Translating the IM behaviour of munitions to operational consequences

Peter Hooijmeijer, Gert Scholtes, Martijn van der Voort

Overview

- Introduction
- Case study in compound environment
  - Mortar attack
  - Detonation of ammunition storage
- Sympathetic Reaction toolbox
  - Case study: M107 155 mm
  - Research mitigating materials
- Conclusions

Introduction

- Protection and Survivability of Compounds
- Countermeasures
  - Situational Awareness
  - Concealment /Camouflage
  - Distance
  - Physical protection
    - Munition storage

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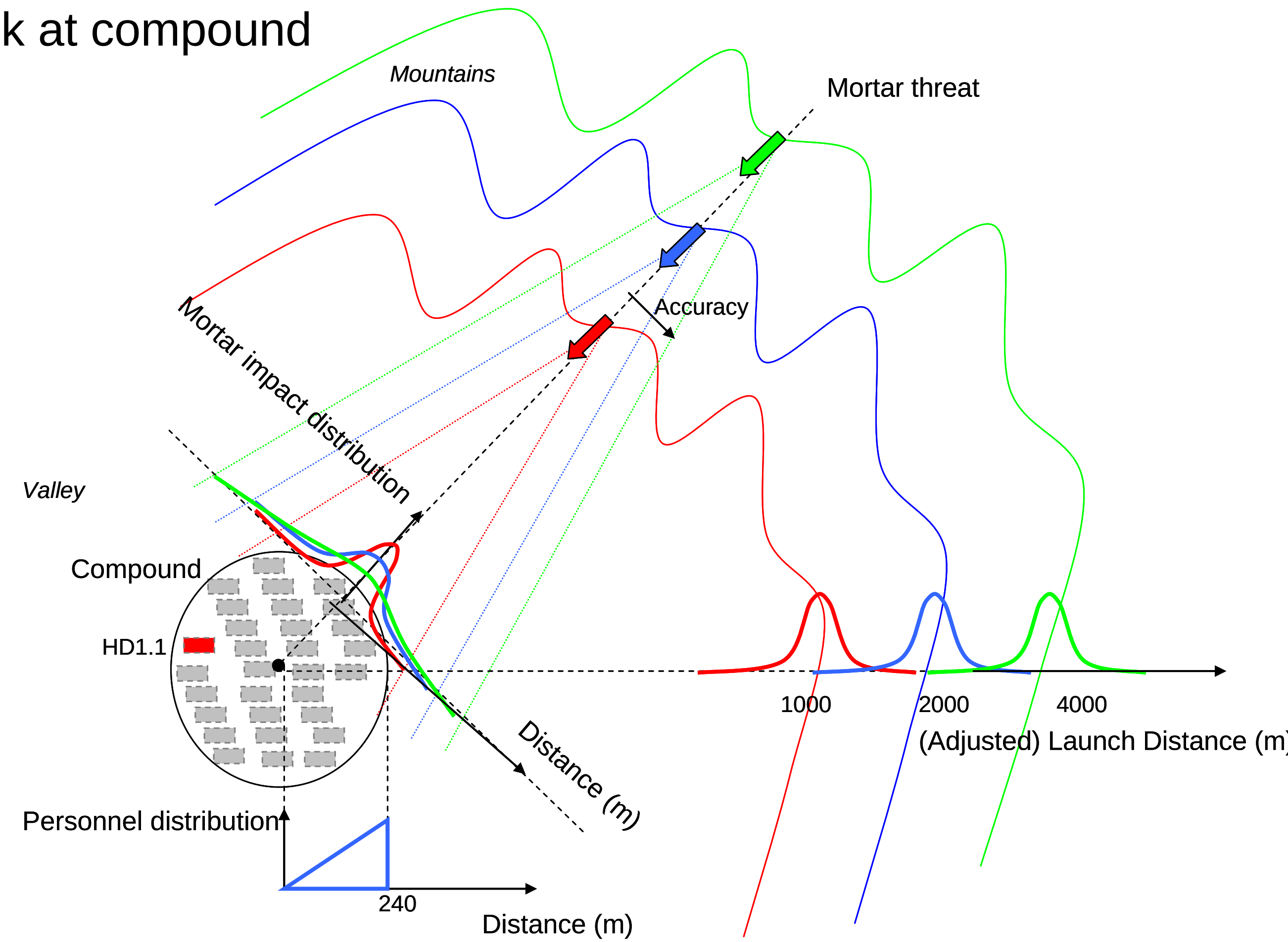
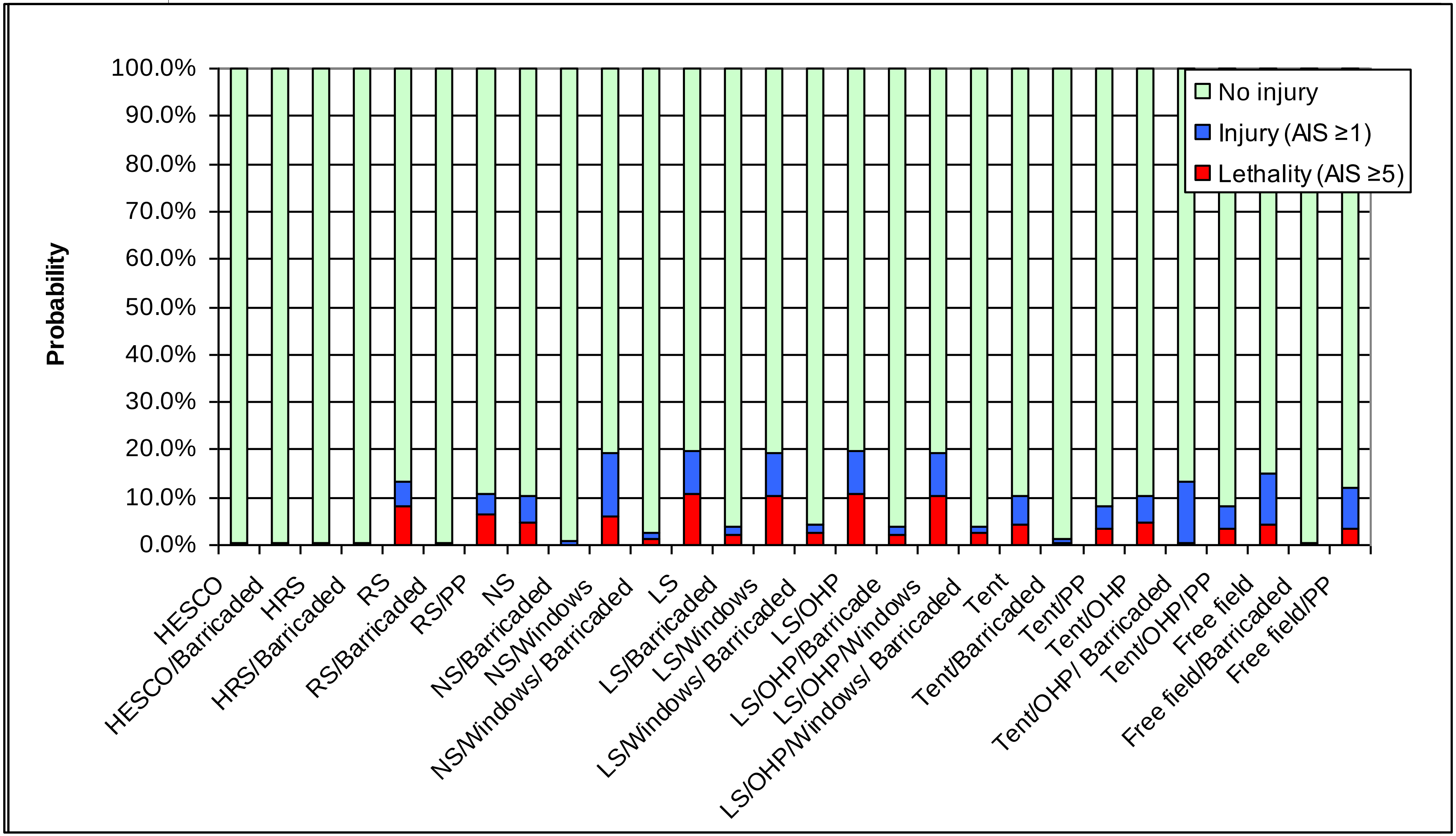
Case study

