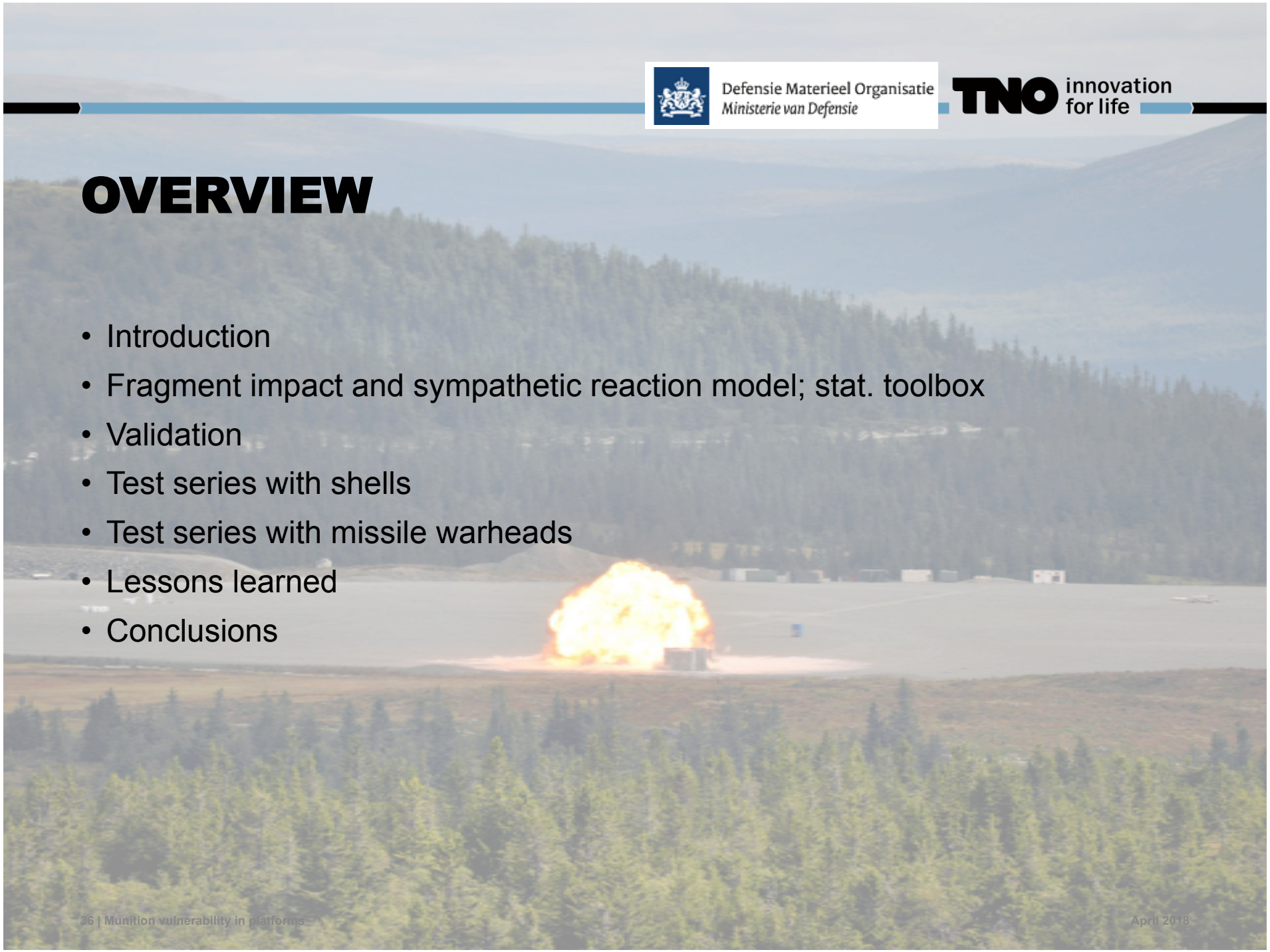
MUNITION VULNERABILITY IN PLATFORMS
Gert Scholtes
TNO innovation for life



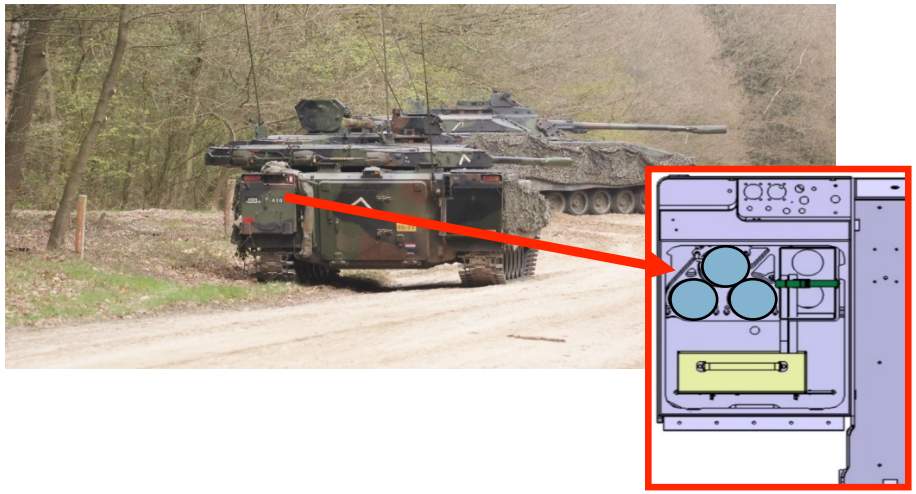
Defensie Materieel Organisatie
Ministerie van Defensie

TNO innovation for life

OVERVIEW

- Introduction
- Fragment impact and sympathetic reaction model; stat. toolbox
- Validation
- Test series with shells
- Test series with missile warheads
- Lessons learned
- Conclusions

LIFE-CYCLE MUNITIONS - THREATS



- Fragments
- SCJ
- Bullets
- Cook-off
- Sympathetic reaction

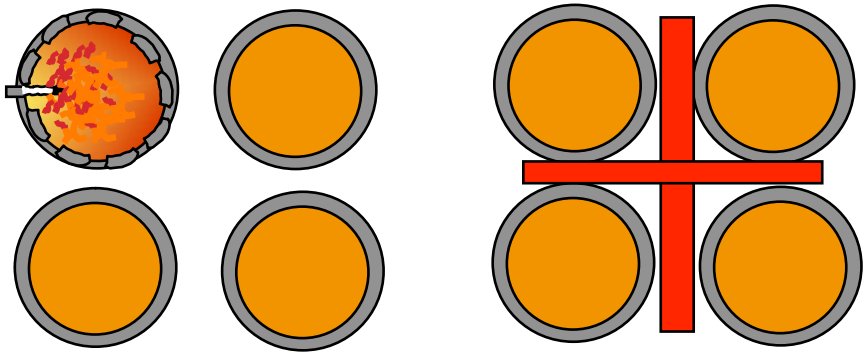
WHAT DOES THE NL MOD WANT/NEED

- The MOD wants to know the danger of certain threats to our stored munitions and the expected reaction and the danger for personnel and materiel/ platforms.

- With validated munition vulnerability calculations coupled to the platform vulnerability code RESIST the MOD/TNO to be able to estimate the effects of their stored munitions when hit by a certain threat and investigate the effect of protection measures.

