of the impacting fragments were not controlled, which could lead to inconsistent test results. The explosive output of the fragment launcher often masked the response of the test item further compounding test assessments. Improved test methods now use gas guns to launch individual fragments (often saboted) to the target. Also the threat fragment shape was standardized to that of a right circular cylinder with a conical tipped nose based on recommendations from subject matter experts in 2002. There continues to be debate within the IM community, particularly in the US, about the fragment velocity. Although 8300 fps remains the test standard, some contend that a lower velocity is a more likely, more appropriate threat for their weapon systems. This debate is likely to continue into the foreseeable future.

Thermal hazards testing has remained relatively unchanged over the years, however, there continue to be issues associated with slow cook-off test requirements and fast cook-off test procedures. The heating rate of 6°F (3.3°C) for the slow heating rate has been in place since WR-50. It was based on safety incidents observed aboard US Navy ships. Some argue that a higher heating rate is more appropriate, especially for land-based weapons. Others have data that show that some intermediate heating rates (not specifically defined) can produce a more violent response than either the slow or fast heating methods presently in effect. These debates will also continue into the foreseeable future.

Fast cook-off tests have used fuel pool fires as the standard test procedure to replicate spillage and ignition of aircraft jet fuel on a flight deck. This method has been used for many years but this type of fire has not been well characterized according to many fire science experts. Furthermore, this type of fire is NOT environmentally friendly and has come under intense scrutiny in several nations for both air and ground water contamination issues. Since 2010, this author has been involved with the Fuel Fire Experts group (directed by AC/310 Subgroup B) and is currently leading discussions to evaluate instrumentation for data collection on the current fuel pool fire and, more importantly, to evaluate an alternate fast cook-off test procedure for propane fueled fires[13] [14]. These international discussions will continue as supporting data is being assembled for recommendations on a future course of action.

13 Tanner, Steven, "Progress Report on Fuel Fire Test Method," Report to AC/326 Subgroup 3, October, 2010

14 Swierk, Thomas, "Fuel Fire Experts – II Summary Report," Report to AC/326 Subgroup B, October, 2012

Finally, sympathetic reaction testing has indeed evolved since the requirement was first established years ago. The sympathetic reaction scenario is not a simple case of donor reaction versus acceptor response anymore. One must consider the appropriate configuration – logistical or tactical. Are the test items bare (i.e., a stack of bombs or projectiles on a pallet or rack) or are they packaged in stowage containers or placed within dual-purpose launchers (logistic AND tactical)? Consideration of shotlines (trajectories of the donor's fragments) is a concern for both adjacent and diagonal directions when items, either bare or containerized, are stacked. A final issue is the consideration of the test item when multiple items are in play. For example, one sympathetic reaction test configuration can have several logistic containers stacked, each of which has multiple items (mortar rounds, small arms projectiles, etc.). If a detonation propagates from donor to acceptor *within* a container but does not propagate to neighboring containers, then a sympathetic reaction response is not recorded for this configuration. Many similar and seemingly complicated sympathetic reaction configurations and test events can be postulated and each must be treated on a case-by-case basis.

IM and Hazard Classification Harmony: For the US, the classification of a munition is a critical element in the overall explosive safety program[15]. The appropriate transportation mode and the proper storage location can be determined with the munition's classification. A DoD final hazard classification (HC) is assigned once the munition' s design has been established and prior to release for service use. The sympathetic reaction and liquid fuel/external fire (i.e., FCO) tests have been the cornerstone for determination of the hazard division (HD), as shown in Table 3, with common IM and HC test highlighted in the third section. For hazard classification, hazard divisions were created to provide storage quantity-distance (QD) benefits. The intent is that munitions should get QD benefits as they improve their insensitivity. This demonstrates a link with IM testing.

