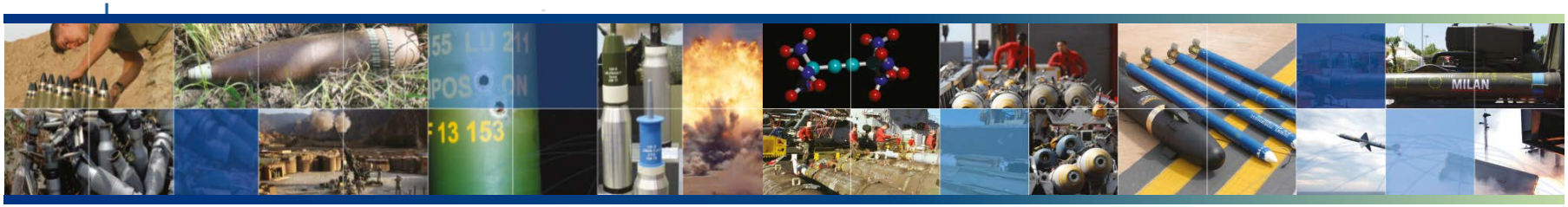
MSIAC

Munitions Safety Information Analysis Center

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



EXPERIMENTAL AND THEORETICAL BASIS OF CURRENT NATO STANDARDS FOR SAFE STORAGE OF AMMUNITION AND EXPLOSIVES

International Explosives Safety Symposium & Exposition,
San Diego, 6-9 August 2018

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- Munitions response
- Quantity Distances (QD) per explosion effect
  - Blast
  - Debris
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- Way forward
  - MSIAC support to CNAD AC/326 SGC
  - MSIAC AASTP-1 and 5 lecture series

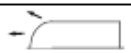
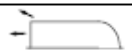
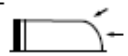
Introduction

- **NATO Standards for safe storage of ammunition and explosives**
  - Developed within NATO CNAD AC/326 SGC
  - Storage in the home country: **AASTP-1**
  - Storage on deployed missions: **AASTP-5**

NATO OTAN — CNAD Ammunition Safety Group (AC/326)

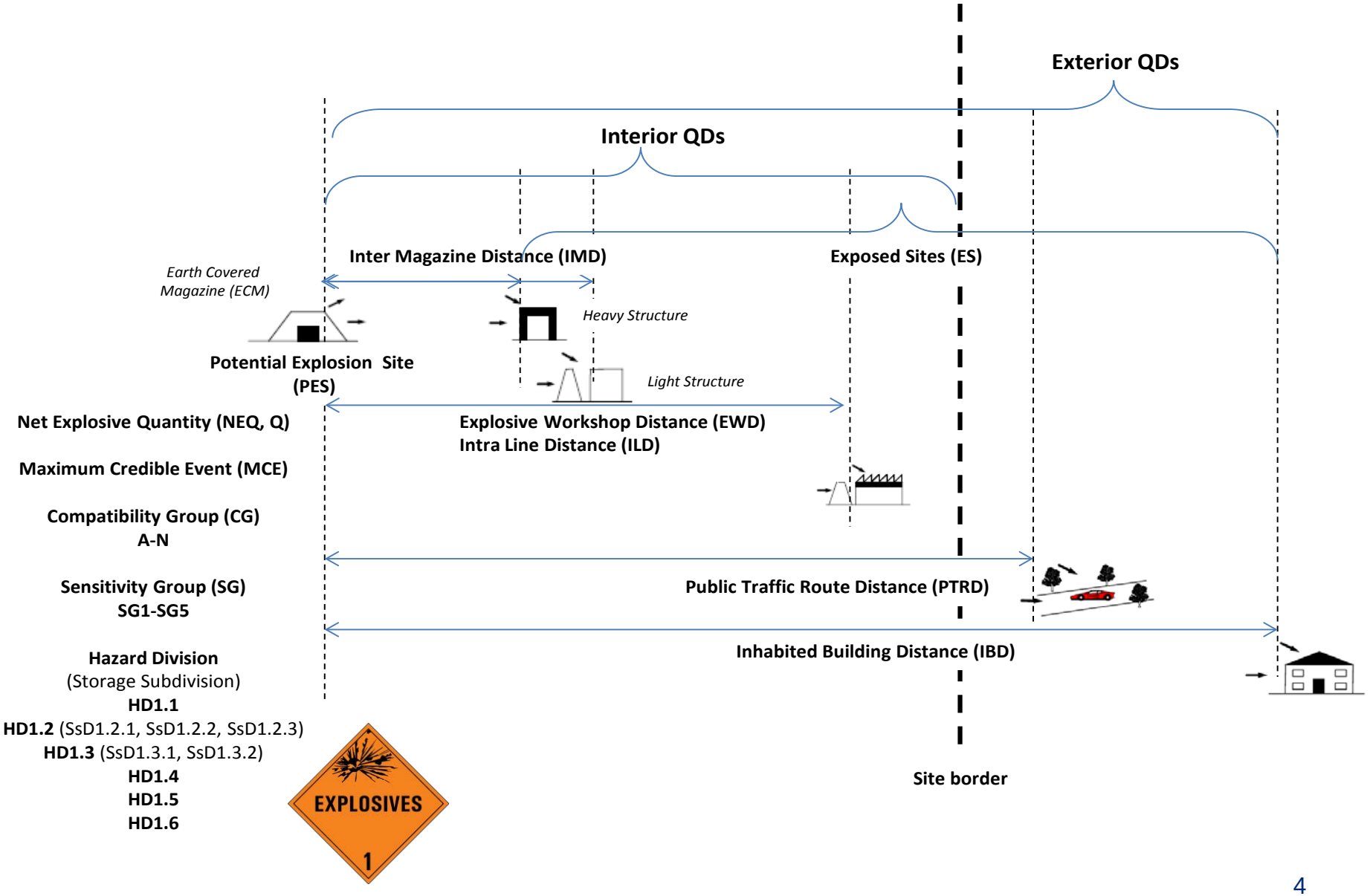
- **Quantity Distances (QD)**
  - Provide an acceptable protection level to Exposed Sites (ES)
  - Due to accidental explosion of Potential Explosion Site (PES)
  - Developed by AC/326 experts over many decades
  - Based on analysis of a large number of tests- and accident data

Table 1A HD 1.1 QD Matrix for Earth Covered Storage

PES ➤ / ES ▼	 Building with earth on the roof and against three walls. Directional effects through the door and headwall are away from an Exposed Site. (a)	 Building with earth on the roof and against three walls. Directional effects through the door and headwall are perpendicular to the direction of an ES. (b)	 Building with earth on the roof and against three walls. Directional effects through the door and headwall are towards an Exposed Site (c)
 1 Standard NATO Igloo, designed for 7 bar in accordance with Part 2, with the door facing away from PES	D3 Virtually complete protection 1.3.3.5 No primary explosives	D3 Virtually complete protection 1.3.3.5 No primary explosives	D4 Virtually complete protection 1.3.3.5 No primary explosives