- Projects/Investigation: Combination of test series with munities, munition vulnerability calculations and Ship/platform vulnerability calculations

PROBLEM AND COMPUTER SIMULATIONS



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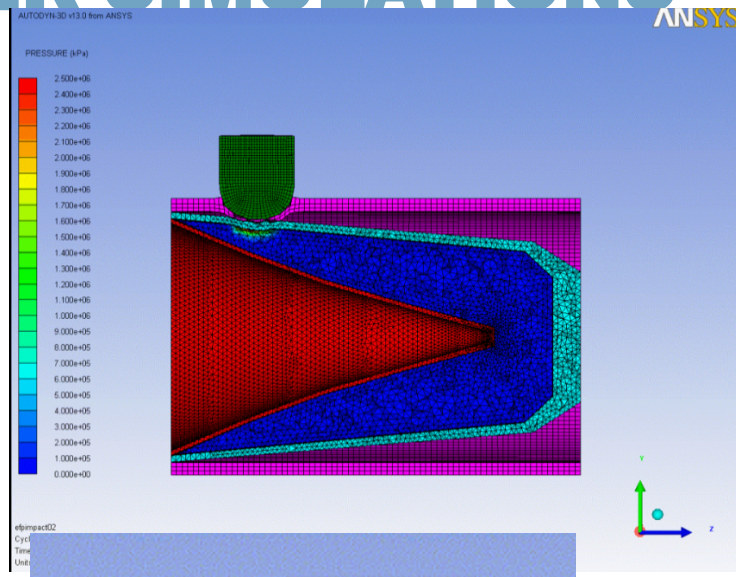
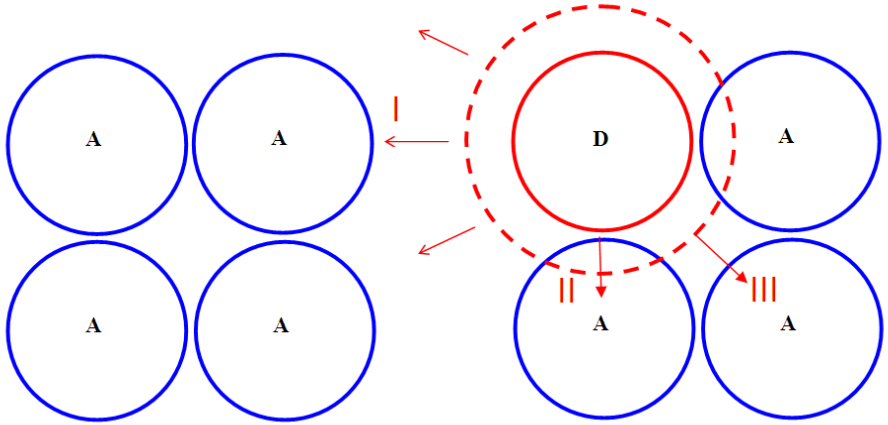
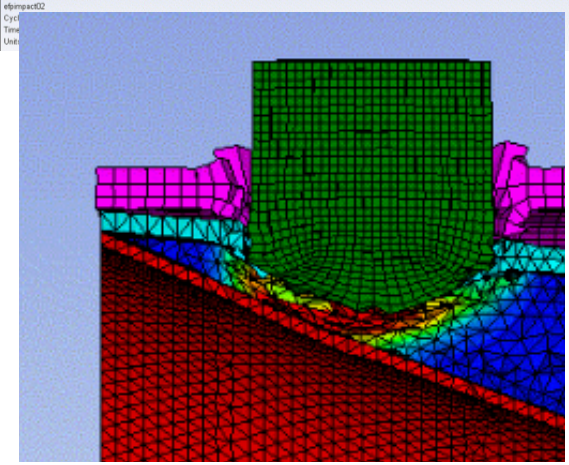
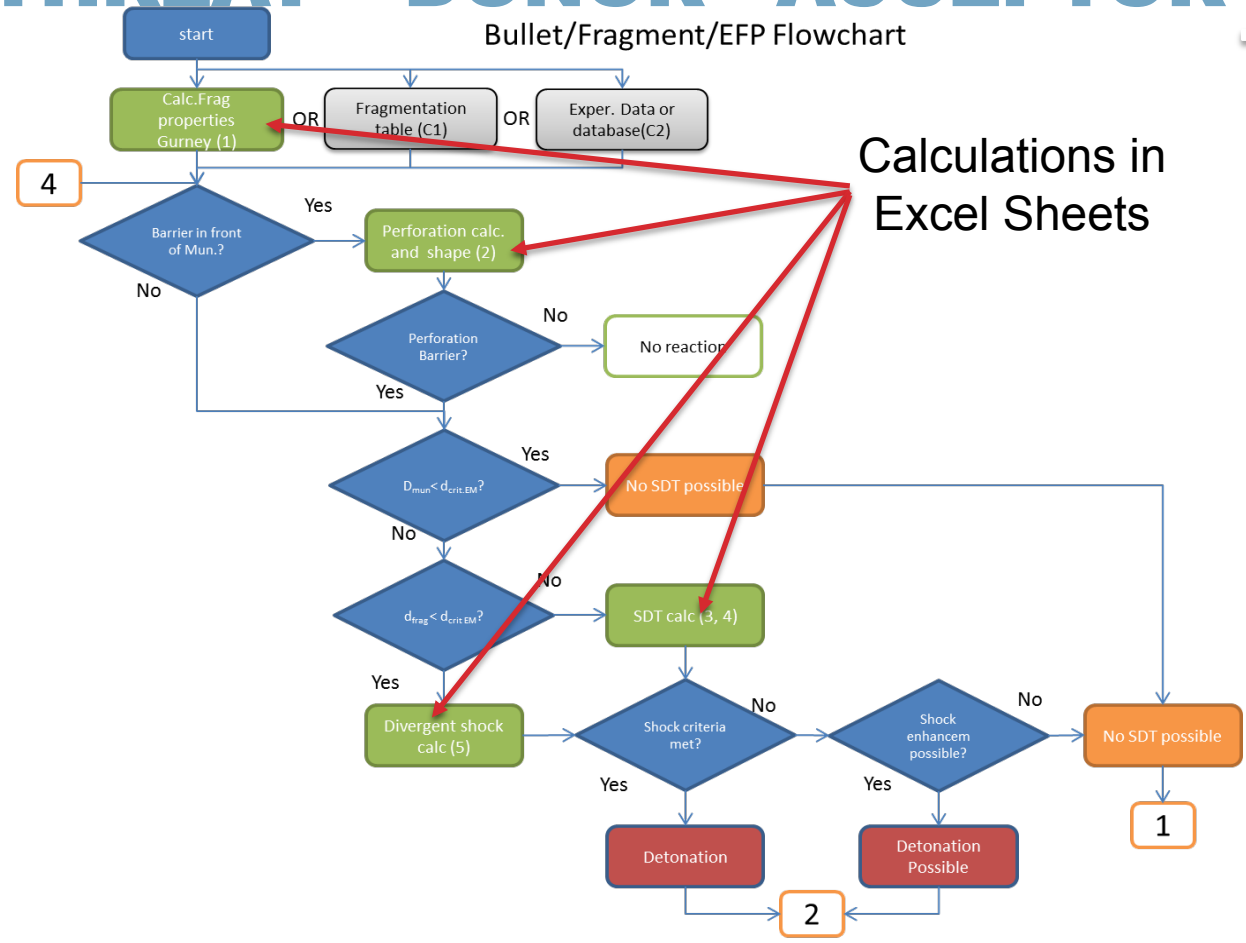


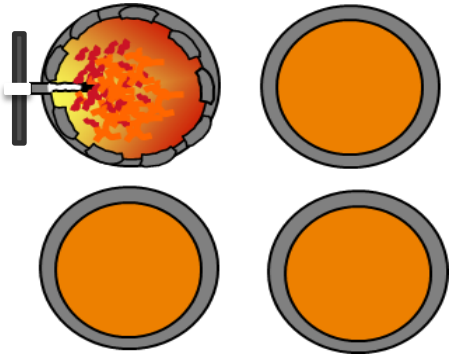




TNO APPROACH
MUNITION VULNERABILITY TOOLBOX
THREAT – DONOR - ACCEPTOR



Calculations in Excel Sheets

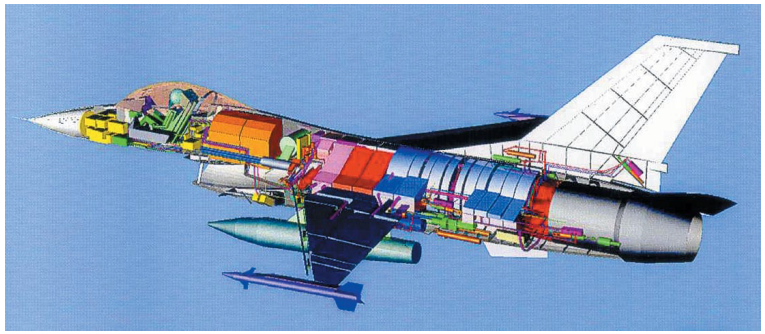


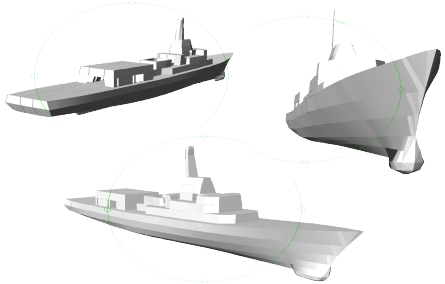
Spreadsheets/comments:
(1) Fragment velocity calculation with Gurney
(2) Perforation calculation using Thor equations
(3) SDT calculation Ec theory Haskins and Cook
(4) SDT calculation Green or Lundstrom
(5) Divergent shock calculation Green/Lundstrom
(6) EM heating due to penetration
(7) EM cook-off 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

