

**FOR A REAL INCREASE IN THE MILITARY PLATFORMS SAFETY,
AS A CONSEQUENCE OF THE TRANSITION TO INSENSITIVE MUNITIONS:
A complex issue which requires intrinsic solutions**

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ABSTRACT

The transition to Insensitive Munitions (IM) is a need coming from the necessity of increasing the safety of weapon platforms which are going to carry, to store or to use munitions. This transition to IM must then bring solutions to the requirements of low vulnerability, as those established by performing life cycle and threat analyses. But this is a complex issue, which can be solved by different ways described in the paper. An IM § IEM approach is proposed, based on the following technical analysis:

- On one hand, an analysis of different examples of munitions or generic units behaviors is presented, mainly for the following accidental situations:

- Thermal threats in general,
- Slow Cookoff in the vicinity or after a fire,
- Bullets impact.

This analysis will illustrate the possibility of very different behaviors according to the stimuli features.

- On the other hand, the corresponding mechanisms will be analysed to demonstrate the fact that the knowledge of some properties of energetic materials can lead to an important increase in the warrant for a good behavior of a munition exposed to a wide variety of accidental or enemy threats during its all life cycle.

A judicious choice of energetic materials appears then as an intrinsical solution, very safe, to solve the problem of real increase in the platforms survivability, whatever could be the potential threats.

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INTRODUCTION

A lot of efforts have been done for more than ten years to develop Insensitive Munitions (IM) as defined by the first draft of MIL-STD-2 105 in 198 1, and by the JRIM in 1987:

" Munitions which reliably fulfill performance, readiness and operational requirements on demand, but which minimize the probability of inadvertant initiation and severity of subsequent collateral damage to the weapon platform (including personnel) when subjected to unplanned stimuli ".

It is then well question of decreasing the chance of a weapon platform destruction, and of human losses, due to accidental or ennemy threats.

But although most of the standards covering the test procedures for assessment of IM characteristics, like MIL-STD- 2105 B [1] and others [2, 3], are promoting the idea of a test plan generated in concert with environmental profile and a THA (Threat Hazard Analysis), those standards are very often requiring only a "pass" to standardized tests like a fuel fire or a slow rate heating at 3.3 °C /hr.

As, logically, the probability of being faced with universal threats, independant of the type of platform and of the kind of accidental situation, is very low, the direct consequence of such an approach is then that **munitions certified IM can only satisfy IM criteria**, without offering a complete warrant for acceptable behaviors, and collateral damages, into the complete scope of stimuli that can be associated to real threats.

So we are now faced to a problem which can be solved by different approaches

DIFFERENT POSSIBLE APPROACHES TO SOLVE THIS ISSUE

There are different ways to find a solution to this problem, which is to provide, with IM, the greatest chance of reducing the weapon platforms vulnerability, when they have to survive to an accidental or enemy threat :

1") The simplest approach is to accept that IM passing **standardized test** criteria are sufficient, even if the procedures for those tests are only covering partially the conditions corresponding to accidental and enemy threats, and are **not always simulating the worst case** of a stimuli. This is mainly the case for the bullets / fragments impacts, and also for the thermal stimuli.

Advantages : **no need** to develop **specific tests, data exchanges easier** from the point of view of interoperability,

Drawbacks : there is a chance of passing the standardized tests, and having **more severe collateral damages** in case of a **real threat**, due to other conditions than the standardized requirements, like those shown by the following examples:

- During the Falklands War, a missile reacted in a battle ship by **Slow Cookoff** after about 3 hours, which means approximatively a 50 °C/hr heating rate, consecutively to a fire spreading in the ship,
- On the " ENTERPRISE " aircraft carrier, a rocket reacted also by **Slow Cookoff** after only some hours, due to a collateral fire,
- In Camp Doha, during the Gulf War, the first munitions reacting were initiated by a fire which was not from fuel, but due to a combustion in a truck.

2") The second way is to design a **test plan generated by a THA**, which is an evaluation of the munition life cycle environmental profile to determine the threats and hazards to which the **munition may be exposed [I]**. An example of such an evaluation has been published by A.VICTOR [4], for the US Navy Advanced Rocket System.

