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INSENSITIVE MUNITIONS INDUSTRY CONTRIBUTION FOR THE AOP 39 RESPONSE DESCRIPTORS IMPROVEMENTS

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ABSTRACT

IMEMG is the European Organisation that brings together the leading armament manufacturing groups working with IM technologies. It aims to express the viewpoint of the armament industry with regards to relevant transnational regulations and requirements. This paper is the result of the work carried out by the Hazard Assessment & Classification Expert Working Group regarding the review of the AOP 39 ed3 Response Descriptors. It summarizes the collective feed-back and thoughts of the experts from the 21 companies taking part to the IMEMG. It highlights several difficulties of reaching full IM Signature with the current maximum allowed reactions according to stimuli and Response Descriptors criteria and munitions characteristics. As an example, Type V is required for the Slow Heating threat; the temperature ramp associated with this threat can only occur in an enclosed space and lasts many hours. In such a context, is it really necessary that reacting ammunition shall not propel any fragment farther than 15 m with a residual kinetic energy exceeding 20 J? Given that such projections cannot even penetrate a 2 mm thick aluminium sheet, it seems more suitable to allow a type IV reaction. Alternatively, perhaps projections should not be considered for the Slow Heating threat, or maybe the Response Descriptors should be reviewed about the allowed projections. More generally, although it is a complex issue, perhaps the Response Descriptors should also be focused on the effects on personnel and platforms vulnerabilities, and not only on the munitions' response itself, independently of the munitions dimensions and the amount of energetic material they contain. In August 2013, MSIAC emitted the O-153 report "Survey on Insensitive Munitions Responses Descriptors", which raised many interesting points. This paper aims to start the review of current response descriptors based on IM industry experience. It is designed provoke the thoughts of the AC326 SGB experts in charge of the future AOP 39 4th edition.

1 INTRODUCTION

IMEMG is the European Organization assembling leading armament companies working with Insensitive Munitions. It represents a total of 21 companies from Austria, France, Germany, Italy, Norway, Sweden and United Kingdom. It has been established for 11 years and can be traced back to the foundation of "Club MURAT" in 1991. It aims to express the viewpoint of the armament industry with regards to transnational regulations and requirements in the field of munitions safety. It is acting as a focal point of contact for members' National Authorities, MSIAC and EDA. It has established several (currently five) Expert Working Groups (EWG), in order to explore technical topics. This paper is a result analysis work prepared by the Hazard Assessment & Classification EWG.

This work has been initiated firstly by the Questionnaire for Survey on Insensitive Munitions Response Descriptors distributed by the MSIAC. It has given the opportunity to elicit feed-back from the 21 IMEMG companies about the current AOP 39 ed3 implementation by test centres and national authorities. This has been followed by the O-153 MSIAC's report "Survey on Insensitive Munitions Responses Descriptors", which raised many interesting points and recently by the "NATO Expert Working Group Meeting on IM Response Descriptors" at the Air Force Research Laboratory located at Eglin AFB, Florida from 10 to 12 February 2015.

Secondly, we have to take into account the classic remark emitted by several army representatives *"IM are more expensive, less efficient and, in addition, there is no-logistic gain"*. Thus, we consider the cause of this problem. It is very difficult to pass the complete STANAG 4439 requirements due to current available techniques and because Energetic Materials are, by nature… energetic! Numerous munitions are partially compliant to STANAG 4439. Nevertheless, they fulfil the development program requirements which take into account the Threat Hazard Assessment according to the life cycle. However, but they are not true-IM so that it might be quite difficult to gain any IMness benefit during transport and storage phases.

We have examined the Response Descriptors in conjunction with the mandatory reactions according to the various vulnerability tests. It appears that several questions deal with the Type V Descriptors. For example, in the fragment impact test, the kinetic energy delivered by the fragment equals 60,000 Joules. But at the same time, the tested munition shall not eject splinters with an individual kinetic energy exceeding 20 Joules farther than 15 meters. Is such a criterion really relevant given the "aggression" context? In fact, it seems that Type V Response Descriptors are designed to meet essentially personnel safety requirements and not platform survivability criteria, for which IM can provide a benefit.

In addition, a few other requirements could be discussed. For example, the slow heating scenario requires a continuous heating of munitions for many hours in order to reach a "room" temperature exceeding 150°C. Such an event can only occur in a confined space, is it really necessary to fulfil type V requirements related either to the propulsion effect or to the projection criterion (20 J fragment at a distance exceeding 15 m) inside this confined space? Indeed, what could be the resulting external effects? It must be reminded that the 20J fragment isn't able to go through a 2 mm thick aluminium sheet (UN Orange Book ST-SG-AC10-11 Rev5).