- Mortar attack at compound



Case study


Probability
100.0%
90.0%
80.0%
70.0%
60.0%
50.0%
40.0%
30.0%
20.0%
10.0%
0.0%
No injury
Injury (AIS ≥1)
Lethality (AIS ≥5)
HESCO
HESCO/Barricaded
HRS
HRS/Barricaded
RS
RS/Barricaded
RS/PP
NS
NS/Barricaded
NS/Windows
NS/Windows/ Barricaded
LS
LS/Barricaded
LS/Windows
LS/Windows/ Barricaded
LS/OHP
LS/OHP/Barricade
LS/OHP/Windows
LS/OHP/Windows/ Barricaded
Tent
Tent/Barricaded
Tent/PP
Tent/OHP
Tent/OHP/ Barricaded
Tent/OHP/PP
Free field
Free field/Barricaded
Free field/PP

Case study

- 2 Scenarios:
  - Mass detonation entire storage (4000 kg)
  - Limited event: one load board (56 kg)

- Setting the stage for R&D in the field of IM munitions
- This is what it’s all about!

Overview

- Introduction

- Case study in compound
  - Mortar attack at compound
  - Detonation of ammunition storage

- Sympathetic Reaction toolbox
  - Case study: M107 155 mm
  - Research mitigating materials

- Conclusions

Sympathetic detonation Toolbox

- Effects external threat on donor
- Effects detonating article on neighbouring articles
- Engineering tools
- Spreadsheet implementation

- Ongoing work!