Advantages : the munition is assessed to **tests** which are **no more severe and neither less severe** than the realistic identified threats. This means that, if the THA is well performed, the munition passing the established criteria is corresponding to the "**just necessary**",

Drawbacks : the munition are only tested in the conditions put into **evidence by the THA**, with results which can be :

- **realistic today but not tomorrow**, due to changes in the strategy of one potential enemy, or to occurrence of a new ennemy,
- limited to **the conception of one or a few people**, having a personal approach, or an uncomplete knowledge of the real potential threats,
- **difficult to use for interoperability**, in that sense that these results are often classified, since they can reveal the weaknesses of the military forces; on another hand, they can lead to assess the munition versus very specific stimuli, probably very pertinent according to the **expected life cycle** of the munition, but sometimes not **useful** at all for other nations. We can find an illustration of that last point when analysing the ARS' THA [4]. For instance:
 - several kinds of fire are identified with heating rates going from 10 °F/hr to 30 °F/s, while the heating rate of a standardized fuel fire is about 15 °F/s,

- slow heating rates are going from 6 to 50°F/hr, with also the possibility of 30 minutes at 600-1000 °F followed by cooldown, (the standardized procedure is presently 6°F/hr)
- bullets impacts identified are covering the caliber range from .22 cal to 30 mm, the greatest probability of occurrence being for 7.62, 20 and 30 mm (10^{-2}), while 10^{-4} for the 0.5 caliber.

So, if a test program manager decides to assess the munition in conditions very specific to the results of a **THA**, like an impact by a 7.62 mm at 400 m/s, the munition response will be of no interest if the same munition has to be used by another nation, or even by another force from the same country, having different life cycles or other requirements. This situation will undoubtedly lead to multiply the tests number, and consequently the assessment cost.

3”) The third way is to assess the munition to the **standardized tests** required by a national or international IM Policy, and to **increase the warrant** for reduced collateral damages, in a stimuli scope covering at least the threats coming from the **THA**, and more if possible. This warrant increase can be obtained by characterization of well **chosen** properties for the main **energetic materials (EM)**. Those properties must correspond to all the mechanisms involved in all possible situations, and validated pass criteria must be established.

For instance, in the case of a bullet impact, the EM characterizations and criteria have to carry on both the mechanical, ignition and burning properties, while considering also the different possible situations : bullet just perforing a little the munition case, bullet lodged in the EM loading, and bullet going out of the case.

Advantages :- no need to develop specific tests,

- the **interoperability needs** are taken into account, since the munition is tested to standardized tests,

- the **stimuli scope covered is larger** than with the second way, since the EM characterizations are designed to cover all involved mechanisms,

- it is also possible to **extend the warrant to other munition configurations**, like packaged munitions, preheated munition, and in some cases preshocked or predamaged munitions,

- in a near future, those EM characterizations will be **useful** for assessments by **models and numerical codes**,

- the **assessment cost is lower** than with the second way, since only one test serie has to be performed on the munition, and since the EM characterizations are generally **cheaper** than scale 1 test; the assessment cost is also not very different than

when the first way (standardized tests only) is followed, because generally most of these EM characterizations are **already available**, from the **research and qualification** programs. This will stay true even if computations become a part of the IM assessments.

- and finally, EM characterizations are probably the only way by which we can afford the **test repetition** necessary to establish unacceptable responses probabilities.

Drawbacks : - **all** likely mechanisms, involved in the munition responses to thk 'stimuli associated to standardized tests and other likely situations, must be **well** mastered, and properly validated, by basic research programs, sometimes heavy, but which are common to several development programs.

This third way, which can be called an **IM & IEM** approach(Insensitive Munition with Insensitive Energetic Materials), is by evidence the safer one for offering a real decrease in weapon platforms vulnerability. It is a good compromise between :

- the need for standardization of tests and criteria,
- the increase of warrant for real safety, in a wide range of stimuli,
- the limitation of IM assessments cost.

Since this demonstration has only been theoretic and " philosophical", we are now developing more deeply our knowledge of munitions response variability according to various kinds of stimuli, for a same generic threat . This will emphasise the need for assessment of IM not only in standardized conditions.

On another hand we will present the potential of the EM characterization approach, to demonstrate that when well mastered, this way allows to perform a wider assessment, with a low cost increase.

The following analysis is only dealing with thermal threats and bullet impacts, but the same could have been done for other threats, like fragment impacts, sympathetic detonation and shape charge jet impact.

THERMAL THREATS

When speaking about thermal threats we have to distinguish between what is called Fast Cookoff , or FCO (**f**uel fire, **t**orching, heating by fast combustion of other materials than **f**uel and EM, like wood or other packaging materials for instance,...), and what is called Slow Cookoff , or SCO (steam leak, fire nearby, removal from fire, jet exhaust, . ..).