So, beyond concerns about personnel safety, the demonstration of advantages of IM should be easier and more effective through the use of a Quantitative Risk Assessment (QRA) including platforms survivability. Perhaps, reviews could be conducted in order to determine if mandatory responses could be different for open battlefield munitions in comparison with munitions embedded on a platform (tank, ship, and aircraft). Additionally, ammunition sizes should be taken into account. Type V response from large munitions (with a weight of active material exceeding a few hundred kilograms) can be much more severe for platforms than, for example, a Type I to III reaction of a hand grenade inside the ship magazine. Does it make sense to use the same Response Descriptors for both cases?

2 FEW REMARKS ABOUT STANAG 4439 ed3

STANAG 4439 ed3 states that ratifying nations agree to *"develop and/or introduce into service munitions that are as insensitive as reasonably practicable"*, and it is written that *"to be considered insensitive, a munition in a particular configuration shall meet the requirements of Table 1"* or *"a munition is considered IM compliant for a given life cycle if, for each considered threat, it meets the requirements expressed in Table 1 for any relevant configuration(s)"*.

Table 1

Threat	Requirement
Magazine/store fire or aircraft/vehicle fuel fire	No response more severe than Type V (Burning)
Fire in an adjacent magazine, store or vehicle	No response more severe than Type V (Burning)
Small arms attack	No response more severe than Type V (Burning)
Fragmenting munitions attack	No response more severe than Type V (Burning)
Shaped charge weapon attack	No response more severe than Type III (Explosion)
Most severe reaction of same munition in magazine, store, aircraft or vehicle	No propagation of reaction more severe than Type III (Explosion)

Practically, a given munition is Insensitive or it is not, even if it is "as insensitive as reasonably practicable", and this for all threats independently of its life cycle. Thus, if a munition meets 80% of IM requirements, it is not an IM and it is not possible to gain any advantage as promised in the STANAG *"In addition, IM provide for more cost effective and efficient transport, storage and handling of munitions. These benefits could be realized through assignment of a more favourable hazard classification".* It is true that a few dedicated regulations exist: the NATO Sub-Storage Division 1.2.3 or the French 1.2 Unitary Risk Division, however, these divisions often bring only virtual gains, while the UN 1.6 Hazard Division is an unreachable objective with only a few exceptions (Have any been awarded to date?). That means it would be useful for the various stakeholders concerned by IM to have pragmatic Requirements and Response Descriptors that allow declaring as IM some practicably insensitive munitions for which levels of reaction are quite close to the ideal requirements.

According to the STANAG 4439 definitions, Insensitive Munitions (IM) / MUnitions à Risques ATténués (MURAT) are defined as: *"Munitions which reliably fulfil their performance, readiness and operational requirements on demand and which minimize the probability of inadvertent initiation and severity of subsequent collateral damage to weapon platforms, logistic systems and personnel when subjected to selected accidental combat threats"* and also *"Introduction of IM/MURAT into service enhances the survivability of logistical and tactical combat systems, platforms and stockpiles, and minimizes the risk of injury to personnel. It accomplishes this significantly reducing the potential for the inadvertent reaction of a munition to occur; the scope and/or violence of a reaction, if it were to occur; and the consequences from such a reaction"*.
These points drive us to think, that several requirements and response descriptors could be adjusted to be more pragmatic:

- When a weapons platform is attacked by an IED (Improvised Explosive Device) or by one specific missile able to propel 18.6g fragment @ 2530 m/s (8300 ft/s), blast and fragments they generate can provoke severe damages and lethal injuries to persons up to 50 meters. In such a case, is it really necessary to require, for the "acceptor" munition, a Type V response and no-injuries farther than 15 meters? In comparison with the violence of the aggression, the "contribution" of the impacted munition seems quite secondary if limited to Type V, IV or even III levels of response. Moreover, such limited levels of reaction will be very hard to reach for most Insensitive Munitions. In comparison, the sympathetic detonation scenario which is finally quite similar requires only a Type III mandatory response.