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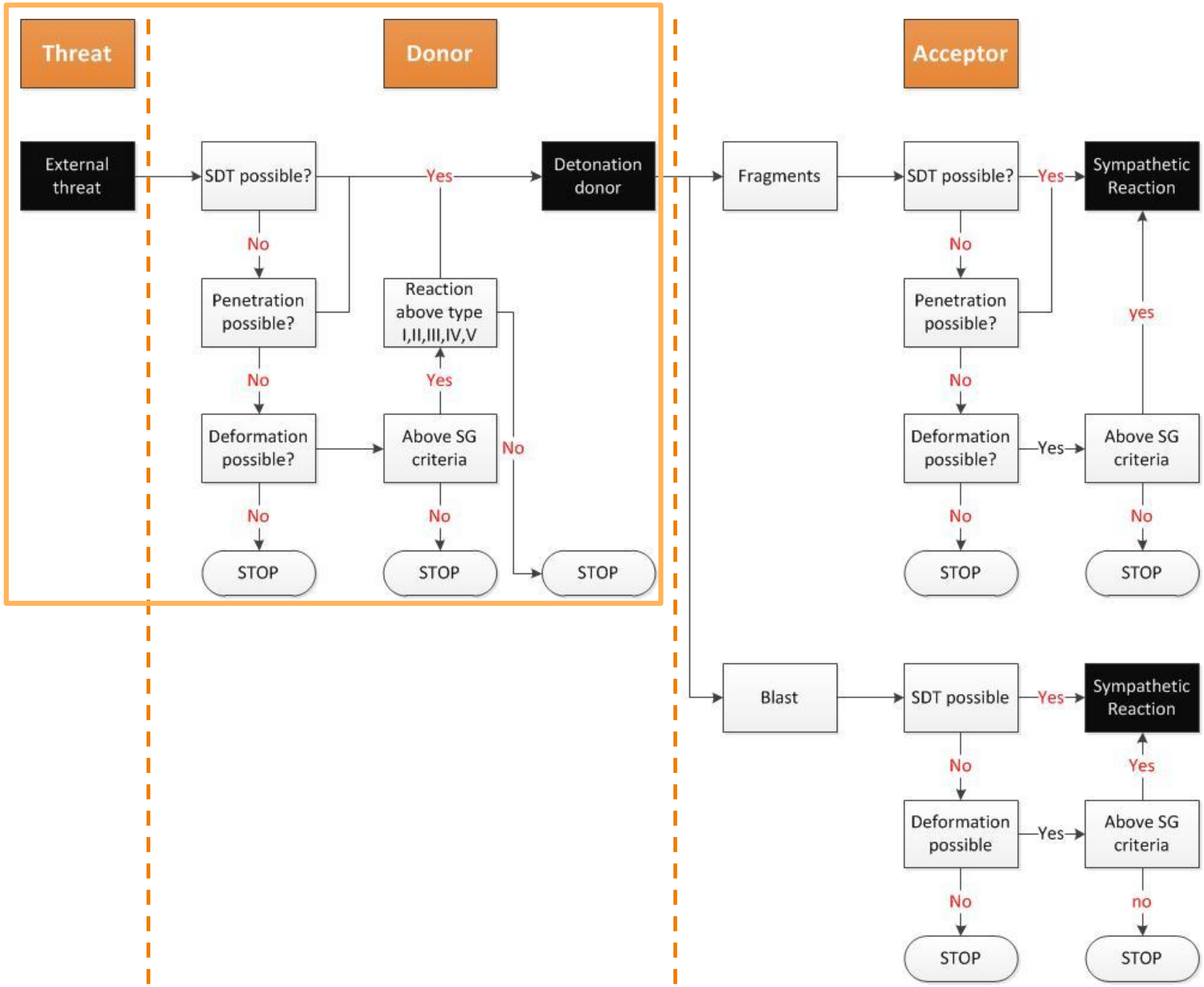
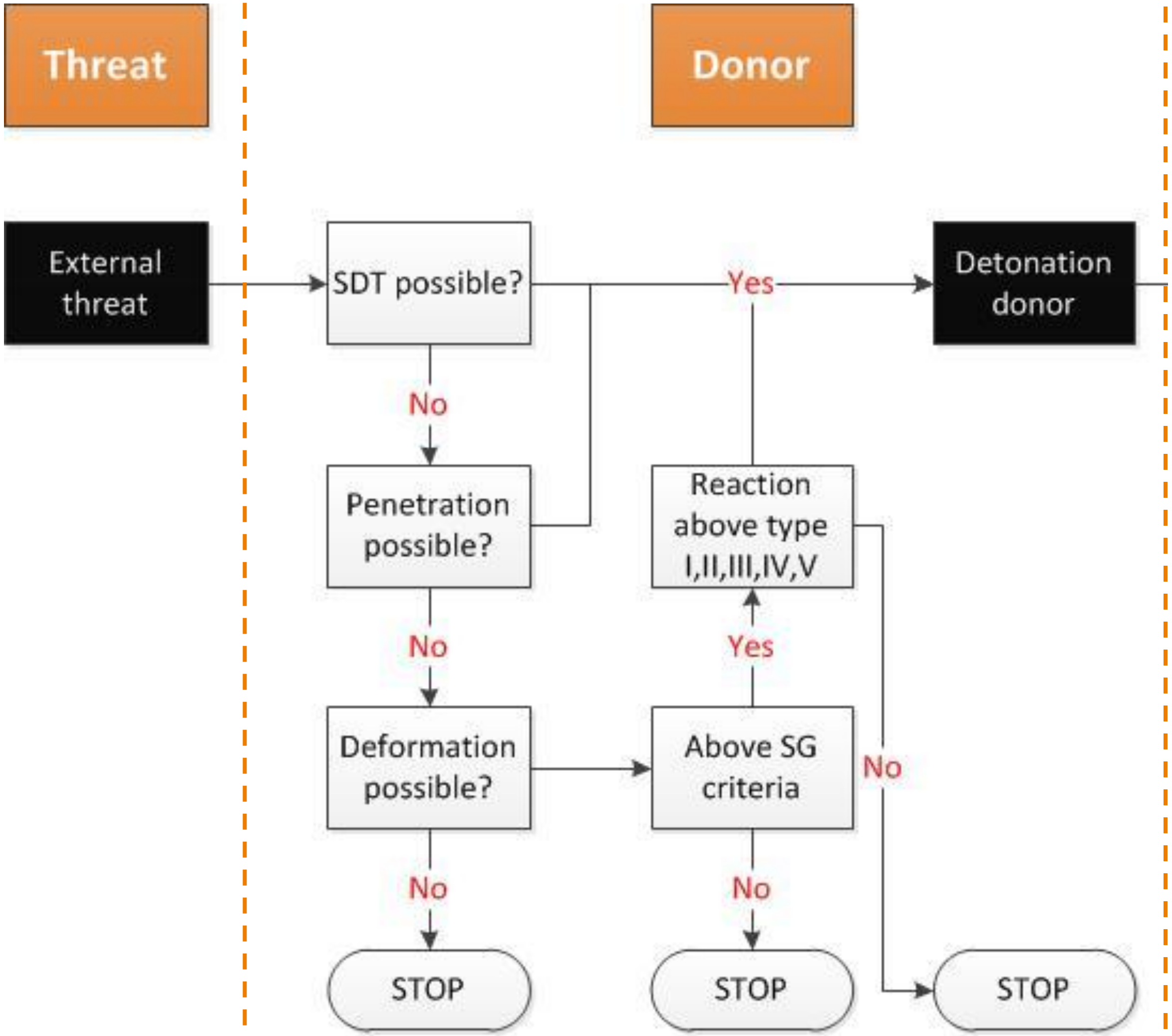
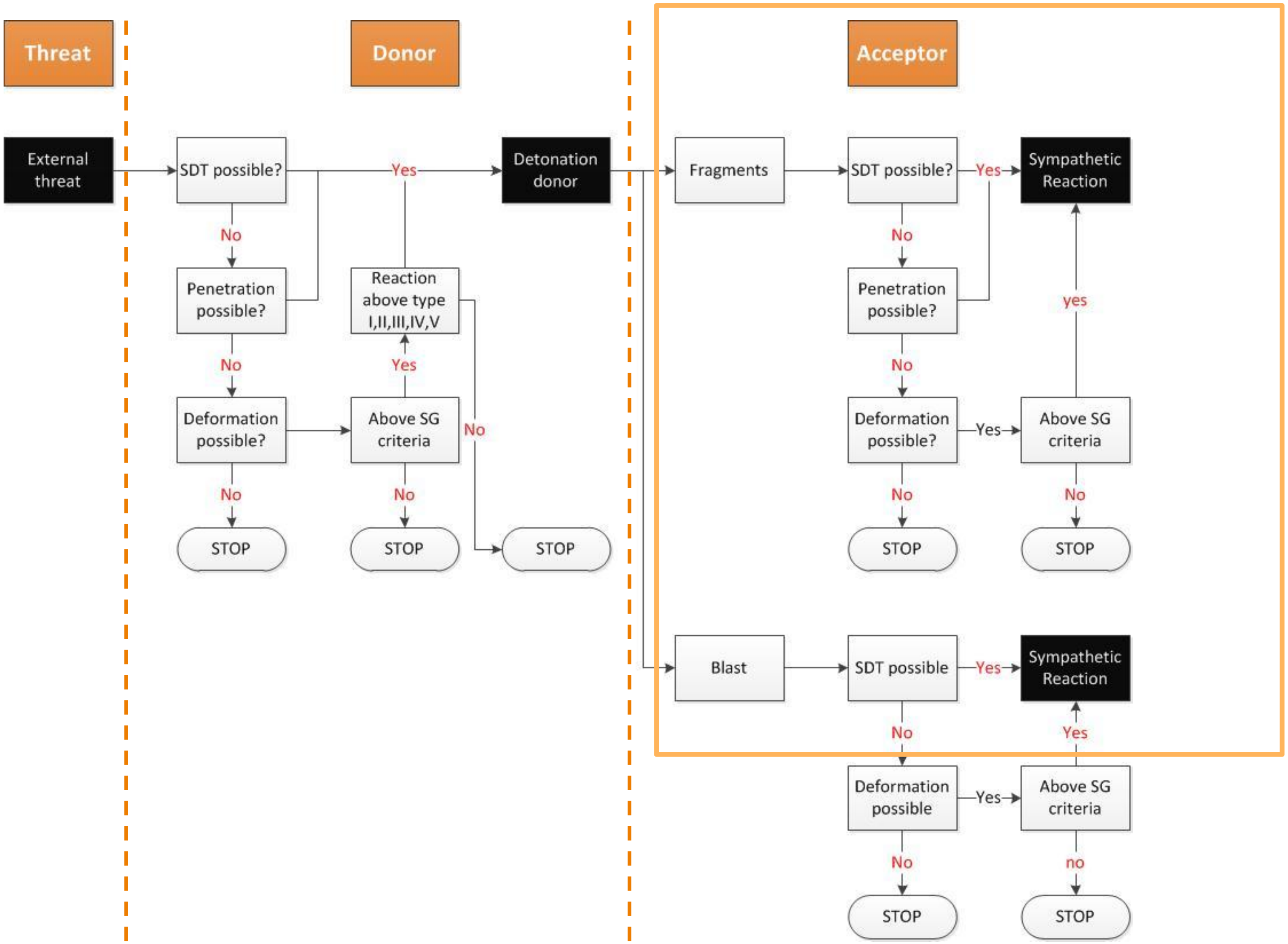
Outline Toolbox