Fast Cookoff :

There are fewer examples of munition response variability in the case of FCO than with SCO, but some available results seem to show that the behavior of some Rocket Motors (RM) to FCO, can be influenced by the following features:

- nature of the case, which can weaken or **deconsolidate**, and then have a different pressure resistance according to the heating rate and maximum temperature,
- design of the nozzle and other combustion gases evacuation devices, which can lead to higher heating inside the motor than at the liner / propellant interface.

Then the same kind of response variability can be expected when a munition is submitted to different thermal stimuli, even if they are all belonging to the FCO family. For instance, a RM will probably not react in the same way in the two following situations:

- in a fuel fire there is a chance of weakening of the metallic case, depending of the kind of steel, and of smooth reaction (Type V or IV) **after** less than two minutes; this behavior can be expected when the metallic case temperature rises much more than the propellant temperature, due to liner and to the very high heating rate,
- in a debris fire, at 1 °F/sec [4], the heating rate is much lower than in the previous example, so the case temperature will be closer to the propellant temperature, and the case will not be weakened when the reaction will occur, at roughly 400 / 500 °F, **a f t e r a t l e a s t 5**

This second situation is not simulated by a standardized **fuel fire test**, and **o n e** predict the RM response is to analyse the behavior of the propellant in such a situation. This is possible by laboratory tests (see [5]).

Slow Cookoff :

On the other hand there are much more **examples of response variability** with features of the tested article and with heating rate, when speaking of Slow Cookoff.

High Explosive Loading	3 l generic unit (1) (reaction temperature)	UN Tube (2) (reaction temperature)	VCCT Vehicles (3) (reaction temperature)
TNT	II (190 °C)	III (185°C)	?
B 2188	TBD	III (143°C)	V (139°C)
ORA 86	IV (213 °C)	III (198°C)	?

Table 1: Influence of the geometry article on the reaction violence to SCO at 3.3 °C/hr.

(1) Diameter = 123 mm, **case** thickness = 10mm, tests performed by GERBAM,

(2) Diameter = **48mm**, case thickness = 4 mm.

(3) **Diameter** ≈ 25 mm, case thickness = 1.9 mm, **tests** performed by NSWG.

The results on Table 1 show that there is a relation between the features of an article (diameter, case thickness, . . .) and the violence of the reaction to SCO. And such a variability can also be expected due to heating rate, as shown by Figure 1, which describes the temperature profile just before thermal ignition, for two different geometries.