FIGURE 1: IEDs

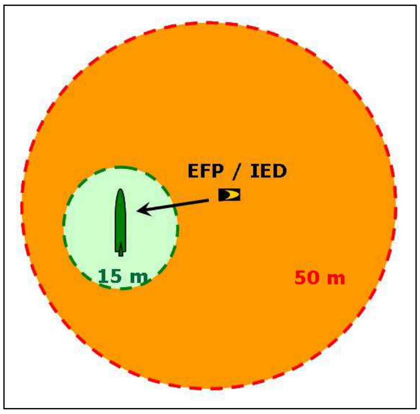

FIGURE 3:
Example to illustrate excessive severity of criteria:
➔ Primary Fragments Injuries Distance for 1kg Explosive Charge with 2mm thick case: 50m (orange zone)
➔ In comparison with :Maximum Projections Distance to pass Type V Response: 15 m (green zone)

- For example, as written previously, the Slow Heating requires a perfect confinement of the storage in order to reach temperatures ranging from 150 to 200°C (300 to 400°F) with a progressive ramp. In such a configuration, a Type V requirement seems pointless given that potential fragments from the envelope of the munition will be easily stopped by the walls which inevitably surround the storage. As a consequence, a Type IV requirement could be sufficient to a great extent.

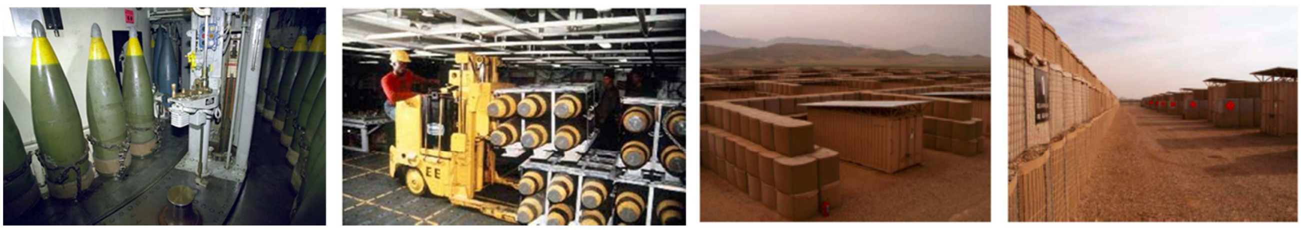

FIGURE 1: Type IV Response appears as sufficient when projections are blocked by walls

3 GENERAL COMMENTS ABOUT RESPONSE DESCRIPTORS

AOP 39 ed1 was issued in 1998 following the 1997 NIMIC IM Testing Workshop. Response Descriptors have been improved through the second and the third editions, especially about quantitative criteria, removing values of blast overpressure and radiative heat fluxes. Indeed, it has been considered that measurements and data interpretations are too dependent on test set-up and munition architecture.

IMEMG experts have identified several difficulties for Response Descriptor implementation and they have proposed a few potential improvements. Main concerns focus on 20 Joules projection criteria and propulsion effects assessment for the Type V response. These topics are analysed in following paragraphs.

Other difficulties are listed below:

- Casing rupture criteria are defined for steel casings and not at all for composite envelopes or even for forged aluminium casings. For example, a forged aluminium casing can fracture due to an impact, which can correspond to type III or IV response descriptor even if the energetic material doesn't react. It highlights the fact that it is desirable, but expensive, to perform preliminary tests on inert items so that aggression effects on the sole munition casing might be determined.

- The multi-components munitions responses are not really considered; sub-systems can deliver Type V effects if tested alone (smooth release of combustion gases) but pressurisation of the munition structure can propel pieces farther than 15 meters (Type IV response) due to its sole pneumatic burst. This is practically ignored for Insensitive Munitions assessments because sub-systems are tested separately. As a consequence, the resulting safety assessment report might not take into account such phenomena.

- Munitions can be tested in packaged or unpackaged configurations. On the one hand, if the package is strong, the aggression may be mitigated but on the other hand, if the munition burns (Type V response), it can pressurize the package until it bursts into fragments. These fragments are likely to be projected at distances exceeding 15 meters. In this particular case, how do we have to consider these projections, as the munition response or not?

- As stated previously, the size of the munition should be taken into account. Indeed, Type V response of large munitions (delivered combustion energy of few hundred kilograms) can be much more severe for the platform than, for example, Type I to III reaction of a hand grenade located inside the ship magazine. Do Response Descriptors have to be identical for all munitions sizes?

- Solid propellant motors contain energetic materials designed to burn and generate huge amount of gases. As a consequence, the best response is Type IV for numerous current rocket motors. But, despite the Type V objective, it corresponds to the *"as insensitive as reasonably practicable"* technology, so that it might be virtually impossible to design Insensitive Solid Propellant Motors fulfilling to STANAG 4439 Requirements. This gives birth to resignation in the designer's mind; why expend effort if the result is known in advance i.e. failure to meet IM requirements? It is a topic for discussions.

4 THE "20 JOULES" PROJECTION CRITERIA

In previous AOP 39 ed1 or ed2, for Type V response, the projection limit was 79 Joules (or 150 gram beyond 15 meters). The 79J energy projection criteria is consistent with AASTP-1, this value is universally used to define Inhabited Building Distance (IBD) which corresponds to a probability below 1% of being hit by such a hazardous fragment (it corresponds to one dangerous projection for 56 m^2).