Table 3: Required Tests for Hazard Classification

I. **Thermal Testing:**

a) UN Test Series 3C for Substances

b) UN Test Series 4A for Articles

II. **Sensitivity Testing:**

a) Article Drop Testing: UN Test series 4B

b) Impact: UN Test series 3A

c) Friction: UN Test Series 3B

d) Article Small Scale Burn: UN Test Series 3D

III. **Identifying a classification:**

a) Single Package: UN Test 6A

b) **Sympathetic Reaction: UN Test 6B/7K**

c) **Liquid Fuel/External Fire: UN Test 6C/7G**

d) **Slow Heating: UN test 7H**

e) **Bullet Impact: UN Test 7J**

c) Extremely Insensitive Detonating Substance (EIDS) tests: UN Test 7A - 7F

15 Clark, Kerry, technical paper, "Synchronization of IM and HC: A Navy Perspective", Proceedings from the 2010 Insensitive Munitions & Energetic Materials Technology Symposium, Munich, Germany, October 2010

The IM and HC programs have had numerous success stories in reducing a munition's sensitivity. The benefit of this reduced sensitivity is obvious in the hazard classification assigned. It should be noted that the slow heating and bullet impact testing required for HD 1.2.3 and 1.6 are also IM tests. Passing criteria for sympathetic reaction for IM and HC testing are identical. The end result is the potential for synchronized test results for both IM and HC.

The harmonization of hazard classification and Insensitive Munitions has been an ongoing effort for many years. The benefits derived from a synchronized or harmonized test program were recognized years ago but only fully implemented recently. NIMIC conducted a Workshop on this topic and offered recommendations to the international community. Only recently was this mandated as a practical measure. In the US, the JROC mandate standardized IM and HC testing in 2006. This is summarized in Figure 5. The end result of a harmonized IM/HC test program is a substantial cost saving by eliminating redundant testing and ensuring a minimum expenditure of expensive test assets.

Test Results Interpretation: You've now completed your IM test program and you're faced with several questions: did the item pass or fail each of the IM tests? What are the pass/fail criteria? How do we describe the response of the test item to the test stimulus? And pass judgment on the test results? You refer back to AOP-39 for help with these issues. From the earliest days of the IM program it was deemed necessary to define various types of responses that would result from any type of IM event, whether they are indeed from thermal, shock or impact stimuli. A list of response descriptors was first documented several years ago as a result of an international workshop sponsored by NIMIC[16]. These were useful for the test and evaluation community but after many years of use and hundreds of trials, both for development purposes and for "score" (i.e., IM qualification), many deficiencies were noted, as were ambiguities in test result interpretation.

A follow-on two-part workshop (sponsored by MSIAC) was held in 2008-9[17] to help clarify the response descriptors as an aid to the IM test and evaluation community. [note: the author led an international group of subject matter experts in these 2008-9 meetings to update these response descriptors.] The end result was an updated set of response descriptors, shown in Figure 7, and officially promulgated as Annex I in the latest edition of AOP-39. These are currently in use in several nations as IM and hazard classification test results are examined by authoritative review boards to assign the appropriate IM label (a "type" classification). The most notable changes included (a) labeling many of the data/test evidence as *primary or secondary* characteristics; and (b) adding a further definition of a *hazardous fragment*, one defined as being greater than 20 joules (the demarcation between HD 1.2 and 1.4 for hazard classification purposes). These features have proven to be extremely valuable aids for test result assessments.

16 Touze, Patrick, "IM Testing – Response Descriptors," NIMIC report #O-40, November 1997

17 Swierk, Thomas, "IM Response Descriptors – an Update for Assessment Processes," MSIAC report #O-125, October 2009

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ANNEX I TO
AOP-39
(Edition 3)

