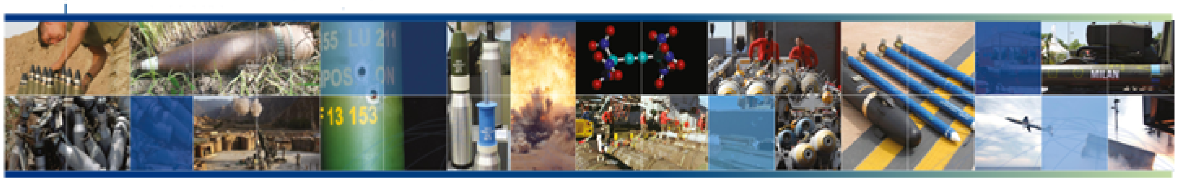
Munitions Safety Information Analysis Center

Supporting Member Nations in the Enhancement of their Munitions Life Cycle Safety



O-202

October 2019

RESULTS OF THE IMPROVED EXPLOSIVES AND MUNITIONS RISK MANAGEMENT WORKSHOP

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Improved Explosives and Munitions Risk Management

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ABBREVIATIONS

AC	Allied Committee
AE	Ammunition and Explosives
CG	Compatibility Group
DLV	Debris Launch Velocity
ECM	Earth Covered Magazine
ENEQ	Effective NEQ
ESMRM	Explosives Safety Munitions Risk Management
ES	Exposed Site
HC	Hazard Classification
HD	Hazard Division
HFD	Hazardous Fragment Distance
IBD	Inhabited Building Distance
IM	Insensitive Munition
KG	Klotz Group
MCE	Maximum Credible Event
NEQ	Net Explosive Quantity
NEM	Net Explosive Mass
NEW	Net Explosive Weight
NEWQD	Net Explosive Weight to be used for QD
PES	Potential Explosion Site
PTRD	Public Traffic Route Distance
QD	Quantity Distance
QRA	Quantitative Risk Analysis
RC	Reinforced Concrete
SG	Sensitivity Group
SG C	Sub Group C
SsD	Storage sub Division

ABSTRACT

The Improved Explosives and Munitions Risk Management (IEMRM) workshop was held from 10 to 14 September 2018, in Granada, Spain. The aim of the workshop was to exploit an improved understanding of munitions vulnerability and consequences to deliver improvements in munitions risk management. The IEMRM workshop brought together three communities related to Hazard Classification (HC), Insensitive Munitions (IM), and Explosive Storage Safety. There was an excellent participation of 73 researchers, policy makers, and practitioners from 12 MSIAC nations.

It was concluded that the current HC system is fit for its purpose of identifying the hazard from articles during peacetime transportation. The limitations have also been identified, which has led to a preliminary proposal that predicts “Hazard Types” throughout the lifecycle, based on relevant threats as well as changing munition configurations. Various recommendations have been made for HC to better inform Quantity Distances (QD) and Quantitative Risk Analysis (QRA).

There was a common understanding that the prediction of blast, primary fragmentation, secondary debris and thermal effects is well established for (mass) detonations. It was concluded that there are many challenges for the prediction and validation of physical effects for less violent (sub-detonative) munition responses, in particular for “deflagration” and “explosion”. This led to recommendations to develop quantitative definitions of the reaction rate (lower and upper limit), and to better store collate and analyse blast, fragmentation and thermal data in IM tests.

A general conclusion is that a lower reaction rate typically leads to larger fragment- and debris masses, while their launch velocities decrease. Various recommendations have been made for the development of models that can predict reduced physical effects and potential reduction in initiation probability. The “whole body of evidence” approach with multiple repetitions of IM tests, is a way forward to generate sufficient input. Also it has been discussed how this information can be implemented in QD and risk standards.

Special attention has been drawn to confined combustion of propellant in storage magazines, which may lead to over pressurization, break-up and a secondary debris hazard. This is an issue for HD1.3 but also for other HD containing propellant.

The various conclusions and recommendations will be addressed within the AC/326 SGs and working groups. Also three new work elements have been defined at MSIAC for the 2019-2020.

INTRODUCTION

The Improved Explosives and Munitions Risk Management (IEMRM) workshop was held from 10 to 14 September 2018, at the PCGR Congress Center in Granada, Spain. The aim of the workshop was to exploit an improved understanding of munitions vulnerability and consequences to deliver improvements in munitions risk management.

The IEMRM workshop brought together three communities related to Hazard Classification (HC), Insensitive Munitions (IM), and Explosives Storage Safety. Also there were a number of key-representatives from the AC/326 Sub Groups (A, B and C). There was an excellent participation of 73 researchers, policy makers, and practitioners from 12 MSIAC nations (Figure 1). The list of attendees is provided in Annex A.

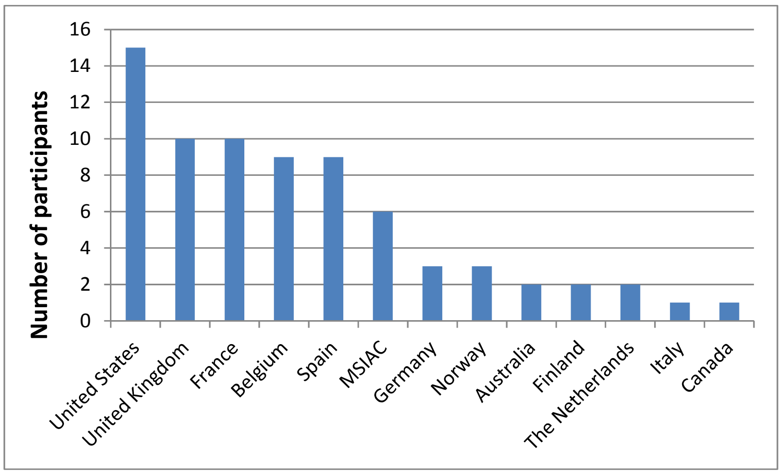

Figure 1: IEMRM participants by nation

A secondary aim of the workshop was 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. In more detail, the workshop addressed 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
  - Realise 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 workshop schedule is shown in Figure 2. This shows a plenary session on the Monday followed by Focus Area sessions from Tuesday to Thursday within the three main topics: (1) Improved HC and IM assessment, (2) Improved Consequences and Risk Analysis and (3)

Implementation of IEMRM. A conclusion and way forward session completed the workshop on the Friday.

