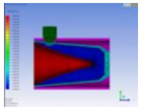

Munition vulnerability in relation to platform Resilience

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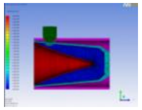
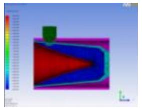
Gert.Scholtes@tno.nl tel: +31 (0)6 2280 1250 www.tno.nl/ammunitionsafety

Overview

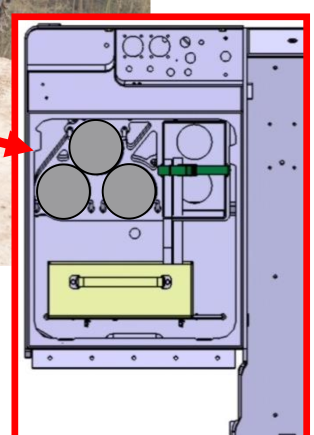
- Introduction Threats/ Sympathetic reactions
- The Munition Vulnerability and Response toolbox
- Example: Scenario in Ship
- Methodology for Vulnerability studies (statistics)
- Mitigation research
- Summary

Life-cycle munitions - Threats





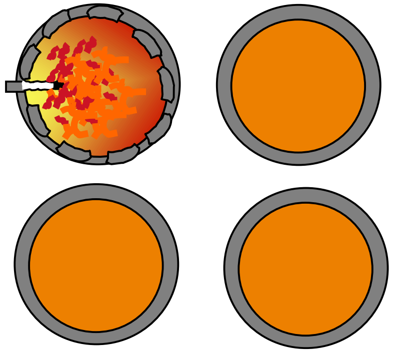


- Fragments
- SCJ
- Bullets

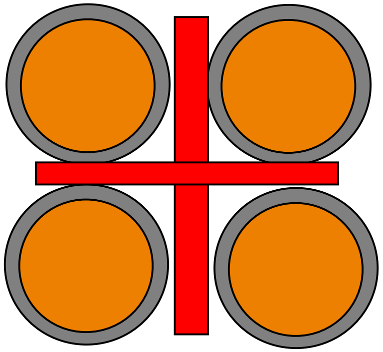
Also other threats:

- Cook-off
- Sympathetic reaction

Threat-sympathetic reaction mitigation



Prevent from sympathetic detonation

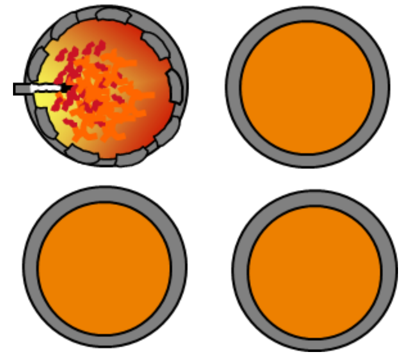


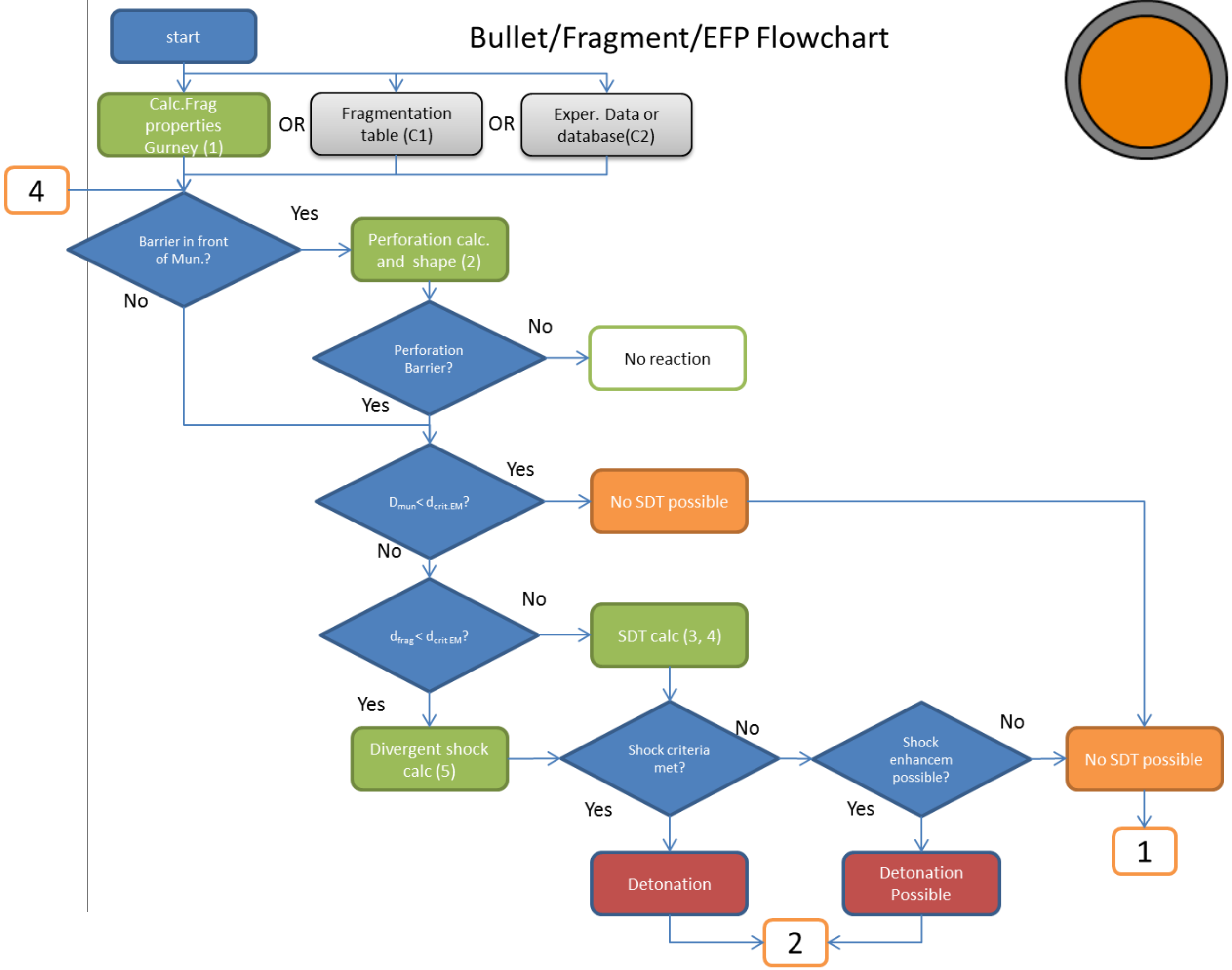
?

Many scenarios → Need for a screening tool

TNO Munitions vulnerability and response toolbox

Flowchart toolbox
Threat – donor - acceptor

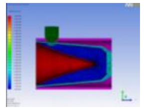




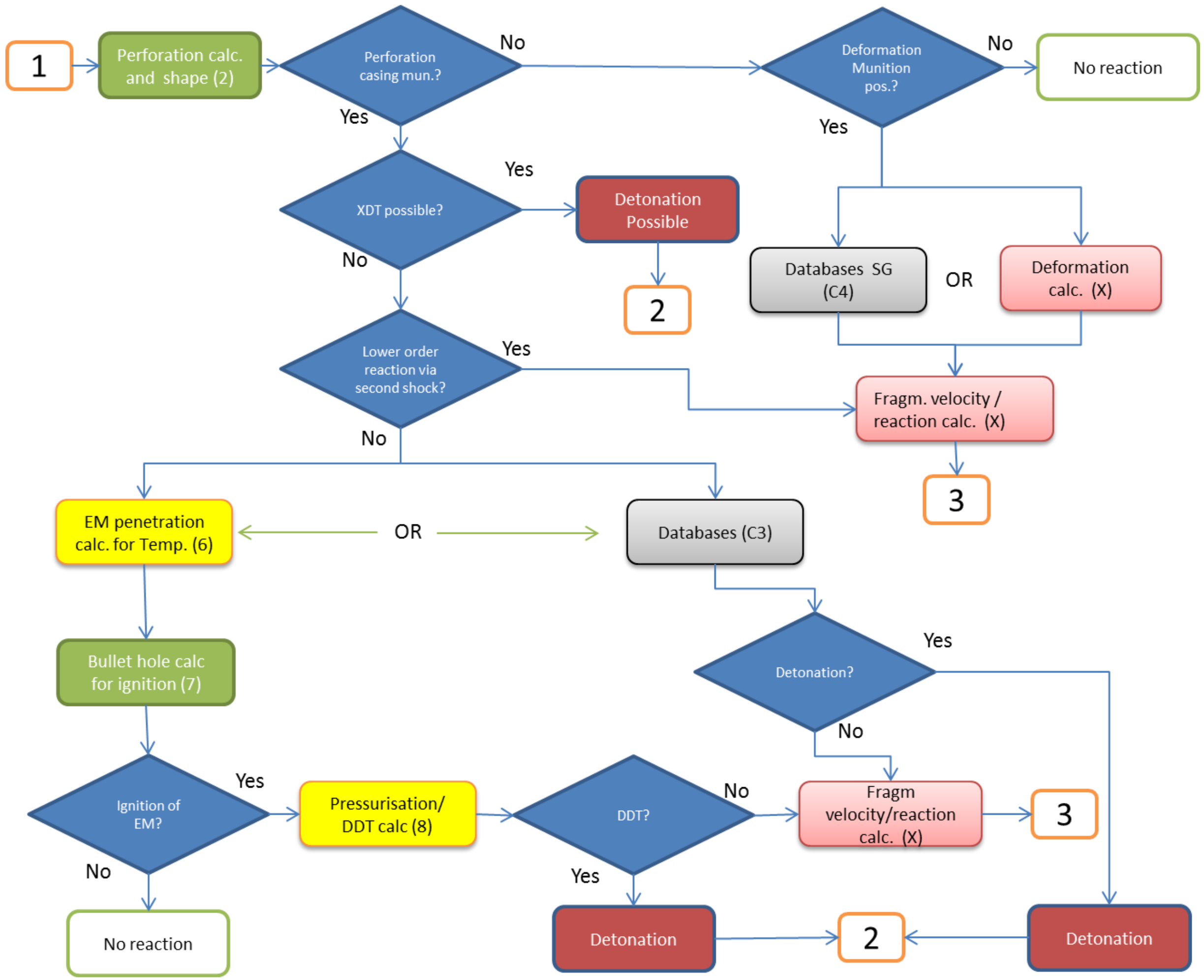
Spreadsheets/comments:

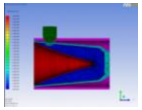
(1) Fragment velocity calculation with Gurney
(2) Perforation calculation using Thor equations
(3) SDT calculation Ec theory Haskins and Cook
(4) SDT calculation Green or Lundstrom
(5) Divergent shock calculation Green/Lundstrom
(6) EM heating due to penetration
(7) EM cook-off reaction calculation after penetration of bullet
(8) Pressurisation calculation after ignition and burning of EM
(9) Sympathetic reaction calculation confined stack and ono-on-one
(10) TNT equivalent blast/shock calculation
(C1) Fragmentation table of munitions (table #.#)
(C2) Fragmentation data from experiments or databases
(C3) Bullet and fragment test result database (e.g. BIRD or FRAID
(C4) SG table ref [#] tabel #.#
(C5) Cook-off database test results