Response Level	Energetic Materials (EM)	Case	Blast	Fragment or EM projection	Other
Type I (detonation)	Prompt consumption of all EM once the reaction starts	**(P) Rapid plastic deformation of the metal casing contacting the EM with extensive high shear rate fragmentation**	**(P) Shock wave with magnitude & timescale = to a calculated value or measured value from a calibration test**	Perforation, fragmentation and/or plastic deformation of witness plates	Ground craters of a size corresponding to the amount of EM in the munition
Type II (partial detonation)		**(P) Rapid plastic deformation of some, but not all, of the metal casing contacting the EM with extensive high shear rate fragmentation**	**(P) Shock wave with magnitude & timescale < than that of a calculated value or measured value from a calibration test** Damage to neighbouring structures	Perforation, plastic deformation and/or fragmentation of adjacent metal plates. Scattered burned or unburned EM.	Ground craters of a size corresponding to the amount of EM that detonated.
Type III (explosion)	**(P) Rapid combustion of some or all of the EM once the munition reaction starts**	**(P) Extensive fracture of metal casings with no evidence of high shear rate fragmentation resulting in larger and fewer fragments than observed from purposely detonated calibration tests**	Observation or measurement of a pressure wave throughout the test arena with peak magnitude << than and significantly longer duration that of a measured value from a calibration test	Witness plate damage. Significant long distance scattering of burning or unburned EM.	Ground craters.
Type IV (deflagration)	**(P) Combustion of some or all of the EM**	**(P) Rupture of casings resulting in a few large pieces that might include enclosures or attachments.**	Some evidence of pressure in the test arena which may vary in time or space.	**(P) At least one piece (casing, enclosure or attachment) travels beyond 15m with an energy level > 20J based on the distance/mass relationship used for HC[1].** Significant scattered burning or unburned EM, generally beyond 15 m.	**(P) There is no primary evidence of a more severe reaction and there is evidence of thrust capable of propelling the munition beyond 15m.** Longer reaction time than would be expected in a Type III reaction.
Type V (burn)	**(P) Low pressure burn of some or all of the EM**	**(P) The casing may rupture resulting in a few large pieces that might include enclosures or attachments.**	Some evidence of insignificant pressure in the test arena.	**(P) No item (casing, enclosure, attachment or EM) travels beyond 15m with an energy level > 20J based on the distance/mass relationship used for HC[1].** **(P) A small amount of burning or unburned EM relative to the total amount in the munition may be scattered, generally within 15m but no further than 30m.**	**(P) No evidence of thrust capable of propelling the munition beyond 15m.** For a rocket motor a significantly longer reaction time than if initiated in its design mode.
Type VI (no reaction)	**(P) No reaction of the EM without a continued external stimulus.** **(P) Recovery of all or most of the unreacted EM with no indication of a sustained combustion.**	**(P) No fragmentation of the casing or packaging greater than that from a comparable inert test item.**	None	None	None

Primary evidence **(P),** shown in **Bold** text, would almost always be observed and would be definitive of the reaction type.
Secondary evidence could be observed, but its lack would not preclude that reaction type.

Note: (1) Fragment energy relationship shown in the Figure I-1

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Figure 6: Response Descriptors used for IM and HC test evaluations

3. IM ASSESSMENTS – UTILITY OF TEST RESULTS

There is an obvious link between the results of an IM test program and the determination of an IM signature for a weapon. An appropriate assessment process must be used for this purpose. As described earlier in this chapter, STANAG 4439 and AOP-39 offer IM testing guidance and stipulate test requirements and procedures. AOP-39 also describes the desired end result, the IM signature, the documented measure of the "IM-ness" of the munition. The needed intermediate step, the assessment process, is the responsibility of each nation to process the test results and arrive at the appropriate IM signature. National policies have been implemented to address this issue and have taken different paths to define their unique processes. Examples of three assessment methods by the US, UK and France are described below.

3.1 US IM Assessment Process:

A unified assessment process was not fully implemented in the US in the early years of the IM program. Each service within the Department of Defense established an IM review authority to pass judgment on test results. They "scored" tests as input for the IM signature for various weapon systems. Exceptions and variances to the IM test requirements were allowed by each service. The following paragraph describes in more detail the approach taken by the US Navy.