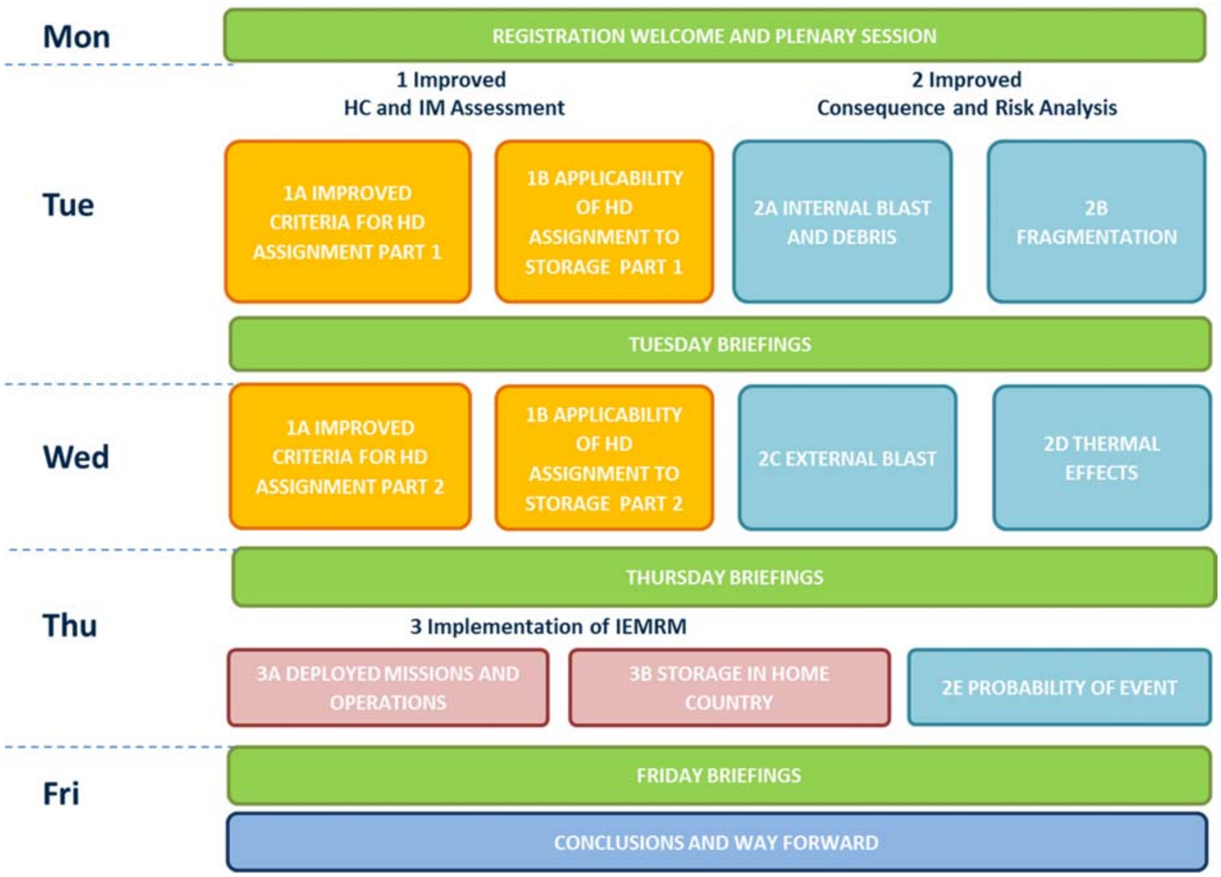

Figure 2: Workshop schedule

The workshop was prepared by MSIAC and participants by producing numerous papers and presentations. After the workshop 8 limited reports (L-231 through L-238) were published with the results of each session, plus an additional report with a summary of the conclusions (L-239). The current open report highlights the main findings of the workshop and proposes recommendations for a way forward.

WORKSHOP MAIN FINDINGS

Detailed output for each of the workshop sessions shown in Figure 2 has been reported in a series of 8 MSIAC limited reports (L-231 through L-238), while report L-239 gives a summary of the conclusions. In this chapter we will present a summary and focus on the main findings.

MONDAY PLENARY SESSION

On Monday the workshop was introduced with 12 presentations in a plenary session.

Martijn van der Voort (MSIAC) started the session by presenting the workshop objectives; to support the IM and HC harmonization initiative, develop improved methods for explosives and munitions risk management, and how these should be implemented in munitions safety standards. He mentioned differences between the HC and IM testing and the larger scale and confinement found in typical ammunition storage scenarios. In HC and IM tests, munition response is recorded with a large granularity (detonation, partial detonation, explosion, deflagration, or burn), whereas only part of that information is used in QD and risk assessments (e.g. explosions and deflagration reactions are not addressed).

Martijn discussed the importance of using a common terminology in this workshop, and asked participants to clarify key terms when used. Examples were given of “small” and “large” scale (molecule, munition component or ammunition storage?), “IM” (compliant with AOP-39 or meeting only some of the criteria?) and “risk analyses” (scope?, qualitative or quantitative?, units?).

Brent Knoblett (DDESB, US) highlighted the importance of standardization of HC procedures for explosive substances, mixtures and articles in relation to military munitions. A correct HC forms the basis for the application of Quantity Distances (QD) and Explosives Safety Munitions Risk Management (ESMRM). He also referred to the fact that an HD assignment assumes the presence of logistic packaging. During the life cycle, packaging may not always be present, which necessitates “in-process” analyses and procedures to determine the appropriate Class 1 Division. Such analysis could also benefit from standardisation across NATO nations.

Michael Sharp (MSIAC) presented on the Working Group that was established under AC/326 to review NATO policy and guidance on IM and HC to assess opportunities for harmonisation and the introduction of a Hazard Frequency Analysis (HFA) approach.

Matt Andrews (MSIAC) presented relevant information from the 2016 MSIAC Science of Cook Off workshop. He discussed the various scales and mechanisms which are relevant for determining munitions response, especially in cook off scenarios (Figure 3). For the current workshop the starting point is still the energetic material inside the munitions, but now we extend beyond the munition scale and also consider aspects of multiple munitions (bulk/stack effects), packaging and confinement offered by storage buildings.