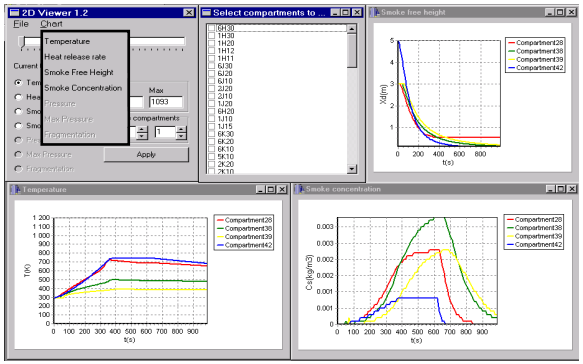
- Excel spreadsheet calculation
- Excel spreadsheet not implemented
- Excel spreadsheet (needs data)
- Data from database or Experiments
- Detonation reaction (possible)
- No Prompt shock detonation (SDT)
- Decision
- Reference Number

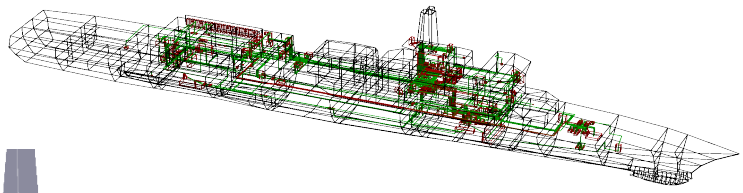
PLATFORM VULNERABILITY CODES

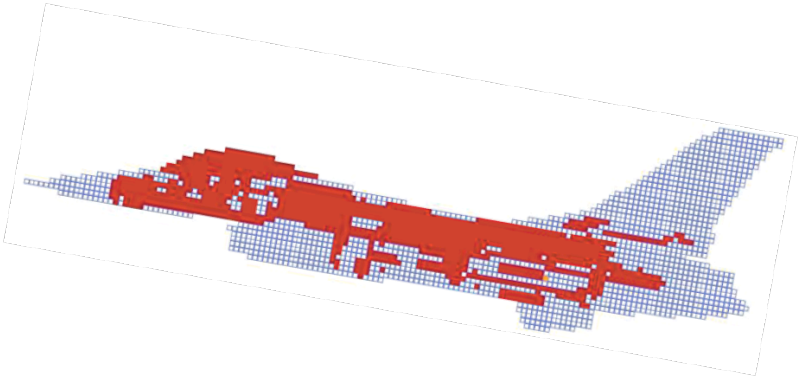
- ‘RESIST’ ship vulnerability assessment
- TARVAC (TARget Vulnerability Assessment Code)