Outline Toolbox



Outline Toolbox



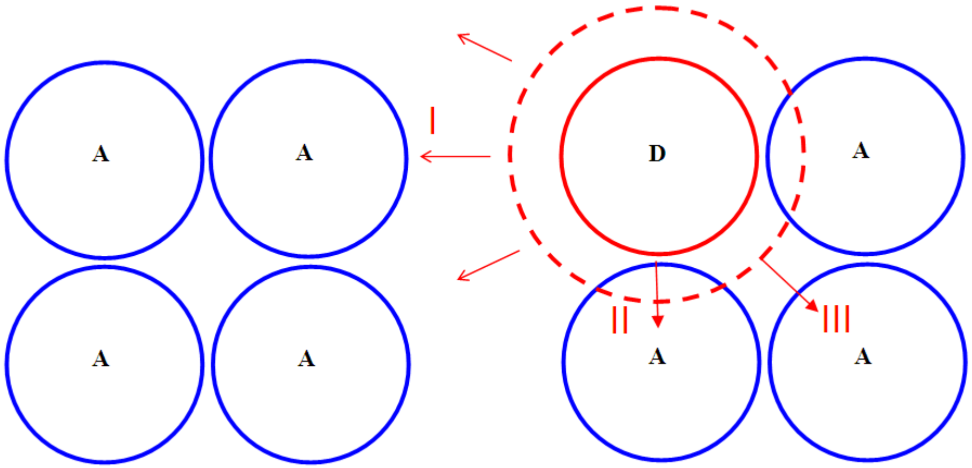
Case study: Sympathetic detonation M107, 155 mm

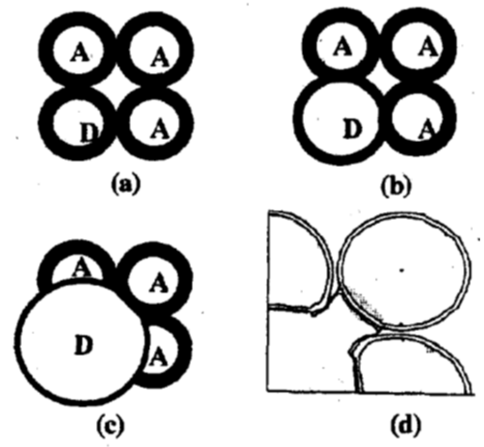
- Threat: effects from incoming mortar
- Donor and Acceptor: M107, 155 mm, TNT filled



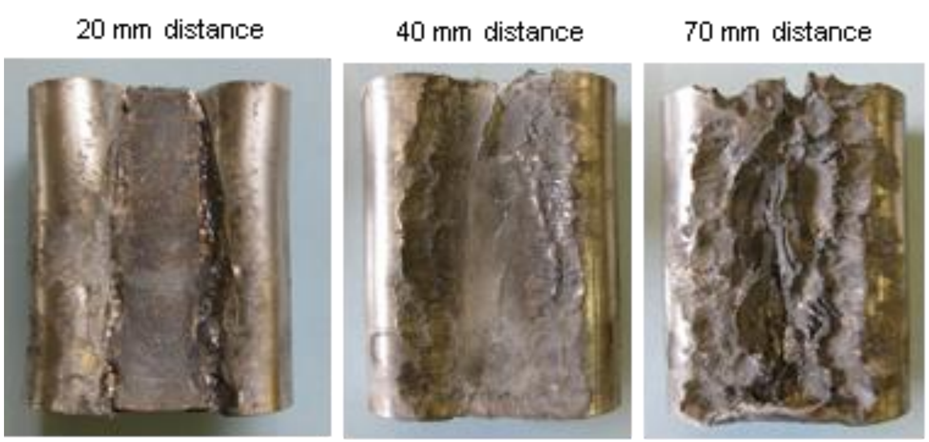
- Three Mechanisms:
  - I. Acceptor in neighboring stack (10-100 cm’s)
  - II. Acceptor in same stack: one-on-one
  - III. Acceptor in same stack: diagonal positioned

Three mechanisms





- Effects on acceptors vary with distance



Results evaluation

- Summary of results

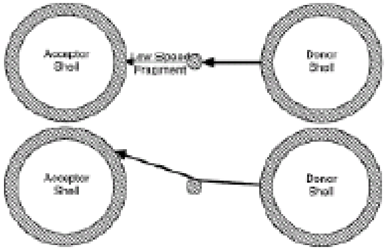
Mechanism	Relevant threat	Result	
I	SDT		Highly likely for different fragments and impact angles
	Acceptor casing penetration		Highly likely for different fragments shapes and impact angles
	Blast		Critical shock pressure of the explosive fill exceeded < 2 m
II	Sympathetic reaction, one-on-one (homogeneous loading of acceptor)		No SDT, effect of deformation not evaluated
III	Sympathetic reaction, diagonal (homogeneous loading of acceptor)		SDT is highly likely

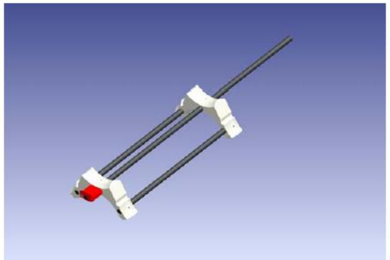
- Results of the Toolbox evaluation guides the search for the right mitigating materials or structural solutions

Approach for barrier research

- A barrier should:
  - Stop Fragments
  - Stop Secundairy fragments (e.g. spall of container)
  - Reduce (Blast) pressure
  - No secundairy fragments from barrier itself
  - Reduce deformation acceptor