- Excel spreadsheet calculation
- Excel spreadsheet not implemented
- Excel spreadsheet (needs data)
- Data from database or Experiments
- Detonation reaction (possible)
- No Prompt shock detonation (SDT)
- Decision
- Reference Number 2

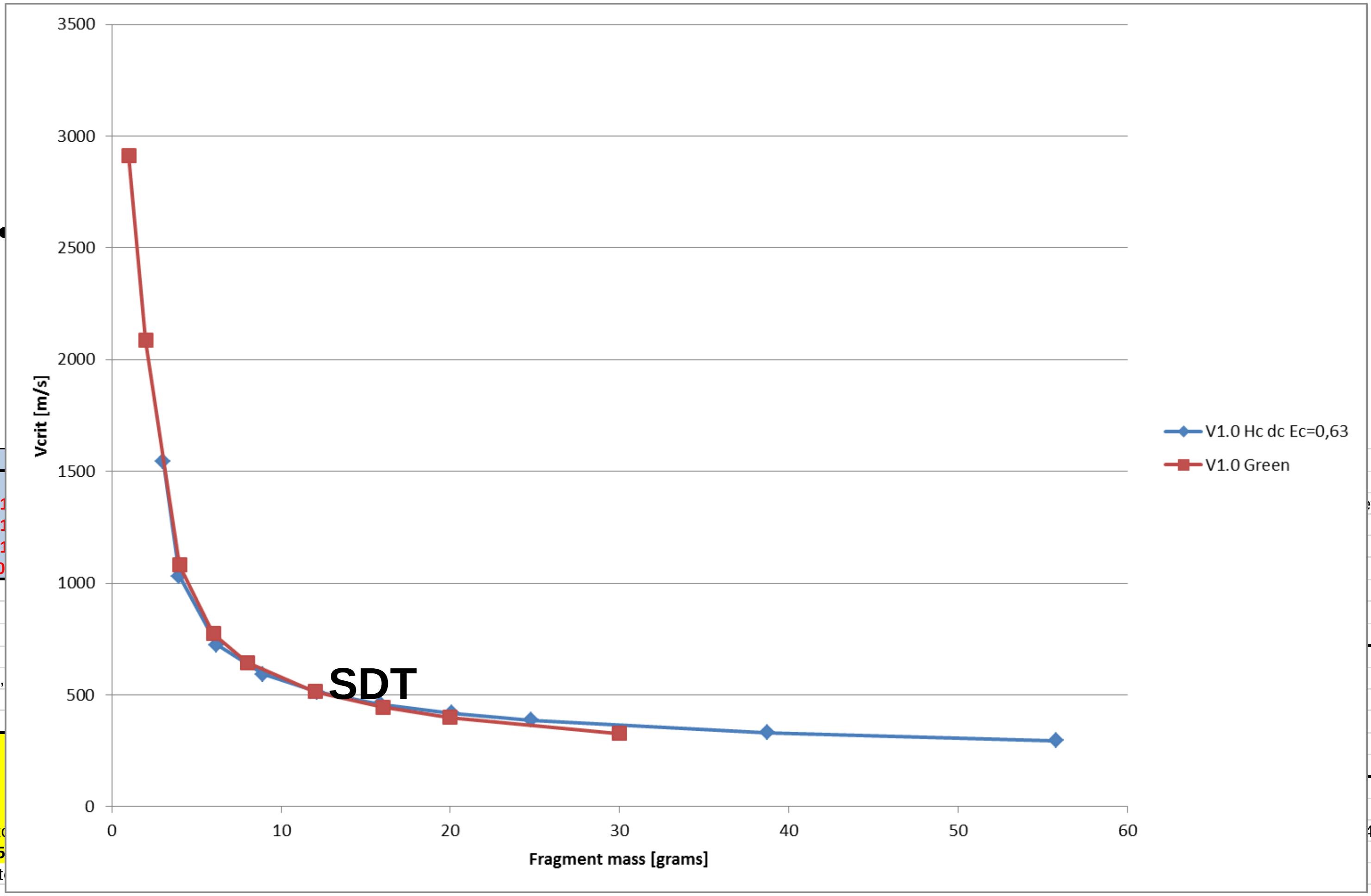


Bullet Fragment flowchart (cont'd)





Redundancy :Two different SDT methods Haskins&Cook VS. Green-Lundstrom

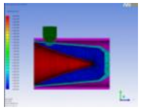


Hugoniot calculations		
Us=Co+sUp	Co	S
staal	4,58	1
staal	4,58	1
Comp B	3,03	1
PBX9404	2,46	2,5300
Imp vel, km/s	2,6086	km/s
Imp vel, km/s	2,2591	km/s
check angel		2,
Quadratic solutions for up		
a=	-1E-07	a=
b=	-125,4	b=
c=	141,63	c=
		Up matc
		1,1295
		1st mat

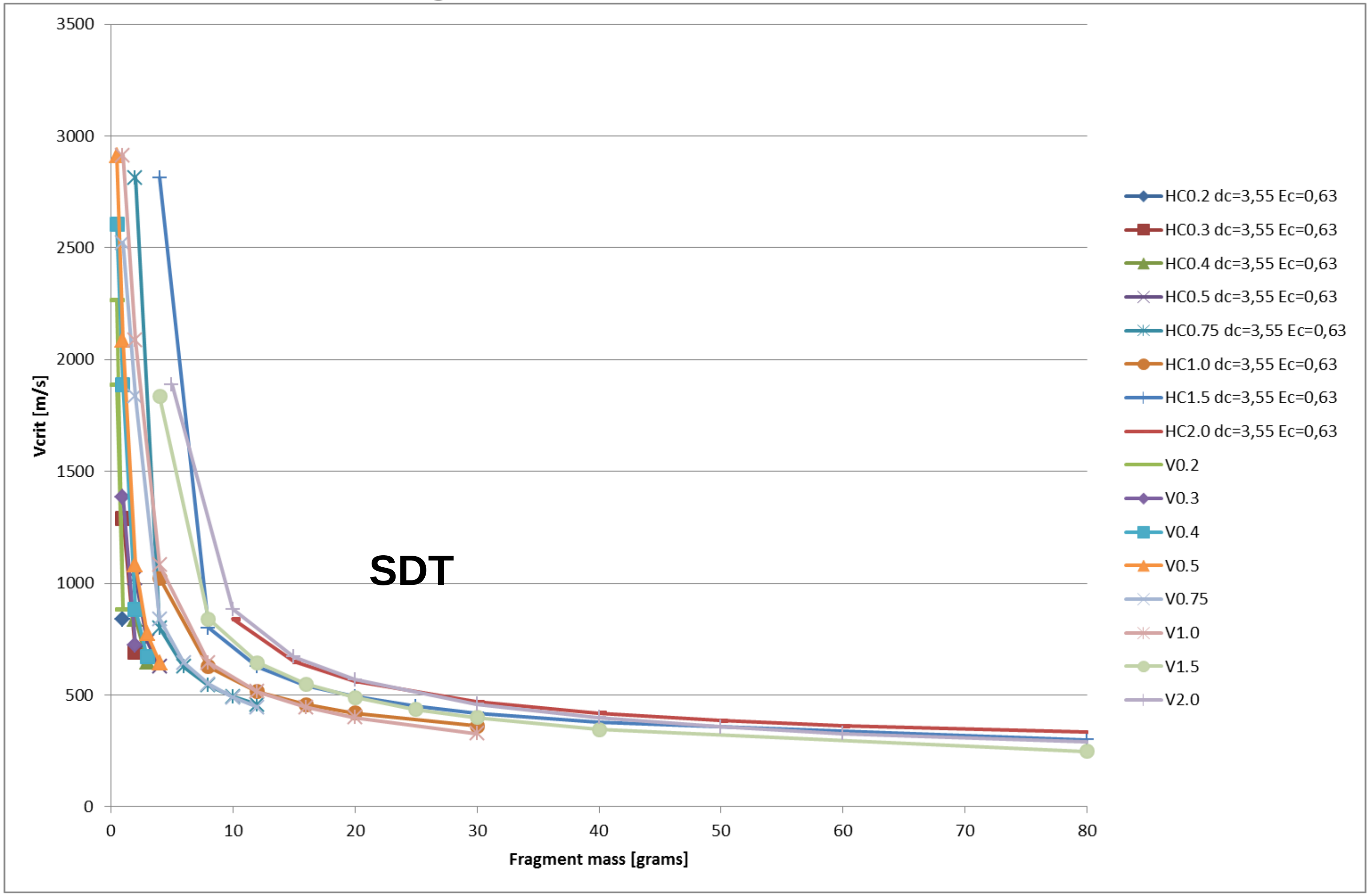
ethode price [1

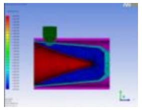
1
1
1,5
1,9
2,7
3

4 vi (green)



Comparison of two methods for different fragment sizes





Coupling of MunVul. toolbox in Platform vulnerability tool RESIST (Resilience SImulation of Ship Targets) or TARVAC

- Some ships transport large quantities of munitions
  - Large variety
  - Navy, Army and Air Force
- Example: Joint Logistic Support Ship, LCF Fregat

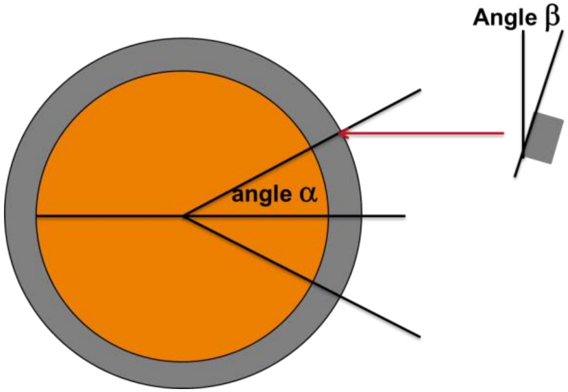
- Vulnerability of the munition?
- Safe storage of munitions
- Design storage compartment

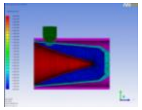
↓

- Proper risk analysis
- Effective safety/security
  - measures

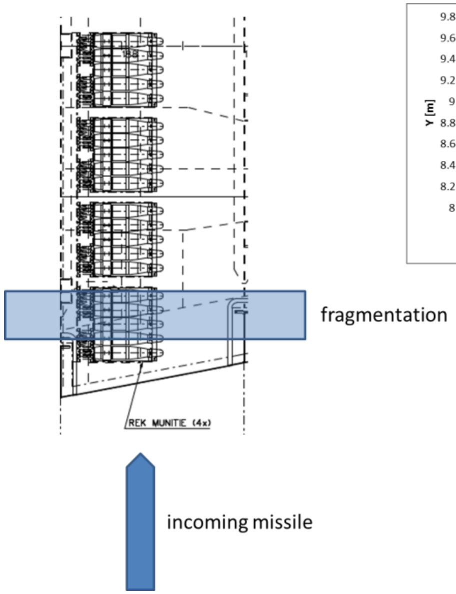
Scenario: Threat of incoming missile on munition storage; methodology

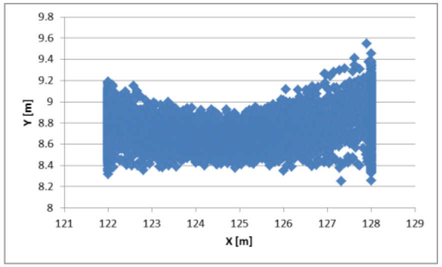
- Certain threat → fragment with certain mass and velocity
- For example: Threat is missile with large warhead
- Mass of fragment → diameter of fragment with certain angle β
- Acceptor: munition article with explosive filling (e.g. 127 mm shell)
- For each location on 127 mm you can calculate probability of SDT reaction (location: angle α)