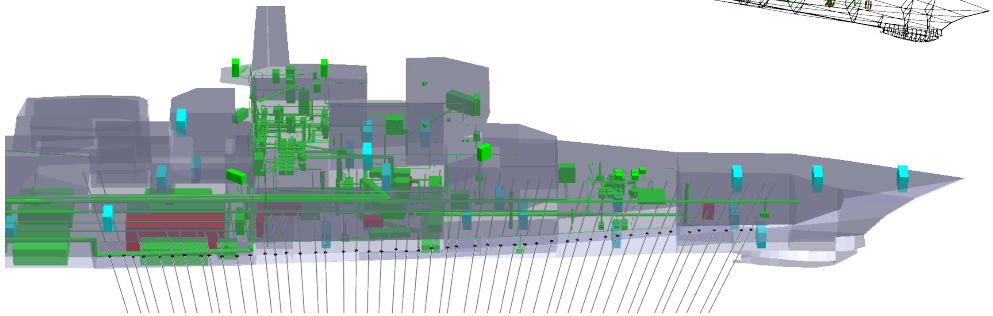




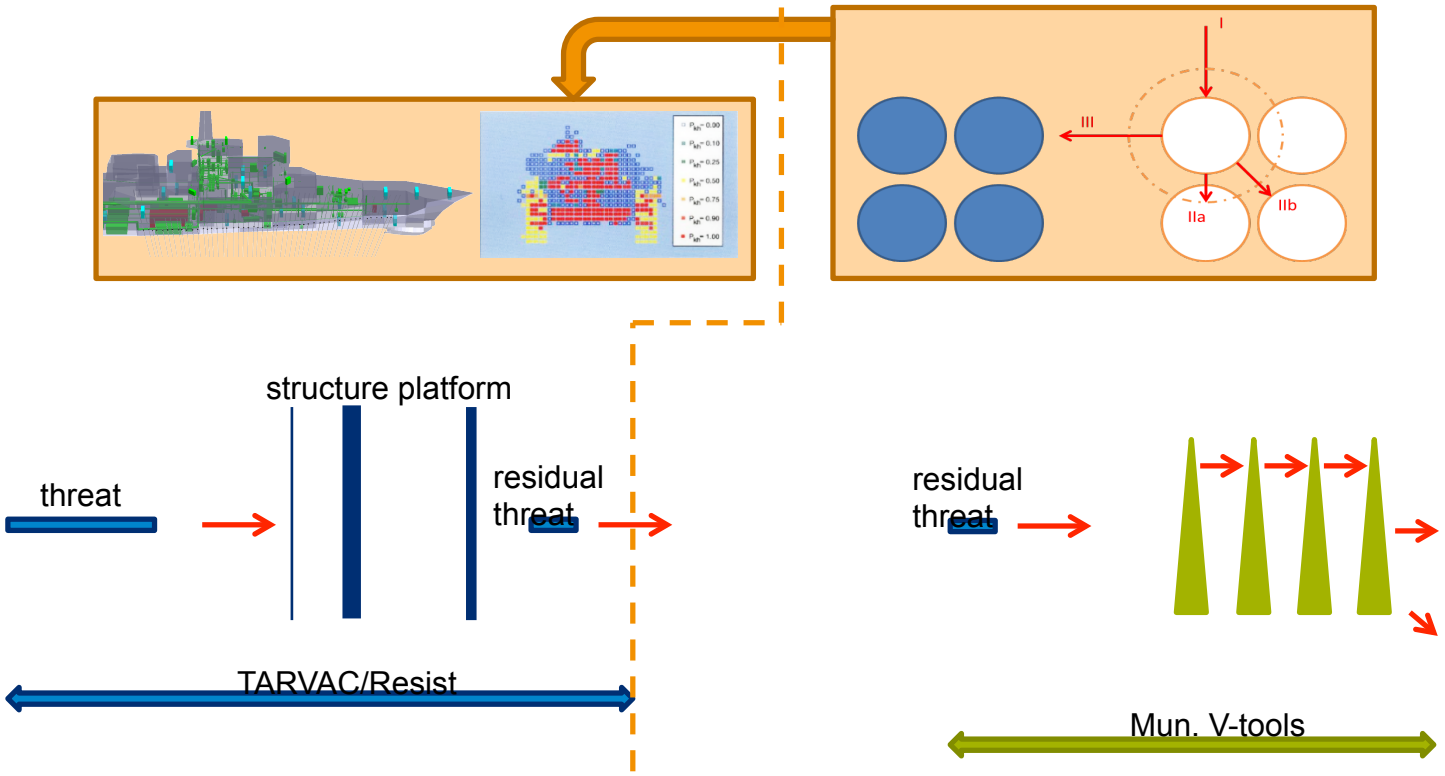








ENVISIONED SITUATION

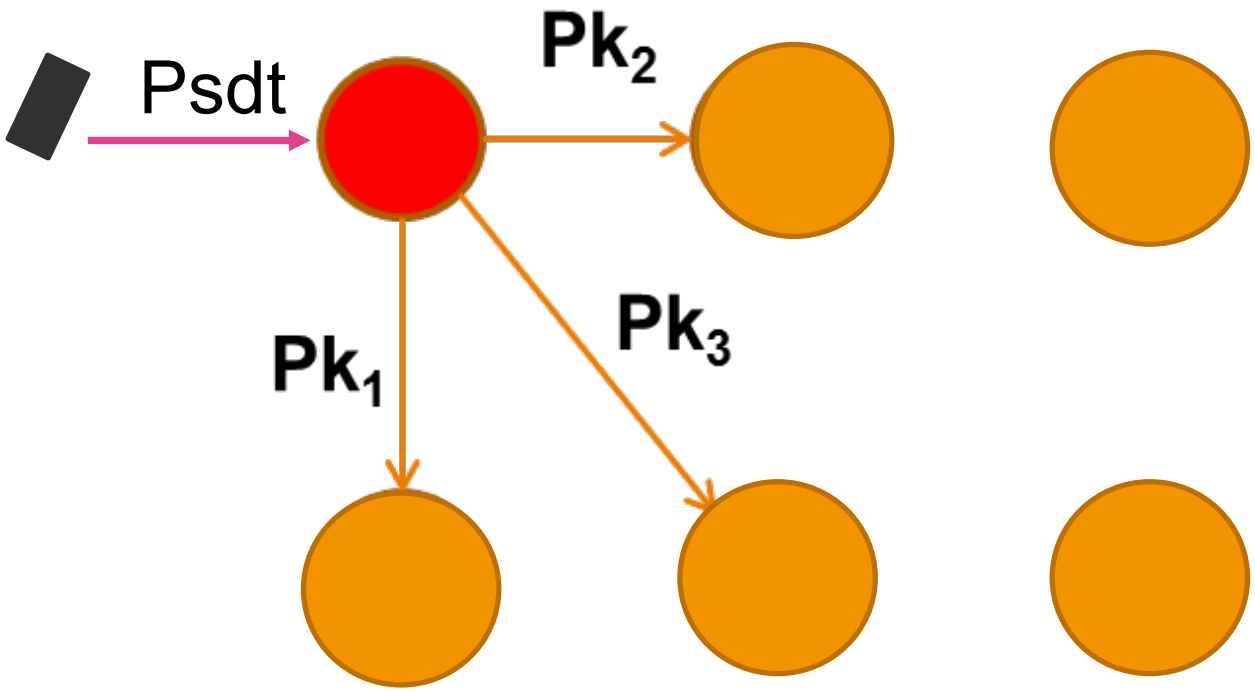


FRAGMENT IMPACT AND SYMPATHETIC REACTION MODELS;

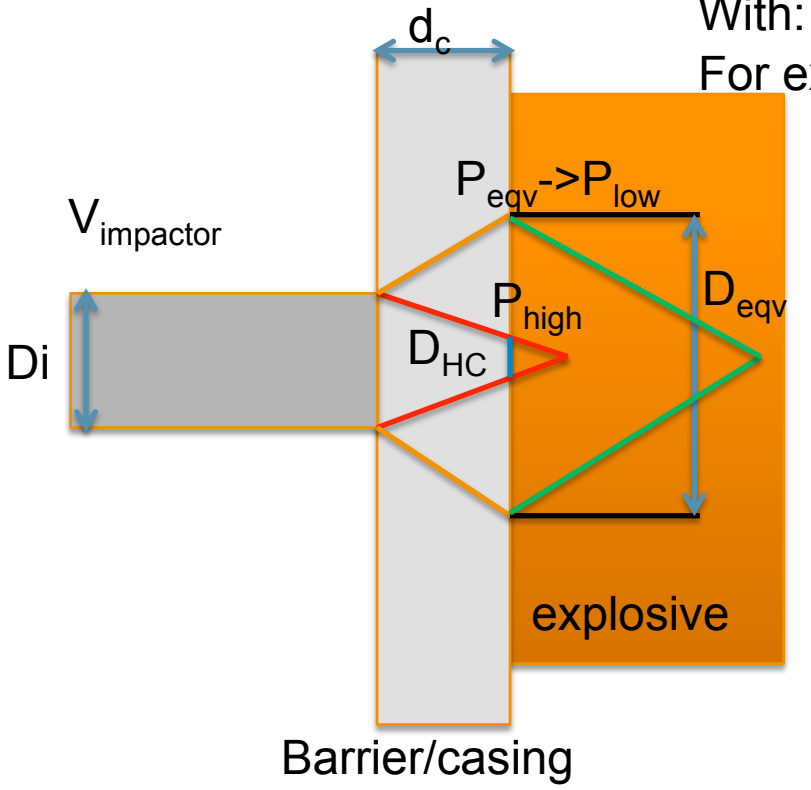
STATISTICAL TOOLBOX

SCENARIO - PROBABILITY

- Missile hit: fragments travelling towards munition storage



NEW SHOCK MODEL: COMBINATION OF HASKINS&COOK AND P_{EQV} IDEA OF GREEN→ E_{FLUX}



Energy Fluence: $E = \int P \cdot u_{p,x} \cdot dt$

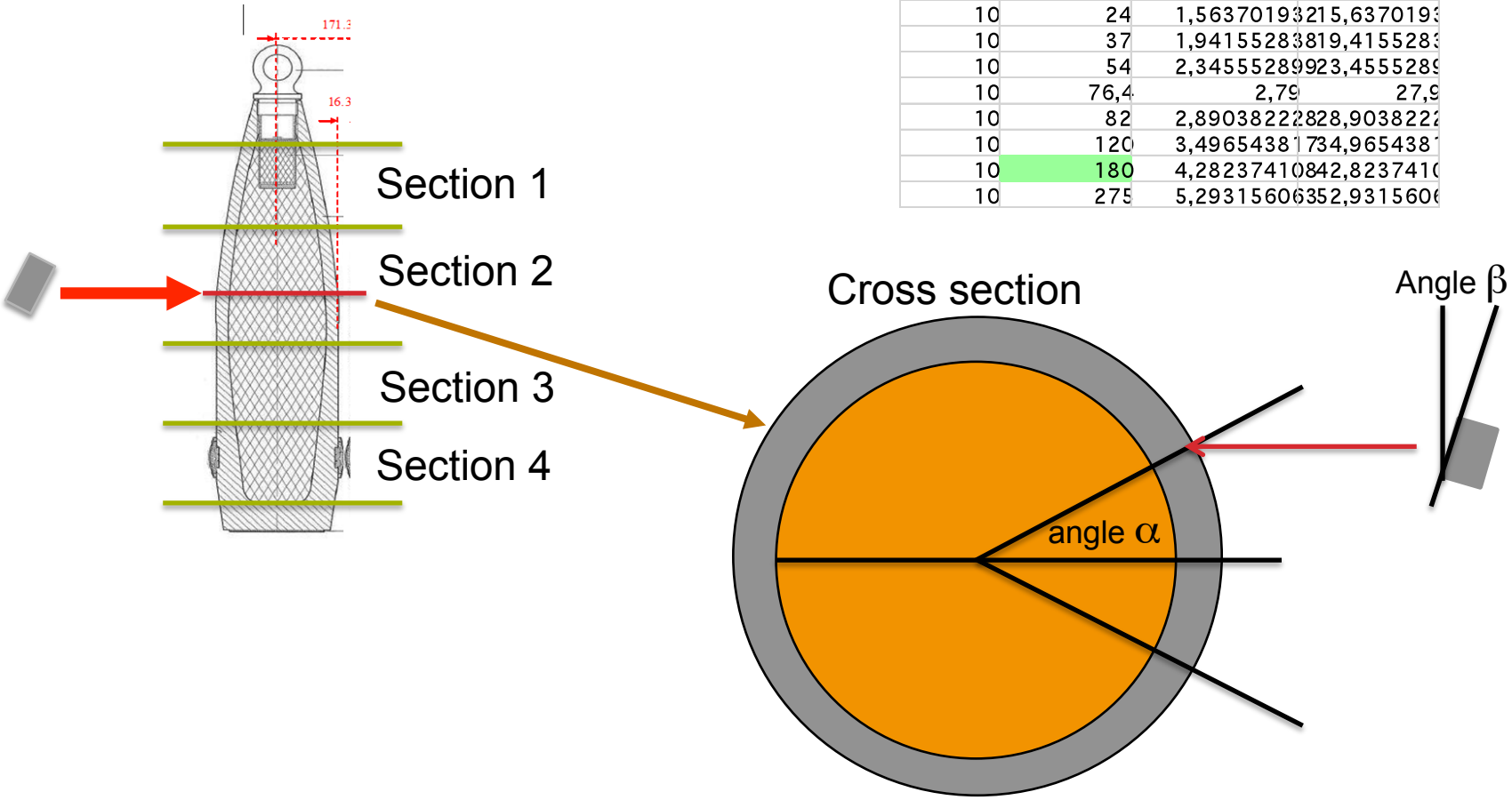
With: P= pressure, Up Part. Velocity and t the time