Pumice

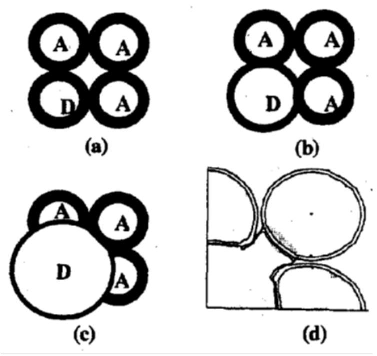


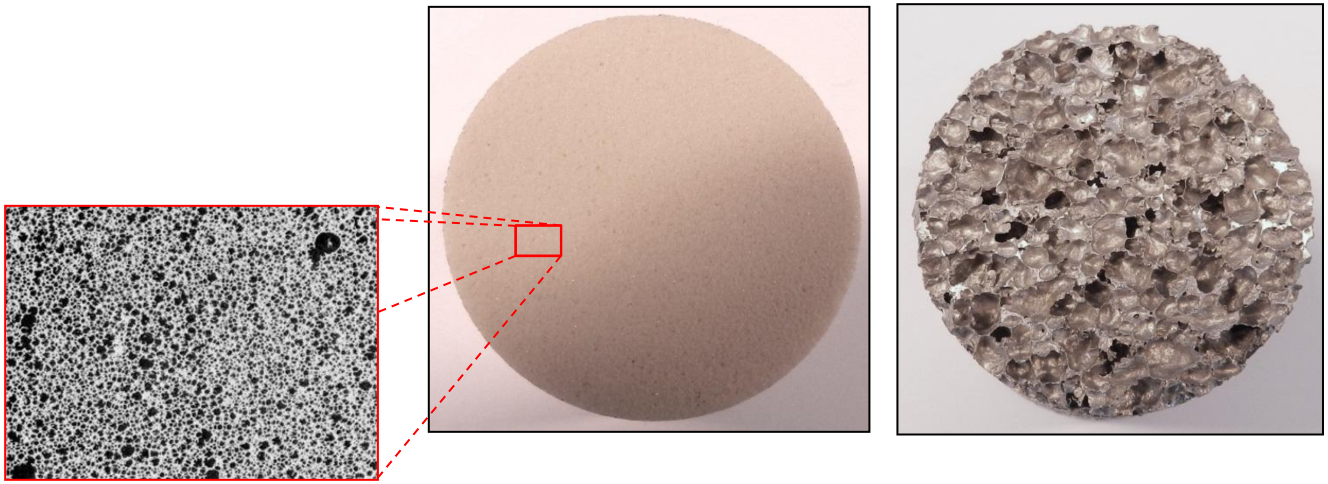


Critical fragment arresting bars

Approach for barrier research – recent advances

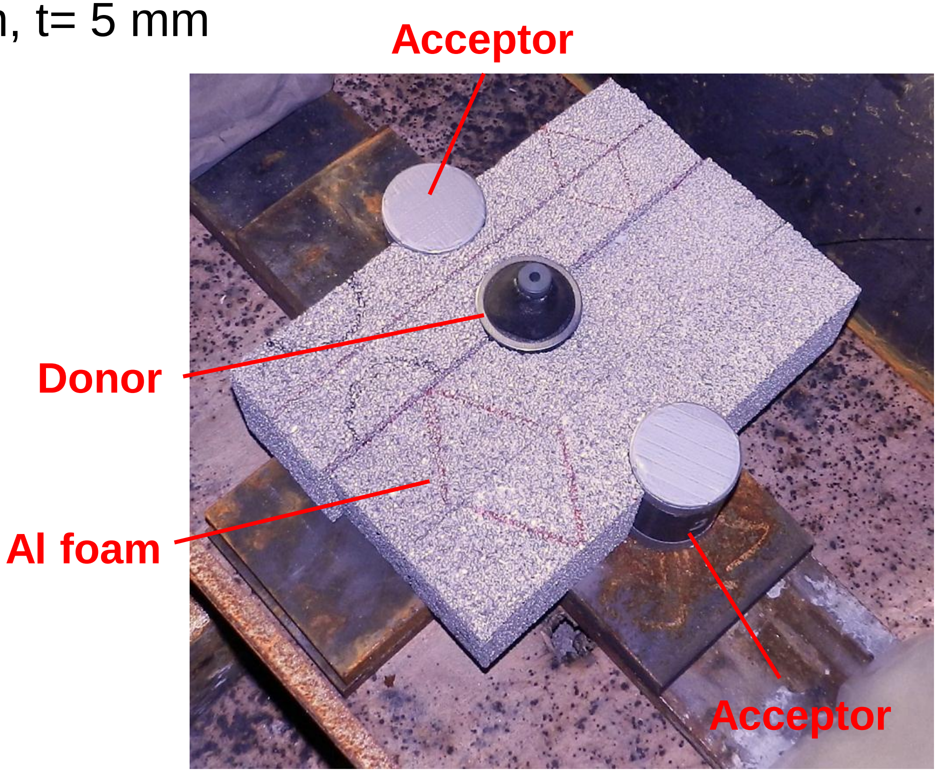
- Blast mitigating materials for situation of SD
  - Based on damage asessement of acceptor
  - Homogeneous load distribution due to intact casing
- Tested materials (a.o.)
  - Aluminium foam
  - Polyurethane foam





Experimental set up

- Experiment in bunker
- 1 donor, 2 acceptors at different distances
- Steel cilinders D=70 mm, t= 5 mm
- Semtex10 or sand-fill