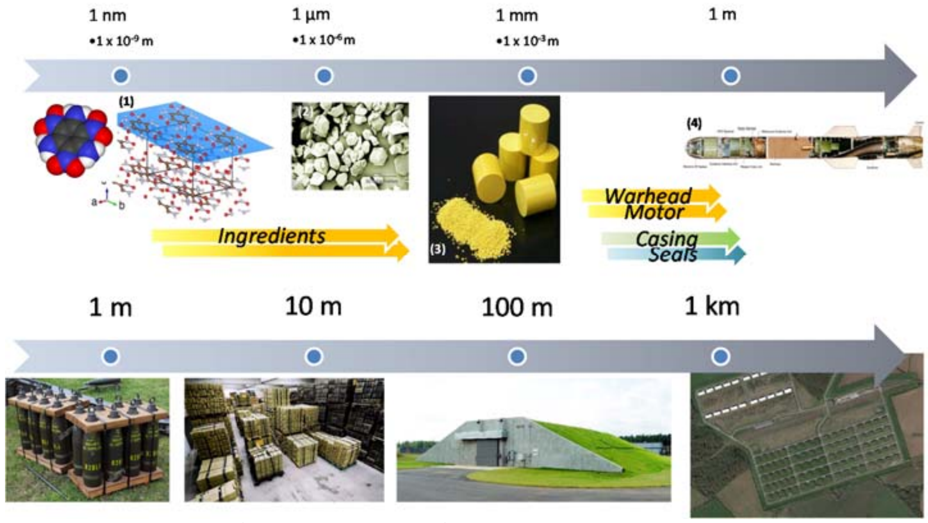

Figure 3: Range of scales relevant for munitions response [Andrews, 2018]

Jo Covino (DDESB, US) presented relevant information from the International Explosives Safety Seminar (IESS&E) held in August 2018. Topics ranged from TNT equivalency estimation, structural debris calculations, and risk models, to combustion of HD1.3 under confinement. Tests performed by [Farmer, et al., 2015 & 2017] showed that M1 propellant ignited in Reinforced Concrete (RC) structures may cause over pressurisation and structural failure for high loading densities and small vent areas (Figure 4). This topic was addressed during the workshop in multiple sessions.

Figure 4: Structural failure after initiation of 540 kg M1 propellant in 8 m^3 RC Kasun structure with a Ø39 cm vent [Covino et al., 2018].

Bob Conway (NAFVAC EXCW, US) went on to present the valuable work conducted by the Klotz Group on explosion effects testing and modelling during the past decades. A number of highlights were mentioned which included the Klotz closing valve, water mitigation, Debris Launch Velocity (DLV) tests and modelling, testing and modelling of Reinforced Concrete (RC) magazines, development of numerical and engineering models (such as the KG-ET) for the prediction of structural break-up and debris hazard. The efforts have focussed mainly on detonations. Suggestions were made to extend the work towards other, less severe munition responses.

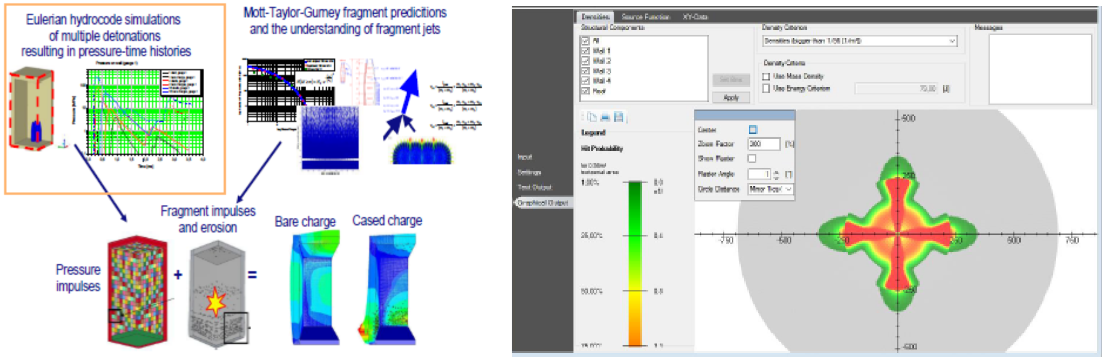

Figure 5: Left: Numerical modelling of RC break-up due to shock and fragment load (left). Right: KG-ET prediction of debris throw field after detonation in RC magazine [Weerheijm & Conway, 2018].

Matt Wingrave (DOS-R, UK) highlighted the work currently being conducted to update the NATO QD standard AASTP-1. This has resulted in restructured QD tables with distinct criteria for blast, fragmentation and debris, the progressive event of HD 1.2 and the thermal event of HD 1.3 (Figure 6).

PES → E S ↓	EFFECT	Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, barricaded	Building constructed with walls of 215 mm brick (or equivalent) and protective roof of 150 mm concrete with suitable support, unbarricaded.	See introduction for full instructions and calculation tables for full formula. 1. Select correct PES/ES interaction. 2. Use HD/SsD table to determine applicable calculations 3. Use HD/SsD table to determine quantity, either NEQ or MCE 4. Use associated formula for min Distance or max Quantity HD/SsD						
				1.1	1.2.1	1.2.2	1.2.3	1.3.1	1.3.2	1.6
25 Vulnerable Constructions (1.3.1.15 for full definition)	BLAST	BD35	BD35	NEQ	MCE		MCE			MCE
	DEBRIS & FRAG	DFD5	For PES internal volume >20m³ DFD3 For PES internal volume ≤20m³ DFD4	NEQ	MCE		MCE			MCE
	PROG' 1.2.1	P1D4	P1D4		NEQ					
	PROG' 1.2.2	P2D4	P2D4			NEQ				
	THERMAL 1.3.1	TD4	TD4					NEQ		
	THERMAL 1.3.2	TD4	TD4				NEQ		NEQ	NEQ

Figure 6: Preliminary example of new QD table structure [Wingrave, 2018]. PES are the barricaded and unbarricaded medium above ground structures, ES is a vulnerable construction.

With respect to structural debris the most recent test results have been used which has led to reduced QDs for small HD1.1 NEQ, whereas for large HD1.1 NEQ, QDs may increase well beyond current minimum distances. The restructured tables ensure consistency across the various Hazard Divisions and provide transparency with respect to the contribution of each explosive effect to a QD for a given exposed site.

This new approach paves the way for future inclusion of less severe munition responses into AASTP-1. Additional effects could be added as new rows to the table and/or effects can be calculated with a reduced amount of energetic material.

The fact that HD1.1 QDs will in some cases substantially increase due to new insights in relation to debris may be a driver for the acquisition of IM. Additionally it may be a driver for the inclusion of more granularity in QD tables and a departure from worst-case assumptions (e.g. mass detonation).