For explosive $E_{impactor} > E_{crit,exp}$ → Detonation

- Barrier old model: High pressure component reduced by rarefaction wave from the edge
- New model expansion of pressure wave:
- E_{green} and E_{HC} component for E. flux
- Ec-{E_{green} (R_{gr}^2 - R_{HC}^2)+ E_{HC} R_{HC}^2}/R_{green} =0
- With R_{gr}= D_{eqv}/2 and R_{hc}= D_{HC}/2
- Advantage : standard Ecrit can be used
- D_{eqv} = Di + 2 d_c
- P_{low} from P_{eqv} and shock impedance match
- P_{high} from P in barrier and shock impedance match

STATISTICS → PROBABILITY OF A KILL: P_{KILL} (SDT)

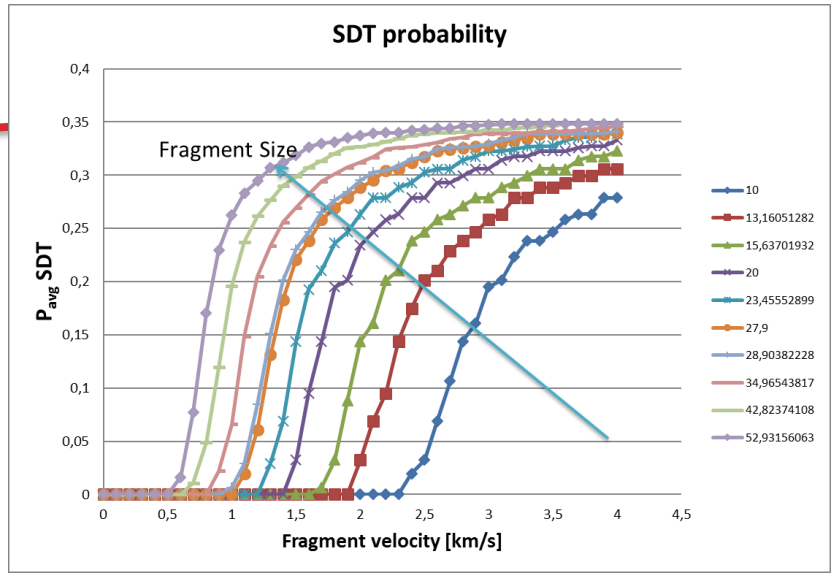
thickness	weight (gr)	diameter [cm]	diameter [mm
10	17	1,31605128	213,160512
10	24	1,56370193	215,637019
10	37	1,94155283	819,415528
10	54	2,34555289	923,455528
10	76,4	2,79	27,9
10	82	2,89038222	828,903822
10	120	3,49654381	734,965438
10	180	4,28237410	842,823741
10	275	5,29315606	352,931560



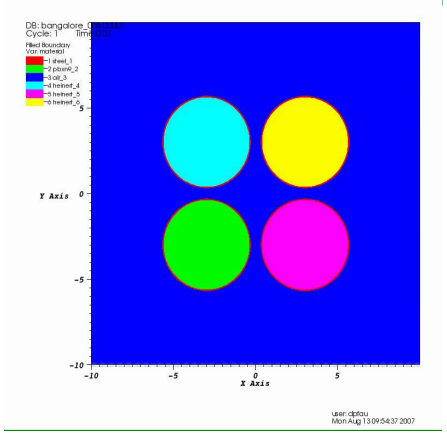
SPREADSHEET CALCULATIONS

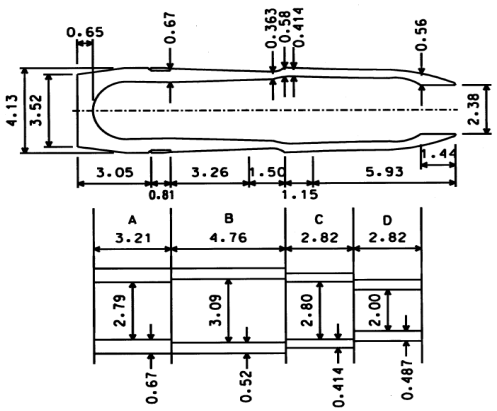
- Results of 10 different fragment diameters
- With 40 different velocities
- 625 different angles (location and fragment impact angle)
- Maximum of 4 different section of warhead
- Graphs display 10 x 625 x 40 X 4 solver calculations
- = 1,000,000 solver calculations (in a few seconds)

Statistical input for Platform vulnerability codes

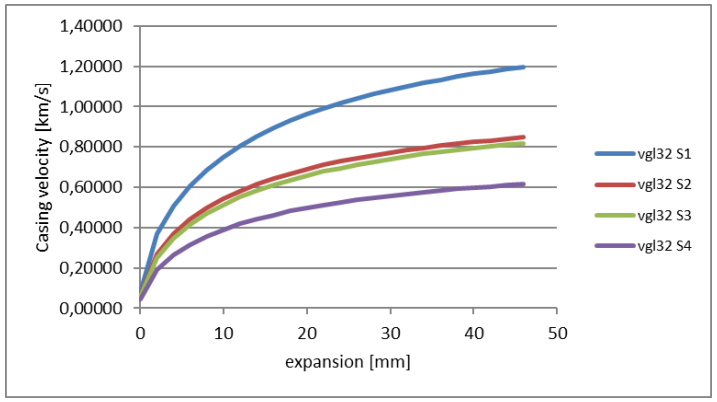


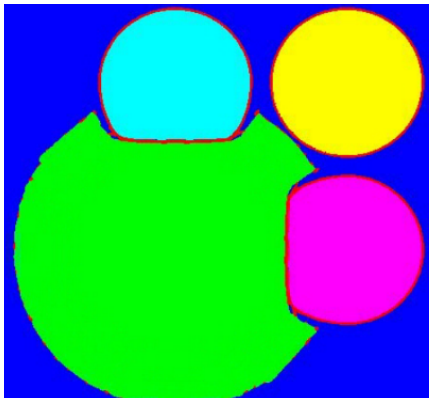
SYMPATHETIC REACTION CALCULATION (GURNEY)

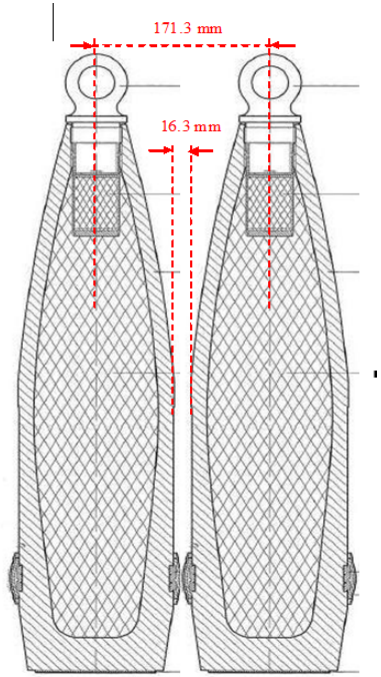




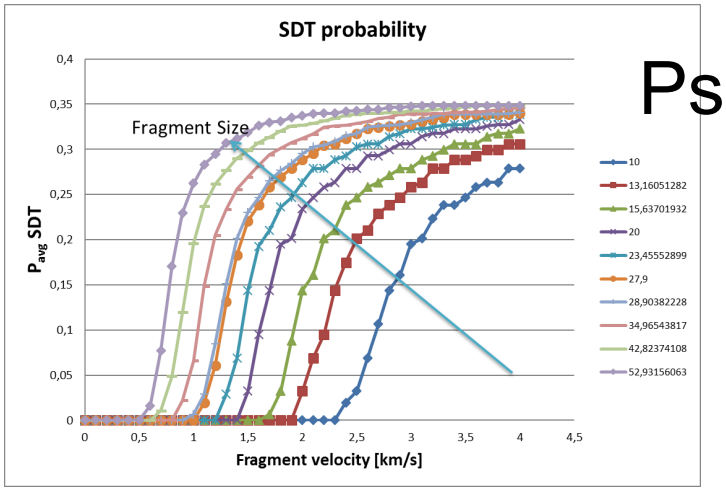
Input parameters:					
Us=Co+sl	Co	S	r	dcrit	Ecrit
1,2	4,58	1,49	7,89	0	0
Steel	4,58	1,49	7,89	0	0
TNT/RDX	3,03	1,73	1,715	0	1,381
Number of Sections		4	max velocity calc		4
		Casing thickness		length section	
		16mm		121mm	
		22mm		150mm	
		25mm		66mm	
		30mm		97mm	
		total length munition		434mm	