Results

- 20 mm distance

No mitigation

PUR foam

Results

- 40 mm distance

No mitigation

PUR foam

Results

- 70 mm distance

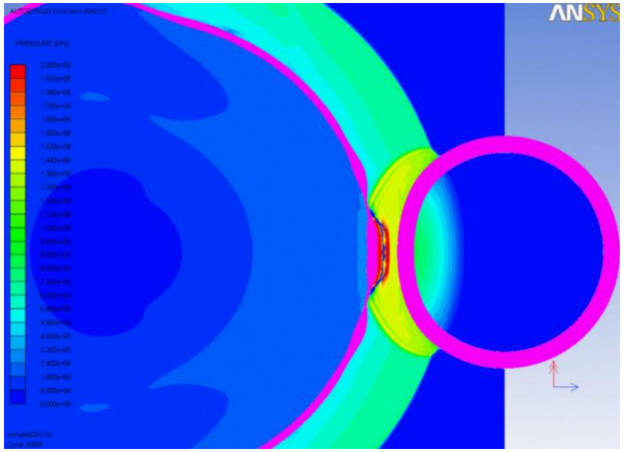
No mitigation

PUR foam

Results

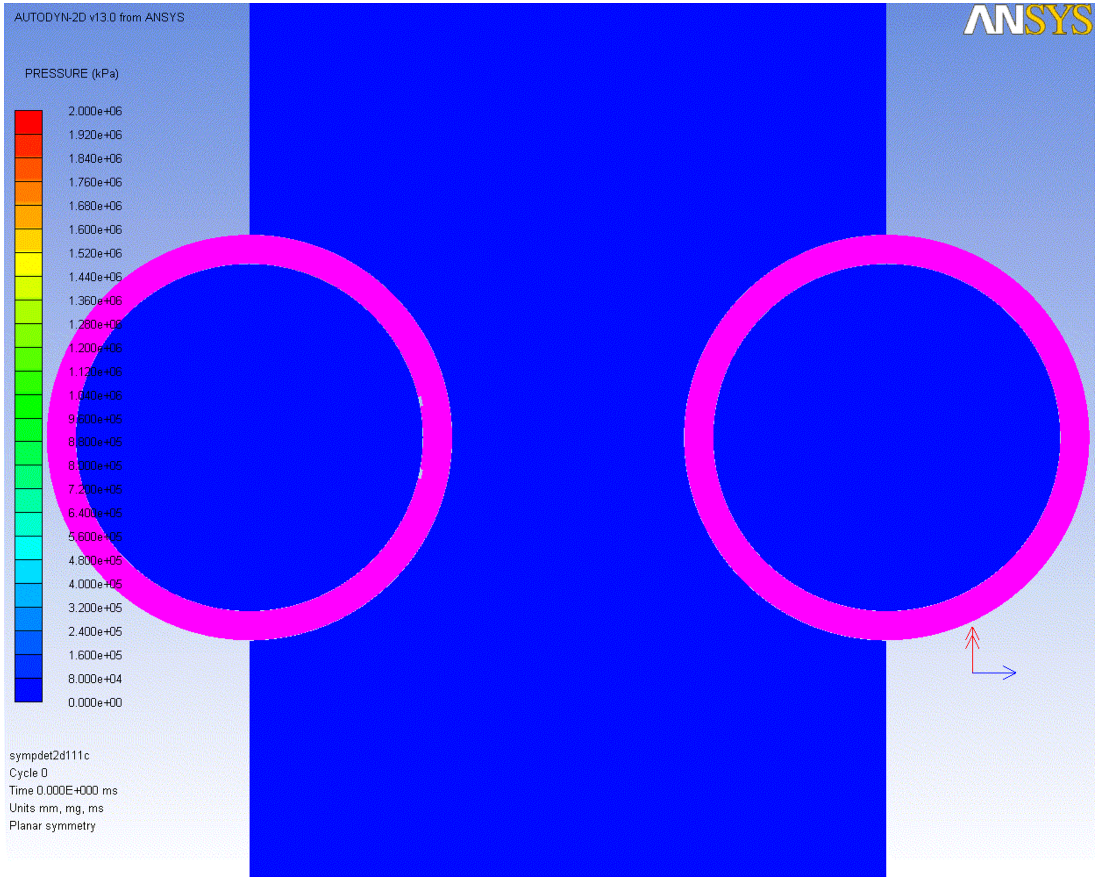
- Both materials excellent fragment arresting capabilities
- PUR and Al foam applied
  - Live acceptors
  - Autodyn simulations

	Distance [mm]		
Material	20	40	70
PUR foam	n.t.		
Aluminium foam	n.t.		



Results

- Simulation of foam behaviour



Conclusions

- Engineering tools in the sympathetic detonation Toolbox guide the search for the right mitigating materials or structural solutions
- Substantial difference between effects mass detonation or limited event in compound environment
  - Quantification of consequences

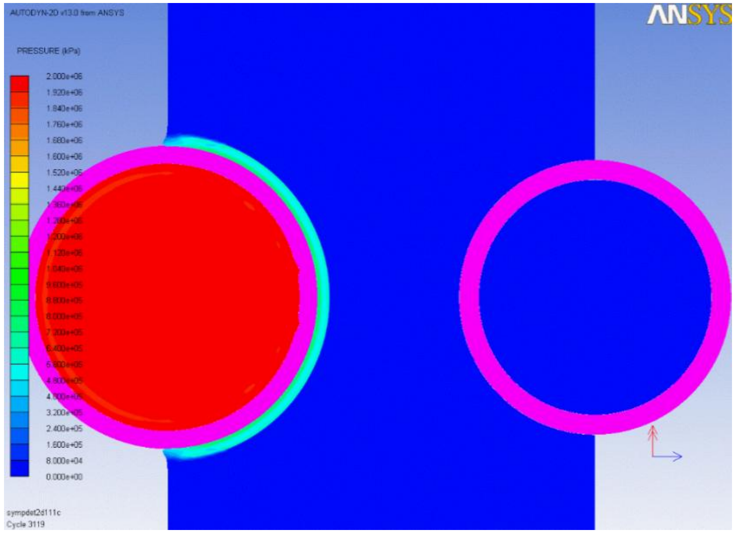
Putting all the work on IM munitions in the right perspective sets the stage and should **motivate** and **challenge you** in your activities. These efforts protect the warfighter in their day to day business.

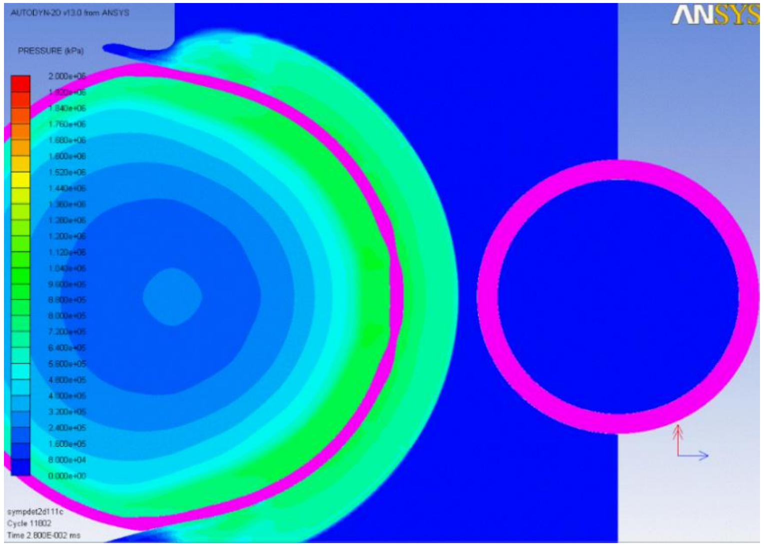
Questions?

Other TNO presentations today

- Mr. Gert Scholtes: *“ AN EFP IMPACT IN COMPARISON WITH THE IM FRAGMENT IMPACT TEST” , Wednesday, 2.50 pm, Session 7A*
- Mr. Wim de Klerk: “IMPROVED IM PROPERTIES OF AN RDX/TPE BASED LOVA PROPELLANT FOR ARTILLERY APPLICATIONS”, Wednesday, 4.30 pm, Session 8A

Numerical simulation foam behaviour





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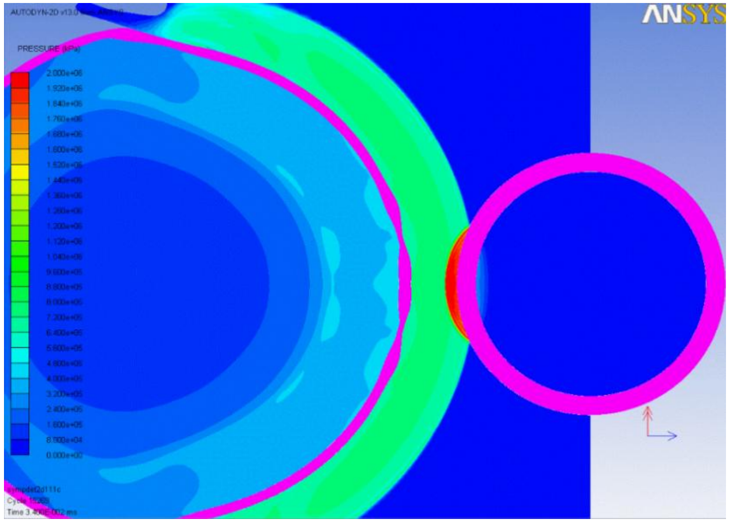