The 20 Joules Projection Criteria for Type V Response, coming from UN Orange Book 6c Test, triggers several concerns:

- The criterion of 20J kinetic energy as the initial energy of the ejected fragment and not its energy at impact. This is illustrated in the table below, showing that this criterion is stricter than usually admitted if we consider the impact energy.

Table 2

UN 6c test / AOP39 ed3		**IMEMG Calculation**		
Mass	**20J Projection Distance**	**20J Initial Velocity**	**Projection Distance**	**Impact Energy**
(g)	**(m)**	**(m/s)**	**(m)**	**(J)**
25	**83.6**	**40.0**	**85**	**7**
50	**58.4**	**28.3**	**58**	**11**
75	**44.4**	**23.0**	**44**	**13.5**
100	**35.6**	**20.0**	**35**	**15**
125	**29.8**	**17.9**	**29**	**16**
150	**25.6**	**16.3**	**25**	**17**
175	**22.43**	**15.1**	**22**	**17**
200	**20**	**14.1**	**19**	**17,5**
277 (*)	***15***	***12.0***	***14***	***18***
300	**13.9**	**11.5**	**13**	**18.5**
400	**10.9**	**10.0**	**10**	**19**
500	**8.9**	**8.9**	**8**	**19**

(*) Calculated value fort projection at 15 meters

- In contrast, for example, projections of 100g pieces can fit with the AOP39 maximum distances (30 m?) but with an impact energy reaching 100 J. This is due to a parabolic trajectory effect after quasi-vertical launching and falling. In that particular case, this criterion is not in concordance with the 20J initial energy limit. This introduces uncertainties between trials, the final response assessment being strongly dependent on the resulting maximum projection distance. The same munition can exhibit Type IV or Type V responses in relation to slight differences on the exact angle of projection of the fragment of interest, regardless of the real induced terminal effects.

- The 20J kinetic energy seems to be considered as the safety limit for projections, but this value is the energy at impact on potential victims. It is considered, for example, in the SAFER software as indicated in AASTP-4 ed1 November 2008 (II-150 fig 63) while in the ASSTP-1 ed1 change 3 April 2010, it is still the table [5-15] which is taken as a reference as presented below. The 20 J criterion in not considered as a critical kinetic energy.

Table 3

LETHALITY DUE TO IMPACT ENERGY				
LETHALITY (p in %)	**IMPACT ENERGY / KINETIC ENERGY (Joule)**			
	HEAD	**CHEST**	**ABDOMEN**	**LIMBS**
1	**55**	**58**	**105**	**155**
5	**65**	**90**	**140**	**240**
20	**79**	**140**	**200**	**380**
50	**100**	**230**	**280**	**620**
99	**200**	**850**	**850**	**2500**

- Moreover, the Inhabited Building Distances (IBD) defines safety distance according to projection density: no more than one 79J projection for 56 m^2, as indicated in AASTP-1 ed1 change 3 April 2010. Thus, if it is admitted to expose civilians to some 79J projections, is the 20J criterion still relevant for the Response Descriptors?

- In leisure world, Paintball or Airsoft gamers are playing with gas guns able to propel 0.68" projectiles up to 40 Joules launching energies. Of course, players wear face protectors, but injuries aren't that frequent. This analysis allows a comparison in terms of projection energies especially for non-metallic fragments.

FIGURE 4: Paintball and Airsoft players

- French Police Forces currently deploy Flash Guns which propel 44mm rubber balls with a 200 Joules residual energy up to 7 meters. Of course, due to the ball diameter and its crushing at impact, most of this kinetic energy is dissipated on a large surface exceeding 35 cm^2, the resulting energy density being around 6 J/cm^2. Even if people injured by this weapon often suffer from broken ribs, the use of such an amount of force is totally legal and permitted. It highlights the gap between various legislations…

FIGURE 5: Flash balls used by French Police

- Illustrating difficulties to mitigate responses about projections, IMEMG paper has been presented during 2010 IMEMTS event, it reports that 3 litres of water in 220 litres barrels submitted to UN fast heating has to be assigned to a Type IV response given that the cover plate (2.5 kg) has been propelled too far away (22 meters).

FIGURE 6: UN 6c test
3 liters of water in 220 liters barrels

So, in order to launch the debate, it is proposed to make the Type V projection criterion evolve to the following statement:

"Only few projections farther than 15 m
with a moderate mass are accepted for the Type V Response."