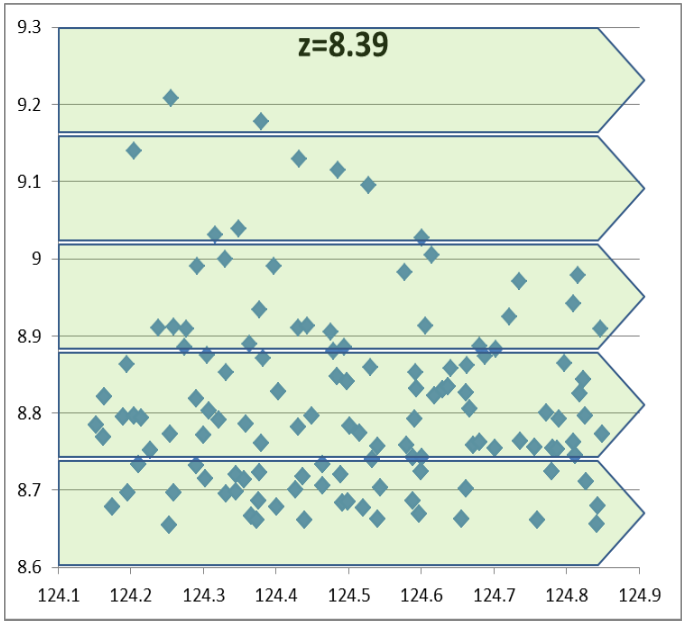


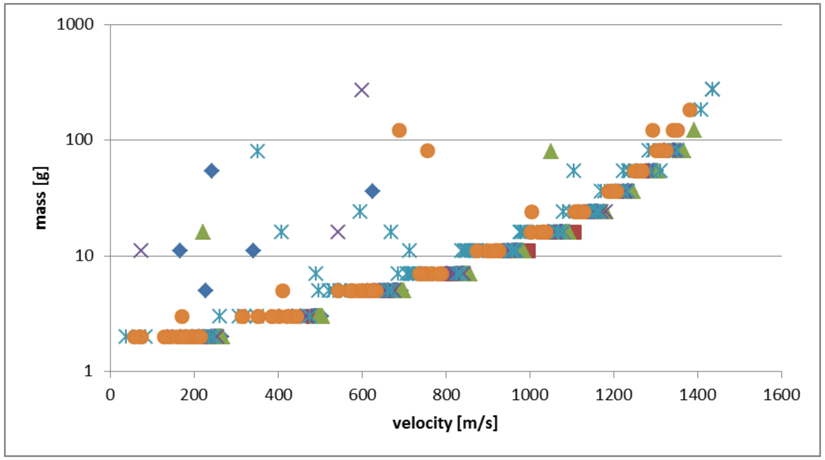


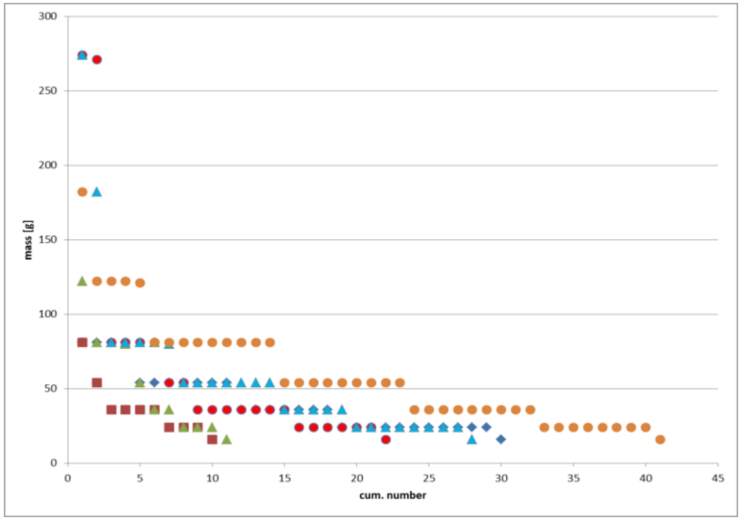
Threat of incoming missile



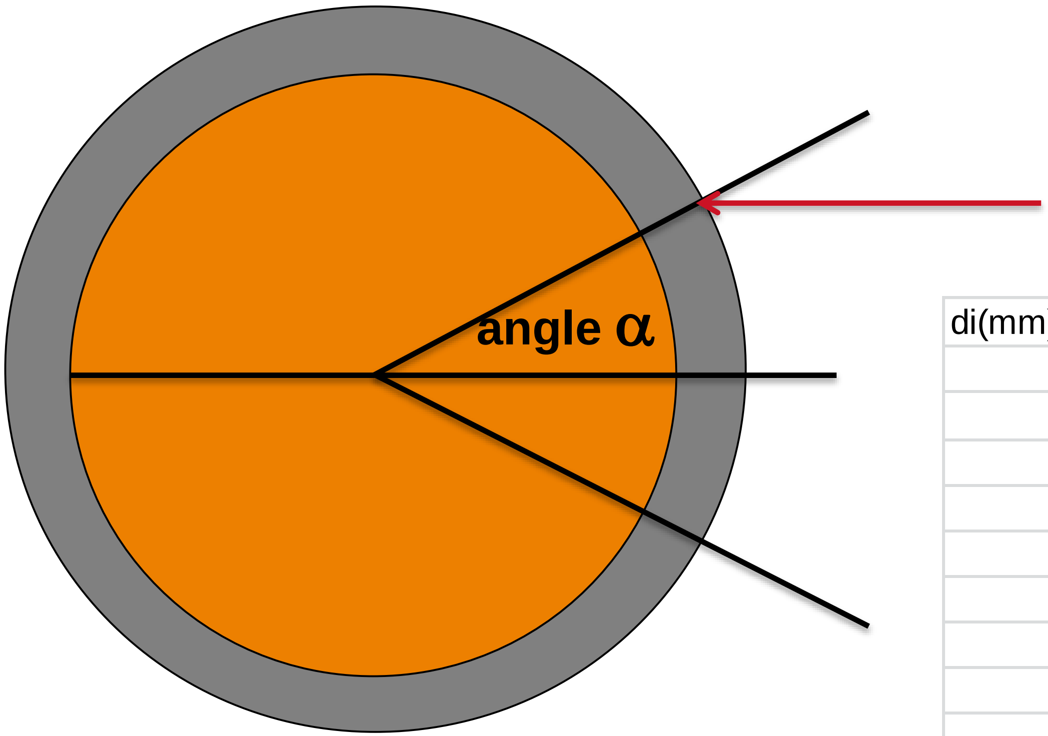


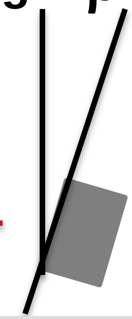




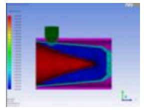


Statistics → probability of a kill: Pkill (SDT)

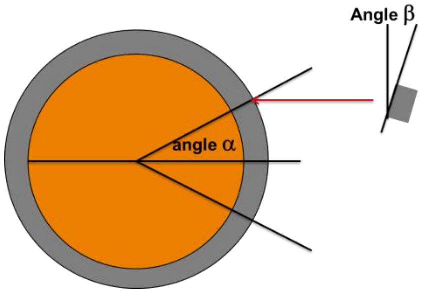




di(mm)	Wfmax (gr	dfmax(cm)
15	17	1,074551
15	24	1,276757
15	37	1,585271
15	54	1,915136
15	82	2,359987
15	115	2,79
15	120	2,854916
15	180	3,496544
15	275	4,321844



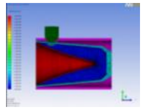
Critical velocity (km/s) for detonation as function of angle α = Lf and β=Fi step of 7.5°



