

MSIAC workshop 2018: Improved Explosives and Munitions Risk Management

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Abstract

MSIAC is organizing a workshop to exploit an improved understanding of munitions vulnerability and consequences to deliver improvements in explosives and munitions risk management. The current management of explosives and munitions risks is a broad area covered by many policy documents and different communities of interest. These documents are based on a combination of best practice and underpinning technical and scientific knowledge.

The workshop will bring together stakeholders from the Hazard Classification (HC), Insensitive Munitions (IM), and explosives storage safety communities to assist in development of a coordinated and optimised approach to managing explosives and munitions risk. A secondary aim of the workshop is to initiate changes that will help realise the benefits of IM, particularly during transportation and storage to improve safety and help safeguard military capability in hazardous operating environments.

This paper presents the workshop goals and how, with support and involvement of the community, MSIAC plans to achieve these. MSIAC also seeks the active participation and support of the communities and request comments on the proposals in this paper.

Introduction

MSIAC is organizing a workshop titled “Improved Explosives and Munitions Risk Management” (IEMRM). This workshop seeks to exploit an improved understanding of munitions vulnerability and consequences to deliver improvements in explosives and munitions risk management. The workshop will be held in Granada, Spain, over the period 10-14 September 2018.

Information about the workshop, including the call for papers, registration and resources can be found on this MSIAC webpage:

<https://www.msiac.nato.int/workshop/improved-explosives-and-munitions-risk-management>

The workshop aims to bring together stakeholders from the Hazard Classification (HC), Insensitive Munitions (IM), and explosives storage safety communities to develop a coordinated and optimized approach to managing explosives and munitions risk. A secondary aim of the workshop is to initiate changes that will help realise the benefits of IM, particularly during transportation and storage, to improve safety and to help safeguard military capability in hazardous operating environments.

The workshop will seek to achieve the following goals:

- Support the IM and HC harmonization initiative
 - Identify how response descriptors can be introduced in HC testing
 - Identify whether there’s a need for revised definition of Hazard Divisions (HD) and Storage sub Divisions (SsD)
- Develop improved methods for explosives and munitions risk management
 - Exploit results from small- and full-scale testing
 - Manage risk with sufficient detail and granularity
 - Realize benefits of IM
 - Efficiently manage munitions presenting the greatest hazard
- Recommend improved methods for explosives and munitions safety risk standards

- Ensuring they reflect the changing nature of the munitions stockpile
- Balancing complexity versus ease of user application

The goals of the workshop are symbolized by the workshop logo in Figure 1. A shield consisting of the colors typically used to indicate munition responses to IM stimuli represents the aforementioned finer granularity and detail. Also a review of the appropriateness of current policy and standards managing risk, spiraling toward better solutions, will be a major benefit of this workshop.



Figure 1 Logo for the MSIAC 2018 “Improved Explosives and Munitions Risk Management” workshop.

This paper presents how MSIAC plans to achieve these goals. First, a preliminary workshop structure is presented. This is then followed by a description for each of the topics and sessions and the central questions that we believe need to be answered.

Preliminary workshop structure

The workshop will contain various plenary and parallel sessions (focus areas) to optimize the exchange of information. The preliminary workshop structure is depicted in Figure 2, and contains the following main topics:

1. Improved HC and IM Assessment
2. Improved Consequence and Risk Analysis
3. Implementation of Improved Explosives and Munitions Risk Management

A more detailed schedule will be made available closer to the workshop incorporating revisions and any changes based on comments received from the community.

The remainder of this paper will provide more details on the various topics and focus areas outlined in Figure 2.