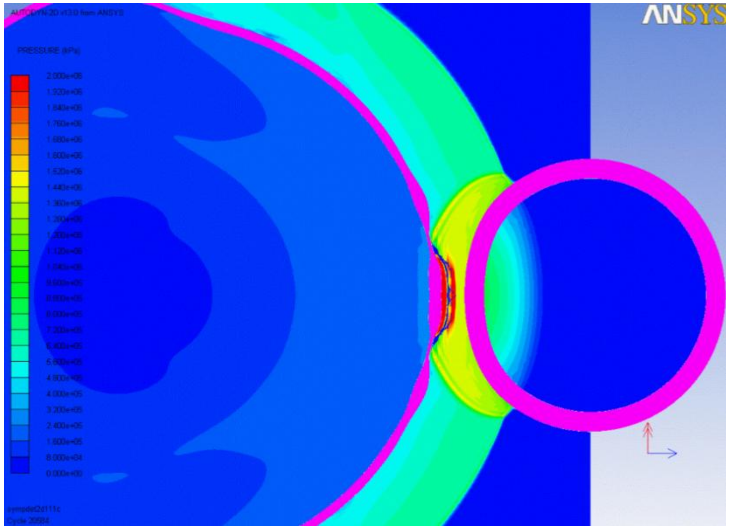

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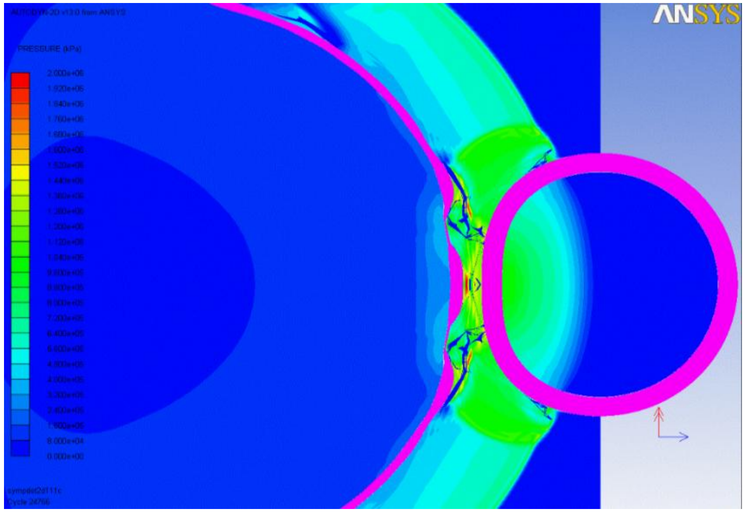
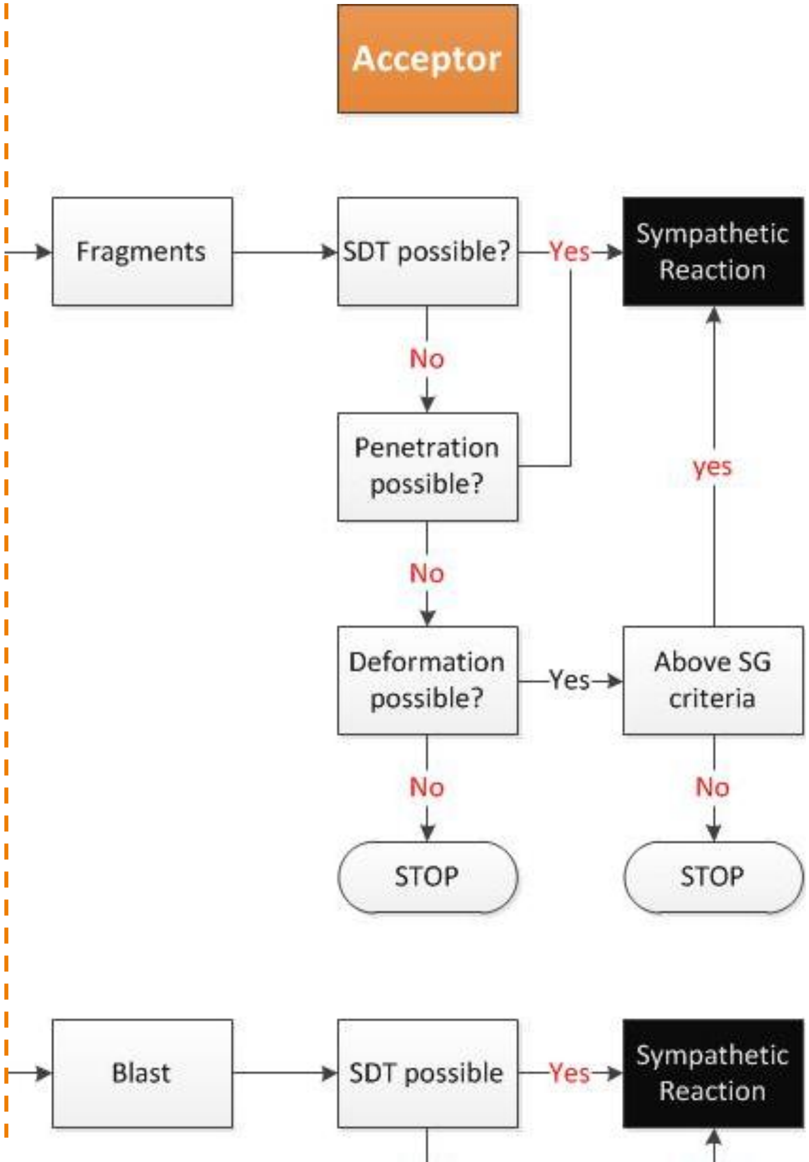
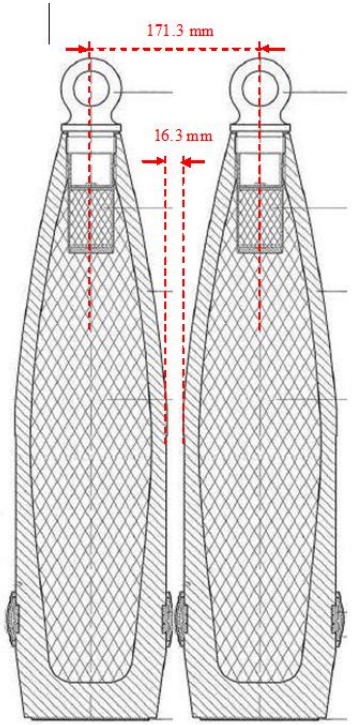
Numerical simulation foam behaviour