Johnny de Roos (Belgium) then presented about his experience with teaching of the MSIAC AASTP-1 and AASTP-5 Lecture Series. This popular course is taught usually 6 times a year and consists of theory and hands-on exercises in relation to explosives storage safety siting and risk analysis. He mentioned that the course is continuously updated to match changes in AASTP-1. The new approach explained by [Wingrave, 2018] will require a significant update of the lecture material.

Figure 7: AASTP-1 and 5 Lecture Series locations [de Roos, 2018].

Hans Øiom (NDEA, NOR) went on to present his paper "Addressing Risk from Handling and Storage of IM". For the purpose of Quantitative Risk Analysis (QRA) he splits up scenarios for the various threats and responses each with their own probability, consequences and risk. The overall risk is then obtained by summing the various risk contributions. The challenge is to derive the partial probabilities for each of the responses. Hans also draws a parallel with HD1.2 bonfire tests conducted in the 90s. Although these munitions are unrelated to IM, the range of munition responses observed in those tests is illustrative.

Another point that was mentioned is that for HD1.1 a mass detonation within a magazine will likely not involve all munitions because of spatial separation. Mass detonation could possibly stay limited to one pallet or stack within the magazine. More knowledge about this aspect could better inform QD and risk analysis.

In his paper Managing Explosive Risk across Disciplines, John Tatom (APT, US) presented the I-A-R-A framework which describes a process involving Hazard **I**dentification and Tracking, Risk **A**ssessment, Risk **R**eduction and Risk **A**cceptance (Figure 8). In his paper he discussed how HC, IM, QD and Risk methods fit in this framework.

	Identify Hazards	Assess Risk	Reduce Risk	Accept Risk
Explosives Safety Process	TB 700-2 and DOT test requirements	QRA HC & IM protocols	Design & test to meet IM requirements & explosive safety rules	Site plan approval (conventional or QRA)
Work	Plan testing program Initiate THA	Plan facility layout Conduct HC & IM tests	Ensure facilities, processes, & product comply with explosive safety requirements	Obtain various approvals (WSESRB, NNMSB, AWSSRB, JSWSRB, IMRB, etc.)
Tools & Techniques	Threat Hazard Assessment Test protocols	SAFER / IMESAFR Compliance checklists	Lightning protection, ESD controls SOPs	Review boards Compliance checklists Safety Data Packages
Products	Approved THA Approved test plans	Safety Assessment Report, Safety Case Test Results	IM compliant design Approved site plans SOPs	IM & FHC approvals Approved site plans Approved SOPs Board approvals

Figure 8: The I-A-R-A framework [Pfitzer & Tatom, 2018]

Phil Pitcher (SDA, UK) introduced the baseline principles to the UK MoD maritime explosives safety. Because of the limited available space on ships, a detailed analysis is carried out with respect to munition response in storage situations. He gives a few examples of the Effective Net Explosive Quantity (ENEQ) and Maximum Credible Event (MCE) Assessments. Figure 9 gives the possible interactions between parts of a missile and between missiles based on testing. Also indicated is the ENEQ and response type.

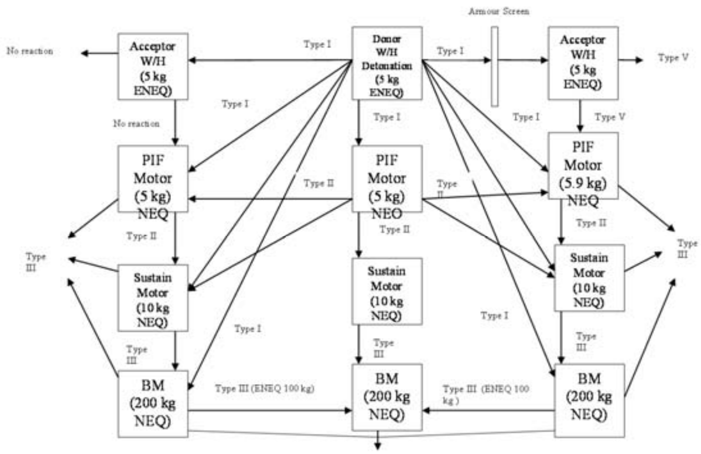

Figure 9: Communication Reaction flow between various parts of missiles and between missiles [Pitcher, 2018].

Martin Pope (MSIAC) closed the Monday plenary session. He discussed the introduction of IM into service and stressed the importance of having the same HC assignment criteria on Multinational operations. He also raised the question how to manage residual risks of IM, and how it would relate to Hazard Division, mixing and aggregation rules, Compatibility Groups and Sensitivity Groups.

<ins>TOPIC 1: IMPROVED HC AND IM ASSESSMENT</ins>

Session 1A: Improved Criteria for HD Assignment – Chair: Brian Fuchs (ARDEC, US)

The group agreed that the current hazard classification system is fit for purpose, in that it meets the needs for identifying the hazard from articles during peacetime transportation. However, there were some concerns over the criteria which govern the selection of HD. Further work was identified with respect to definition of the Mass Explosion Hazard (MEH), and the potential to use more widely within HC the improved Response Descriptors of UN TS 7.

What was clear to participants is that the current HC system has been exploited more widely than is sometimes appropriate, beyond peacetime transportation, resulting in the hazard not being accurately reflected for some lifecycle scenarios. This has not been a purposeful misuse of data, but rather using what data is available. The group developed a preliminary proposal based on “Hazard Types”, a matrix of responses for the wider threats (Figure 10). This requires further work but has some advantages in that it achieves the goal of communication of the hazard and its changing nature over the lifecycle whilst leaving the current HC system and HDs for transportation that is generally appropriate.

HD	1.1			1.2			1.3			1.4		
CONFIG.	BARE	TAC	LOG	BARE	TAC	LLOG	B	T	L	B	T	L
	X	X	X									
	X							X				X
							X				X	
	X							X				X
				X	X	X						

Figure 10: Preliminary proposal which gives the “Hazard Types” for a given combination of threat and configuration [Sharp, et al., 2018]

The current system of demarcating hazards into HD and NATO SsDs, as hazard types, was believed to give the required levels of granularity to effectively communicate and manage the explosive risk. However, there could be wider adoption of the NATO SsDs to ensure that the benefits of reduced vulnerability brought about by the introduction of IM can be identified whilst ensuring that those managing explosive safety can direct their efforts at munitions presenting the highest risk.