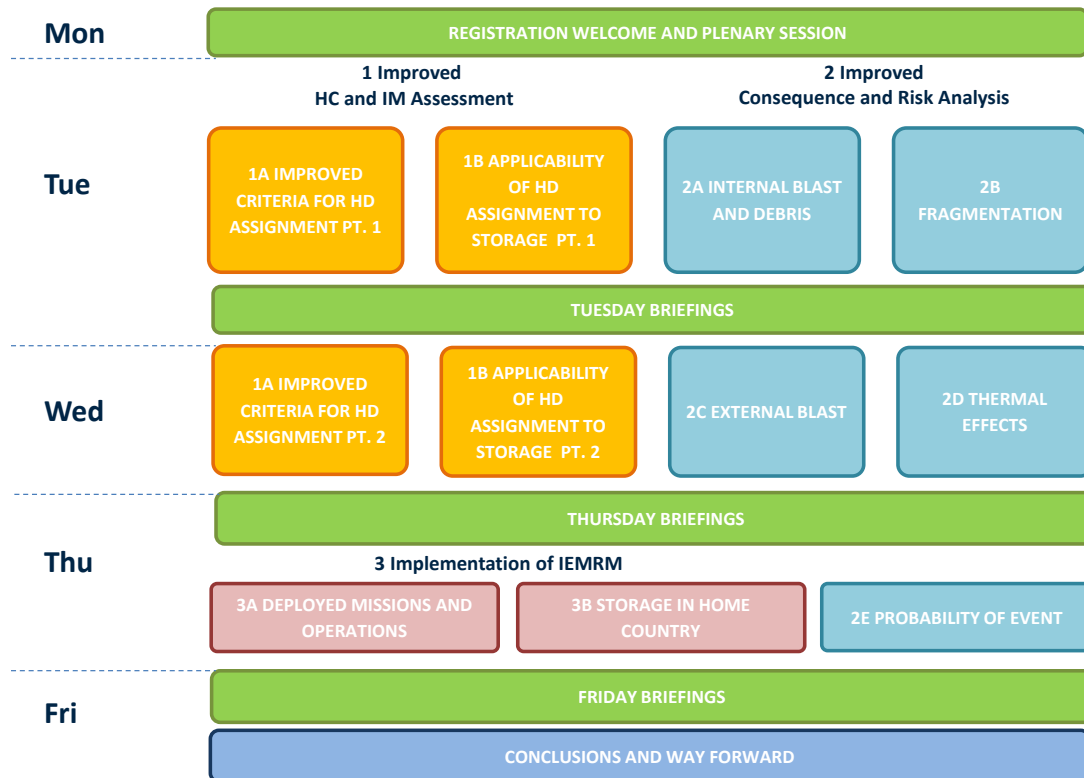


Figure 2 Preliminary workshop structure.

1. Improved HC and IM Assessment

1A. Revised Criteria for HD Assignment

Introduction

The current UN HC system contains criteria, test methods and procedures to determine a munitions' Hazard Division (HD1.1 through HD1.6). These criteria, test methods and procedures are detailed in the UN Model Regulations, more specifically in the [Recommendations on the Transport of Dangerous Goods, Manual of Tests and Criteria, 2015]. The pass/fail criteria described in this document (in terms of thermal, projection/explosion, mass explosion effects) are somewhat loosely defined and hence can be subjective. This can lead to differences in HD assignment between national authorities.

IM response type is assessed based on the tests and criteria described in [AOP-39, 2010]. This publication defines the more detailed response descriptors as criteria, which are aimed at reducing subjectivity. The AOP-39 tests and criteria, as well as a number of national criteria for IM response type, are shown in Figure 3.

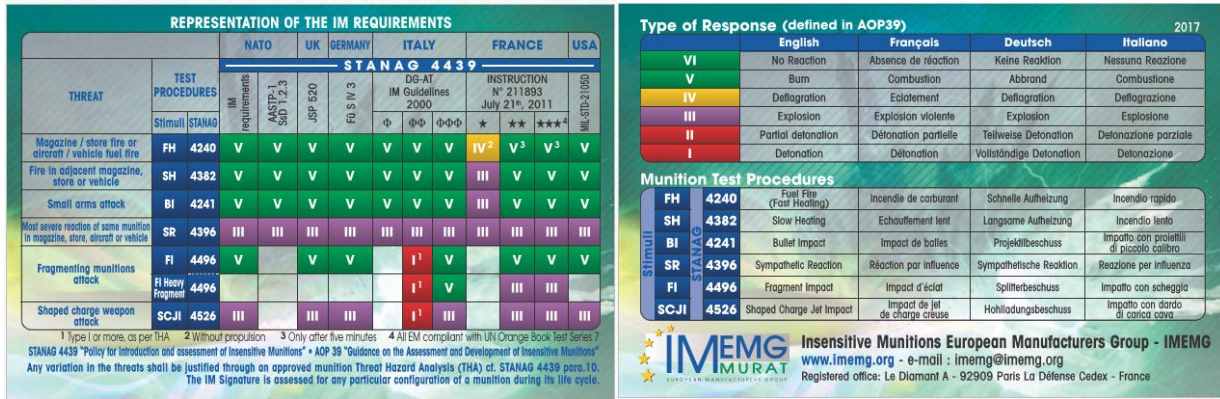


Figure 3 Overview of national and international IM requirements (IMEMG, 2017).

In this session we will discuss the harmonization of HC and IM. The current proposal is that criteria used to assign HD to military articles will make use of results from the additional NATO IM tests as well as the IM/HC tests procedures for sympathetic reaction and fast heating. In addition, the improved response descriptors would be used. It should be noted that response descriptors have already been introduced in UN Test Series (TS) 7 (2015), used to assign munitions to HD1.6. They have however not yet been introduced in UN TS 6, used to assign munitions to HD1.1 through HD1.4

Furthermore, the current HC system with its HDs, SsDs and other criteria, may not be accurately representing the hazards from the current and future munitions stockpile. Analysis of the MSIAC HC database [Leroy, et al., 2018] resulted in an overview of the HD assignments made by various nations (Figure 4)¹. While HD1.1 through HD1.4 all represent the overwhelming majority of ammunition types, HD1.5 and HD1.6 assignments are almost non-existent.