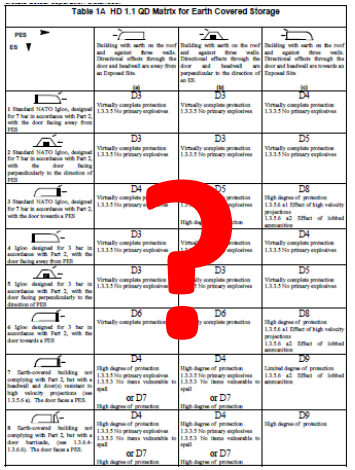
AASTP-1 QD table

Introduction



Introduction

- **Issues**
  - Basis of QDs not easy to understand for new people in the field
  - Not clear which explosion effects determine QDs
  - Comprehensive and transparent overview is missing



- **MSIAC project: "Experimental and theoretical basis of QDs"**
  - Collect relevant references with experimental work and analysis
  - Explain the science of explosion effects at the right level of detail
  - Identify knowledge gaps and advice on areas for further development

Munitions response

- **Hazard Division categorises munitions response and relevant explosion effects**
  - Mass detonation (blast, debris, fragments)
  - Progressive event (fragments and lobbed ammunition)
  - Burn (thermal effects)

- **QD is determined by most dominant effect:**
  - Note: this may also depend on direction!

$$QD = \max(QD_{blast}, QD_{debris}, QD_{frag}, QD_{therm})$$

- **Influence of protection measures**
  - PES and ES barricades stop low angle fragments and debris
  - Protective ES roofs stop high angle fragments and debris
  - Reduced blast for side and rear of ECMs

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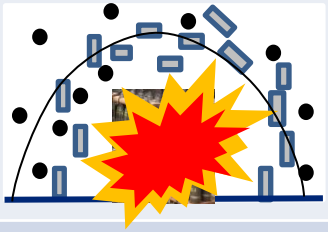
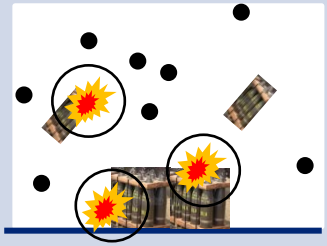
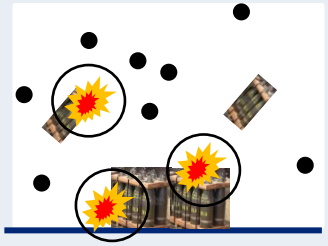
Munitions response

Munitions Response	Detonation MCE (instantaneous)	Progressive event, popcorn (duration)	Burn (duration)
Explosion effects	Blast, Debris, Fragments	Fragments, Lobbed ammo	Thermal
HD1.1 	Total NEQ 	-	-
SsD1.2.1 (>0.136 kg/round) 	50 kg or 3 packages, etc.. 	Total NEQ 	-
SsD1.2.2 (<0.136 kg/round) 	*AASTP-1: can be neglected*	Total NEQ 	-

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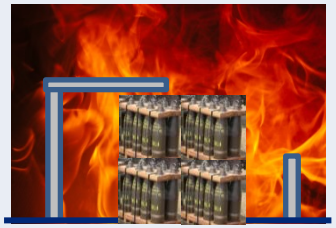
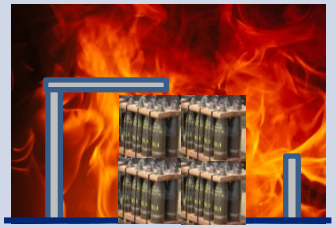
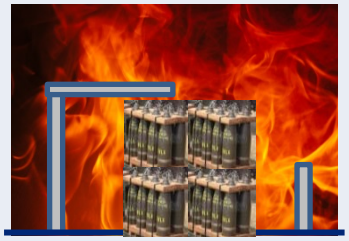
Munitions response

Munitions Response	Detonation MCE (instantaneous)	Progressive event, popcorn (duration)	Burn (duration)
Explosion effect	Blast, Debris, Fragments	Fragments, Lobbed ammo	Thermal
SsD1.2.3 (>0.136 kg/round) 	Single article  *AASTP-1: only blast and frag*	-	Total NEQ 
SsD1.2.3 (<0.136 kg/round) 	*AASTP-1: can be neglected*	-	Total NEQ 
HD1.3 (1.3.1 & 1.3.2) 	*AASTP-1: Behaviour of propellants under confinement not considered!*	-	Total NEQ 