α →

β ↓

	LR											richting van plek op ring waar munitie getroffen wordt															
dfmax (mn	HC Fi = 0	HC Fi = 0	HC Fi = 0	HC Fi=0 Lf	HC Fi = 0	HC Fi = 0	HC Fi=0 L	HC Fi = 0	HC Fi = 0	HC Fi=0 L	HC Fi = 0	HC Fi = 0	HC Fi = 0	HC Fi = 0	HC Fi = 0	HC Fi = 0	HC Fi = 0	HC Fi = 0	HC Fi = 0	HC Fi = 0	HC Fi = 0	HC Fi = 0	HC Fi = 0	HC Fi = 0	HC Fi = 0	Lf =90°	0
10	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000		
12	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000		hoek van fr
14	10000	10000	10000	10000	10000	10000	10000	10000	3,715019	2,478498	1,942613	1,348041	1,348041	1,348041	1,942613	2,478498	3,715019	10000	10000	10000	10000	10000	10000	10000	10000		
16	10000	10000	10000	10000	10000	10000	10000	10000	1,891289	1,483622	1,263542	0,965501	0,965501	0,965501	1,263542	1,483622	1,891289	10000	10000	10000	10000	10000	10000	10000	10000		
18	10000	10000	10000	10000	10000	10000	10000	10000	1,490178	1,19591	1,03287	0,80594	0,80594	0,80594	1,03287	1,19591	1,490178	10000	10000	10000	10000	10000	10000	10000	10000		
20	10000	10000	10000	10000	10000	10000	10000	10000	1,277666	1,035576	0,900022	0,70919	0,70919	0,70919	0,900022	1,035576	1,277666	10000	10000	10000	10000	10000	10000	10000	10000		
22	10000	10000	10000	10000	10000	10000	10000	10000	1,138833	0,928306	0,809736	0,641754	0,641754	0,641754	0,809736	0,928306	1,138833	10000	10000	10000	10000	10000	10000	10000	10000		
24	10000	10000	10000	10000	10000	10000	10000	10000	1,038385	0,849587	0,742855	0,59103	0,59103	0,59103	0,742855	0,849587	1,038385	10000	10000	10000	10000	10000	10000	10000	10000		
26	10000	10000	10000	10000	10000	10000	10000	10000	0,961106	0,788447	0,690582	0,550972	0,550972	0,550972	0,690582	0,788447	0,961106	10000	10000	10000	10000	10000	10000	10000	10000		
28	10000	10000	10000	10000	10000	10000	10000	10000	0,899146	0,73909	0,648192	0,518244	0,518244	0,518244	0,648192	0,73909	0,899146	10000	10000	10000	10000	10000	10000	10000	10000		
	12	11	10	9	8	7	6	5	4	3	2	1	0	1	2	3	4	5	6	7	8	9	10	11	12		
dfmax (mn	HC Fi=7,5	HC Fi = 7,	HC Fi = 7,	HC Fi=7,5	HC Fi = 7,	HC Fi = 7,	HC Fi=7,5	HC Fi = 7,	HC Fi = 7,	HC Fi=7,5	HC Fi = 7,	HC Fi = 7,	HC Fi = 7,	HC Fi = 7,	HC Fi = 7,	HC Fi = 7,	HC Fi = 7,	HC Fi = 7,	HC Fi = 7,	HC Fi = 7,	HC Fi = 7,	HC Fi = 7,	HC Fi = 7,	HC Fi = 7,	HC Fi = 7,5	Lf =90°	1
10	10000	10000	10000	10000	10000	10000	10000	10916,01	10668,04	10455,11	10264,19	10086,29	9914,449	9742,608	9564,705	9373,791	10000	10000	10000	10000	10000	10000	10000	10000	10000		
12	10000	10000	10000	10000	10000	10000	10000	10916,01	10668,04	10455,11	10264,19	10086,29	9914,449	9742,608	9564,705	9373,791	10000	10000	10000	10000	10000	10000	10000	10000	10000		
14	10000	10000	10000	10000	10000	10000	10000	4,055319	2,644072	2,031022	1,383655	1,359673	1,336509	1,892611	2,37061	3,482381	10000	10000	10000	10000	10000	10000	10000	10000	10000		
16	10000	10000	10000	10000	10000	10000	10000	2,064533	1,582734	1,321046	0,991009	0,973832	0,957241	1,231019	1,419041	1,772855	10000	10000	10000	10000	10000	10000	10000	10000	10000		
18	10000	10000	10000	10000	10000	10000	10000	1,62668	1,275802	1,079877	0,827233	0,812895	0,799045	1,006285	1,143853	1,396862	10000	10000	10000	10000	10000	10000	10000	10000	10000		
20	10000	10000	10000	10000	10000	10000	10000	1,394702	1,104757	0,940982	0,727927	0,71531	0,703123	0,876856	0,990498	1,197658	10000	10000	10000	10000	10000	10000	10000	10000	10000		
22	10000	10000	10000	10000	10000	10000	10000	1,243151	0,990321	0,846587	0,658709	0,647292	0,636264	0,788894	0,887898	1,067518	10000	10000	10000	10000	10000	10000	10000	10000	10000		
24	10000	10000	10000	10000	10000	10000	10000	1,133502	0,906343	0,776662	0,606644	0,596129	0,585973	0,723734	0,812605	0,973361	10000	10000	10000	10000	10000	10000	10000	10000	10000		
26	10000	10000	10000	10000	10000	10000	10000	1,049144	0,841118	0,722011	0,565528	0,555726	0,546258	0,672807	0,754126	0,900921	10000	10000	10000	10000	10000	10000	10000	10000	10000		
28	10000	10000	10000	10000	10000	10000	10000	0,981509	0,788464	0,677691	0,531936	0,522716	0,513811	0,631508	0,706918	0,842841	10000	10000	10000	10000	10000	10000	10000	10000	10000		
dfmax (mn	HC Fi=15	HC Fi = 15	HC Fi = 15	HC Fi=15	HC Fi = 15	HC Fi = 15	HC Fi=15	HC Fi = 15	HC Fi = 15	HC Fi=15	HC Fi = 15	HC Fi = 15	HC Fi = 15	HC Fi = 15	HC Fi = 15	HC Fi = 15	HC Fi = 15	HC Fi = 15	HC Fi = 15	HC Fi = 15	HC Fi = 15	HC Fi = 15	HC Fi = 15	HC Fi = 15	HC Fi = 15	Lf =90°	2
10	10000	10000	10000	10000	10000	10000	12247,45	11645,25	11153,55	10731,32	10352,76	10000	9659,258	9318,517	8965,755	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000		
12	10000	10000	10000	10000	10000	10000	12247,45	11645,25	11153,55	10731,32	10352,76	10000	9659,258	9318,517	8965,755	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000		
14	10000	10000	10000	10000	10000	10000	4,549951	2,886272	2,166703	1,446626	1,395595	1,348041	1,87642	2,309592	3,330795	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000		
16	10000	10000	10000	10000	10000	10000	2,316347	1,727715	1,409298	1,03611	0,99956	0,965501	1,220488	1,382516	1,695683	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000		
18	10000	10000	10000	10000	10000	10000	1,825088	1,392667	1,152017	0,86488	0,834371	0,80594	0,997676	1,114411	1,336057	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000		
20	10000	10000	10000	10000	10000	10000	1,564815	1,205954	1,003844	0,761055	0,734208	0,70919	0,869354	0,965003	1,145524	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000		
22	10000	10000	10000	10000	10000	10000	1,39478	1,081036	0,903143	0,688687	0,664393	0,641754	0,782145	0,865044	1,02105	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000		
24	10000	10000	10000	10000	10000	10000	1,271757	0,989365	0,828547	0,634253	0,611879	0,59103	0,717543	0,791689	0,930991	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000		
26	10000	10000	10000	10000	10000	10000	1,17711	0,918166	0,770244	0,591266	0,570408	0,550972	0,667051	0,734715	0,861704	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000		
28	10000	10000	10000	10000	10000	10000	1,101224	0,860688	0,722964	0,556145	0,536526	0,518244	0,626105	0,688722	0,806152	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000		
dfmax (mn	HC Fi=22,5	HC Fi = 22	HC Fi = 22	HC Fi=22,5	HC Fi = 22	HC Fi = 22	HC Fi=22,5	HC Fi = 22	HC Fi = 22	HC Fi=22,5	HC Fi = 22	HC Fi = 22	HC Fi = 22	HC Fi = 22	HC Fi = 22	HC Fi = 22	HC Fi = 22	HC Fi = 22	HC Fi = 22	HC Fi = 22	HC Fi = 22	HC Fi = 22	HC Fi = 22	HC Fi = 22	HC Fi = 22,5	Lf =90°	3
10	10000	10000	10000	10000	10000	14226,02	13065,63	12175,23	11448,22	10823,92	10264,19	9742,608	9238,795	8734,983	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000		
12	10000	10000	10000	10000	10000	14226,02	13065,63	12175,23	11448,22	10823,92	10264,19	9742,608	9238,795	8734,983	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000		
14	10000	10000	10000	10000	10000	5,284995	3,238314	2,365175	1,543267	1,459109	1,383655	1,892611	2,289833	3,245063	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000		
16	10000	10000	10000	10000	10000	2,690552	1,938446	1,538391	1,105327	1,045051	0,991009	1,231019	1,370688	1,652038	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000		
18	10000	10000	10000	10000	10000	2,119931	1,562532	1,257543	0,922658	0,872343	0,827233	1,006285	1,104877	1,301668	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000		
20	10000	10000	10000	10000	10000	1,817611	1,353045	1,095797	0,811897	0,767622	0,727927	0,876856	0,956748	1,116039	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000		
22	10000	10000	10000	10000	10000	1,620106	1,212891	0,985872	0,734694	0,69463	0,658709	0,788894	0,857643	0,994769	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000		
24	10000	10000	10000	10000	10000	1,477209	1,110038	0,904443	0,676624	0,639726	0,606644	0,723734	0,784916	0,907028	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000		
26	10000	10000	10000	10000	10000	1,367272	1,030155	0,840799	0,630765	0,596368	0,565528	0,672807	0,72843	0,839524	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000		
28	10000	10000	10000	10000	10000	1,279127	0,965667	0,789188	0,593297	0,560944	0,531936	0,631508	0,68283	0,785402	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000		
dfmax (mn	HC Fi=30	HC Fi = 30	HC Fi = 30	HC Fi=30	HC Fi = 30	HC Fi = 30	HC Fi=30	HC Fi = 30	HC Fi = 30	HC Fi=30	HC Fi = 30	HC Fi = 30	HC Fi = 30	HC Fi = 30	HC Fi = 30	HC Fi = 30	HC Fi = 30	HC Fi = 30	HC Fi = 30	HC Fi = 30	HC Fi = 30	HC Fi = 30	HC Fi = 30	HC Fi = 30	HC Fi = 30	Lf =90°	4
10	10000	10000	10000	10000	17320,51	15176,38	13660,25	12496,89	11547,01	10731,32	10000	9318,517	8660,254	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000		
12	10000	10000	10000	10000	17320,51	15176,38	13660,25	12496,89	11547,01	10731,32	10000	9318,517	8660,254	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000		
14	10000	10000	10000	10000	6,434602	3,761463	2,653658	1,684632	1,556584	1,446626	1,942613	2,309592	3,217301	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000		
16	10000	10000	10000	10000	3,275809	2,251602	1,72603	1,206576	1,114865	1,03611	1,263542	1,382516	1,637904	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000		
18	10000	10000	10000	10000	2,581064	1,814959	1,410927	1,007175	0,93062	0,86488	1,03287	1,114411	1,290532	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000		
20	10000	10000	10000	10000	2,212983	1,57163	1,229453	0,886267	0,818902	0,761055	0,900022	0,965003	1,106491	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000		
22	10000	10000	10000	10000	1,972516	1,408833	1,10612	0,801993	0,741034	0,688687	0,809736	0,865044	0,986258	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000		
24	10000	10000	10000	10000	1,798536	1,289365	1,014758	0,738603	0,682462	0,634253	0,742855	0,791689	0,899268	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000		
26	10000	10000	10000	10000	1,664684	1,196577	0,943352	0,688544	0,636208	0,591266	0,690582	0,734715	0,832342	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000		
28	10000	10000	10000	10000	1,557366	1,121671	0,885446	0,647644	0,598417	0,556145	0,648192	0,688722	0,778683	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000		
dfmax (mn	HC Fi=37,5	HC Fi = 37	HC Fi = 37	HC Fi=37,5	HC Fi = 37	HC Fi = 37	HC Fi=37,5	HC Fi = 37	HC Fi = 37	HC Fi=37,5	HC Fi = 37	HC Fi = 37	HC Fi = 37	HC Fi = 37	HC Fi = 37	HC Fi = 37	HC Fi = 37	HC Fi = 37	HC Fi = 37	HC Fi = 37	HC Fi = 37	HC Fi = 37	HC Fi = 37	HC Fi = 37	HC Fi = 37,5	Lf =90°	5
10	10000	10000	10000	22630,33	18477,59	15867,07	14021,15	12604,72	11448,22	10455,11	9564,705	8734,983	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000		
12	10000	10000	10000	22630,33	18477,59	15867,07	14021,15	12604,72	11448,22	10455,11	9564,705	8734,983	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000		
14	10000	10000	10000	8,407213	4,579667	3,082356	1,890109	1,699169	1,543267	2,031022	2,37061	3,245063	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000		
16	10000	10000	10000	4,280051	2,741376	2,00487	1,353743	1,216987	1,105327	1,321046	1,419041	1,652038	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000		
18	10000	10000	10000	3,372322	2,209754	1,638862	1,130021	1,015865	0,922658	1,079877	1,143853	1,301668	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000		
20	10000	10000	10000	2,891401	1,913495	1,428071	0,994366	0,893915	0,811897	0,940982	0,990498	1,116039	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000		



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Probability of SDT as function of location and mass; Fragment velocity is 1 km/s

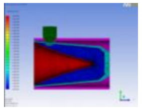
α →

mass (g)	dfmax (mm)	0	7,5	15	22,5	30	37,5	45	52,5	60	67,5	75	82,5	90
	1	0	0	0	0	0	0	0	0	0	0	0	0	0
17	10	0	0	0	0	0	0	0	0	0	0	0	0	0
24	12	0	0	0	0	0	0	0	0	0	0	0	0	0
37	15	0	0	0	0	0	0	0	0	0	0	0	0	0
54	20	0	0	0	0	0	0	0	0	0	0	0	0	0
82	25	0	0	0	0	0	0	0	0	0	0	0	0	0
115	27,9	0,12	0,12	0,12	0,12	0,12	0,12	0	0	0	0	0	0	0
120	30	0,2	0,2	0,12	0,12	0,12	0,12	0	0	0	0	0	0	0
180	35	0,36	0,28	0,28	0,28	0,28	0,28	0,2	0,12	0	0	0	0	0
275	45	0,36	0,36	0,36	0,36	0,36	0,36	0,28	0,2	0,12	0	0	0	0