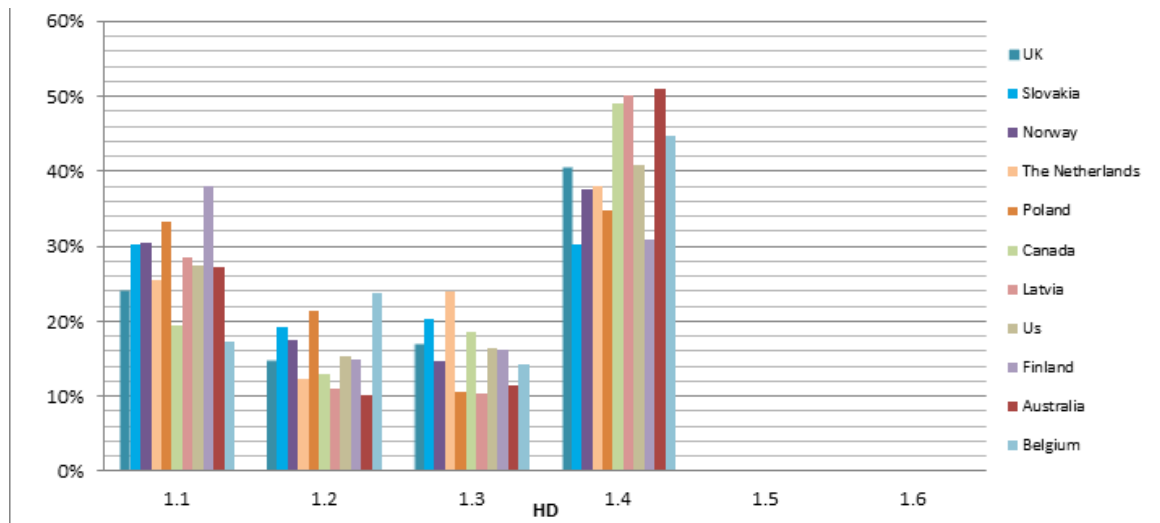


Figure 4 Percentage of HD assignment by nations [Leroy, 2018].

Within HD1.2, we distinguish between SsD1.2.1 and 1.2.2 with a criterion based on the individual munition’s HE content greater or smaller than 0.136 kg respectively. This rather pragmatic criterion is based on the availability of large scale test data for which Quantity Distances (QDs) have been derived [Tomasello, et al., 2014]. We know however that the hazard posed by these articles also depends on other factors such as the ammunition casing, wall thickness and the explosive substances used. SsD1.2.3 which has been defined as an intermediate form of IM, currently has 57 HD assignments in the US, 4 in the UK,

¹ It should be noted that in absolute numbers there are large differences between the nations; most ammunition assignments have been made by the US (over 17.000), while the smaller nations have just a few hundred.

and none in the other nation's data available in the MSIAC HC database. This is only a small fraction (in the order of 0.1%) of the total number of reported assignments.

These observations raise the question whether a revision of HD, SsD and Compatibility Groups (CG) is necessary. A better representation of the munition stockpile could allow for more appropriate quantification of the risk. It is obvious that any changes will have an effect on mixing, aggregation rules, QD and risk analysis.

Central questions

The central questions within this session are:

- Can IM test responses be introduced into HC assessment and what would be the assessment criteria?
- Can additional evidence (including IM test) be introduced into HC assignment?
- Is it necessary to revise the definitions of HD and SsD and what would be the implications?

1B. Applicability of HD assignment for storage

Introduction

The current HC system was developed for transport by the UN, but has been adopted for storage by NATO as per [AASTP-3, 2009] and [AASTP-1, 2015]. HC and IM assessment involves a limited number of tests and is conducted with small quantities of munitions. Storage of ammunition and explosives typically takes place at a much larger scale and often confined within robust structures as illustrated in Figure 5. This can lead to different reponse mechanisms than expected based on the HC system. In this session we will discuss improved guidance and an expansion of the assessment process .

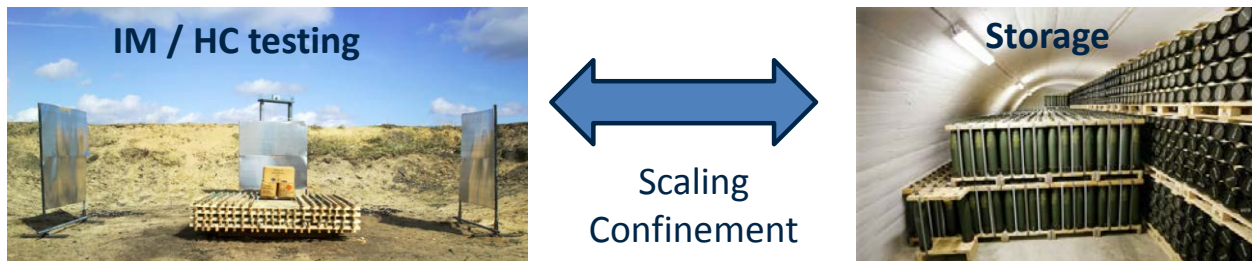


Figure 5 Differences between IM and HC testing and storage conditions; scaling and confinement

Confinement

In order to show the effect of confinement we refer to tests conducted by [Farmer, et al., 2015]. M1 propellant which was ignited in reinforced concrete magazines with a vent area as shown in Figure 6. Dependent on the loading density and size of the vent area, it was found that ignition could lead to over-pressurization and break-up of the magazine including significant debris throw.





Figure 6 Initial setup (top) and results (bottom) from test with 540 kg M1 propellant (each barrel initiated). (Farmer, et al., 2015).