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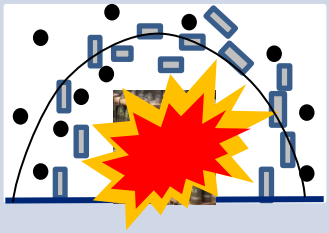
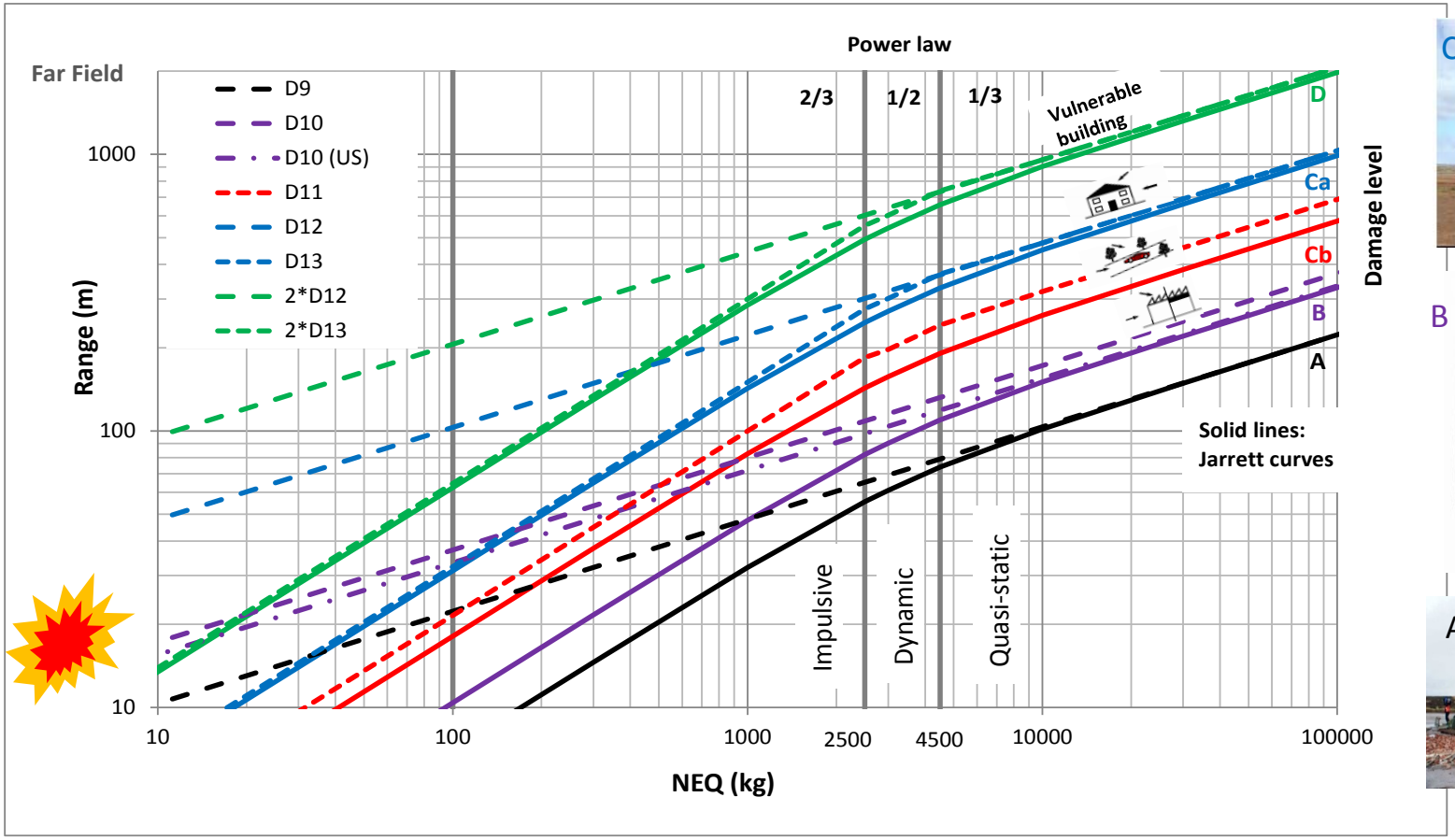
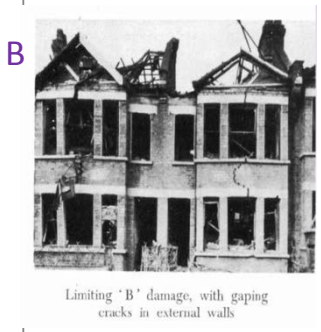
Munitions response

Munitions Response	Detonation MCE (instantaneous)	Progressive event, popcorn (duration)	Burn (duration)
Explosion effect	Blast, Debris, Fragments	Fragments, Lobbed ammo	Thermal
HD1.4 	-	-	-
HD1.5 	Total NEQ 	-	-
HD1.6 	Single article  *AASTP-1: only blast*	-	Total NEQ 

Blast

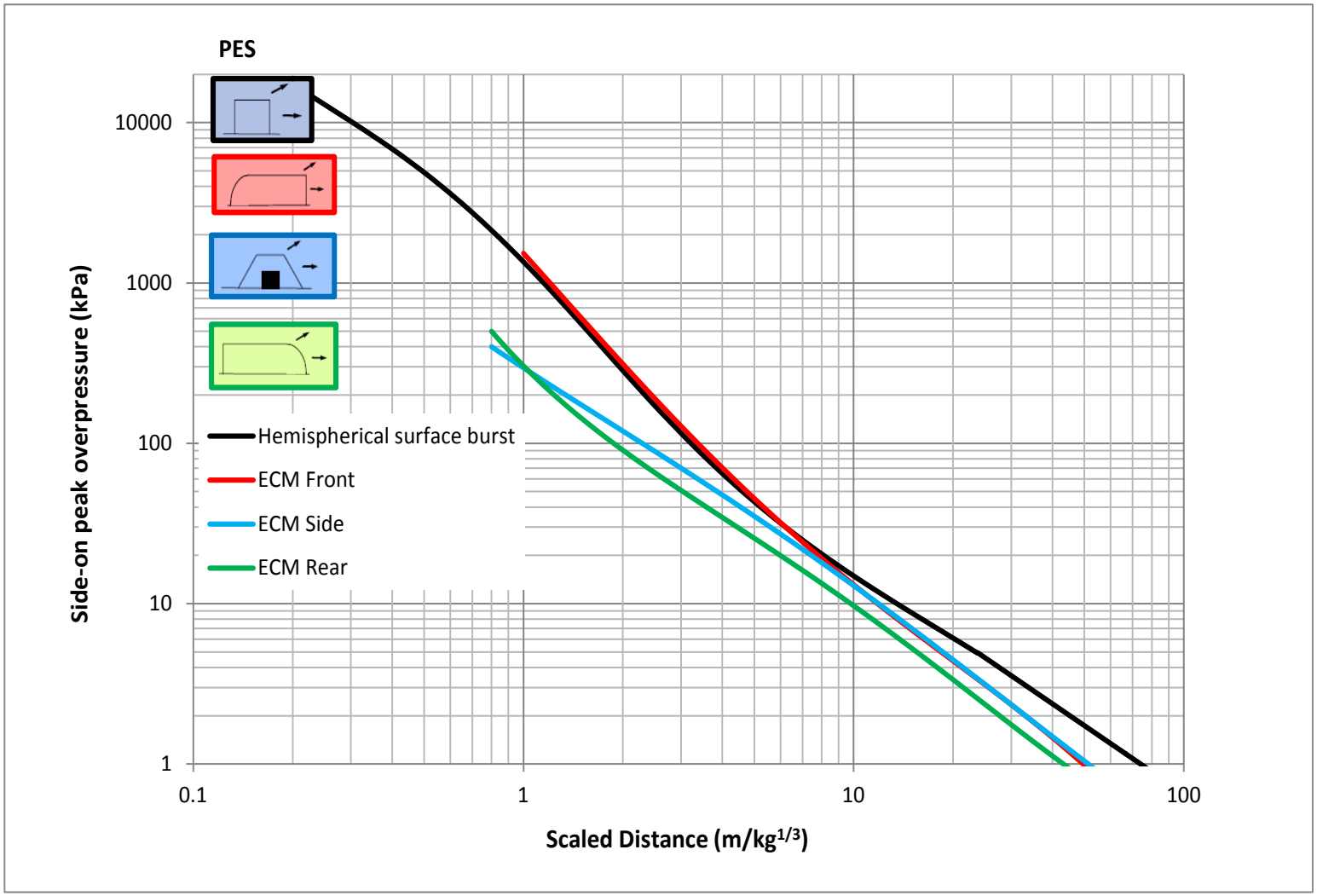
- **Blast QDs (AASTP-1) related to damage WWII (Jarrett)**
  - Mostly based on peak overpressure (1/3 power law)
  - Dependency on impulse (2/3 power law) not consistently addressed