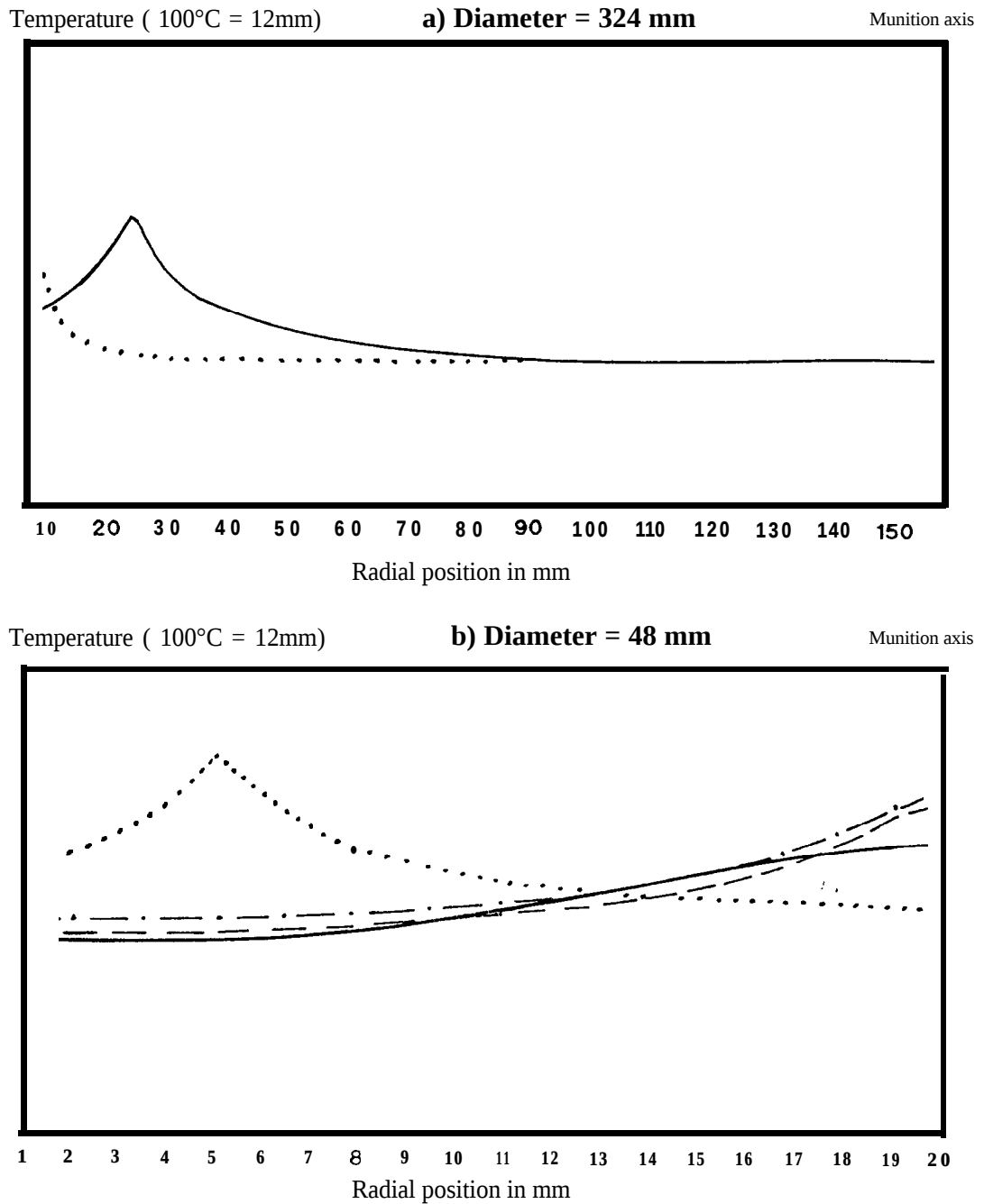


Figure 1: Influence of the heating rate on the temperature profile just before ignition
 (— : 3.3°C/hr - - : 10°C/hr - . - : 30°C/hr : 60°C/hr)

The results in Figure 2, obtained by numerical computations taking into account the internal heat generation, show clearly that the heating rate and the article size are very influent on the temperature profile just before thermal ignition. The consequence is that the point of ignition will move in a munition when the heating rate will change, this motion having a great influence on the reaction violence. It is also important to notice that this process will take place differently according to the article size.

Those results show also that for not too large articles the 3.3°C/hr test is well simulating the worst credible case, since it leads to ignition on the centerline. In the present example, this is true up to 200mm diameter; above this size the ignition point will progressively move from the center to the periphery, and will become more and more different from the worst credible case, which here will be an isothermal heating at a temperature close to the critical temperature.

So, it is obvious that the warrant for a smooth reaction to SCO can't be obtained by performing only one test, being a standardized one or a specific one. According to the **IM & IEM approach proposed before**, this warrant can only be reached by performing:

1° - a complete characterization of chemical (kinetics of all decomposition processes, corresponding reaction heat and gas production ability) and thermal properties (specific heat, thermal diffusivity, if possible as a function of temperature) of the energetic materials involved in the munition to be assessed,

2° - numerical computations to well evaluate the influence of heating conditions, and also of packaging features, on the munition behavior (point of ignition),

3° - the standardized test at 3.3°C/ hr, and , if this test seems to not simulate the worst credible case, generic unit or laboratory tests allowing to check that in the worst credible case (ignition on the centerline) the reaction has still an acceptable level. Such tests have been described in [5].

BULLET IMPACTS

There are also several examples of reaction variability with bullet impacts, on both munitions and generic units. To avoid the publication of classified data, our analysis will only carry on generic unit examples, with the french 3 liters model (143 mm outer diameter, 260 mm high, steel case with 10 mm thickness, referenced FV- DD - EX - 3L - 1).

High Explosive Loading	Reaction at 400m/s	Reaction at 600m/s	Reaction at 850m/s
B 2170 A	No reaction	No reaction	Type V
HEXABU 88	Type V	Type I	Type V
ORA 86	No reaction	Type I	Type V

Table 2 : Influence of the .5 cal bullet velocity on the reaction violence (GERBAM results).