Another example is the test series conducted in the CHAF project (Quantification and Control of Hazards Associated with the Transport and Storage of Fireworks). Various types of fireworks articles were tested in closed vessels and ISO-containers. Tests with so-called “waterfall fireworks”, classified as HD1.3G, led to a mass detonation in an ISO-container. A number of propellant and fireworks accidents have shown a similar behaviour, e.g. in Enschede [Weerheijm, et al., 2002].

These examples show behaviour that is not consistent with expectations for HD1.3 classified materials. Although the articles discussed may be very different from IM, the effect of confinement may also influence response of IM compliant munitions stored in bulk.

Scaling Factors

The munitions’ response is determined by a large range of scaling factors; from the smallest scales at the energetic material level, to the munitions component level and the all up round. This has appeared to be especially relevant for cook off related scenarios and was discussed in detail during the MSIAC Science of Cook Off workshop held in 2016 [Andrews, et al., 2017]. Also relevant is that, dependent on the community, there can be a misunderstanding of what is considered small and large scale. Beyond the scale of the munitions itself we have stacks of munitions and the storage magazine. The dynamic response of typical magazine construction materials such as the break-up of reinforced concrete is also scale dependent.

In order to show the effect of scaling at the storage level we refer to tests conducted by [Edwards, 2011]. In these tests one-layer stacks of 105 mm HE IM shells were exposed to various threats. The stacks contained a larger number of munitions than typically tested in an IM or HC test. The results are shown in Figure 7. When a single shell was detonated the rest of the stack showed a Burn (type V) or a Deflagration (type IV) response, which is in agreement with IM requirements. When the threat was however increased by simultaneously detonating two shells, multiple other shells showed a more severe response than Burning or Deflagration, e.g. Explosion (type III). This result shows that at a larger scale and with a more severe threat, the munition’s response can be worse than from IM or HC testing. Although a mass detonation is not expected, the severity of the munitions’ response could potentially increase further for multiple layer stacks. This was however not tested.

Central questions

The central questions within this session are:

- Can we develop improved guidance to clarify the applicability of HC assessments?
- What complementary information (related to scaling and confinement) is needed to make a reliable estimate of munitions response in storage conditions?
- What information is needed from the explosive (storage) safety community?
- What is a sufficient number of test repetitions?
- Are there best practices?

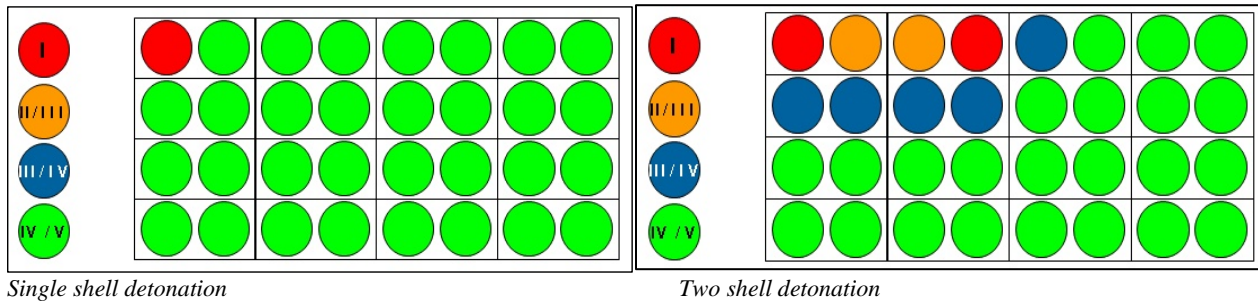


Figure 7 Results from tests with stacks of 105 mm HE IM shells [Edwards, 2011]. Detonation (I), Partial Detonation (II), Explosion (III), Deflagration (IV), Burn (V).

2. Improved Consequence and Risk Analysis

Introduction

Within the risk management of explosives and munition, consequence and risk analysis plays an important role. We start with an overview of relevant risk management standards and the relation with consequence and risk analysis.

The NATO Explosives Safety Munitions Risk Management (ESMRM) process is described in [ALP16, 2015]. An MSIAC visualisation of the linkage between the various NATO standards is shown in Figure 8. The starting point is to have hazard classified ammunition as described in [AASTP-3, 2009].

Quantity Distances (QDs) and Field Distances (FDs) are consequence-based distances to be kept between Potential Explosion Sites (PES) and Exposed Sites (ES). [AASTP-1, 2015] provides QDs for storage in the home country, whereas [AASTP-5, 2016] provides FDs for storage on deployed missions and operations. Some of the terminology is explained in Figure 9 [Van der Voort, 2016]. This reference also describes the experimental and theoretical basis of the QD standards. A more recent reference [Van der Voort & Keefe, 2018] focuses on the basis of QDs for Insensitive Munitions (IM), e.g. SsD1.2.3 and HD1.6.