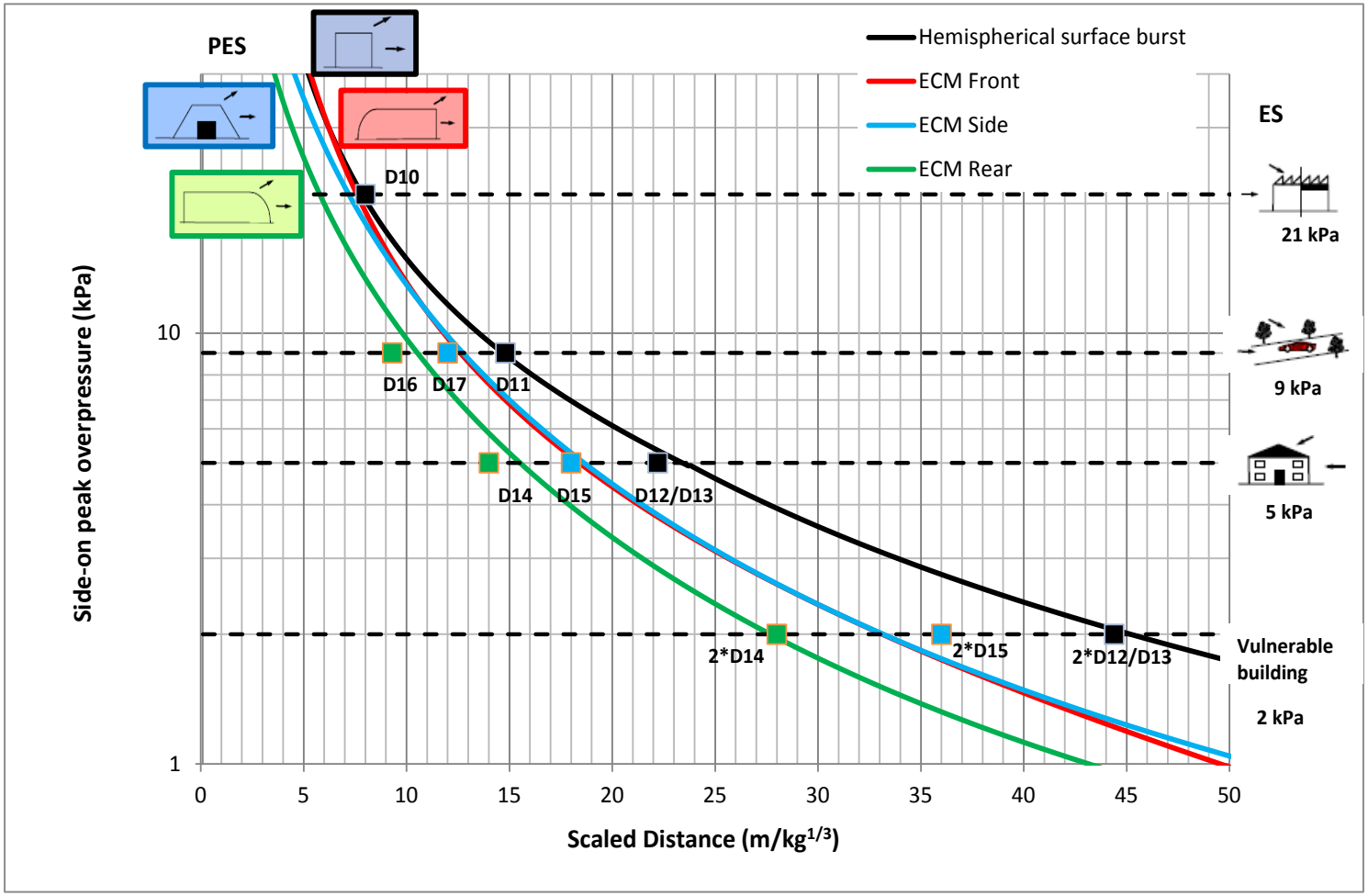
Blast

- **Blast wave prediction model (US TP17, 2016)**
  - For hemispherical surface burst, ECM front, side and rear



Blast

- **Comparison blast wave prediction model with QD**
  - Model predictions consistent with most blast QDs
  - Blast attenuation from the front of an ECM is neglected



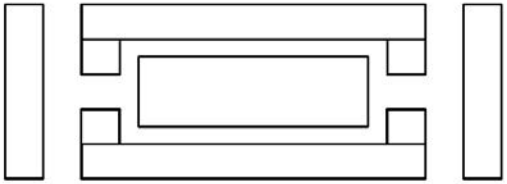
Blast

- **Blast FDs for structures on deployed missions (AASTP-5)**
- **E.g. barricaded tents and light containers**



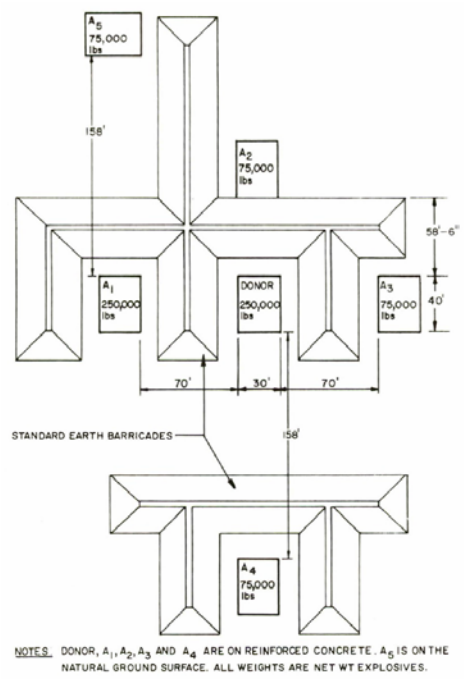
  - Prevention of (lethal) blast damage (**FD7**)

- **E.g. hardened and semi-hardened structures**
  - Blast ingress only remaining effect
  - Prevention of lung injury (**FD4** and **FD5**)
    - Ear drum rupture however still possible!