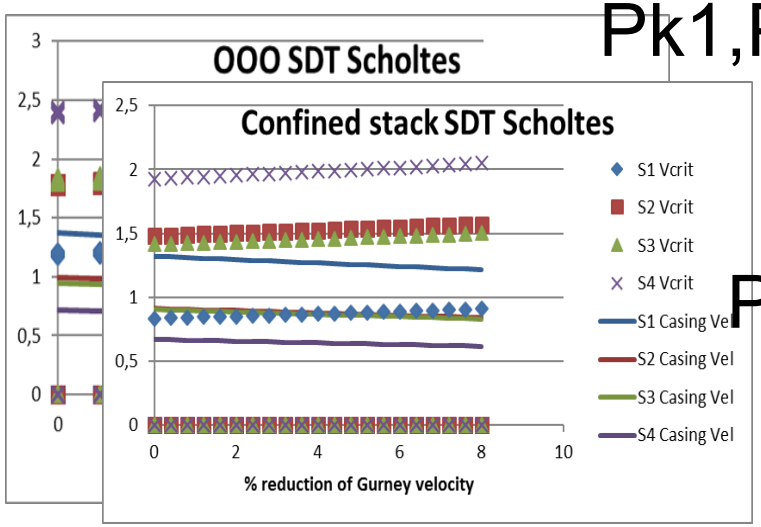




TYPE OF RESULTS

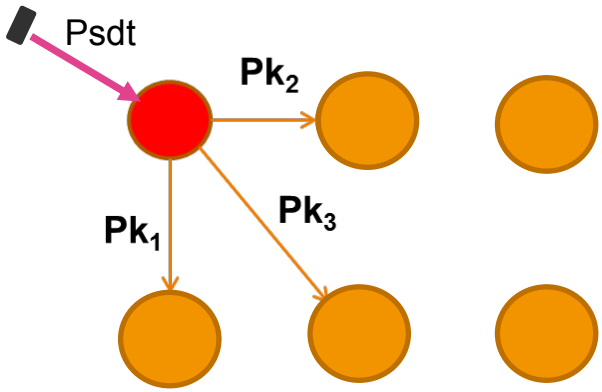


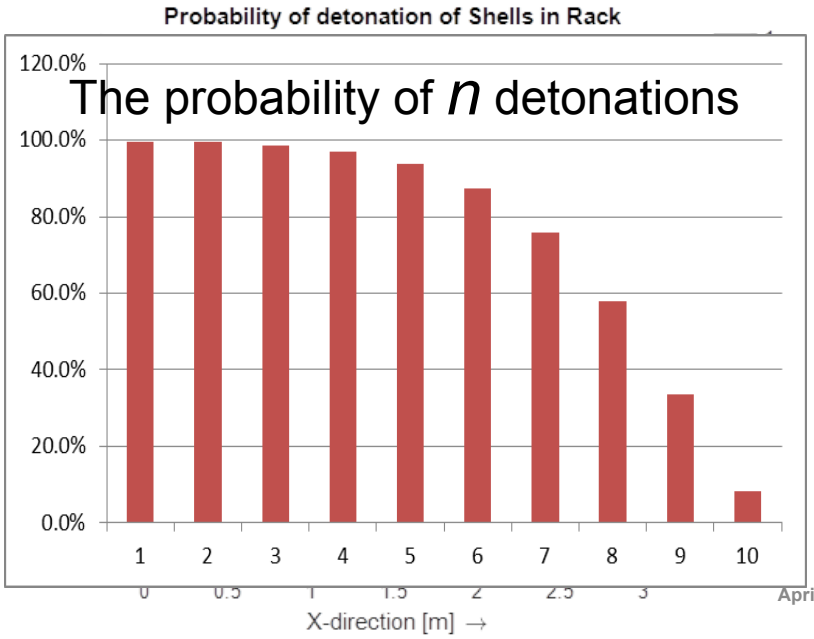
Psdt



Pk1,Pk2

Pk3

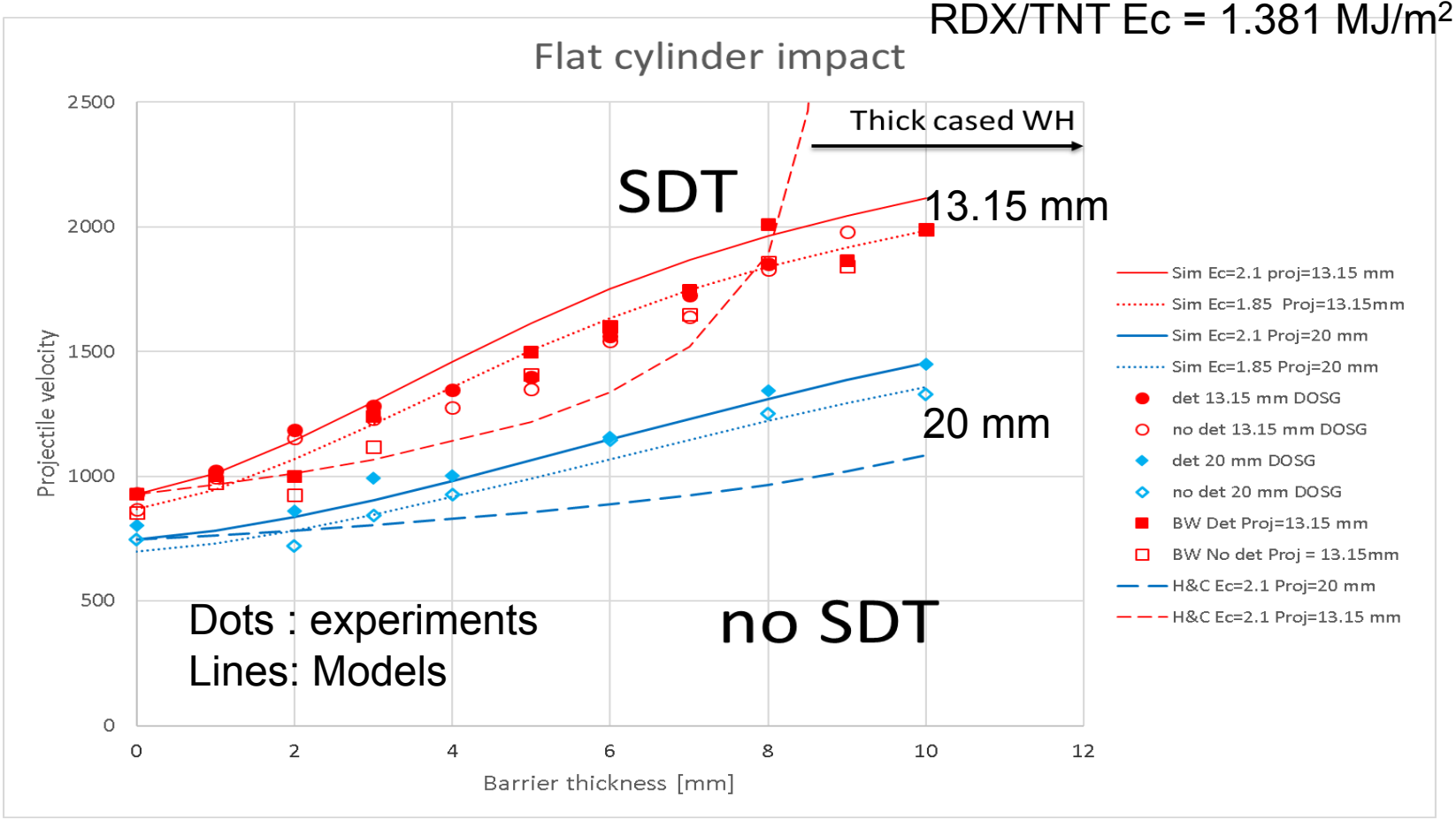




VALIDATION: LITERATURE VALUES

VALIDATION WITH DATA FROM LITERATURE

Comp B Ec = 1.85/2.1 MJ/m^2
RDX/TNT Ec = 1.381 MJ/m^2

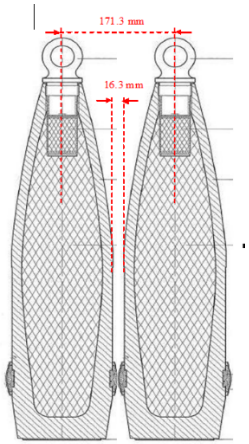


MUNITIONS TEST SERIES

TEST PROGRAM WITH SHELLS

3 types of experiments:

- Reaction of a certain threat?
- Sympathetic reaction?
- Effect of the detonation to the surrounding of the ship and personnel.