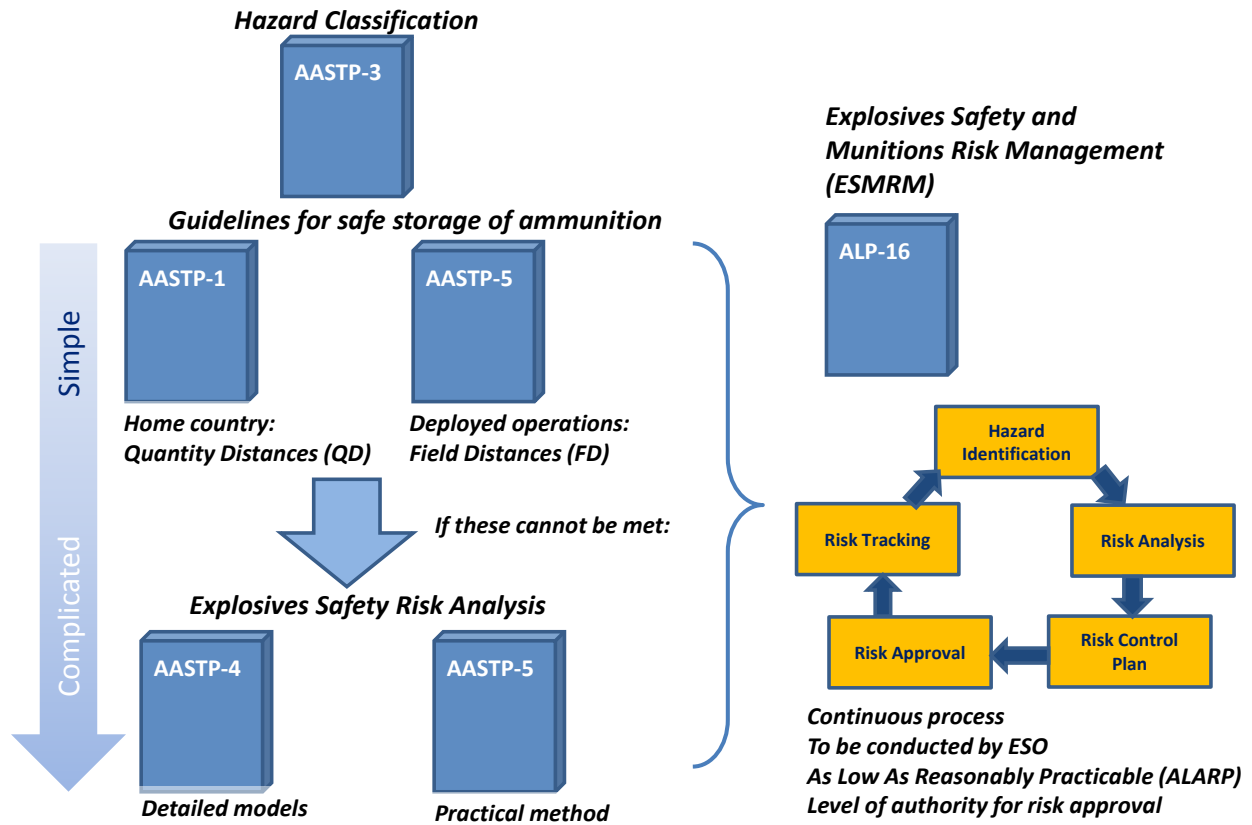


Figure 8 MSIAC visualization of the linkage between the various NATO standards on Explosives and Munitions Risk Management