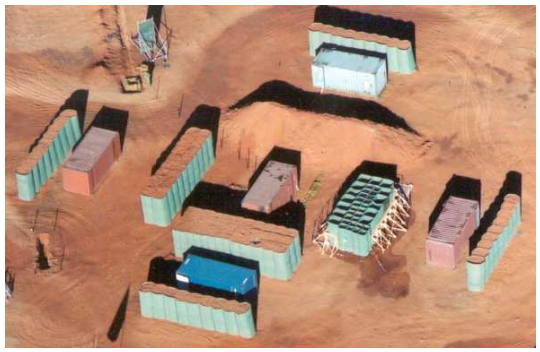



Blast

- **Inter Magazine Distances (IMD)**
  - Aimed to prevent prompt propagation, based on historical test data
  - IMD follow 1/3 power law, besides blast also crater, debris, …
  - Rationale for some of the IMDs is currently unavailable

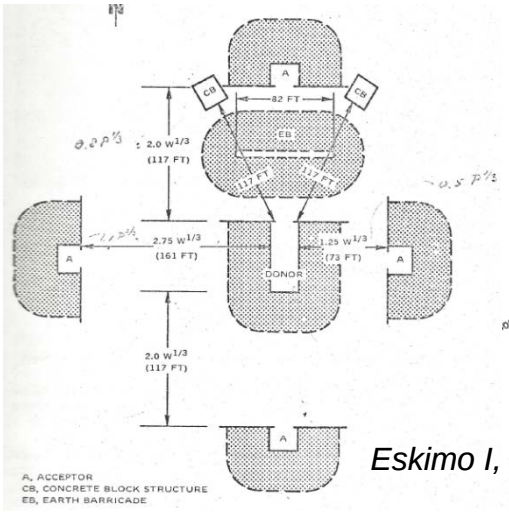


Big papa, 1968

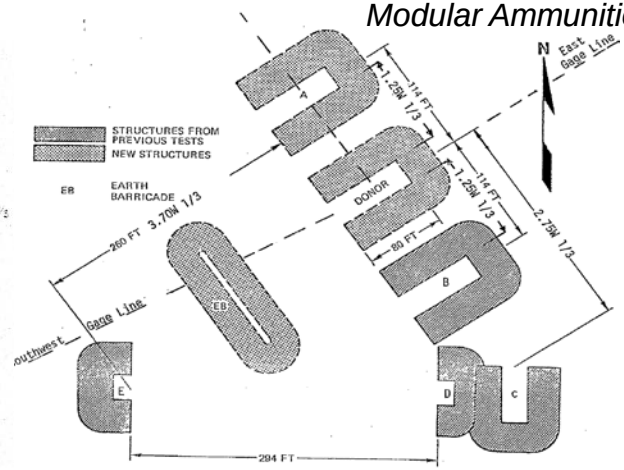


5 tonnes trial, 2002

Modular Ammunition Magazine, 2006



Eskimo I, 1973

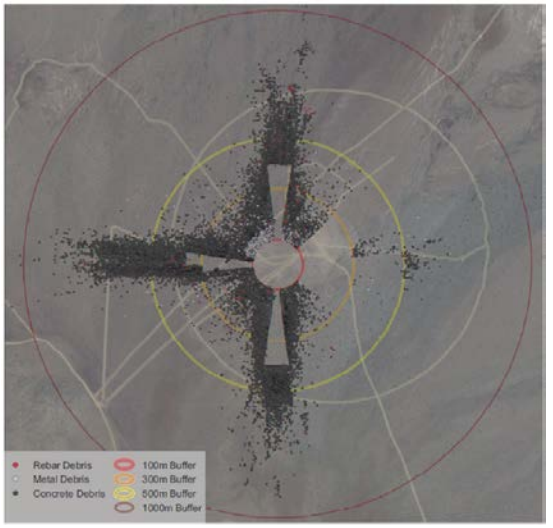


Eskimo III, 1976

Debris

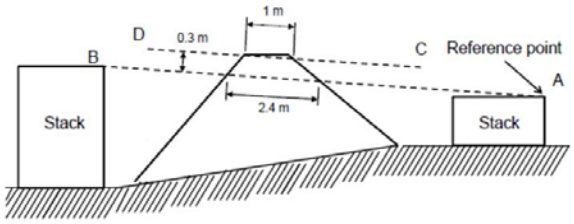
- **QDs dominated by debris hazard**
  - Important for small quantities of explosives (SQQD): 1<NEQ<500kg
  - QDs for brick and RC are based on the wall-normal direction
  - The debris hazard in other directions is generally much smaller

Kasun, 2009



Sci Pan, 2015

- **IBD definition**
  - Debris density = 1/ 56 m^2, hit probability about 1%
  - Hazardous debris/fragment 79 J .
- **Effectiveness of barricades**
  - For IMD but not for IBD