The results on table 2 show that very different responses may be obtained to bullet impact, with the same article and energetic material, just by changing the bullet velocity:

- in the first example we observed a variability with limited consequences, but which shows that we can have no reaction at low velocities, and ignition at higher velocity,
- the two other examples exhibit a dangerous variability, since at low and high velocities we have got just a burning, and a no reaction in one case, while at a medium velocity we observed a detonation. As shown by Figure 2, this has an influence on the internal. These behaviors are expected to be the result of two different processes :

1°) It seems that the damage produced in some energetic materials loading are higher at medium velocity ($\approx 600\text{m/s}$) than at 850m/s ,

2°) at low and medium bullet velocities (between 350 and 700m/s with our generic unit), the projectile is lodged within the energetic loading. In this case there is only one vent created consecutively to the impact, while for higher velocities two vents are allowing the escape of the combustion gases. This last point is well described by the results of the numerical simulations on Figure 2. [6]

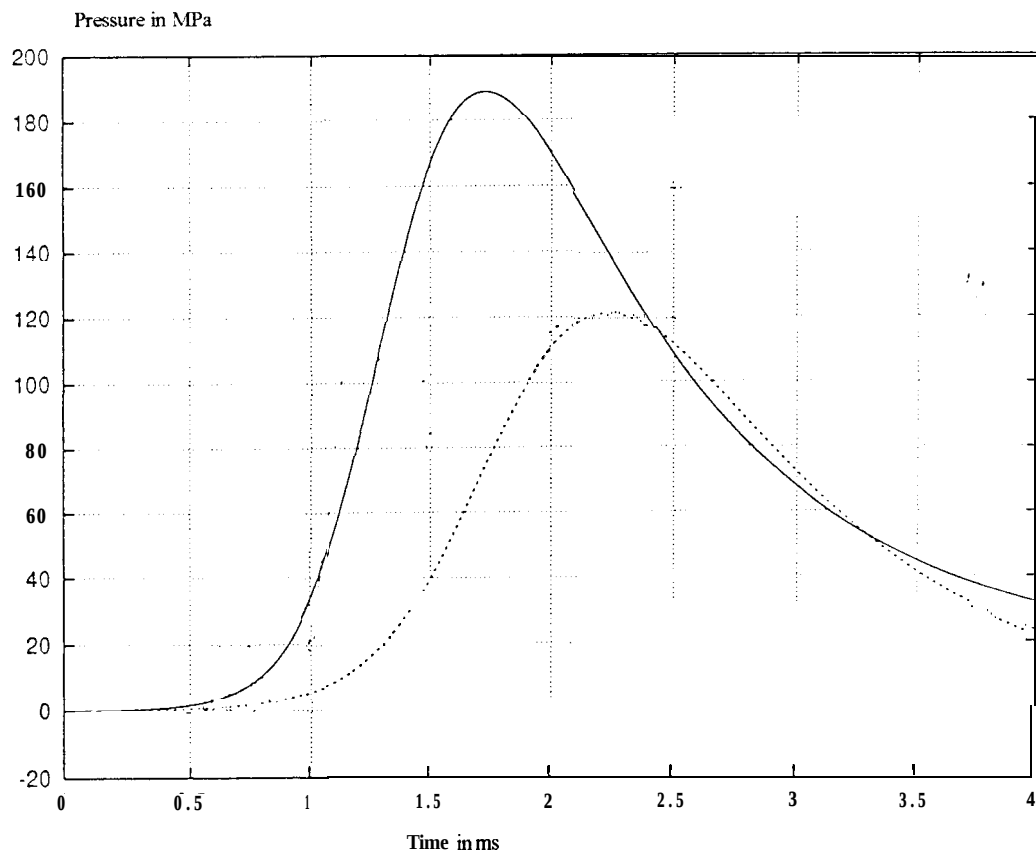


Figure 2 : Influence of venting features on the internal pressure evolution, in the case of the 3 liters generic unit , with a .5 cal bullet impact at 850m/s .
(— : 1 vent ··· : 2 vents)

These computations show very well that the number of vents created by the bullet impact is influencing the internal pressurization rate, and of course the reaction violence.

And the effects of such differences may not be exhibited by a standardized test at 850 m/s, especially with all the munitions which are completely perforated by a 0.5 cal bullet. There are many examples of identical reaction obtained at the standardized bullet impact test, with a conventional and with an insensitive high explosives loading, while their behaviors may be quite different in other impact conditions.