Facts and Figures

Several Shells

3 weeks of testing

40 experiments

All test in duplo

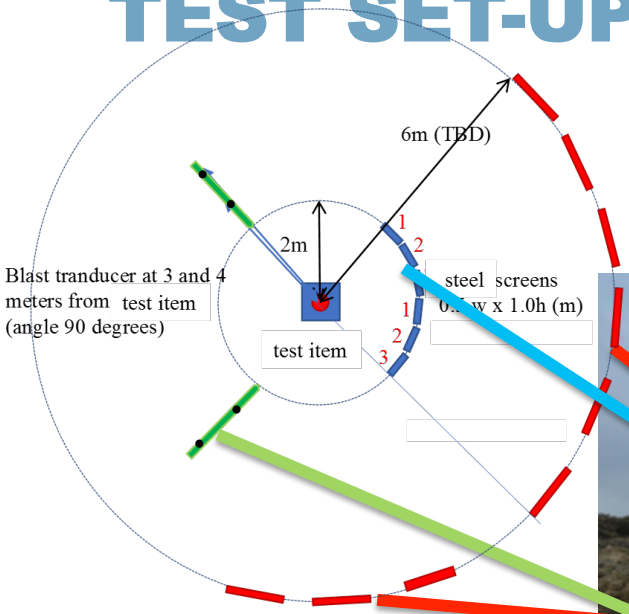
6 DMO employees

4 TNO employees

2 international visitors

Terabytes of data

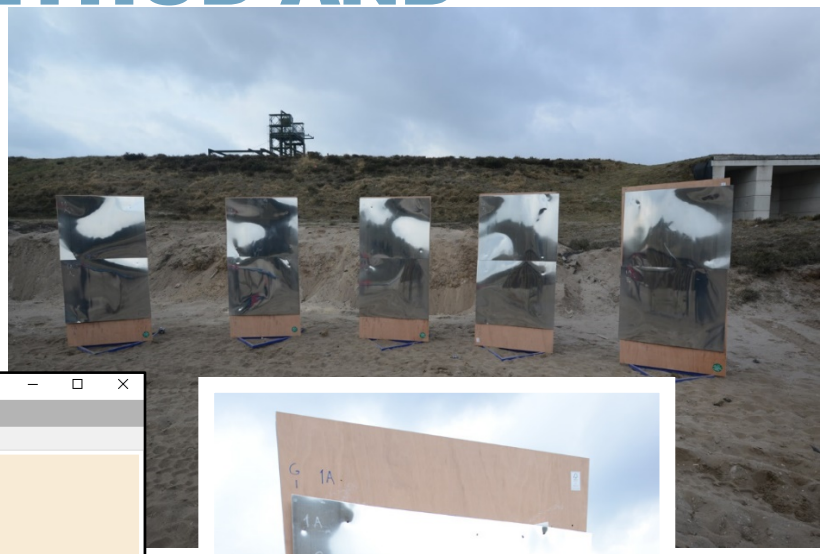
TEST SET-UP OF REFERENCE TEST

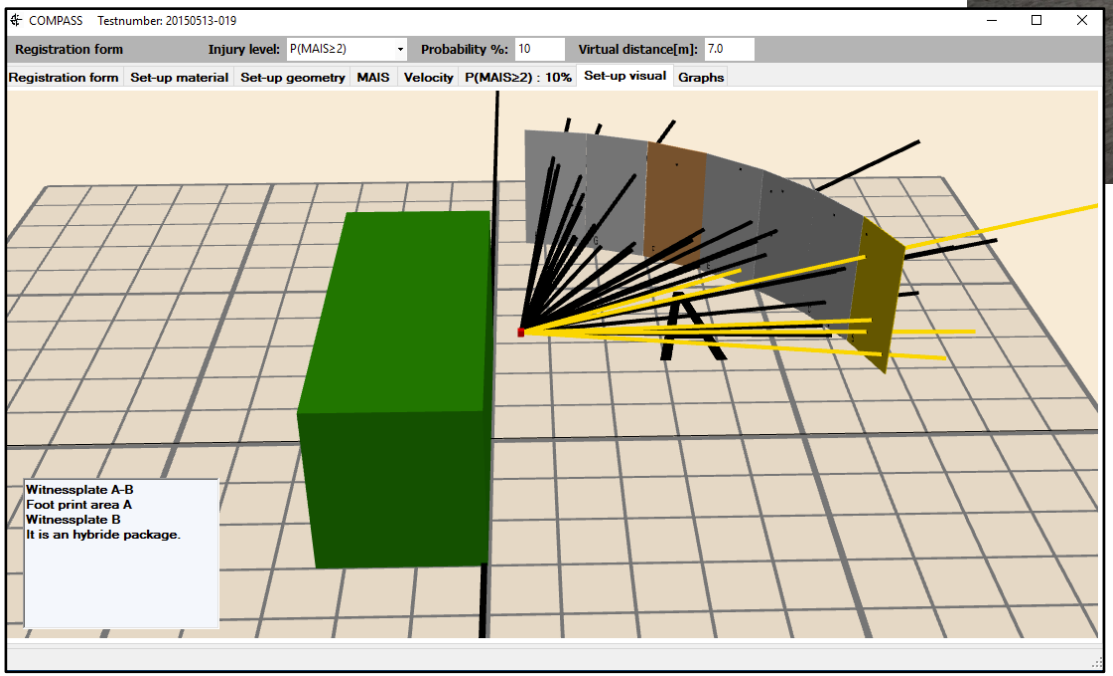


Hybrid screens (Al and wood)
1.22 w x 2. 44 h (m)