In the 1980's, the only recognized IM review authority was the Ordnance Hazards Evaluation Board at NAWC/China Lake (originally formed to evaluate cook-off test results). As the Navy's IM program gained traction and IM testing dramatically increased, another review authority, the Insensitive Munitions Review Board was established at NSWC/Dahlgren (the author was the motivating individual for this Board). These Boards were merged in the late 1990's to form a unified Navy authority, the Munitions Reaction Evaluation Board (MREB). The MREB had an expanded role within the Navy, not just an evaluation of the IM test results[18]. The MREB's duties and responsibilities are outlined below.

- • Provide a unified Navy position of munition reaction levels, consistent IM test evaluations, and improve the review process.
- • Provide guidance and recommendations for optimal test design and procedures for IM testing as part of the overall ordnance hazard assessment.
- • Provide consistent evaluation and rating of IM test results to the requirements of NAVSEAINST 8010.5 and evaluate the munition reactions in accordance with MIL-STD-2105 and the applicable STANAGs and AOPs.
- • Review and evaluate all munitions to be “officially” scored for IM compliance.
- • Review any deviations from test requirements and encourage standardization and harmonization with Hazard Classification test requirements prior to testing.
- • Munition assessments not for score may be reviewed at the MREB’s discretion to aid in the advancement of IM technologies.

The MREB served as a model for the other US services. The Army and Air Force review authorities expanded their roles as well. All of this coincided with the DoD initiatives that first mandated the requirements for IM into US law and then as part of US DoD policy. In so doing this, a single set of IM Standard Tests were approved by the Joint Requirements Oversight Council in 2006. Furthermore, it was mandated that IM and Hazard Classification be harmonized. Test harmonization was no longer a “nice to do” but finally a “must do.” This single set of IM test standards, shown in Figure 6, does not allow (with very few exceptions such as alternate test methods) deviations from the prescribed STANAG test methods. The findings among the US service review boards should be consistent and based on technically sound judgment. These findings, when submitted to and approved by Joint Service authorities, are the basis for a munition IM signature in the US.

[18] Till, Michael and Kosar, Kevin, technical paper, “*Formation of the US Navy’s Munition Reaction Evaluation Board (MREB)*”, Proceedings from the 2006 Insensitive Munitions & Energetic Materials Technology Symposium, Bristol, UK, October 2006

IM Test	Number of Required Tests	Test Configuration	Test Procedure
FCO	2	1 Operational, 1 Logistical	STANAG 4240, Standard Procedure, Excluding Annex B
SCO	2	2 Logistical	STANAG 4382, Procedure 1
BI	2	1 Operational, 1 Logistical	STANAG 4241, Procedure 1
FI	2	1 Operational, 1 Logistical	STANAG 4496, Standard Procedure
SR/ SD	2	2 Logistical	STANAG 4396, Procedure 1
SCJ	2	1 Operational, 1 Logistical	STANAG 4526, Procedure 2, PG-7V Surrogate (81mm precision Shaped Charge)**

** PG-7V Surrogate configuration is identified by US Army/ARDEC Dwg #7GP20078.

Figure 7: US Test Standards and Required Configurations

3.2 UK IM Assessment Process:

The UK has formalized their IM assessments in recent years with a very thoughtful and deliberate process. Their national IM program began in 1990 and used the services of their Ordnance Board to evaluate test results and assign appropriate IM labels as well as formulating recommendations on safety and suitability for service use. The Board considered the application of the IM technology to UK weapons and published their criteria for insensitive munitions. The UK adopted the same tests and criteria as the US Navy and recommended that "…the requirement for Insensitive Munitions be addressed in Staff Targets and Requirements." The Ordnance Board Proceeding 42657 stated the following:

> "The benefits of IM will accrue in both peace and war: in peace, the lower risk of adverse events occurring and the reduced accident damage will lead to economies in logistics; and during combat, through improved overall effectiveness by improving safety and survivability of weapon systems. The survivability of the weapon system platform – be it ship, tank or aircraft – in or on which they are carried will be improved; this applies particularly to HM Ships which carry embarked armament stores, and to RAF carrying reloads."