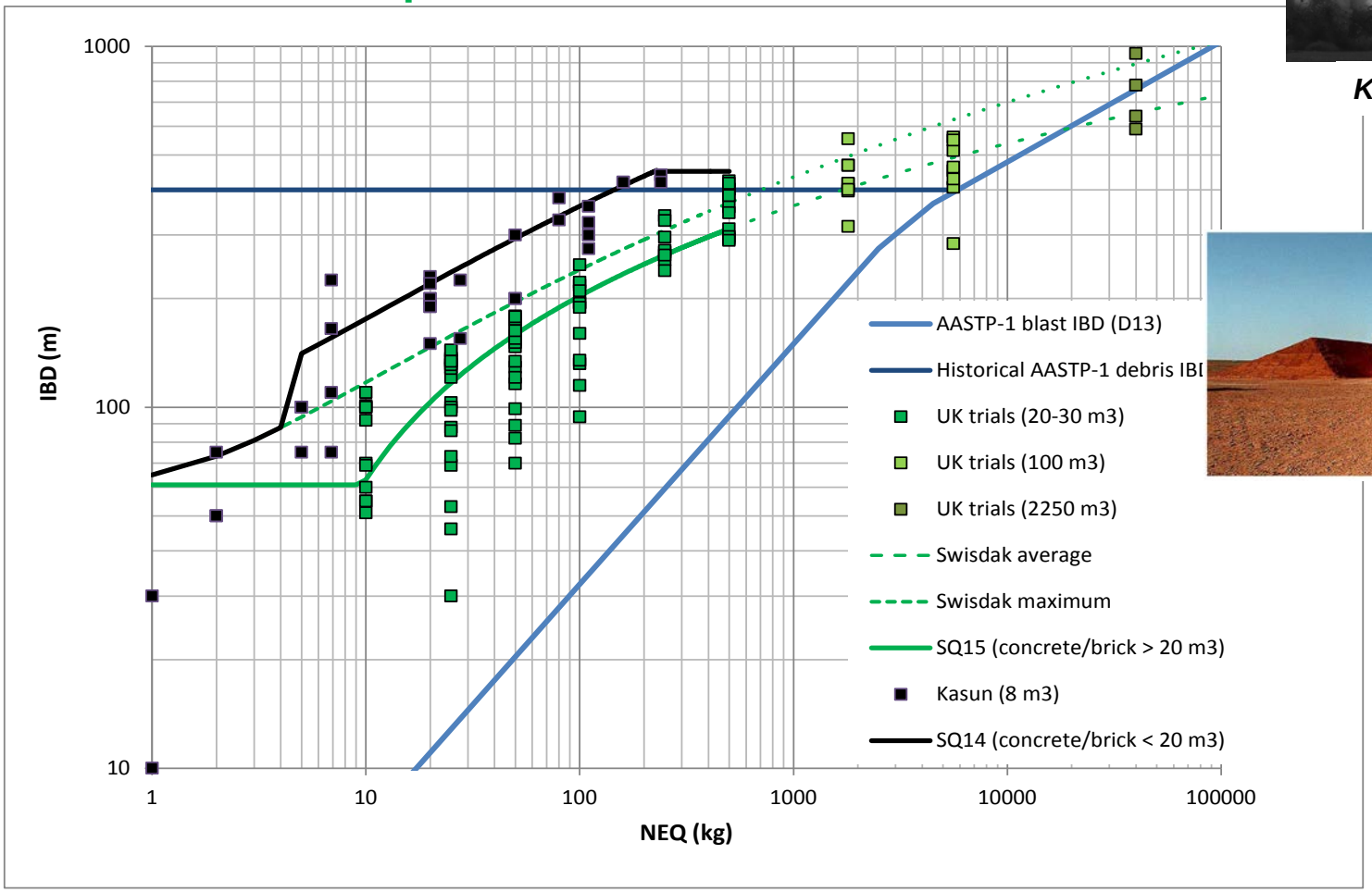


Debris

- **IBD for brick and RC structures**
  - **Traditionally 400 m minimum**
  - **Kasun trials representative for Volume < 20 m^3**
  - **UK trials representative for Volume > 20 m^3**

Kasun trials, 2006-2009

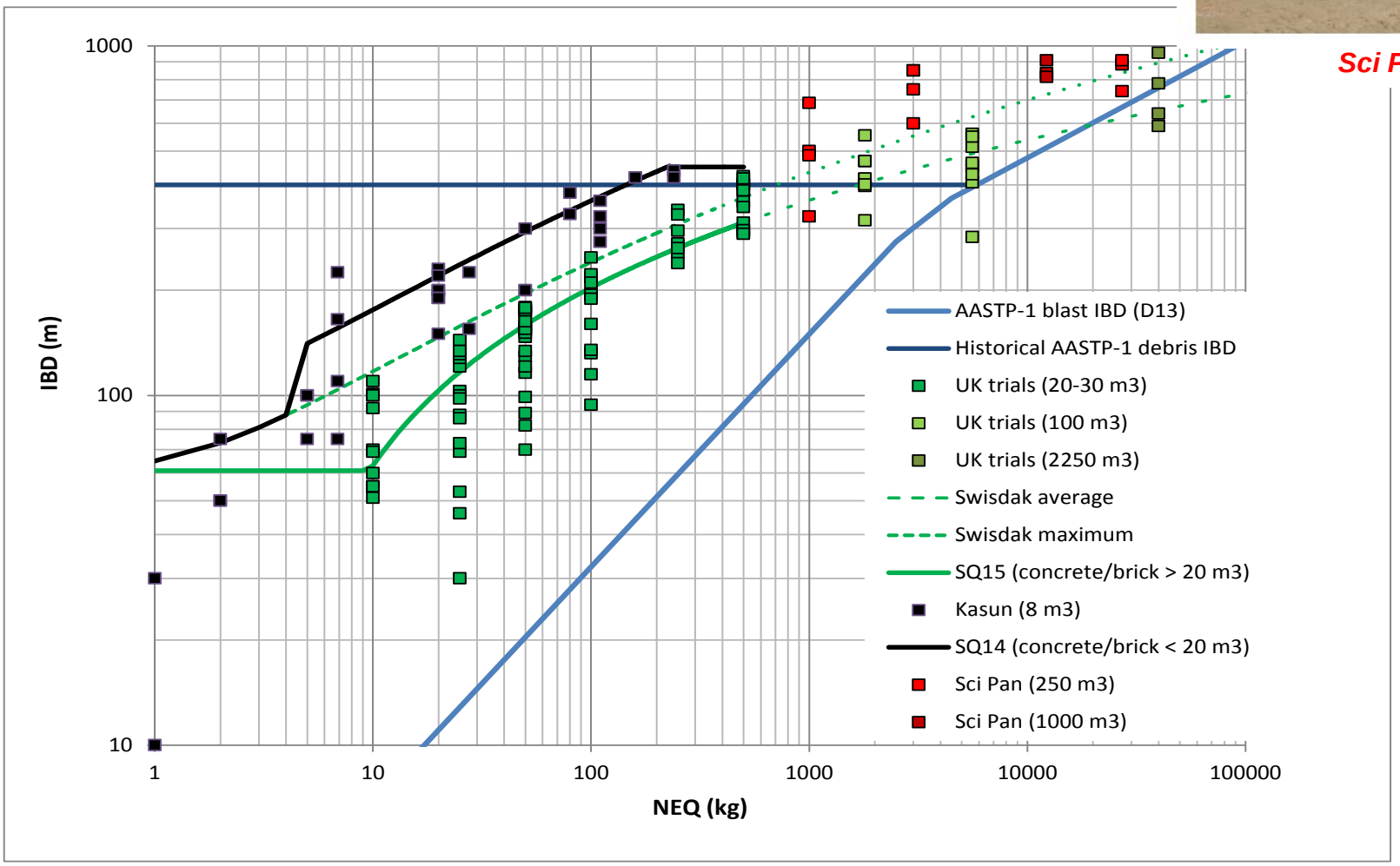
UK trials, 1991 - 2002



Debris

- **IBD for brick and RC structures for large NEQ**
  - **Inclusion of Sci Pan data (large NEQ)**
  - **IBD is much larger than 400 m!**