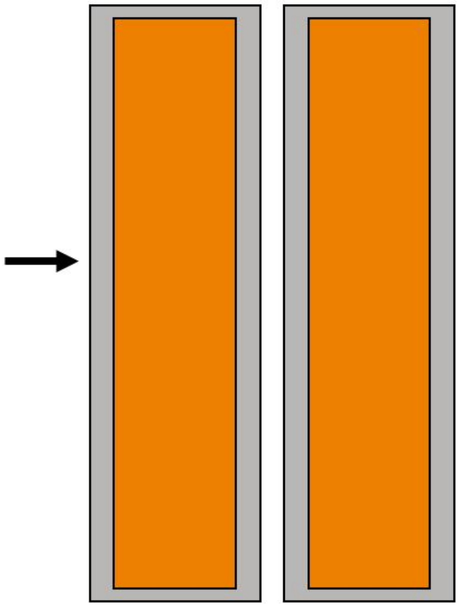


Outline Toolbox



Conversion to representative cylinder





Dimension		Type	
		CompB	TNT
Mass metal part	kg	35,0	35,0
Design explosive mass	kg	8,41	8,39
Total mass	kg	43,41	43,39
External diameter	mm	155,0	155,0
Internal diameter	mm	112,3	113,2
Thickness casing	mm	21,35	20,90
Length	mm	494,0	509,0

Mott fragment distribution equations

Parameter		Type	
		CompB	TNT
Mott constant	kg^0.5 m^-7/6	2,714	3,815
Fragment distribution factor	kg^0.5	2,00	2,75
Average fragment mass	gr	7,89	15,16
Heaviest fragment	gr	280	455
Design fragment mass	gr	36	68
Total number of fragments	-	658	346

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TNO innovation for life

SDT

- Energy criterium (Haskins/Cook)
- Critical diameter (Green/Lundstrom)

	A	B	C	D	E	F	G	H	I	J
1	**Hugoniot calculations**					Vatmin	0,1	km/s		
2	Us=Co+sUp	Co	S	r		Vatmax	0,3	km/s		HU45 hugoniot is
3	**staal**	**4,58**	**1,49**	**7,89**		angle2	-0,978961515	degree		vorm of vlak (1,0)
4	**Aluminium**	**5,38**	**1,34**	**2,712**		angle2	-2,934601533	degree		
5	**Comp B**	**3,03**	**1,73**	**1,715**		angle3	-1,476123403	degree		**cook/haskins/**
6	Octol	1	1	1		angle3	-4,420557984	degree		"Projectile impact
7	Imp vel, km/s	**0,5**	km/s	angle	**0**	degree				c2=
8	Imp vel, km/s	0,500	km/s	**pressures in GPa**						c3=
9	P1=P2=ro1*Us1*(V-Up1)=ro2*Us2*Up						Barriere dikte	10	mm	Us2=
10	V= Up1+P2/(ro1*Us1)						c(explosief)	4,13181	km/s	c2^2-(Us2-Up2)^2
11	P3=ro3*Us3*Up3=ro2*Us2*(V2-Up)						diameter fragment	**40,00**	mm	Rc=
12	V2=2*Up1						Eflatrod	2596,22	KJ/m2	tau
13							Eroundrod	865,406	KJ/m2	Eflux
14	Quadratic solutions for up						tan(alfa)	0,38505		Ec=
15	a=	8,122	a=	0,66713	a=	1,96695	alfa	21,059		Ec-Eflux
16	b=	-62,483	b=	-24,9087907	b=	-12,0318716				
17	c=	21,007	c=	12,0864109	c=	7,97949904				
18			Up match	Pmatch	Up match	Pmatch	Up match	Pmatch		
19			**0,352344**	**5,5920487**	**0,491702**	**3,272427**	0,756837751	1,32964		
20			1st match up & P		2nd match up & P		3rd match up & P			
21										
22	Up	P, steel	P,st refl	P, Al	P, Al refl	P, comp B	P,comb B refl	P, octol		
23	0	0	21,007125	0	12,0864109	0	5,717946851	0		
24	0,2	7,6975	11,898909	3,0634752	8,28930595	1,157968	3,795638236	0,24		
25	0,4	16,335	3,731181	6,4176768	4,7829274	2,553292	2,11068562	0,56		
26	0,6	25,914	0	10,0626048	1,56727526	4,185972	0,663089005	0,96		
27	0,8	36,433	0	13,9982592	0	6,056008	0	1,44		
28	1	47,892	0	18,22464	0	8,1634	0	2		
29	1,2	60,292	0	22,7417472	0	10,508148	0	2,64		
30	1,4	73,633	0	27,5495808	0	13,090252	0	3,36		
31	1,6	87,914	0	32,6481408	0	15,909712	0	4,16		
32	1,8	103,13	0	38,0374272	0	18,966528	0	5,04		
33	2	119,3	0	43,71744	0	22,2607	0	6		
34	2,2	136,4	0	49,6881792	0	25,792228	0	7,04		
35	2,4	154,44	0	55,9496448	0	29,561112	0	8,16		
36	2,6	173,43	0	62,5018368	0	33,567352	0	9,36		

Penetration of casing

- Fragment stuck in EM
- THOR code

	A	B	C	D	E	F	G	H	I	J	K	L
1	THOR Fragment Penetration Spreadsheet for steel projectile											
2		Residual velocity equation constants					Residual mass equation constants					
3	Material	c1	a1	b1	g1	l1	c2	a2	b2	g2	l2	
4	Mild steel	3,69	0,889	-0,945	1,262	0,019	-2,478	0,138	0,835	0,143	0,761	
5	hard homo st	3,766	0,889	-0,945	1,262	0,019	-2,671	0,346	0,629	0,327	0,88	
6	face-hard st	2,305	0,674	-0,791	0,989	0,434	-1,534	0,234	0,744	0,469	0,483	
7	Cast iron	2,079	1,042	-1,051	1,028	0,523	-8,89	0,162	0,673	2,091	2,71	
8	2024T-3 Al	3,936	1,029	-1,072	1,251	-0,139	-6,322	0,227	0,694	-0,361	1,901	
9												
10	Layer 1											
11	Vs, m/s	2000			Assume random fragment (A=K*ms^.667), K random =0.5199							
12	ms, g =	16	A=	3,3012	sq cm		Other fragments		K cube=	0,3799		
13	targ thick,cm	0,635							K sphere	0,3079		
14	obliq. ang. de	0										
15	TARGET MATERIAL: Hard homogeneous steel (row 5)											
16												
17	Residual vel=	1052	m/s			NOTE: For different target materials, different						
18	Residual mas	3,341	grams			constants from rows 4-8 must be used.						
19	limit velocity	934,1	m/s for perforation									
20	max obl	56,91	deg for perforation									
21												
22	Layer 2											
23	targ thick,cm	0,389	A=	1,1618	sq cm							
24	obliq. ang. de	0										
25	Residual vel=	0,014	m/s			NOTE: For different target materials, different						
26	Residual mas	1,761	grams			constants from rows 4-8 must be used.						
27	TARGET MATERIAL: Hard homogeneous steel (row 5)											