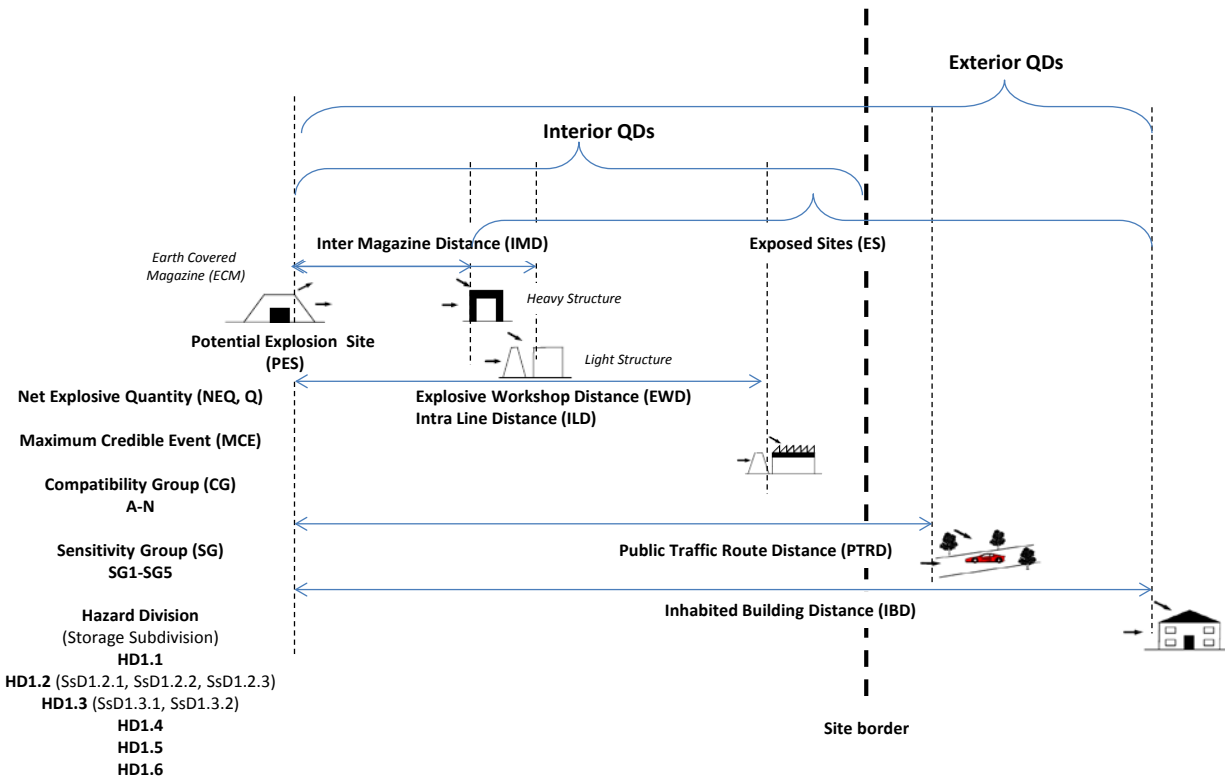


Figure 9 Illustration of QD terminology [Van der Voort, 2016].

If QDs or FDs cannot be met due to operational requirements, ESMRM² (and/or) national policy prescribes an explosives safety risk analysis to be conducted. The NATO risk management process [ALP-16, 2015] describes risk management as a continuous process where a risk analysis is followed by a risk control plan, risk approval and risk tracking.

A relatively simple qualitative risk analysis method for deployed missions is available in [AASTP-5, 2016]. More advanced engineering models for use in Quantitative Risk Analysis (QRA) are described in the Explosives Safety Risk Analysis Manual [AASTP-4, 2016]. Even more advanced models have been developed in the international Klotz Group (KG), with a focus on the break-up of reinforced concrete structures. The work of the KG has led to the KG-Engineering Tool (KG-ET) [Van der Voort, et al., 2013] as well as finite element approaches [Weerheijm, et al., 2017].

Consequence and risk analysis for less violent munition responses

The aforementioned standards have their limitations. They are primarily based on data from experiments and models for (mass) detonations. As a result the benefits of less violent munition responses can't always be exploited. There is a mismatch with the finer granularity offered by the response descriptors used for IM assessment [AOP-39, 2010] and HC (only for TS7). Table 1 shows that consequence and risk analysis models are not available for the Explosion (type III) and Deflagration (IV) munitions response.

Table 1 Mismatch between response descriptors and standards for QD and risk analysis

Munitions response descriptors (AOP-39)		Models available for consequence and risk analysis, e.g. AASTP-4?
I	Detonation	Yes
II	Partial Detonation	Yes/No (fraction that will detonate uncertain)
III	Explosion	No
IV	Deflagration	No
V	Burn	Yes
VI	No Reaction	NA

The most striking case is the [AASTP-5, 2016] which states that for deployed missions all ammunition has to be aggregated as HD1.1, i.e. assumes a mass detonation. The disadvantage is that the benefits of any HD other than HD1.1 cannot be exploited on deployed missions. Also QDs for airfields and ports in [AASTP-1, 2015] are only specified for HD1.1.

Under this topic we will discuss what experimental data and models would be required to quantify consequences and risks based on the response descriptors, in particular for munitions responses Deflagration (Type IV) and Explosion (Type III). In this effort various aspects should be considered: weapon fragmentation, Quasi-Static Pressure (QSP), break-up of an ammunition magazine or container, blast, and debris throw. It is essential to include the effects of scaling, confinement and venting in these models. Some modelling efforts are shown in Figure 10 below.

² NATO ESMRM policy describes the risk management process to be followed on deployed missions. Some nations have a national risk management policy for storage in the home country.

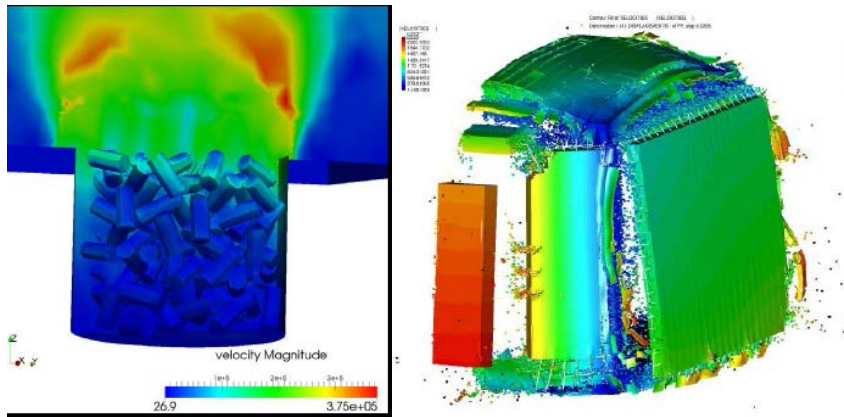


Figure 10 US research effort 2017: Modelling of propellant combustion (left) and detonation in ammunition magazine (right) by Applied Simulations, Inc (ASI) [Conway & Covino, 2017].

The following paragraphs briefly describe the various sessions under this topic. A more detailed overview will be presented in another paper at this symposium [van der Voort, et al., 2018].