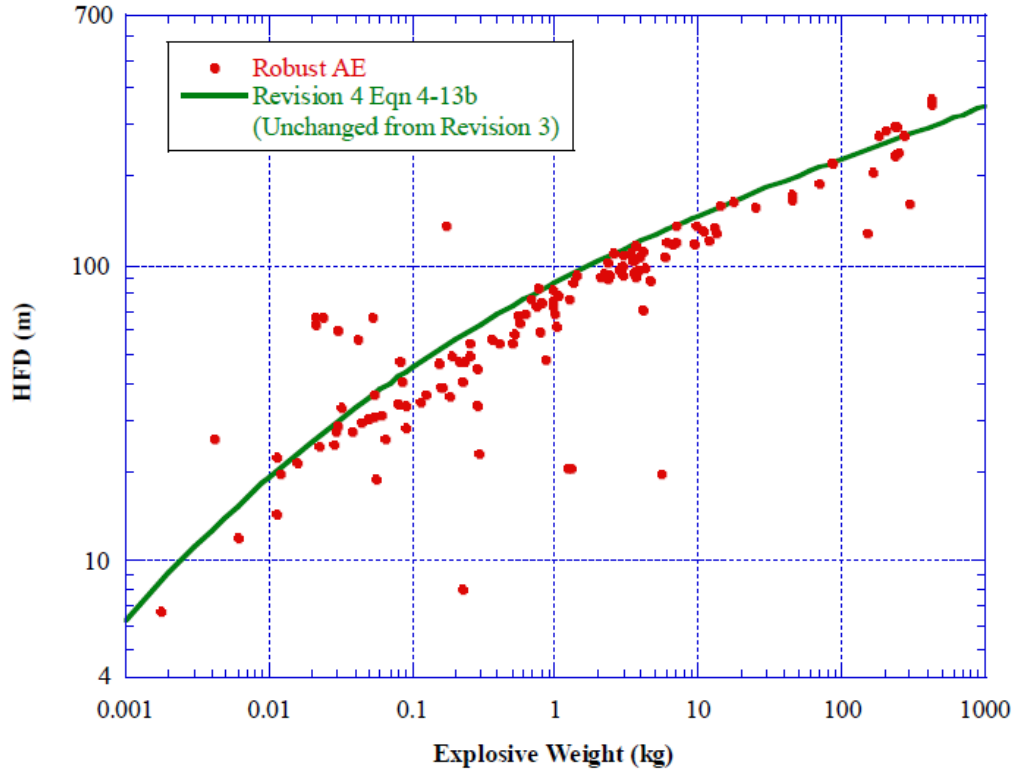
Sci Pan, 2003 - 2011



Fragments

- **QDs dominated by fragments**
  - Important for open stacks and light structures (ISO containers)

- **Unbarricaded situations**
  - Hazardous Fragment Distance (US TP16) (**SQ17** and **FD9**)



Fragments

- **Barricaded situations**
  - QD based on upward launched fragments (**FD8**)

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A universal throw model and its applications

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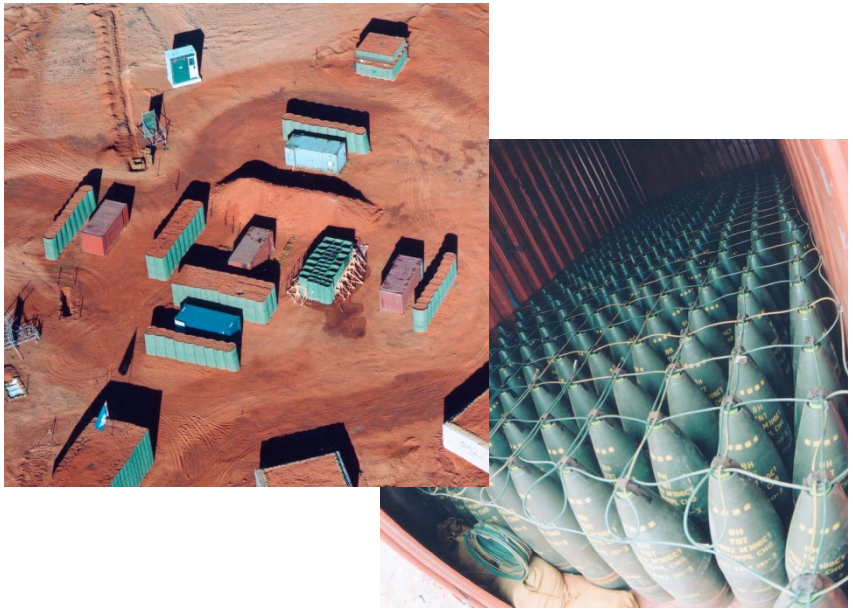
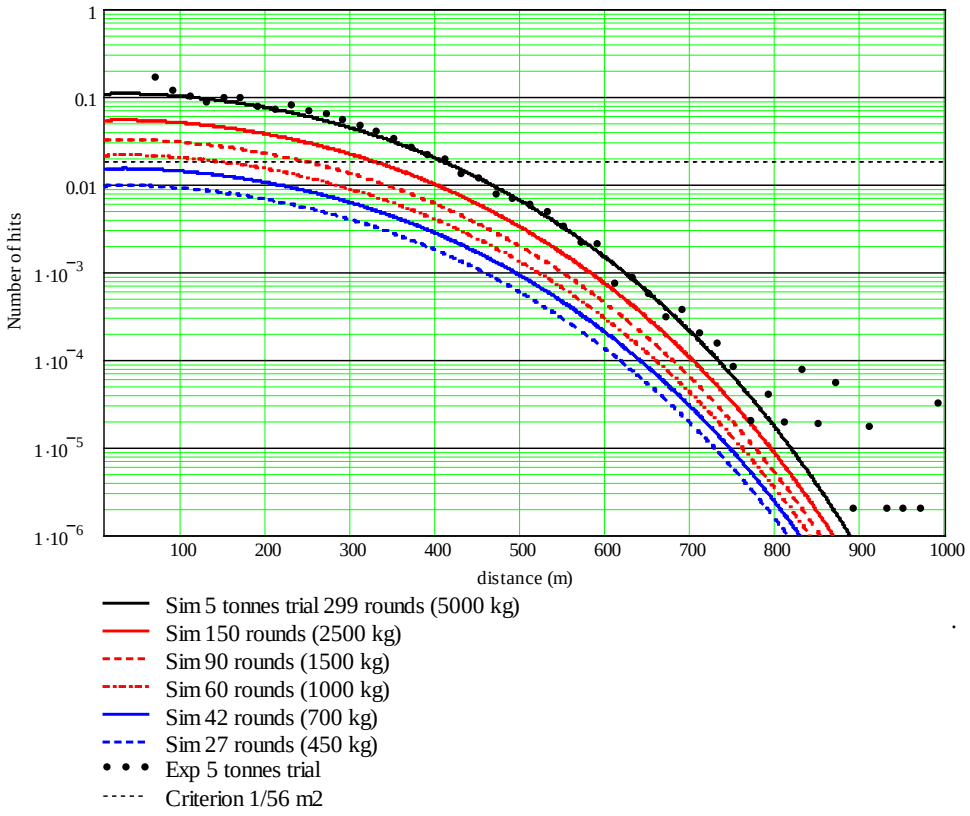




Conclusions

- **AASTP-1 QDs:**
  - Blast QDs consistent with state-of-the-art blast wave prediction
  - Proposed debris/fragment QDs have solid experimental basis

- **AASTP-1 conservative assumptions:**
  - For HD1.1 a mass detonation of all ammunition is assumed
  - Blast QDs are mostly based on peak overpressure, while the dependency on impulse is not consistently addressed
  - Blast attenuation from the front of an ECM is neglected
  - Debris QDs are based on the wall-normal direction

- **AASTP-5 conservative assumptions:**
  - All HD are aggregated as HD1.1
  - Benefits of any HD other than HD1.1 cannot be realised