For instance, this is the case for two PBXs, ORA 86 (HMX / PU) and B 2214 (HMX/NTO/HTPB), like shown by Figure 3, which is the result of numerical simulations performed to assess the difference of internal pressurization rate.

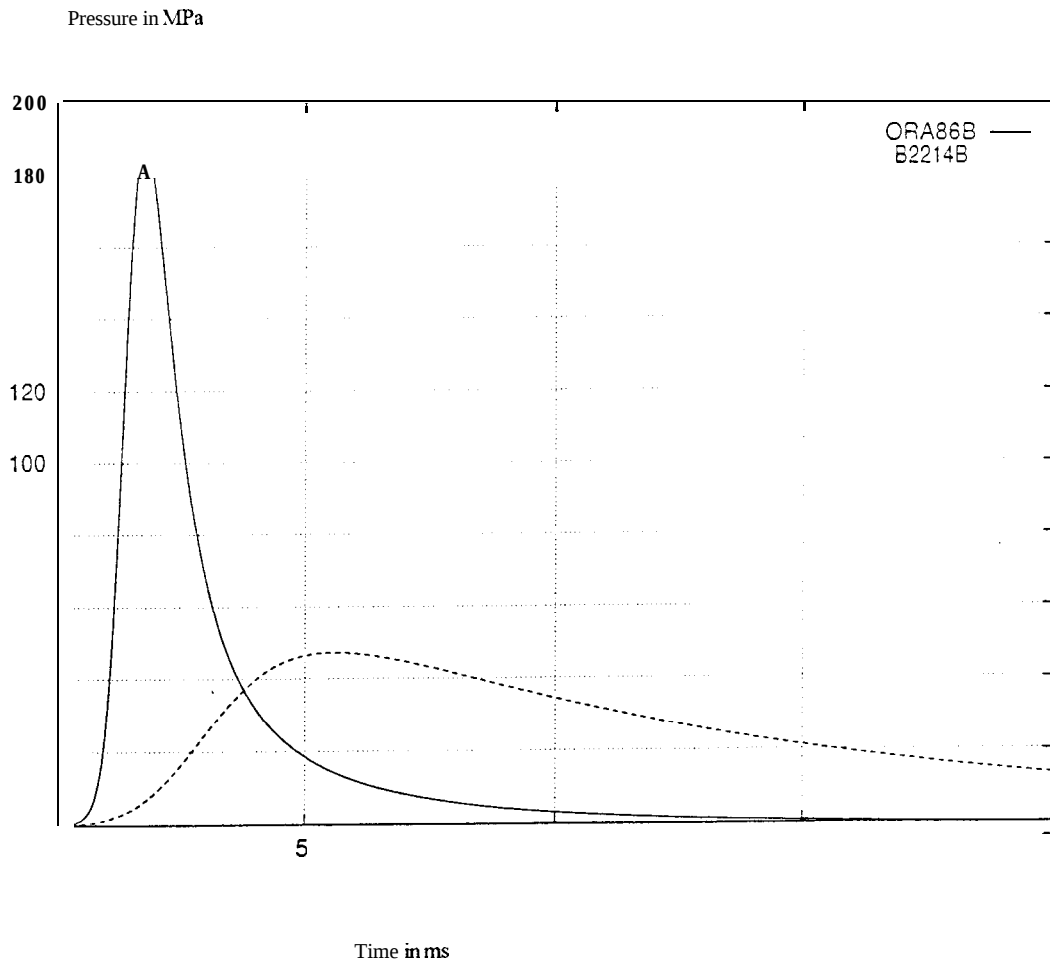


Figure 3: Internal pressure evolution wPBXs,at 0.5 cal bullet impact.

So, such computations which are based on energetic materials properties (mechanical and burning properties), are a better way to assess the behavior of a munition, than performing only a

Like for SCO, it is then obvious that the warrant for a smooth reaction to bullet impact can't be obtained by performing only one test, standardized or not. According to the **IM § IEM approach proposed before**, this warrant can only be reached by the following procedure:

1°-performing of a complete characterization of mechanical properties(if possible under dynamic conditions), and of burning parameters (if possible after dynamic impact **solicitation**) of the energetic materials involved in the munition to be assessed. At this point, it is important to evaluate also the shock sensitivity (by a gap test for example), in the cases where an initiation by SDT could occur: thin munition case and high shock sensitivity of the EM.