2A. Internal Blast and debris

Introduction

In this session we will discuss blast loads inside ammunition magazines and the formation of structural debris for munitions that exhibit less violent munition responses.

For detonations, the blast loading of an ammunition magazine wall consists of a series of reflected shockwaves, followed by a Quasi Static Pressure (QSP). Roughly speaking the shockwave damages the structure resulting in a debris cloud, while the QSP is driving the acceleration. During acceleration the QSP reduces due to expansion and venting. The semi-empirical Debris Launch Velocity (DLV) equation gives a reasonable approximation.

For less severe munition responses the shocks (or pressure waves) are expected to be less pronounced, whilst the QSP will have a rise time related to the reaction rate. Of interest is the effect of these phenomena on debris mass and velocity distribution. In order to gain an insight current efforts are aimed at extending the DLV with a dependency on explosive substance and reaction rate.

Central Questions

The central questions within this topic are:

- What models need to be developed in order to quantify internal blast and debris effects for less violent munitions responses?
- What experimental data is needed to develop and validate these models?
- What information is needed from the HC/IM community?

2B. Fragmentation

Introduction

In this session we will discuss fragmentation for munitions that exhibit less violent responses.

The general expectation is that for less severe munitions response, the effects and consequences will reduce. [Baker, et al., 2009] have shown that this is not necessarily the case for fragmentation. They describe tests with M107 155 mm Comp B filled artillery shells which were initiated in non-design mode. The larger fragments created in the sub-detonative response travelled further due to a lower deceleration by air drag. An example of a 840 g steel fragment reaching 1824 m is given (Figure 11), thereby greatly

exceeding the established Hazardous Fragment Distance (HFD) and the Maximum Fragment Distance (MFD)³ for this munition. This observation raises the question what is an appropriate methodology to determine safety distances. Although the maximum throw distance observed in the test was large, we should also consider that a small number of large fragments will only cause a small hit probability and consequently HFD. Also relevant is how these fragmentation effects change from a single munition to munitions in bulk storage.



Figure 11 840 g steel fragment from a M107 155 mm artillery shell that reached 1824 m after a sub-detonative response [Baker, et al., 2009].

Central Questions

The central questions within this topic are:

- What models need to be developed in order to quantify fragmentation effects for less violent munitions responses?
- What experimental data is needed to develop and validate these models?
- Is the concept of MFD and HFD still valid as a basis for safe separation distances?
- What information is needed from the HC/IM community?

2C. External Blast

Introduction

In this session we will discuss external blast and TNT equivalency for munitions that exhibit less violent munition responses.

For blast, there are indications that as long as all the energetic material reacts in a short enough period, the far field blast is comparable to a detonation [Reaugh, 2014]. A similar phenomenon is observed in the research field of gas explosions. The Multi-Energy method developed by [van den Berg, 2005] shows that the far field blast overpressure from fast deflagrations coincides with those of detonations in the far field. This seems to occur when overpressures in the explosion source are on the order of 1 bar or greater. This is shown by the blast chart in Figure 12, which was created by numerical blast simulation. We expect a similar behaviour for condensed explosives.

³ HFD = 137m, MFD = 801m.

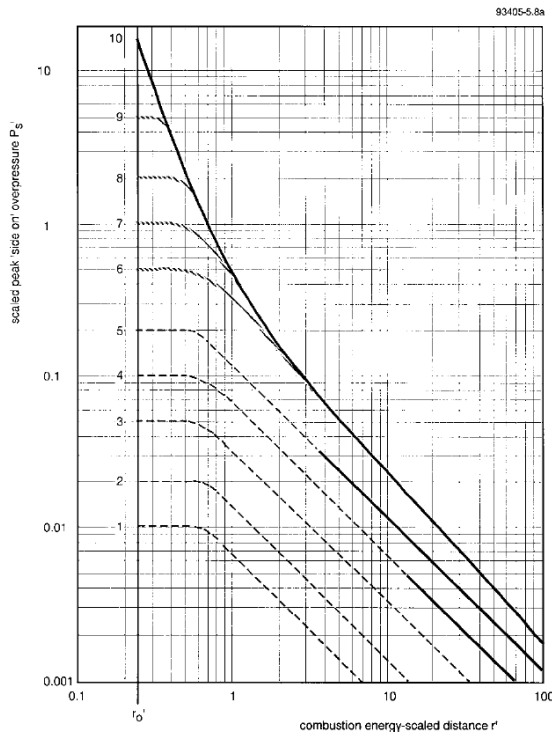


Figure 12 Multi-Energy blast charts [PGS2, van den Berg, 2004]. Curve 1 is a weak deflagration, curve 10 a detonation. Curves 6 to 9 (fast deflagrations) coincide with curve 10 in the far field.

Central Questions

The central questions within this topic are:

- What models need to be developed in order to quantify external blast effects for less violent munitions responses?
- Can TNT equivalency be used to model less violent munition responses?
- What experimental data is needed to develop and validate these models?
- What information is needed from the HC/IM community?

2D. Thermal effects

Introduction

In this session we will discuss thermal effects for munitions that exhibit less violent munition responses.