In moving forward there are a number of topics and issues which should be worked on through the UN Transportation of Dangerous Goods Explosive Working Group and AC326, which includes:

- Better definitions of HD, particularly Mass Explosion Hazard (MEH) and use of improved response descriptors
- The need to standardise mode of initiation/ignition in single package/stack test/sympathetic reaction test.
- Refinement of proposals to introduce “Hazard Type” and take this forward for consideration/policy development
- Review of the definition of 1.3 NATO SsDs to ensure this is standardised
- Review of the definition of HD 1.6 and appropriate QDs
- Review of policy to ensure that additional evidence can be introduced to increase confidence in HC assessments
- Development of an agreed revised set of small scale tests which provide confidence in article behaviour

Session 1B: Applicability of HD Assignment to Storage – Chairs: John Tatom (APT, US) & Patrick Lamy (DGA, FRA)

The group agreed that Hazard Classification alone may not adequately define hazards in storage, but this was dependent upon how the classification process was carried out. It was suggested to at least understand the limitations or benefits of each national approach when accepting another classifying authority’s (CA) classification.

The discussion on hazard classification throughout the life cycle was presented by Clint Guymon that covered fundamental principles of explosives safety. This included a thorough process for hazards analysis that provided an understanding to the nature of explosives during in-process, storage, or transport (Guymon, 2018). In Figure 14, the life cycle was depicted graphically to aid understanding:

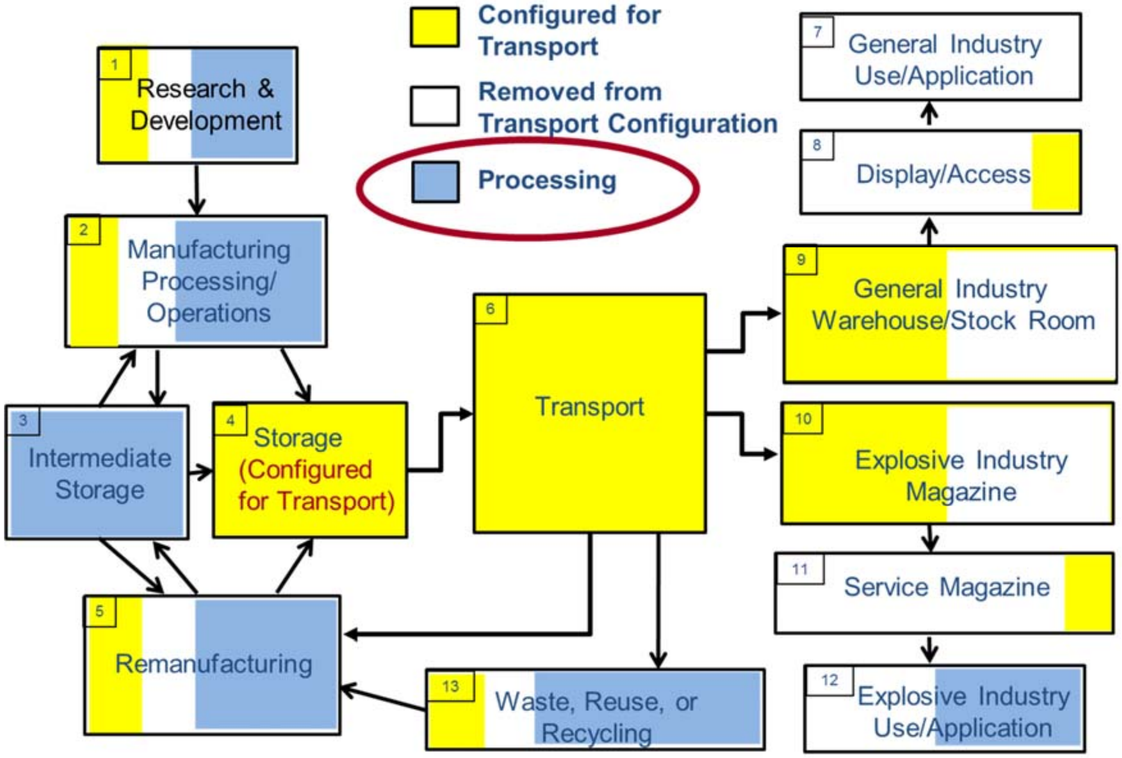

Figure 11: Life cycle stages of explosives (Guymon, 2018)

The group agreed that the HC process does not have to change for post-transportation concerns, so storage rules need to change instead. Classification currently places materials/articles into 4 'buckets'. There is a range of responses within UN HC tests but the criteria for the tests is only pass or fail, so that fidelity of information is lost. It was recommended to place a higher priority on test data collection (pressure, fragmentation, heat flux etc). This information is essential for populating models, and conducting consequence and risk analysis.

The summary of the session was divided in three parts:

Improve HC specifically for transportation

- Prevent "over-classification" of munition through reviewing different national rules or interpretations,
- Improve classification by sharing of pertinent information,
- Consider full incorporation of available IM information in assessments, and adequacy of data (enough test results?)

Reconsider HC with storage legitimately in mind

- Standardise methods to improve storage solutions
    - o As an example the US is using Storage sub Divisions within HD1.2 but not within HD1.3, whereas the French are doing this the other way round.

Better requirement from Storage community to HC and IM

- Develop scenarios/threats/concerns not considered by HC and IM:
- Understand dependency on packaging, confinement, scaling concerns (tested versus stored quantities), environmental concerns and aging concerns.
- Sharing of post-transportation guidance for HD. This could lead to an agreement on and refinement of AASTP-1 guidance.

TOPIC 2: IMPROVED CONSEQUENCE AND RISK ANALYSIS

The sessions under Topic 2 looked into improved consequence and risk analysis, in particular for less violent (sub-detonative) munition responses:

- Session 2A: Internal Blast and Debris – Chair: Bob Conway (NAFVAC EXWC, US)
- Session 2B: Fragmentation – Chair: Malte von Ramin (EMI, DEU)
- Session 2C: External Blast – Chair: Emmanuel Lapéble (CEA, FRA)
- Session 2D: Thermal – Chair: Josephine Covino (DDESB, US)
- Session 2E: Probability of Event – Chair: Hans Øiom (NDEA, NO)

In these sessions there was a common understanding that for detonations, the prediction of blast, primary fragmentation, secondary debris, and thermal effects is relatively well established. Many numerical codes and engineering models have been developed and validated over the years as was illustrated by presentations from, among others, Christelle Collet (MSIAC, FRA), Mike Giltrud (Figure 12) (ASI, US), Emmanuel Lapébie (CEA, FRA), Johannes Schneider (EMI, DEU) and Stéphane Suleau (KMS, BE). Remaining issues include modelling of early venting in magazines, mesh dependency, mixing and afterburning, and scaling issues. Also, the inherent stochastic variation of debris throw was mentioned as an issue. In some areas there is a lack of internationally agreed models (e.g. thermal effects: fireball, flame jet effects, thermal radiation).