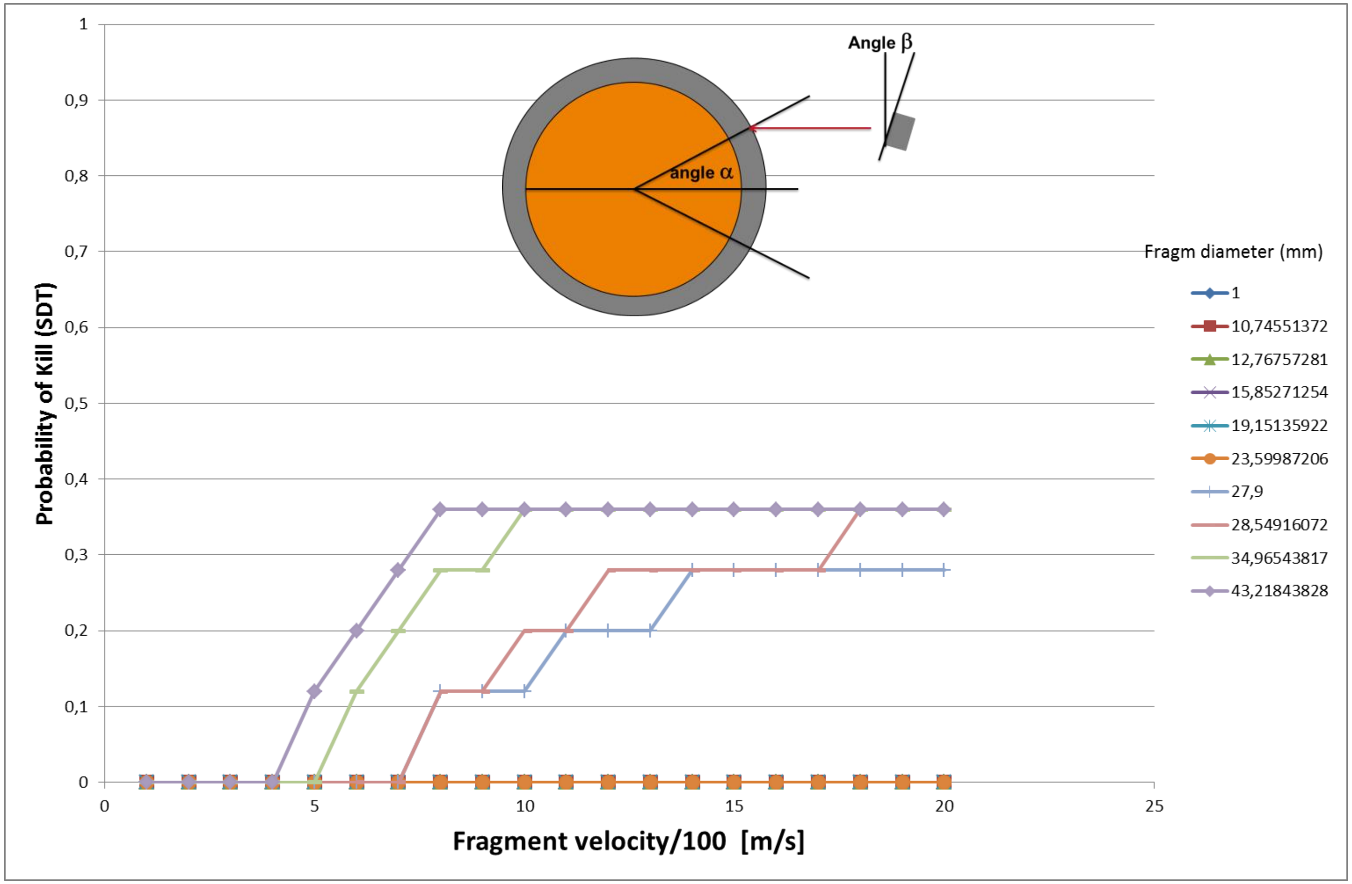
Probability of SDT as function Fragment size and Velocity of fragment

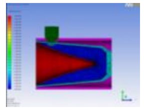
Fragment velocity →

dfmax ((mm)	)	Vp=0,1	Vp=0,2	Vp=0,3	Vp=0,5	Vp=0,6	Vp=0,7	Vp=0,8	Vp=0,9	Vp=1,0	Vp=1,1	Vp=1,2	Vp=1,3	Vp=1,4	Vp=1,5	Vp=1,6	Vp=1,7	Vp=1,8	Vp=1,9	Vp=2,0
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27,9	0	0	0	0	0	0	0	0,12	0,12	0,12	0,2	0,2	0,2	0,28	0,28	0,28	0,28	0,28	0,28	0,28
30	0	0	0	0	0	0	0	0,12	0,12	0,2	0,2	0,28	0,28	0,28	0,28	0,28	0,28	0,36	0,36	0,36
35	0	0	0	0	0	0,12	0,2	0,28	0,28	0,36	0,36	0,36	0,36	0,36	0,36	0,36	0,36	0,36	0,36	0,36
45	0	0	0	0	0,12	0,2	0,28	0,36	0,36	0,36	0,36	0,36	0,36	0,36	0,36	0,36	0,36	0,36	0,36	0,36



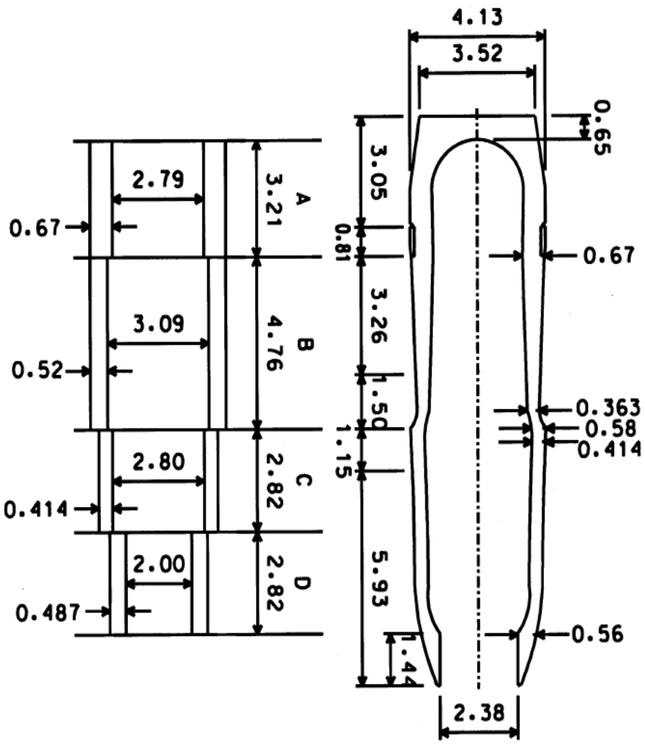
Probability of SDT reaction as function of fragment diameter and velocity (α= 0) on 127mm

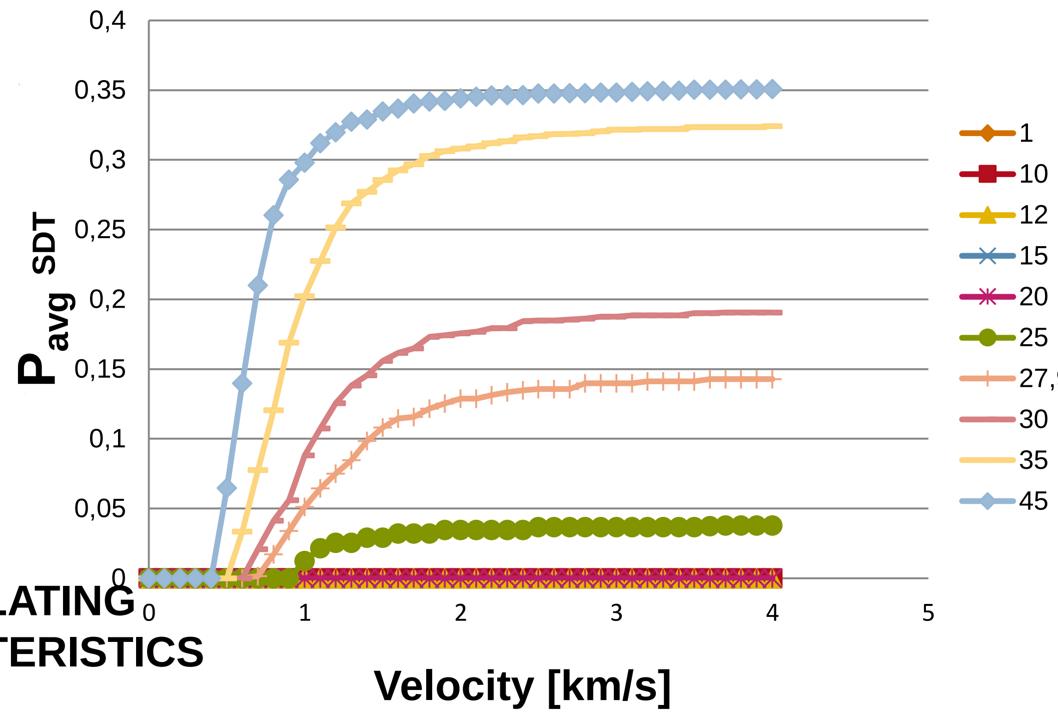




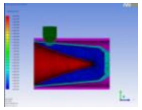
Automization of calculations

Us=Co+sU	Co	S	r	dcrit	Ecrit
Steel	4,58	1,49	7,89	0	0
Steel	4,58	1,49	7,89	0	0
Comp B	3,03	1,73	1,715	4,32	1
Number of Sections	4	max velocity calc	4		
	Casing thickness	length section			
	15 mm	100 mm			
	17 mm	50 mm			
	20 mm	60 mm			
	22 mm	100 mm			
	total length munition	310 mm			



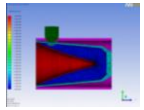


Technical Paper No. 16
Revision 4
METHODOLOGIES FOR CALCULATING PRIMARY FRAGMENT CHARACTERISTICS