Indeed, for example, it seems acceptable to observe 12 projections (around 100 g) at 40 meters or 8 projections (around 300 g) at 20 meters or only 1 projection (about 3kg) at 25 meters.

It is consistent with other qualitative criteria and National Authorities should take into consideration both the influence of the munition architecture and the type of material which is propelled (steel, aluminium, composite, plastic …) on the response.

5 PROPULSION EFFECT ASSESSMENT

The propulsion effect assessment is an usual topic of discussion with test centres, the discussion being sometimes quite difficult. Indeed, both in the table and text, the propulsion effect is not well enough defined. Furthermore, there is often a lack of instrumentation (thrust transducer). Some test centres state a "propulsion effect" as soon as a flame (not a plume) is observed through the nozzle, even if this flame is not energetic enough to shift the motor.

Propulsion definition is not accurate enough. Indeed, the standard definition is not sufficient to define that propulsion for a Type V reaction as *"There is no evidence of thrust capable of propelling the munition beyond 15m"* and this doesn't fit with the criterion given in the table *"for rocket motor a significantly longer reaction time than if initiated in its design mode"*. Thus, information concerning platform survivability assessment is missing given that potential consequences induced by a 20 meters shifting or a 2 kilometres flight (in comparison with a 40 kilometres range motors) can be quite different.

It is necessary to clarify which is the feared event about propulsion effects: traumatic effects against personnel, platform survivability concerns or fire propagation:

- Concerning people's safety, munition shifting is tolerable beyond 15 meters because the probability to be injured is quite similar at 10 meters or at 30 meters, the victim being hit by the projectile or not. This probability isn't a monotonous decreasing function with the distance contrary to the blast overpressure effect for example.

- Concerning the platform survivability, the question is about the mechanical and thermal damages generated by the munition shifting. Inside a warship magazine, or a storage igloo, the question is more about possible exit of the munition. Thus, the 15 meters shifting of unattached item is too strict. On an aircraft carrier deck, if we consider the Forrestal disaster example, it appears that the main factor of damages were kerosene leakages on the deck, rocket explosion being just a secondary factor.

- About fire propagation, this parameter is relevant in the case of an internal storage igloo, however if your munition has been impacted by a 0.5" bullet or a 18.6g fragment, you have already a big problem. Furthermore, ammunition boxes are generally closer than 15 meters, and the domino effect is independent of a potential shifting farther than 15 meters.

Moreover, when a cruise motor is tested separately, it is possible to observe propulsion effect which is insufficient to move the complete missile. It would be mandatory to check this point on the complete missile so as to justify IM requirements.

So, in the aim to launch debate, it is proposed to change for the following statement:

*"Munitions shifting should be limited to around 30 meters
to respect Type V response as for energetic material projections"*.

and

*"Munitions response generating strong propulsion effect
with a potential flight farther than few hundred meters
would be identified to feed quantitative risk assessment
and/or be assigned to type III response*

6 CONCLUSIONS AND PERSPECTIVES

IMEMG experts offer as a topic of discussion to AC326 SGB National Experts the following proposals:

- Move from Type V to Type IV, the maximum response allowed to slow heating *"Fire in an adjacent magazine, store or vehicle"*, because munitions effects are contained inside such a magazine, storage or vehicle and because nobody can survive to the aggression itself.

- Move from Type V to Type III (or IV), the maximum response to fragment impact because hazardous effects of the threat itself largely overpass all tolerated effects of Type V response.

- Review projection criterion for the Type V response, it could be: *"Only few projections farther than 15m with moderate mass are admitted for the Type V Response ".*

- Review propulsion effect assessment for the Type V response, it could be: *"Munitions shifting would be limited to around 30 meters to respect Type V response as for energetic material projections. Munitions response generating strong propulsion effect with a potential flight farther than few hundred meters would be identified to feed quantitative risk assessment and/or be assigned to type III response.*

Of course, some other changes are desirable like precision about the packaging, multi-component munitions responses, etc. The MSIAC Survey on Insensitive Munitions Response Descriptors is also a source of improvements.

For industry, IM development is a difficult challenge, munitions designed to be "*as insensitive as reasonably practicable",* have to be sold necessarily. So, buyers must gain benefits coming from reduction of logistical costs in addition to improvements in terms of platform survivability and people's safety. For that, it is necessary to have good clarity about IM or near-IM advantages.

In terms of Quantitative Risk Assessment, main threats are Fast Heating, Bullet Impact and Sympathetic Reaction. So the proposed evolution about the maximum response to Slow Heating and Fragment Impact seems to be quite reasonable. The proposed reviewing in Response Descriptors corresponds to the same objective because the current response descriptors appear too strict about 20J projection and propulsion effect.