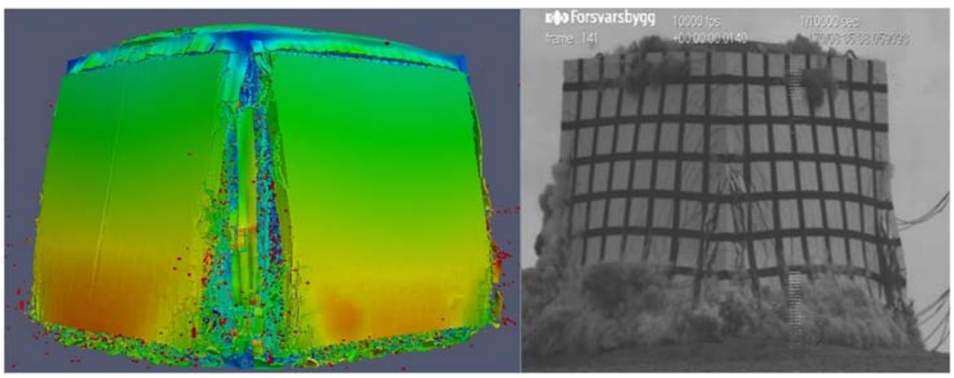

Figure 12: Comparison of coupled combustion and structural analysis (FEFLO) with Kasun III high speed recordings [Giltrud, et al., 2018]

It was concluded that there are many challenges for the prediction and validation of physical effects for less violent munition responses (in particular for deflagration and explosion):

- A quantitative definition of the reaction rate (lower and upper limit) for the defined munition response types is missing,
- Blast, fragmentation and thermal data in IM tests should be better recorded, collated and analysed,
- Knowledge about reaction rates within stacks including the effect of packaging and overpressure is limited,
- Extrapolation of IM test results to full scale storage should be supported by large scale (stack) tests for validation.

A general conclusion was that a lower reaction rate typically leads to larger fragment- and debris masses, while their launch velocities decrease. With respect to deflagrating warheads the combined effect of these phenomena will result in fewer fragments that may reach larger distances due to their higher ballistic efficiency, as was shown by Michelle Crull (USAESC, US). Pressure vessel burst models may be a good starting point for sub-detonative fragmentation. It was also discussed whether the concepts of Maximum Fragment Distance (MFD) and Hazardous Fragment Distance (HFD, 1 fragment per 56 m^2) are still applicable for sub-detonative responses; the MFD could become very large, whereas the HFD could be close to zero. Alternative metrics based on Individual Risk (IR) and Group Risk (GR) where explored (Figure 13). These hold the advantage that other relevant aspects can be taken into account, such as a lower probability of initiation, the nature of the ammunition activities, population density, and whether exposed persons are related (personnel) or unrelated (third parties).

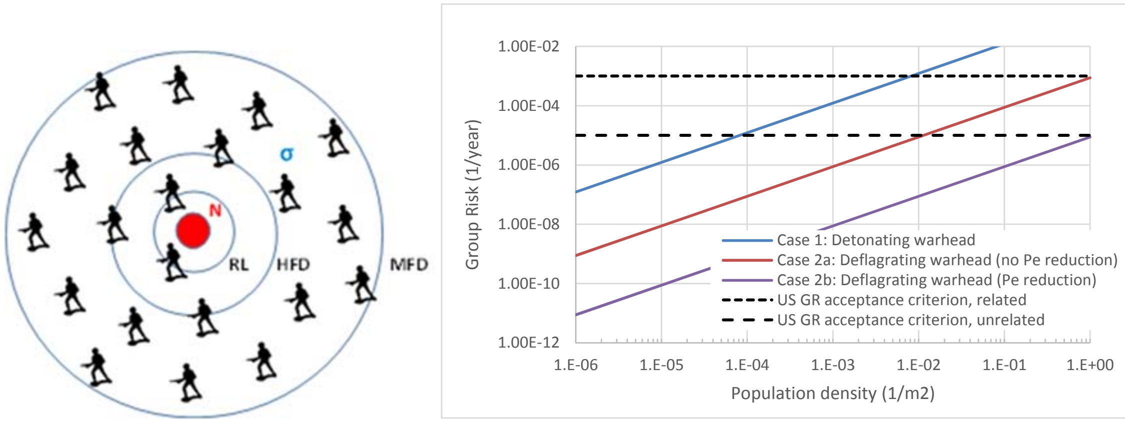

Figure 13: Group Risk (GR) calculation for detonating (case 1) and deflagrating (case 2) warheads and a comparison with US GR criteria for related and unrelated persons. This yields acceptable population density [Baker, et al., 2018]

Compared to detonations, break-up of storage structures for less violent munition responses will occur at higher loading density (NEQ per volume). Detailed knowledge about the storage construction and in particular vent areas, is essential to determine the overall structural response. Debris will increase in size and reduce in velocity, and may also become more directional. As a way forward a number of approaches were discussed. One option proposed by Bob Conway (NAFVAC EXWC, US) was to review existing experimental data and case studies using Blast-X and P-I diagrams. A second option was to adapt the Debris Launch Velocity (DLV) equation for a reduction in either the available energy for acceleration or a reduction of the effective acceleration path length.

Less violent munition responses also lead to weaker blast effects. This can be represented by a reduced TNT equivalency, but it was concluded that the empirical determination is not standardised. As an alternative, models for blast from e.g. gas explosions can be applied, which take into account the explosion overpressure and available energy in the source. Malte von Ramin (EMI, DEU) presented a model for the prediction of injury due to complex blast waves. This model can also be used to make predictions for pressure waves which have a reduced damage potential compared to shockwaves.