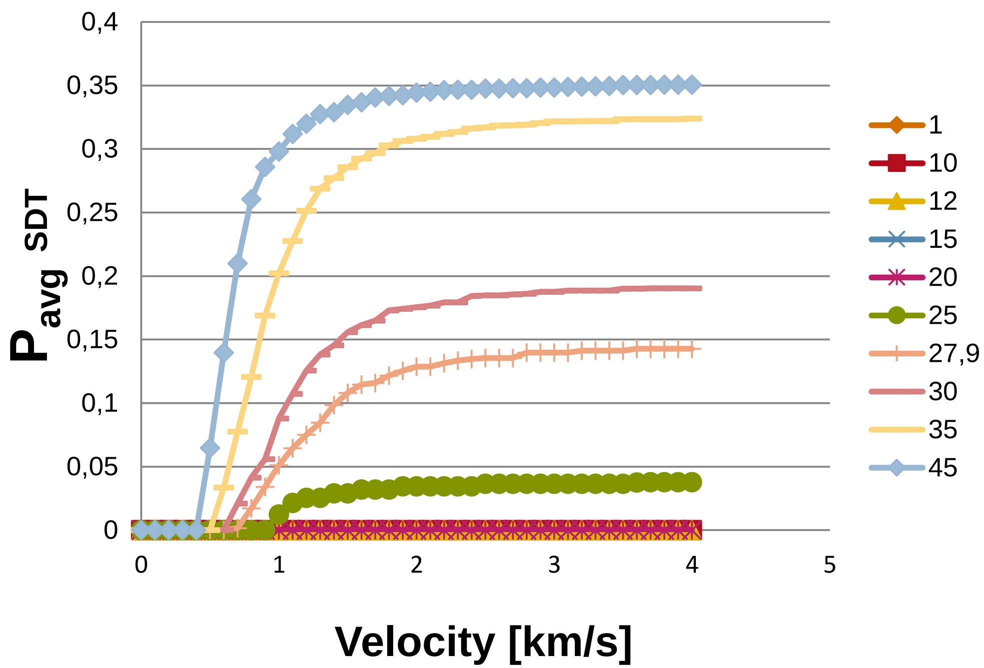
Spreadsheet example calculation

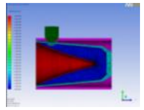
Microsoft Excel
97-2003 Worksheet



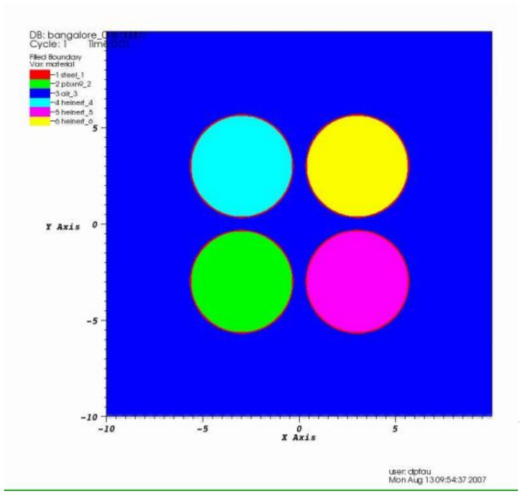
Spreadsheet calculations

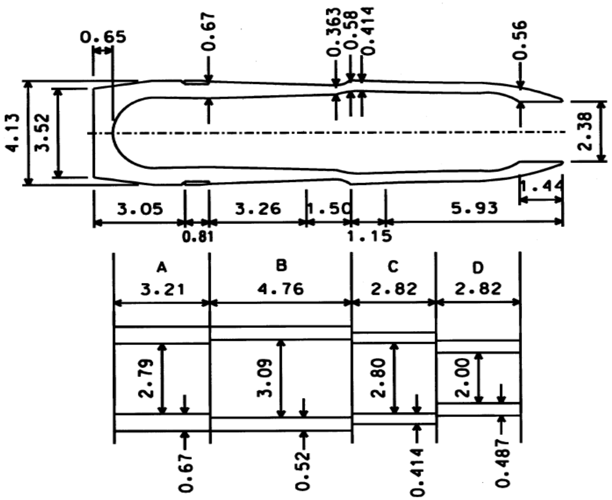
- Results of 10 different fragments
- With 40 different velocities
- 625 different angles (location and fragment impact angle)
- Maximum of 4 different section of warhead
- Graphs display 10 x 625 x 40 X 4 solver calculations
- = 1,000,000 solver calculations (within 1 minute)

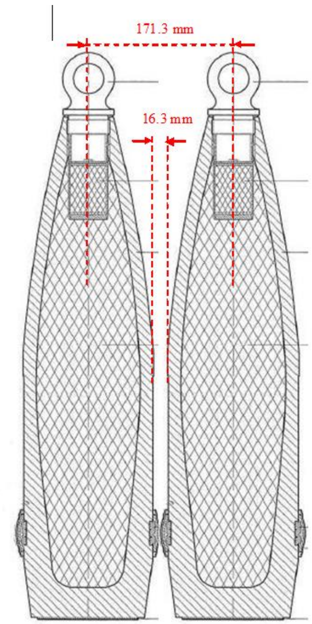


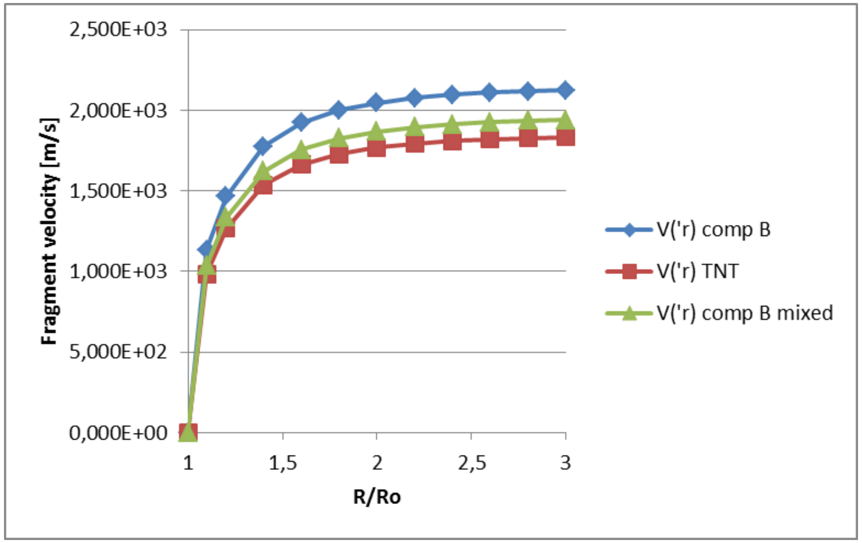


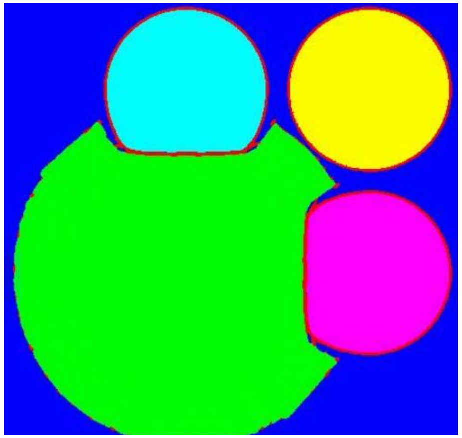
Sympathetic reaction calculation (Gurney)