For HD1.6 and SsD1.2.3, the thermal effects are currently represented by QDs that were originally developed for HD1.3 and are based on tests conducted using large quantities of propellant (Figure 13). We expect that these QDs lead to an overestimation when applied to SsD1.2.3 and HD1.6. It could therefore be considered to perform large scale fire validation tests with stacks of SsD1.2.3 and HD1.6. For SsD1.2.3 the QD is currently set to zero when the fragments from the Maximum Credible Detonation Event (MCDE) are stopped by the structure or a barricade. The aforementioned large scale fire tests could also verify whether a structure or a barricade can equally well stop or divert thermal effects.

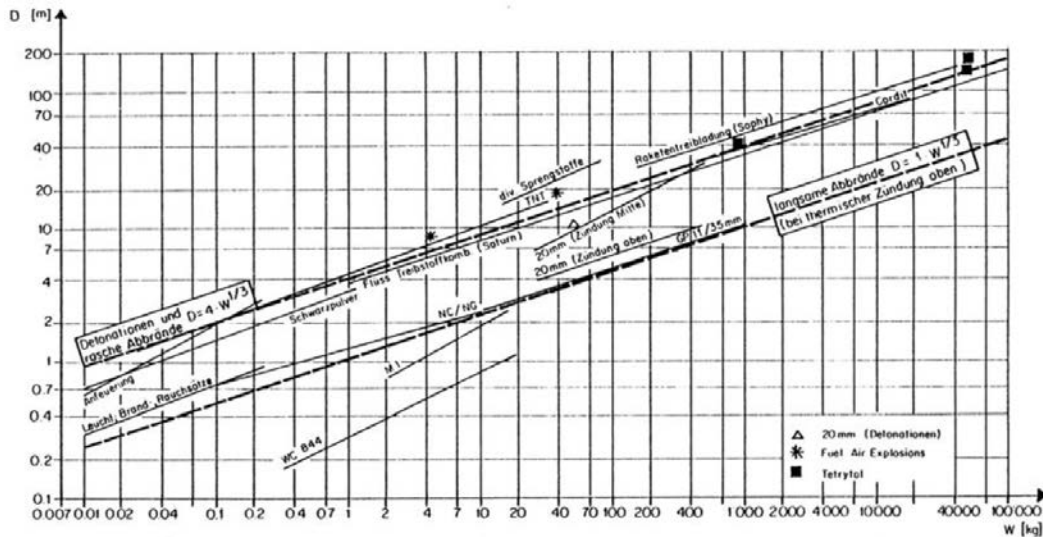


Figure 13 Fire ball diameters for various propellants and explosives [AASTP-4, 2016]

Central Questions

The central questions within this topic are:

- What models need to be developed in order to quantify thermal effects for IM?
- What experimental data is needed to develop and validate these models?
- What information is needed from the HC/IM community?

2E. Probability of Event

Introduction

In this session we will discuss the probability of event for munitions that exhibit less violent munition responses.

Munitions that show less violent responses are typically also less vulnerable and have a smaller probability of initiation in impact and fire scenarios. This means that two factors in the risk equation are affected; event frequency and consequence. The probability of event can be derived by the historical method or by analytical means. Both strategies will be discussed.

Central Questions

The central questions within this topic are:

- How can we quantify the probability of event for IM?
 - Using the historical methods
 - Using analytical approaches
- When taking the analytical approach how can we be sure not to miss scenarios (black swan events)?
- What experimental data is needed to develop and validate these models?
- What information is needed from the HC/IM community?

3. Implementation of Improved Explosives and Munitions Risk Management

In the last topic of the workshop we will discuss how the new insights gained in the previous sessions can be implemented in Explosives and Munitions Risk Management standards. This offers the opportunity for a reappraisal on how risk should be managed during the different phases of the munition lifecycle. This topic is split up in two focus areas: the first on *Deployed Missions and Operations (3A)*, and the second on *Storage in the home country (3B)*.

Areas and issues to be addressed would include:

- An increased granularity and detail could lead to more complex QD tables as well as consequence and risk analysis methods. As an alternate approach the introduction of computer-based tools into the standards could be considered. This will make application easier, and less prone to error, but also leads to a dependency on IT equipment which may be an issue e.g. during operations.
- More detailed methods could also lead to munition-specific consequence and risk analysis. This will improve the reliability of the results, but on the other hand also limits the range of applicability.
- In some cases assumptions made in standards prohibit progress. Currently AASTP-5 requires that all munitions are to be aggregated as HD1.1 in order to keep its application simple. This assumption should be challenged to enable recognition of the benefits of IM and focus efforts on munitions which present the greatest hazard.
- An holistic approach could be developed considering the cost and benefits of using simplistic and conservative assessment methods versus more detailed quantitative assessment methods. Dependent on the lifecycle phase and situation the most suitable approach could be selected.

Closing remarks

In this paper we have presented the goals and the preliminary structure of the MSIAC 2018 workshop “Improved Explosives and Munitions Risk Management”.

The envisaged results of the workshop are:

- Revised approach to munitions hazards and risks in light of development and introduction of IM
- Improved methods for consequence and risk analysis
- Improved understanding of the true nature of hazards and risks and how this can improve ownership and associated costs

We kindly invite interested MSIAC members to participate and contribute; further details will be published on the MSIAC website.

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