Concerning the energetic materials characterizations dealing with the DDT (Deflagration to Detonation Transition) hazard, which are mainly the resistance to dynamic mechanical stimuli and the ability to burn quickly when damaged, the Friability Test can bring a very good information, and offer the potential for a pertinent criteria concerning the behavior to bullet impact [7,8]. For instance :

- the Friability level of ORA 86, which led to the higher internal pressure in the results of the computations on Figure 3, and on a detonation at the 600m/s impact(Table 2), is above 10 MPa/ms,
-

pressure in our computations, is only 0.5 MPa/ms.

2°-although the knowledge of the Friability level is already a good information to assess the possibility of a violent response to bullet impact, it is better to perform

kind of situations identified by a THA. These computations will allow a better choice of energetic materials, by taking into account both the features of the

3°-the standardized test, with a 0.5 cal bullet impact can be performed **usefully** if it can be demonstrated that it will simulate the worst case (bullet lodged into the energetic loading). Otherwise, it is **recommanded** to perform at least one other testing, which can be done on a generic unit, like those described in [9]

CONCLUSION

The experiments and numerical simulations available today allow to demonstrate that for the **IM** assessments, concerning the thermal threats and the bullets impacts, performing only a **standardized test is very often not sufficient to bring the warrant** for smooth responses when a munition is submitted to the worst case.

On the other hand, performing a **test plan generated by a THA may be hazardous**, because it very often simulates only the threats corresponding to the just necessary.

That's the reason why we propose an intermediate way, which could be called an **IM § IME** (Insensitive Munition with Insensitive Energetic Materials), based on a good knowledge of all likely mechanisms, on a complete energetic material characterization and on standardized tests. This way is the only one to allow the **best choice for selection of appropriate energetic materials**, and seems to be **a good compromise** between :

- the need for standardization of tests and criteria,
- the increase of real warrant for safety of the weapon platforms, in a wide range of stimuli,
- the limitation of IM assessments cost,

The demonstrations we presented were only carrying on **SCO** and **BI**, but of course the same approach can be followed for other threats: fragment impacts, sympathetic detonation,

Then many elements are available to show the advantages of such an approach, which should usefully be taken into account during the elaboration of the NATO document for implementation of STANAG 4439: the AOP TM in preparation.

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Figure 1 a)

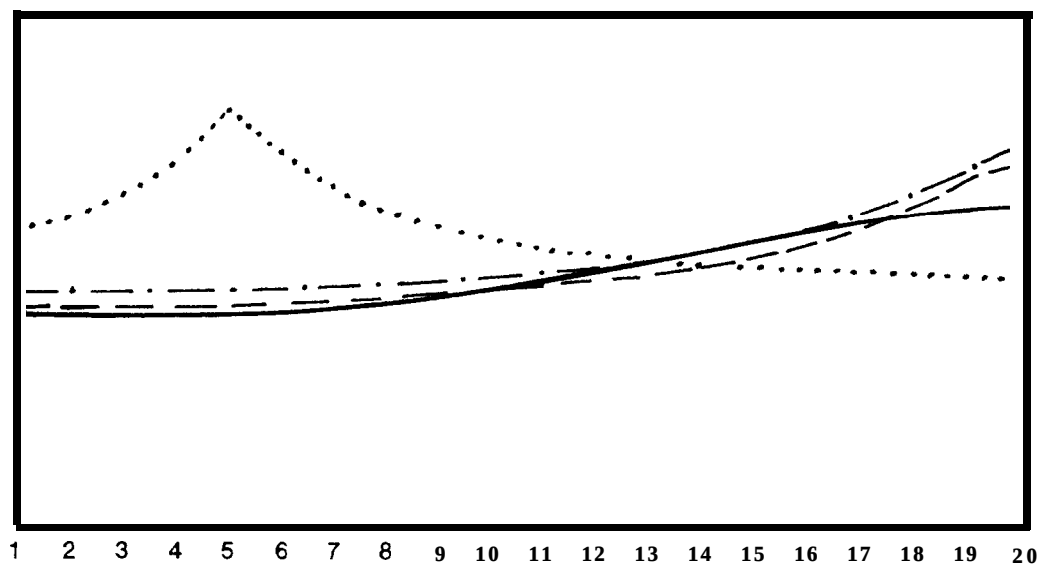


Figure 1 b)