The IM testing review authority in the UK later changed when the Insensitive Munitions Assessment Panel (IMAP) was established in the early 2000's by the MOD. The findings of the IMAP are provided to higher authority in the MOD for final approval and disposition. In 2005 the IMAP published the document IM Testing: A Guide to Best Practice. This document was used to set forth test guidance, assessment practices and policies. The UK MOD has recently updated the IMAP guidance document and the following information is provided regarding the Panel and its approach to IM assessments19.

IMAP roles:

- PRIMARY - UK national Authority for IM signatures.
    - Assigns signature on the basis of full body of evidence, not just AUR tests.
    - Endorses test plans and states requirement for additional evidence and scores AUR tests.
- Reviews technical content of project IM implementation plans.
- Increasingly, IMAP will
    - Provide vulnerability assessments for IM, HD **and** Risk Assessment
    - Define targets for IM, HD, and overall vulnerability for weapon projects
    - Provide technical input to ALAR**P** judgement (i.e. Practicable?)
    - Set research goals
- IMAP is supported by the Energetic Materials Expert Advisory Group
    - Under the Weapon Science and Technology Centre umbrella, the EAG plans all future energetics research under the MOD funded programme. Chaired ny an academic, its membership includes QinetiQ, Academia, Dstl, DOSG, Industry.

The *full body of evidence* approach to assessment:

- As allowed by AOP-39, the full body of evidence can include the following: laboratory scale tests; component level tests; munition level tests; read across from similar formulations or munition designs; modeling and simulation analyses; and expert judgement.
- Full Scale tests are: not always necessary (e.g., low explosiveness PBXs in bullet attack and FCO); potentially misleading - high explosiveness materials cannot be trusted under any circumstances; or sometimes the only option - sympathetic reaction.

IM, HD and Risk:

- IM and HD are *snapshots* of vulnerability, taken for a selection of threats at arbitrary levels.
- For this reason, neither IM or HD classification are *sufficient* for assessment of the risks in specific situations.
- A comprehensive assessment of the response of munitions to credible threats to find reaction thresholds, is *necessary* to assess the actual risk to people and materiel.
- Such an assessment will inevitably provide enough information to assign both HD and IM signature.

[19] Cheese, Philip, "*Update on the UK IMAP Process*," conversation with Mr. Cheese, IMAP Chairman, Head of Vulnerability and Chief Technologist, MOD/DOSG

3.3 French IM Assessment Process:

France formalized their IM program in 1985 as *Munition a Risque Attenuée*, also known as "MURAT." Their approach to IM assessment was established as general policy in 1992 in a completely different manner than their NATO counterparts. Although their national policy was closely aligned to STANAG 4439 and AOP-39 for test procedures and guidance information, IM assessments were conducted with the following guidelines.

- MURAT Assessments: are evaluations of the intrinsic safety level ("IM-ness") of the munition, independent of any specific application; are based on possible reaction mechanisms generated by most probable stimuli/threats; and should demonstrate that worst possible threat parameters are covered.
- MURAT Signature - is compared to reference IM-ness levels for a possible assignment of a "MURAT Label."
- MURAT Labels (1-star ★, 2-star ★★, and 3-star ★★★): are defined for a common understanding and to allow an adaptation of requirements to required level of performance, operational use and financial constraints and available technologies.

In 2010, the French Ministry of Defense prepared an updated MURAT Policy Document in line with STANAG 4439 to better define the logistical benefits of MURAT characteristics[20]. This document was prepared jointly with the active participation of military staff and government technical experts. The new MOD MURAT policy instruction was finalized in 2011. The key elements of this instruction included the following:

- Reference (STANAG) Requirements specified in any acquisition.
- Any waiver to the MURAT Reference Requirements must be justified using risk based analysis methods.
  - Process involving Project Team (DGA) - IPE - Armed Forces (end user);
  - Minimum IM signature – risk based methodology (mainly focused on consequences on warfighter and assets) to be conducted by IPT;
  - IM signature to be contracted (i.e., minimum acceptable IM signature): and
  - Exclusion for Munitions with low risk in logistics phases (HD filtering).
- IM Signature Assessment generalized (including inventory munitions) to give Forces information and a better understanding of explosive hazards in operations.
- Necessary coherence and communality between HD and IM Level:
  - For Testing and Evaluation.
  - Complementarity between HD (maximum credible event focused) and MURAT signature (risk based) for a better management of risks during logistical & operational phases.
  - Final IM signature to be considered as any other S^3 requirement
  - Confidence level assigned for each threat considered in the IM signature.
  - MURAT Labels (★, ★★ and ★★★) slightly modified to better link with STANAG 4439 and HD regulation.

[20] Bordachar, Serge, and Lamy, Patrick, technical paper, "*A New Impulse for the French MURAT (IM) Policy*", Proceedings from the 2012 Insensitive Munitions & Energetic Materials Technology Symposium, Las Vegas, NV, US, May 2012

- Implementation of the policy should create a MoD common dialogue tool to insure the coherence between operational needs and R&T priorities.
- For all new munitions: IM signature, HD classification, S^3 assessment compiled in a Global Safety Datasheet.
- For (families of) inventory munitions: IM signature assessed or estimated in order to inform the Forces about risks associated with already in service munitions, create and maintain a database of IM signatures of munitions in service in French Forces, and use it as a MoD common dialogue tool to insure the coherence between operational needs and R&T / retrofit priorities.

3.4 Assessment Summary:

Three IM assessment methods have been presented and although they differ somewhat in their approach, they all have the same desired outcome – an IM signature for a munition. As both IM testing and IM assessments have been presented in this chapter, several comments apply to these assessment methodologies, regardless of national origin.

First, large scale test and evaluation in accordance with IM technical requirements is the culmination of development and system integration of IM technology. Second, a thorough and consistent evaluation of test results must be made in order to allow for comprehensive assessment of the vulnerability of munitions during transportation, storage and operational use. And finally, thorough assessment processes allow for better collaboration among technical experts to ensure a more comprehensive assessment of progress in achieving an IM compliant munitions inventory.

4. REVIEW – LECTURE SUMMARY

IM testing is a vital component of any national IM program. Insensitive munitions have been described in detail in the introductory chapters, as was their urgent need and how they benefit and help preserve a national warfighting capability. Further exploration of this subject involves the “how to” of insensitive munitions, that is, the technology and tools available to the weapon development community to design and develop insensitive munitions. These topics will be explored in detail in the following chapters.

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[5] AOP-39, Edition 3, “*Guidance On The Assessment And Development Of Insensitive Munitions”,* March 2010.

[6] STANAG 4240, Edition 2, "*Liquid Fuel / External Fire, Munition Test Procedures*," April 2003.

[7] STANAG 4382, Edition 2, "*Slow Heating, Munition Test Procedures*," April 2003.

[8] STANAG 4241, Edition 2, "*Bullet Impact, Munition Test Procedures*," April 2003.

[9] STANAG 4496, Edition 3, "*Fragment Impact, Munition Test Procedures*," March 2010.

[10] STANAG 4396, Edition 2, "*Sympathetic Reaction, Munition Test Procedures*," April 2003.

[11] STANAG 4526, Edition 1, "*Shaped Charge Jet Impact, Munition Test Procedures*," October 2002.

[12] "*Standardization of IM Tests and Passing Criteria*, " JROCM 235-06 Memo 2006, US Joint Requirements Oversight Council.

[13] Tanner, Steven, "*Progress Report on Fuel Fire Test Method*," Report to AC/326 Subgroup 3, October, 2010.

[14] Swierk, Thomas, "*Fuel Fire Experts – II Summary Report*," Report to AC/326 Subgroup B, October, 2012.

[15] Clark, Kerry, technical paper, "*Synchronization of IM and HC: A Navy Perspective*", Proceedings from the 2010 Insensitive Munitions & Energetic Materials Technology Symposium, Munich, Germany, October 2010.

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