Conclusions

- **AASTP-1 potentially unsafe situations:**
  - Brick buildings at the Explosive Workshop Distance are likely to collapse, with injury and lethality as a consequence
  - In trials with large NEQ, the debris IBD exceeds 400 m
  - The door of a PES is not taken into account in most cases
- **AASTP-1 knowledge gaps:**
  - Rationale for some of the IMDs is currently unavailable
  - Lack of information on debris IBD from the rear and side of ECMs

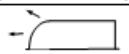
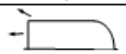
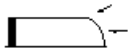
Recommendations

- **Consistency**
  - Availability of QDs for the same protection levels
  - Consistency between HD1.1 SQQD and MCE for other HD
- **Development towards physics-based QDs**
  - More advanced debris IBD models
  - Take into account building properties (dimensions, thickness,…)
  - Take into account reduced debris effects in off-normal directions
- **Development towards tools**
  - As an alternative to tables
  - Reduction of human error, rounding and interpolation issues
- **Cooperation with expert groups**
  - Testing and modeling, e.g. the Klotz Group

MSIAC support to AC/326 SGC

Supporting Munitions Safety

- **MSIAC conclusions and recommendations have triggered revised QD table format in AASTP-1**
  - Combining all Hazard Divisions in one table
  - Treating all explosions effects separately
  - Enhances overall consistency and reduction of amount of tables
  - Ongoing work to update the required QD formulas

PES → / ES ↓	EFFECT	 Building with earth on the roof and against three walls. Directional effects through the door and headwall are away from an Exposed Site. **(a)**	 Building with earth on the roof and against three walls. Directional effects through the door and headwall are perpendicular to the direction of an ES. **(b)**	 Building with earth on the roof and against three walls. Directional effects through the door and headwall are towards an Exposed Site **(c)**	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
 **4** Igloo designed for 3 bar in accordance with Part 2, with the door facing away from PES	BLAST				NEQ	MCE	MCE	MCE			MCE
	DEBRIS & FRAG				NEQ	MCE	MCE	MCE			MCE
	PROG' 1.2.1					NEQ					
	PROG' 1.2.2						NEQ				
	THERMAL 1.3.1								NEQ		
	THERMAL 1.3.2							NEQ		NEQ	NEQ

AASTP-1 and 5 lecture series

Supporting Munitions Safety

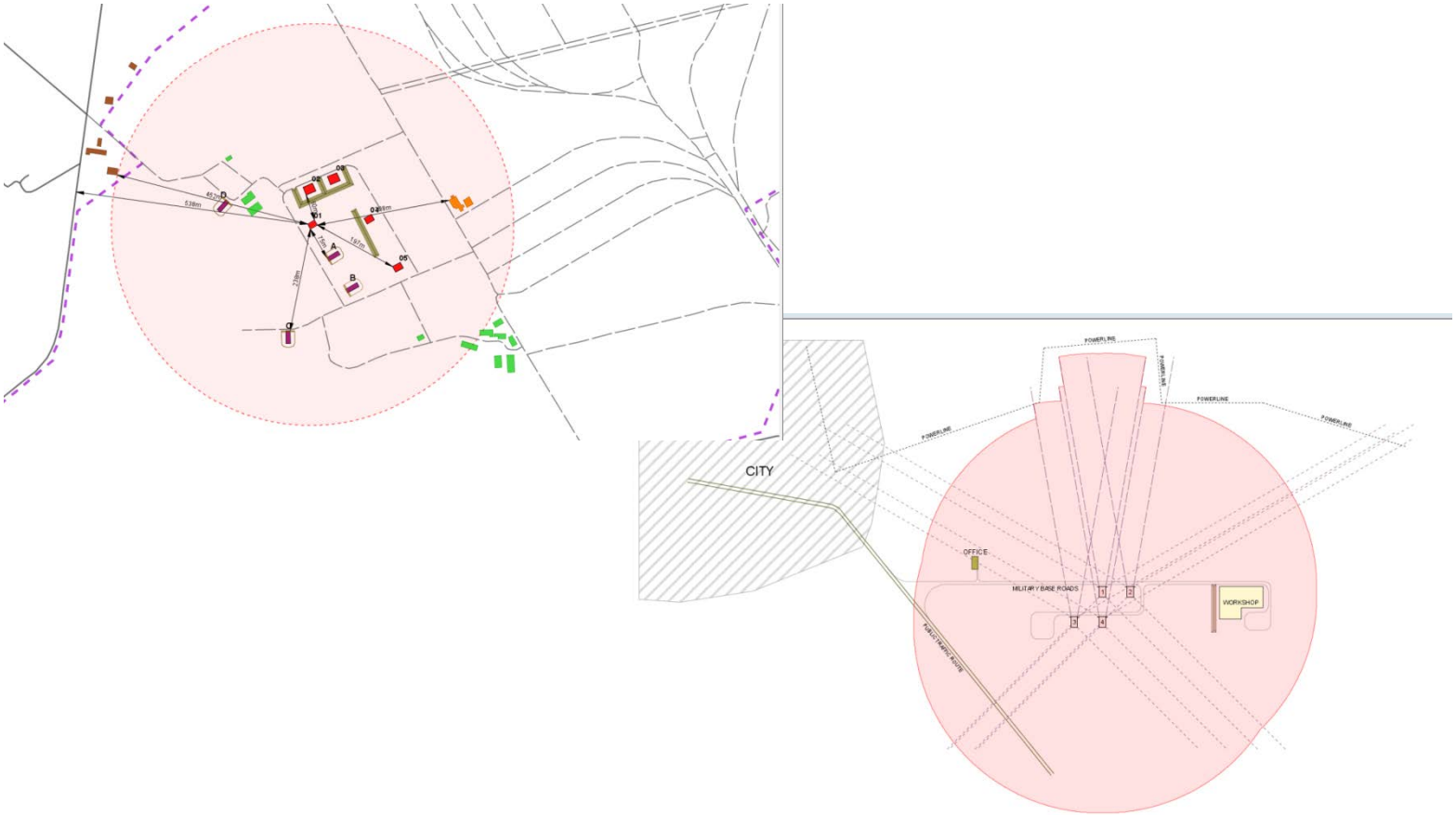
- One week certified course on NATO standards AASTP-1 and 5
- Developed by MSIAC and contractors
- Typically 5-6 courses per year, 20 students per class

AASTP-1 and 5 lecture series

- For ESOs and anyone involved in safe storage of ammunition
- For MSIAC member nations and other (NATO) nations (at a cost)
- Instructors include subject matter experts:
  - Mr. Johan de Roos (ex BE MoD)
  - Mr. Eric Deschambault (ex US DDESB)
  - Mr. Matt Wingrave (UK DOSG)

AASTP-1 and 5 lecture series

- Theoretical presentations and hands-on exercises
- Course material available through MSIAC website




ANY
QUESTIONS
?