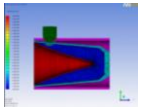






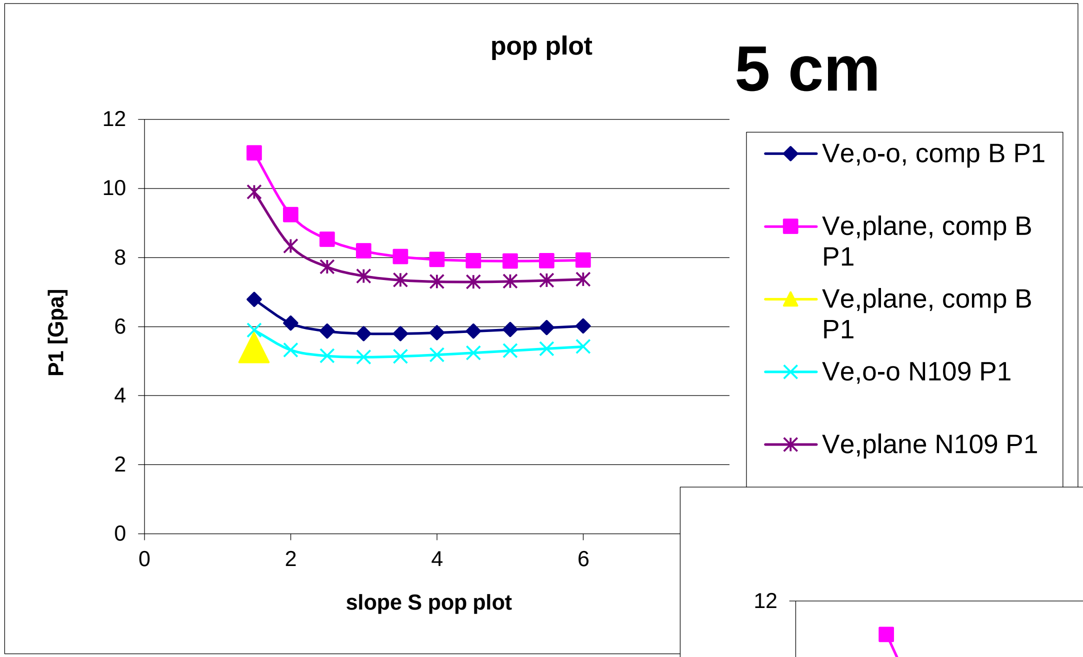


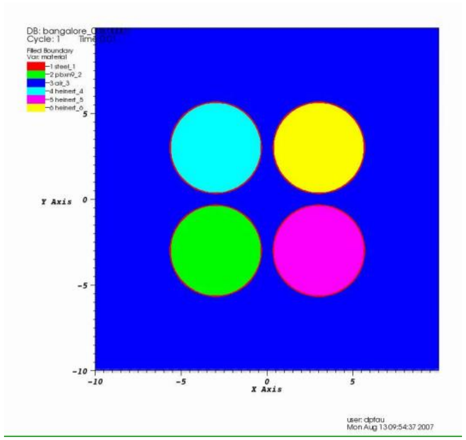


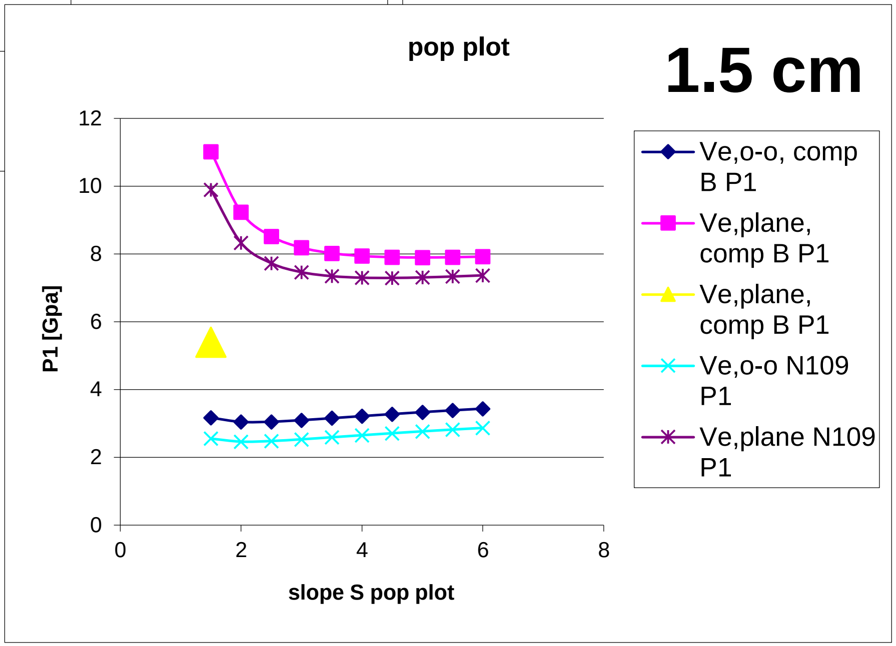


innovation for life

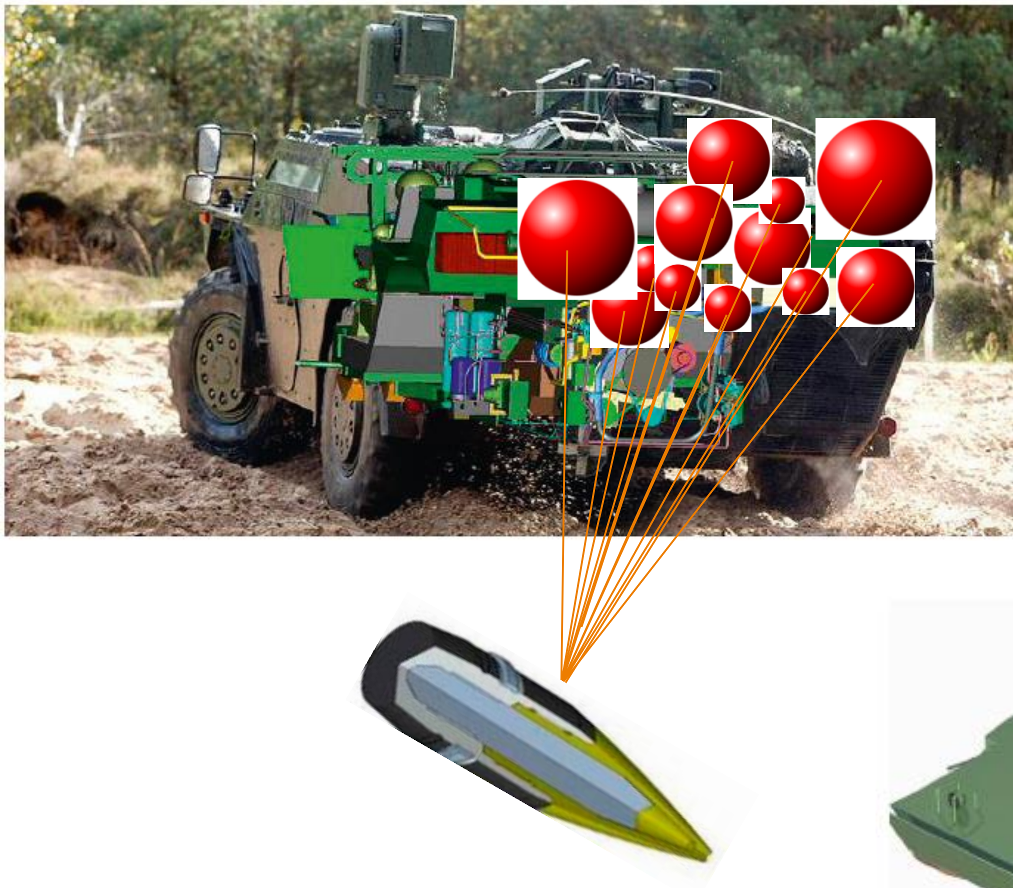
SR results 5 cm and 1.5 cm distance in between

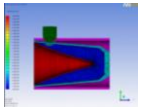






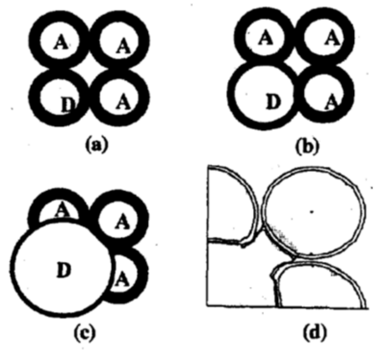
Tarvac (Target vulnerability assessment tool) or RESIST

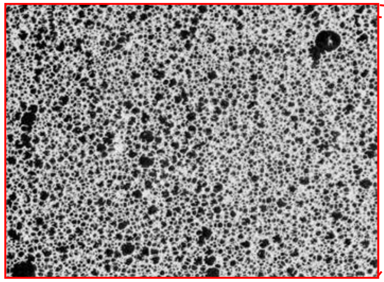


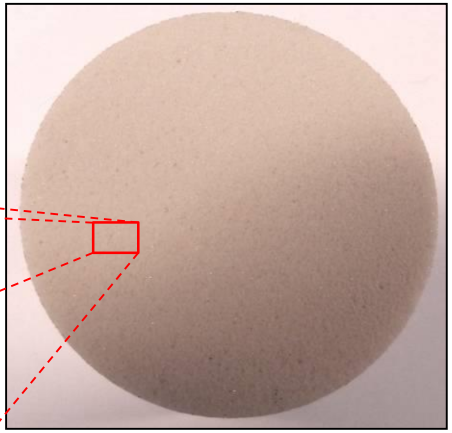


Barrier research for mitigation shock and impact

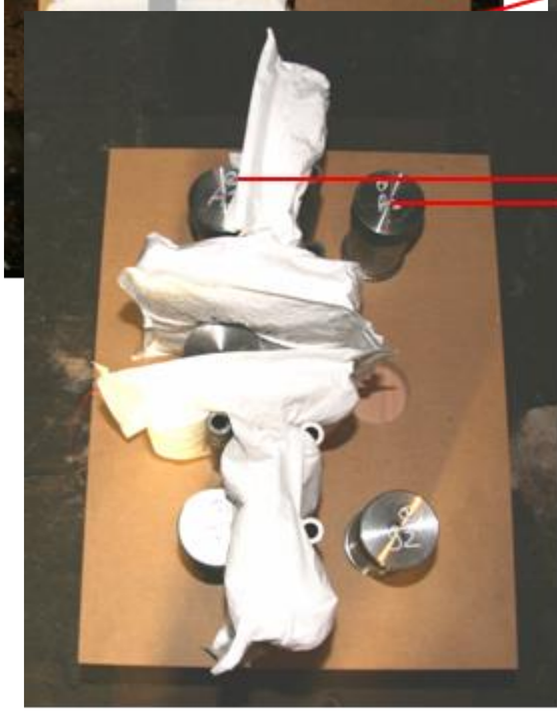
- Pressure/fragment mitigating materials for situation of SD
- Tested materials/solutions
  - Aluminium and Polyurethane foams
  - Fracticide bars and porous ceramics
  - New: Rubber, PE, Ceramics and layered materials
- Goal: Set of mitigation options





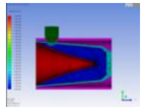


Mitigation (comp B)

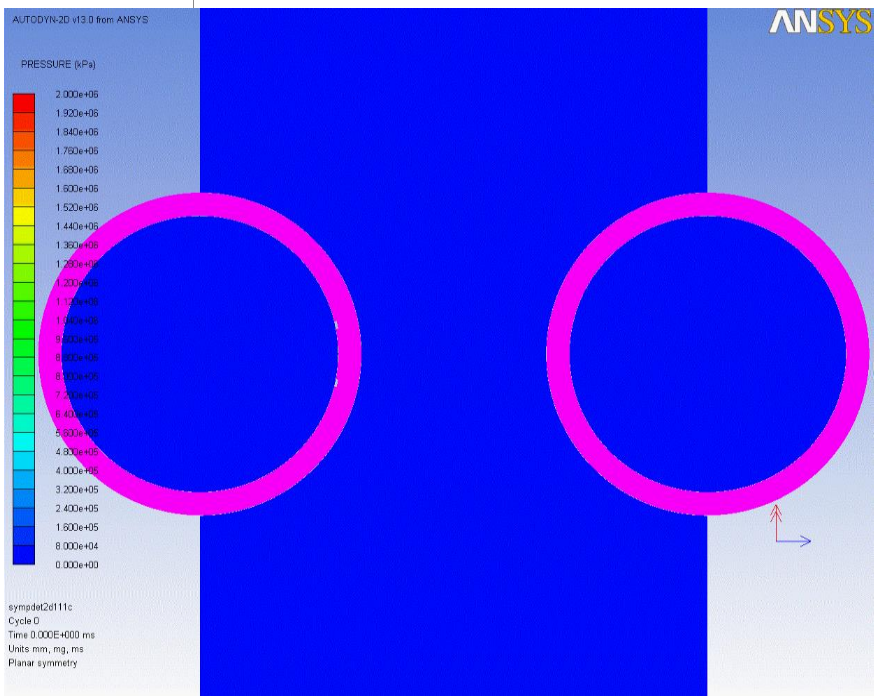

Mitigation techniques:
- **Barrier BlastWrap®**
- **Fracticide Bar**

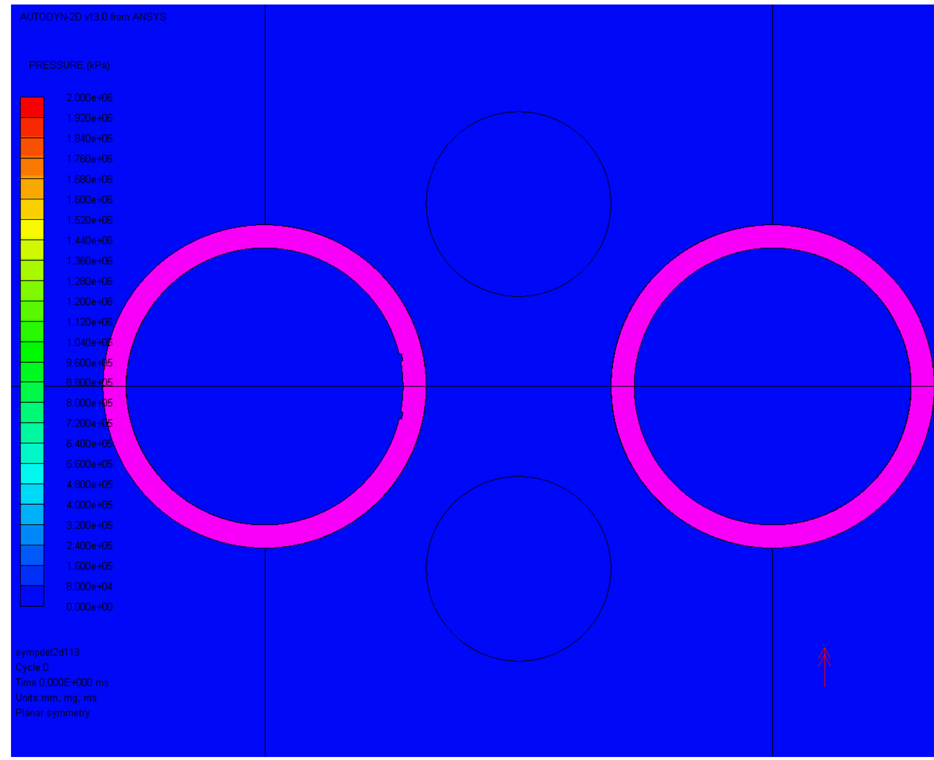
Mitigating materials (PUR Foam 0.3 g/cm^3)