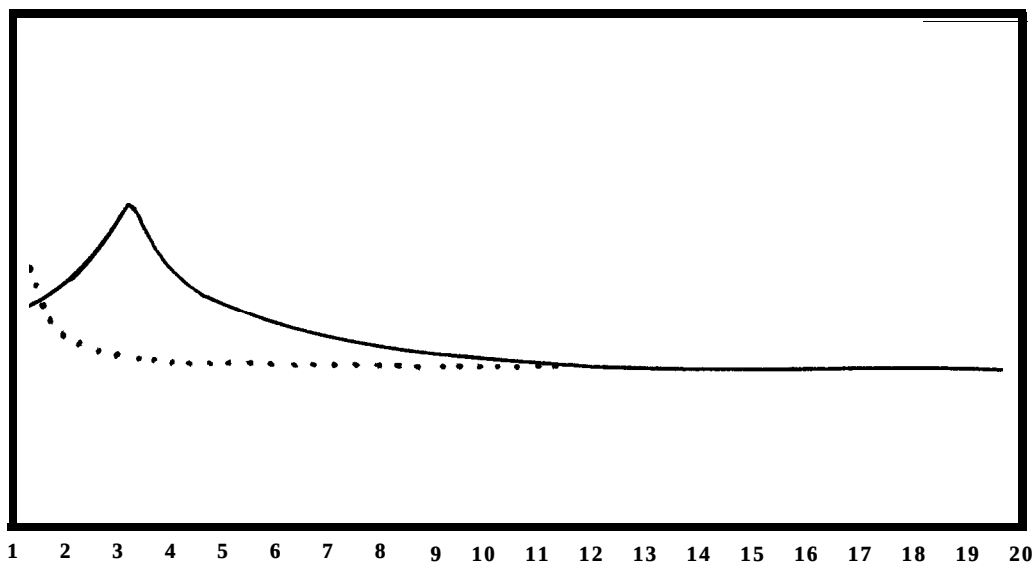


Figure 2

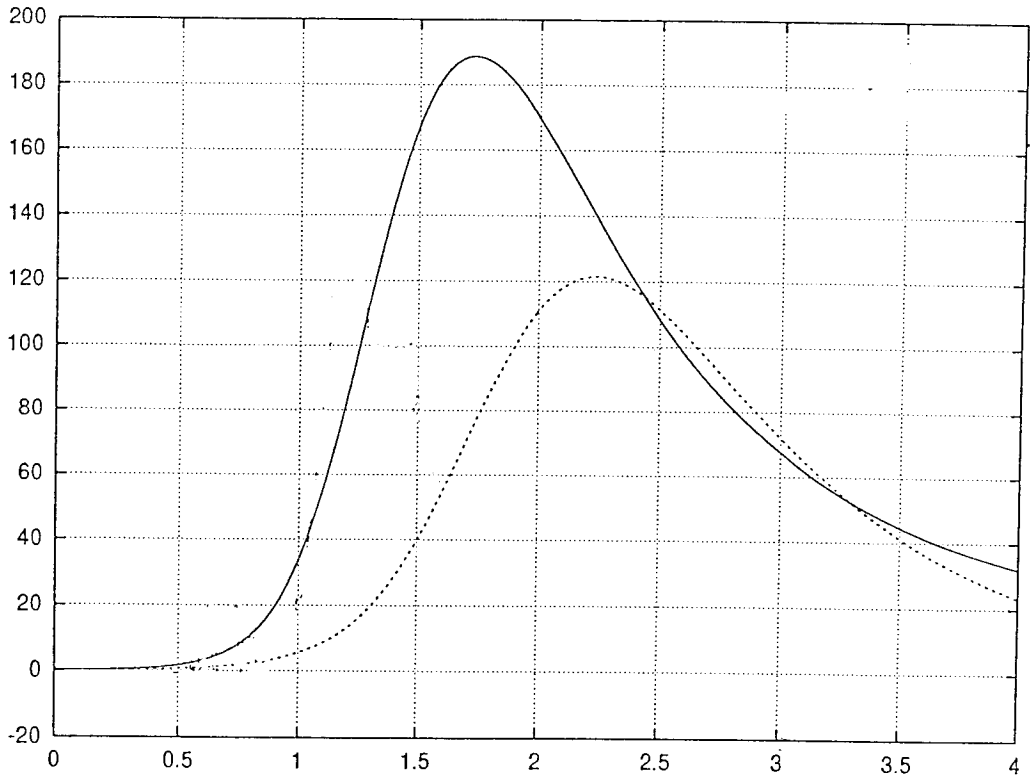


Figure 3