For (mass) detonations the blast, fragment and debris effects are dominant and the thermal effects are typically neglected. With the introduction of less sensitive munitions the thermal effects will become more important. This is highlighted by the fact that current QD for SsD1.2.3 and HD1.6 are based on a detonation (or explosion) of a single round and a burn of the rest of the stack (based on thermal effects of HD1.3 bulk propellants, whichever gives the largest distance). One recommendation is therefore to perform fire validation tests to measure how the thermal effects of SsD1.2.3 and HD1.6 compare to those of HD1.3 bulk propellant). Another recommendation is to develop common thermal models, to have an agreed basis for QD and risk analysis.

An important discussion topic dealt with confined combustion in storage magazines, which may lead to over pressurization, break-up and a secondary debris hazard. This is relevant for propellants (HD1.3) in RC structures, as was shown in tests conducted by Jo Covino (DDESB, US) [Farmer, et al., 2015 & 2017]. This effect may however also apply to other HD (SsD1.2.1, 1.2.2, 1.2.3 and HD1.6) as well as IM (AOP-39), because these munitions may also contain propellants which is often ignored for siting purposes. The HD1.2 test series conducted in the nineties involved in-structure testing of HD1.2 munitions but did not show over pressurisation. However, because in these tests the doors were left open the conditions for over pressurisation may not have been produced. A recommendation is to reproduce these tests with ideal conditions (e.g. closed doors) for over pressurisation.

It was concluded that combustion hazards need to be better addressed in QD and QRA for the relevant HD. A criterion would need to be developed to identify problem areas in terms of reaction rates, structural resistance, internal volume, and vent areas. A promising modeling approach presented by Clint Guymon (SMS, US) (Figure 14) and experimental data from Cynthia Romo (NAWCW, US) provided possibilities for the development of such a criterion.

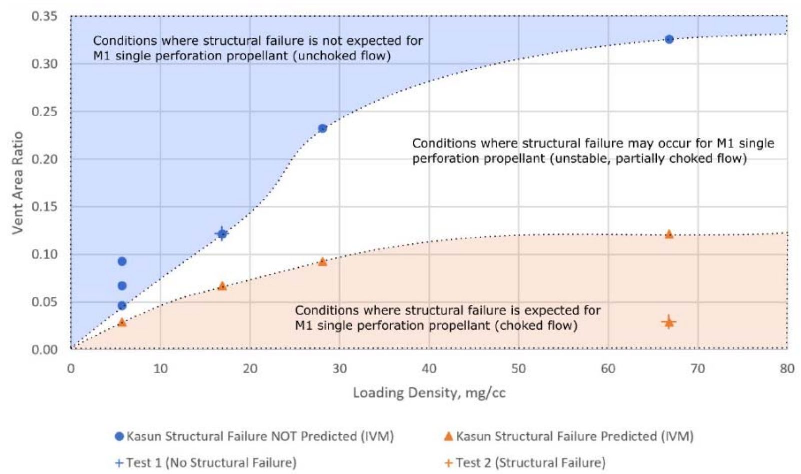

Figure 14: Structural failure conditions dependent on vent area ratio and loading density [Guymon, et al., 2018]

As a next step a preliminary analysis of the aforementioned test series with propellant in RC structures was carried out. The maximum observed overpressure was compared with the QSP in a high explosive detonation event. It appeared that an equivalent high explosives loading density (that gives a QSP equal to the pressure in a propellant event) gives less damage (and debris) than the propellant event. Further study is required to explain the difference.

The probability of event is a key parameter in Quantitative Risk Assessment (QRA), and is typically based on historical data. In order to quantify a reduced probability of initiation for less sensitive munitions and to distinguish between possible munition responses a more detailed approach is necessary. This approach would need to address the threats/hazards, the reduced vulnerability, and possible responses. Models and experimental data were presented by Hans Øiom (NDEA, NOR), Gert Scholtes (TNO, NL), and Ben Keefe (DOSG, UK). The “whole body of evidence” approach with multiple repetitions of IM tests, may generate the necessary input and/or validation for these models (Figure 15). It was also noted that dedicated storage magazines for IM are necessary in order not to lose reduced probability benefits, e.g. avoid mixed storage with conventional ammunition.

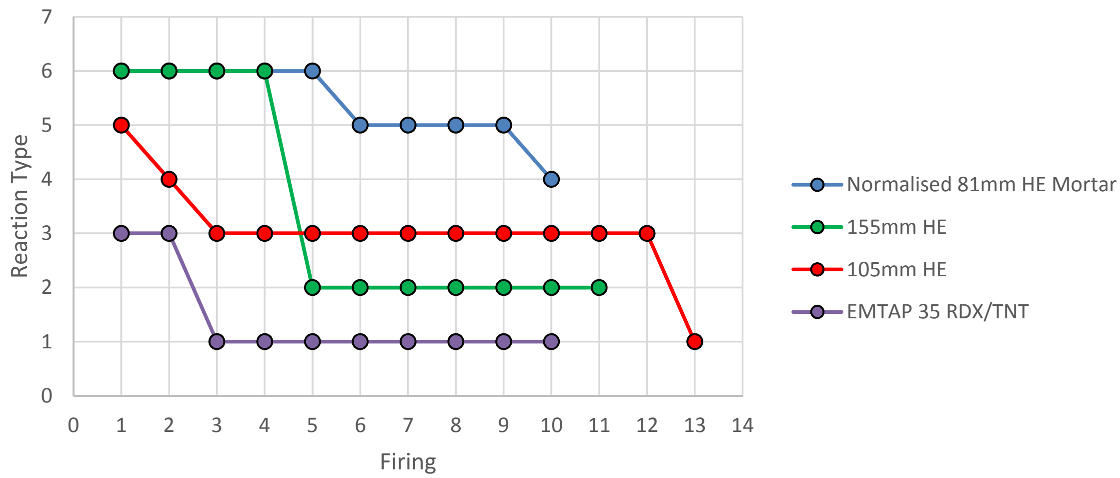

Figure 15. Variation in reaction type for 81 mm HE, 155 mm HE, 105 mm HE and EMTAP tests. Reaction Type I: Detonation, II: Partial Detonation, III: Explosion, IV: Deflagration, V: Burn, VI: No Reaction [Cheese and Keefe, 2018].

TOPIC 3: IMPLEMENTATION OF IEMRM

In the last topic of the workshop it was discussed how the new insights gained in the previous sessions could be implemented in explosives safety standards. This topic was split up in:

- Session 3A: Deployed Missions and Operations – Chair: Philip Cheese (DOSG, GBR)
- Session 3B: Storage In Home Country – Chair: Helen Stewart (DAER, CAN).