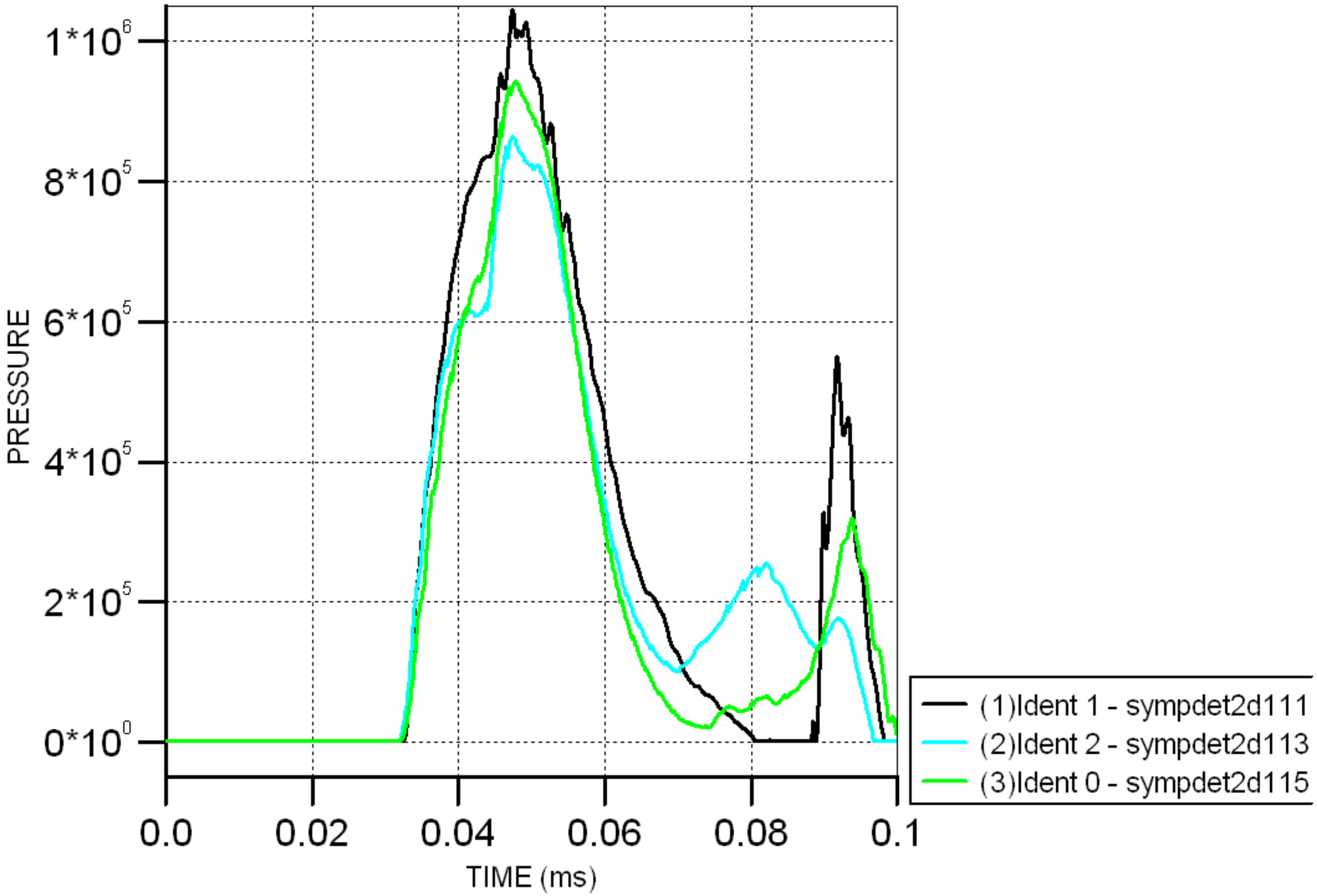
TNO innovation for life

Simulation of Foams and forms





Pressure Drop due to foam barrier, no barrier results in a pressure of 4.9 GPa



Same areal density but change # of layers (Rubber/Al)

Case	Upstream side		Downstream side			Overall areal density (g/cm^2)	$\frac{\rho_{ar,HI}}{\rho_{ar,LI}}$
	Material	Thickness (mm)	Material	Thickness (mm)	Number of units		
1	Al	4.00	Rub	8.00	2	4.47	1.00
2	Al	2.00	Rub	3.00, 5.00	4	4.47	1.00

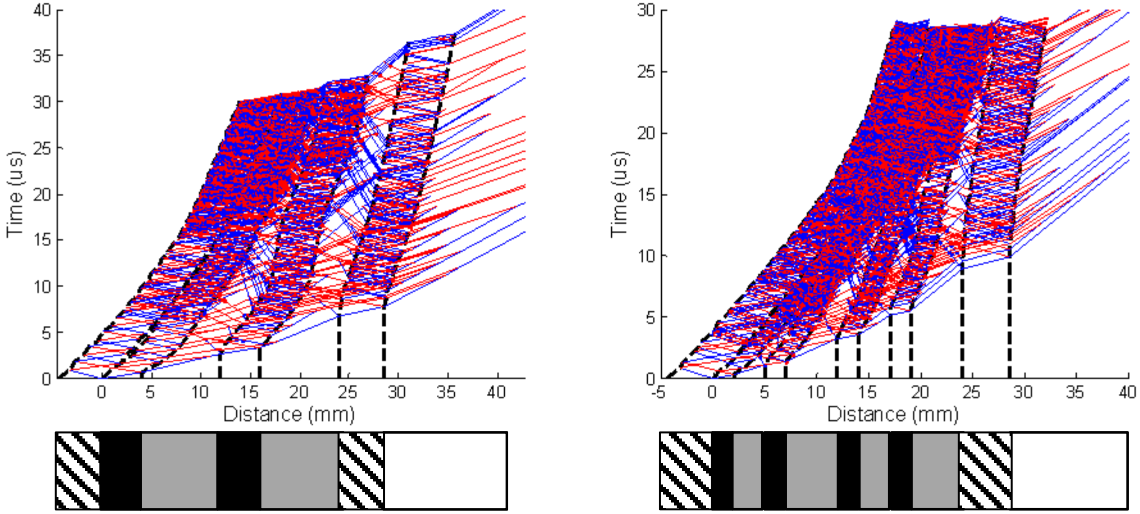
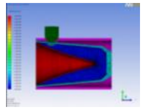


Figure Wave diagram for Case 1 (left) and Case 2 (right) of the previous TNO experiments of layered materials. Blue lines refer to shock (compression) waves and red lines refer to rarefaction (expansion) waves.



Same areal density but change # of layers (Rubber/Al); Pressure and Energy fluence

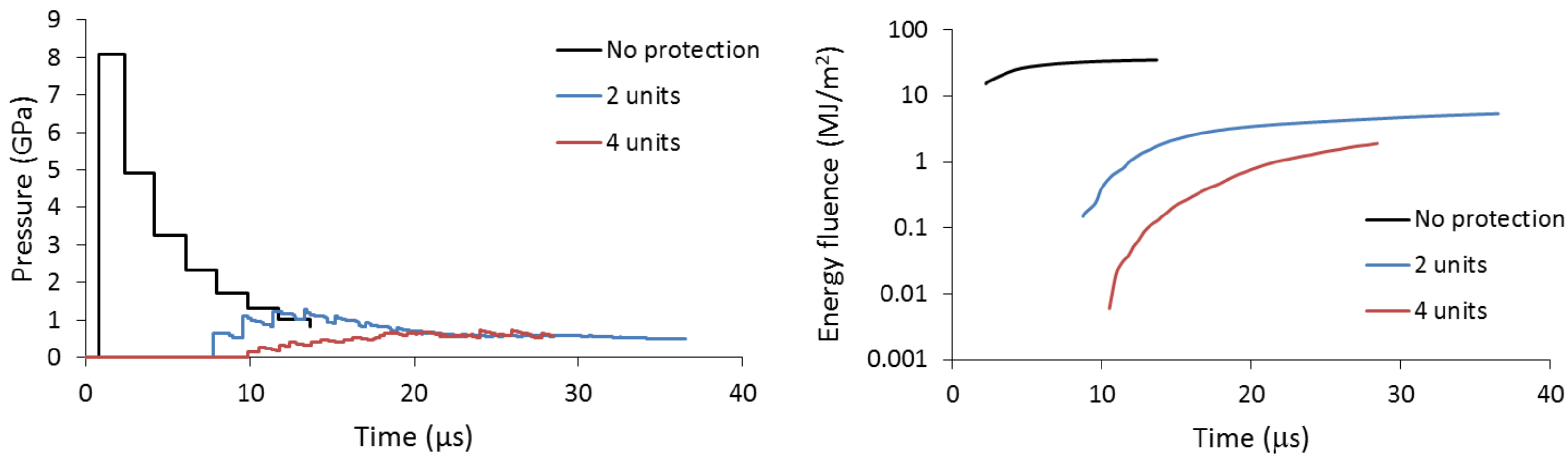
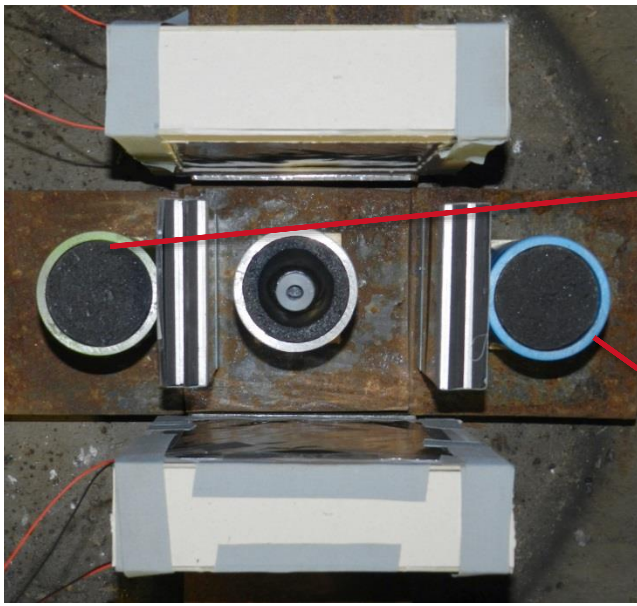
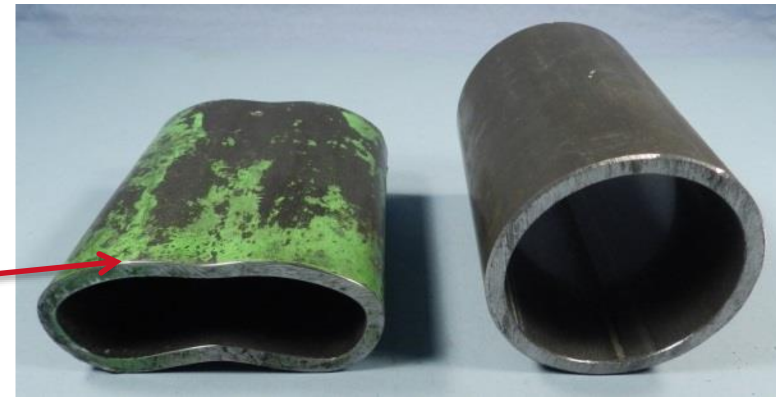
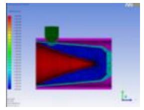


Figure Pressure (left) and energy fluence (right) profiles in the acceptor explosive for Case 1 (left) and Case 2 (right) of the previous TNO experiments of layered materials.

Experimental results







Summary

- During life-cycle of munitions, many threats possible
- IM is one part of the solution, but many also mitigation of SR
- Need for Munition Vuln. and response screening tool; and coupling to platform vulnerability tools (RESIST and TARVAC)
- Toolbox works well but still needs some validation:
  - Implementation of statistics → can be implemented in vulnerability/lethality codes for ships/vehicles and compounds
  - Still need for data for new explosives and/or simple equations (e.g. Ec, Shock hugoniot, critical diameter Dc etc.)
- Making progress in mitigation research
- Barrier research gives understanding of processes: layered mat. and foams: what is the best solution for certain munition item/storage!!
- Automization of coupling of Munition vulnerability-response toolbox to Platform vulnerability toolbox (RESIST), next step is autom. ff SR