Two points were addressed that did not get attention in previous sessions:

- Compatibility groups and the need for review in to take into account introduction of new munitions technologies.
- Definitions for terminology such as Net Explosive Mass (NEM), Net Explosive Quantity (NEQ), Effective NEQ (ENEQ), Net Explosive Weight (NEW) and NEW to be used for QD (NEWQD) need to be reviewed to ensure that there is international consensus. This involves various aspects such as:
  - Can parts of a munition be excluded (e.g. rocket motor does not contribute)
  - Should an equivalency be used (is TNT the appropriate standard? Based on which parameter?, e.g. peak overpressure, impulse, quasi static pressure)
  - Can we extrapolate results for a single munition to large scale (e.g. single rocket motor may be excluded, but what about large stack?)
  - How does the approach vary with Hazard Division (e.g. TNT equivalency applies to HD1.1, but what about HD1.2 and HD1.3?)

Moving on to the main topic of Session 3A and 3B, participants agreed that the increased granularity and detail discussed in previous sessions will 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, allowing the user to benefit from easier application and being less prone to error. Development of such tools requires careful consideration, such as setting common end user requirements, proper documentation and training. Furthermore it has to be realised that more detailed methods could imply that consequence and risk analysis becomes more munition-specific. This will improve the reliability of the results, but on the other hand also limits the range of applicability.

A balance between simple and more complicated approaches could be found in a holistic approach, considering the costs and benefits. Dependent on the lifecycle phase and situation the most suitable approach could be selected.

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.

CONCLUSIONS AND WAY FORWARD

In reviewing the discussion, it was concluded that the workshop successfully met its objectives and that there are promising results and recommendations.

The limitations of Hazard Classification, which was originally developed for peace-time transportation, have been identified. This has led to a preliminary proposal that predicts “Hazard Types” throughout the lifecycle, based on relevant threats as well as changing munition configurations. This includes the presence/absence of packaging, and could help capture hazards due to confined combustion of e.g. propellants, as well as issues with large scale (bulk) storage.

It was recommended to better define Hazard Divisions, in particular by improving the definition of the Mass Explosion Hazard (MEH) and by applying more detailed response descriptors. Furthermore, definitions for terminology such as NEM, NEQ, ENEQ, NEW and NEWQD needs to be reviewed to ensure that there is international consensus. Compatibility groups require review to ensure that changes in munition technologies are taken into account. Furthermore it was recommended to review the mode of initiation/ignition in the single package/stack test/sympathetic reaction test and to achieve consensus internationally on how this should be done. Also, use of additional evidence (“whole body of evidence” approach) to increase confidence in HC assessments should be encouraged through policy improvements which can play a key role in ensuring that this approach is more widely used. Finally, Storage sub Divisions (SsD) and HD1.6 QDs should be reviewed and their standardisation promoted, so that benefits of less vulnerable munitions can be exploited.

There was a common understanding that the prediction of blast, primary fragmentation, secondary debris and thermal effects is relatively well established for (mass) detonations. It was concluded that there are many challenges for the prediction and validation of physical effects for less violent (sub-detonative) munition responses, in particular for deflagration and explosion:

- A quantitative definition of the reaction rate (lower and upper limit) for the defined munition response types is missing
- Blast, fragmentation and thermal data in IM tests should be better stored, collated and analysed,
- Knowledge about reaction rates within stacks including the effect of packaging and overpressure is limited,
- Extrapolation of IM test results to full scale storage should be supported by large scale (stack) tests for validation.

A general conclusion is that a lower reaction rate typically leads to larger fragment- and debris masses, while their launch velocities decrease. With respect to deflagrating warheads the combined effect of these phenomena will result in fewer fragments that may reach larger distances due to their higher ballistic efficiency. Pressure vessel burst models may be a good starting point for sub-detonative fragmentation. Separation distances based on Individual Risk and Group Risk criteria were explored as an alternative to the MFD and HFD. This holds the advantage that other relevant aspects can be taken into account, such as a lower probability of initiation, the nature of the ammunition activities, population density, and whether exposed persons are related or unrelated. Detailed knowledge about the storage construction and in particular vent areas, is required to determine the overall structural response. For secondary debris it was discussed to adapt the Debris Launch Velocity model for sub-detonative munition response, by specifying a reduced available energy or reduced acceleration path length.

Blast reduction can be represented by a reduced TNT equivalency, but it was concluded that the empirical determination is not standardised. As an alternative, models for blast from e.g. gas explosions can be applied, which take into account the explosion overpressure and available energy in the source.

With the introduction of less sensitive munitions the thermal effects will become more important. One recommendation is to perform fire validation tests to measure how the thermal effects of SsD1.2.3 and HD1.6 compare to those of HD1.3 bulk propellant. Another recommendation is to develop common thermal models, to have an agreed basis for QD and risk analysis.

An important discussion topic dealt with confined combustion of propellant (HD1.3) in storage magazines, which may lead to over pressurization, break-up and a secondary debris hazard. A recommendation is to perform tests to show if this can also take place for other HDs (e.g. SsD1.2.1, 1.2.2, 1.2.3) while creating ideal conditions for over pressurisation (e.g. closed doors). It was concluded that combustion hazards needs to be better addressed in QD and QRA for the relevant HD.

It appeared that an equivalent high explosives loading density (that gives a QSP equal to the pressure in a propellant event) gives less damage (and debris) than a propellant event. Further study is required to explain the difference.

An improved understanding of the physical effects of sub-detonative response can be implemented in NATO QD standards. The new approach taken in AASTP-1 where each physical effect is treated separately paves the way for this implementation.

For QRA purposes, besides the physical effects and consequences, the probability of event will need to be determined in more detail. The “whole body of evidence” approach with multiple repetitions of IM tests, would be necessary to have sufficient input. It was also noted that dedicated storage magazines for IM are necessary in order not to lose reduced probability benefits, e.g. avoid mixed storage of IM with conventional ammunition.

An increased granularity and detail will 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, with an easier application and being less prone to error.

A balance between simple and more complicated approaches could be found in a holistic approach, considering the costs and benefits. Dependent on the lifecycle phase and situation the most suitable approach could be selected.

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.

The various conclusions and recommendations will be addressed within the AC/326 SGs and working groups. Furthermore, new work elements have been defined at MSIAC for the period 2019-2020, in order to address some of the workshop recommendations:

- Guidance on instrumentation for IM test data
- Collation and analysis of IM test results
- IEMRM follow-on work

Furthermore there are plans for another work element on “Review of national HC processes”.

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