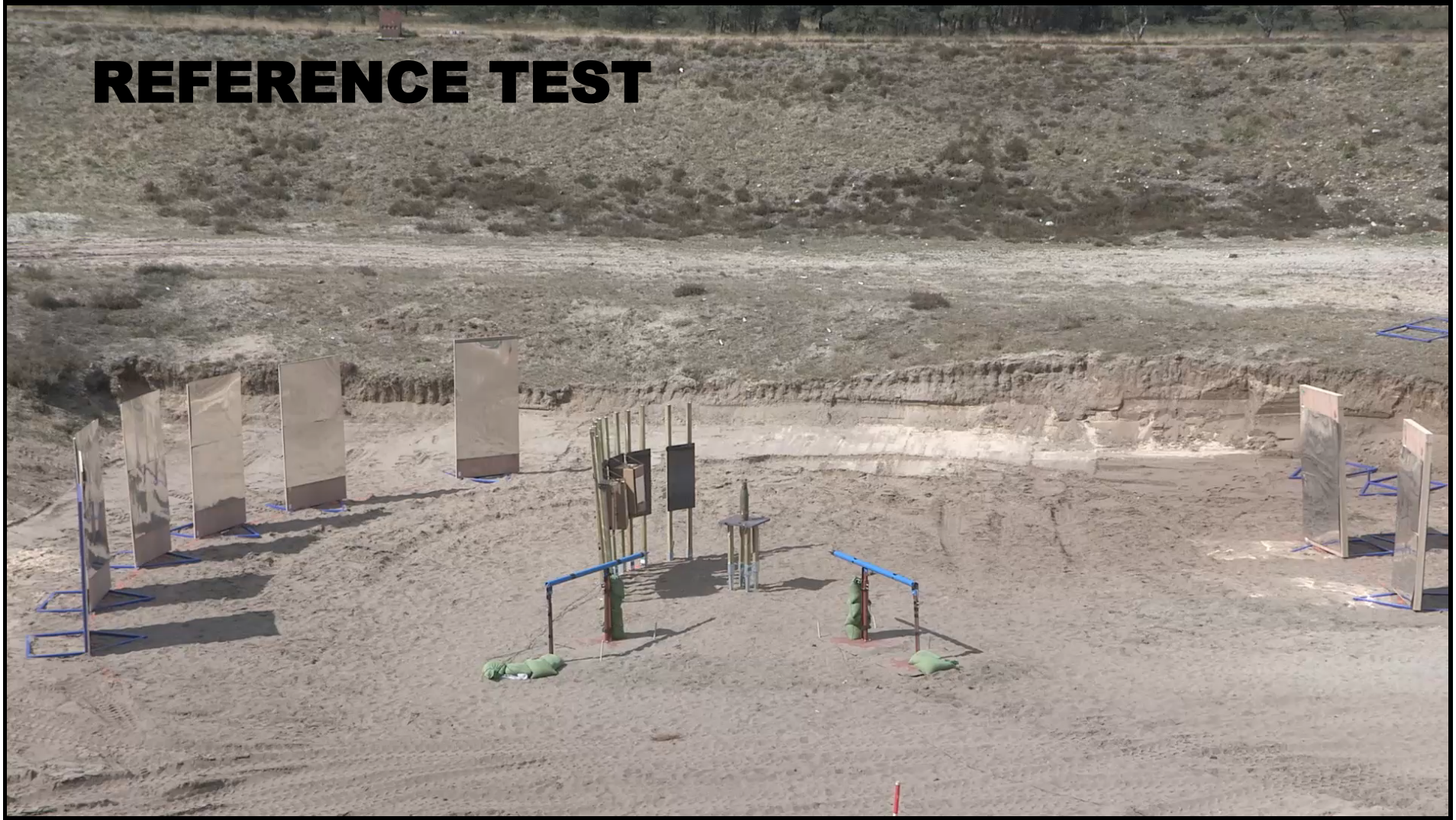
HYBRIDE SCREEN METHOD AND COMPASS ANALYSES

Method from STANAG 4686, under development

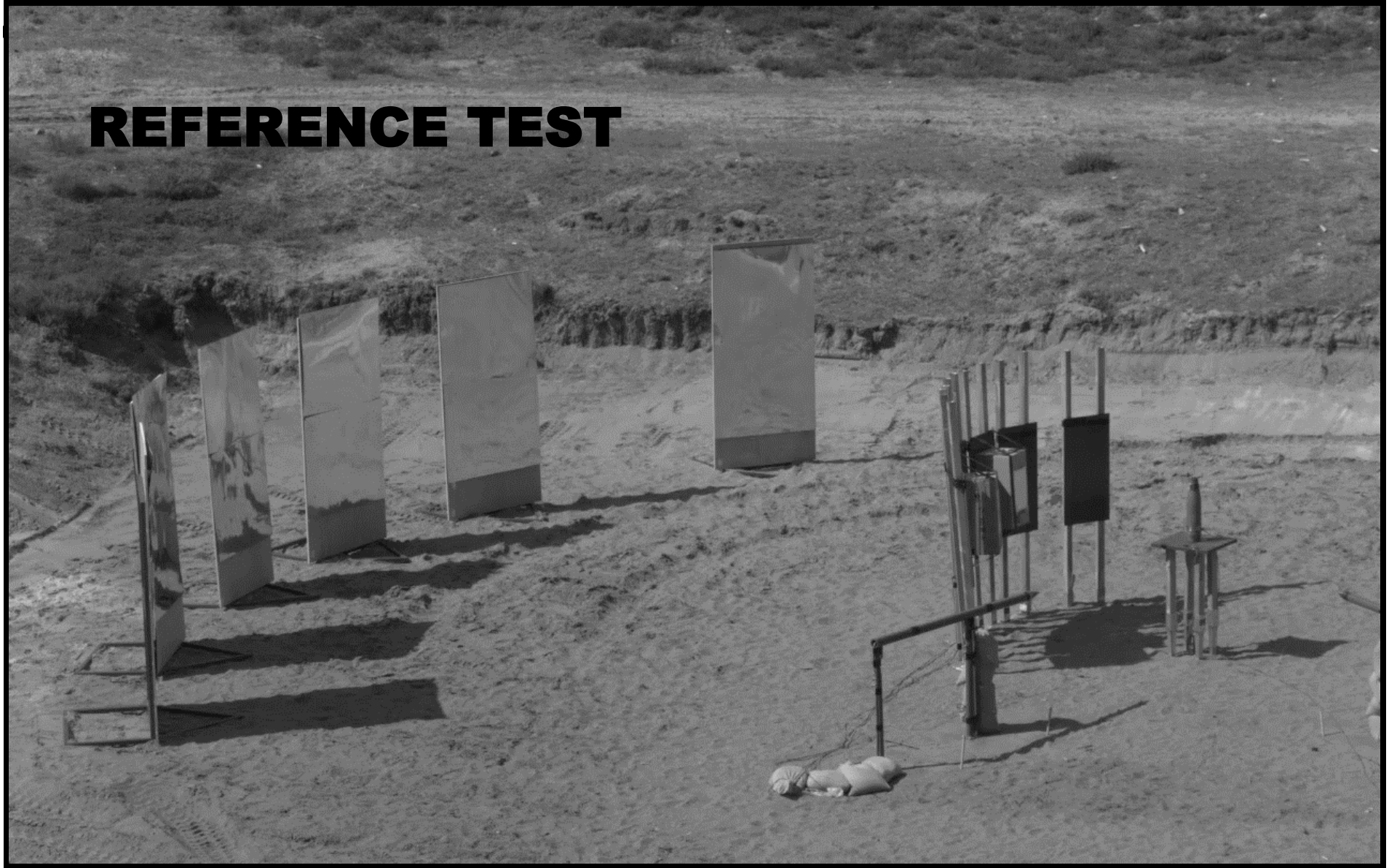




REFERENCE TEST



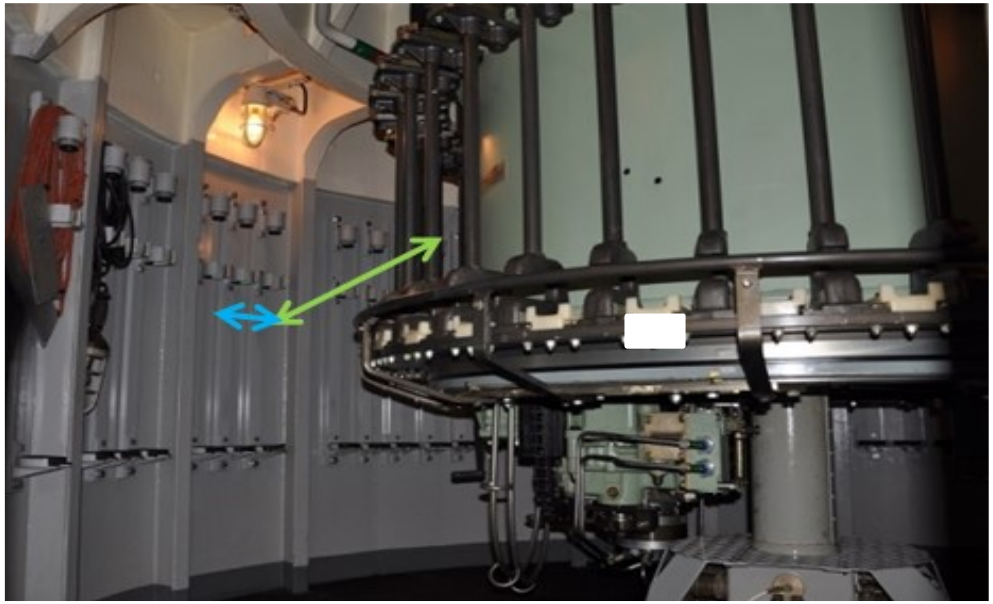
REFERENCE TEST



REFERENCE TEST

MUNITION TEST SET-UP

- Testing of all kind of storage situation of munitions
  - Distances
    - Adjacent munitions
    - Munition in near area
  - Barriers
    - Metal plates
    - Foams etc



SYMP REACTION TEST

NORWAY, WEEK 34-36, 2018
RENA TEST SITE

TESTPROGRAM SHELLS

3 types of experiments:

- Reaction of a certain threat?
- Sympathetic reaction?
- Effect of the detonation for the surrounding of the ship and personnel.

Facts and Figures

Several warheads/32 WH tot.

~3 weeks of testing

18 experiments

8 MOD NL employees

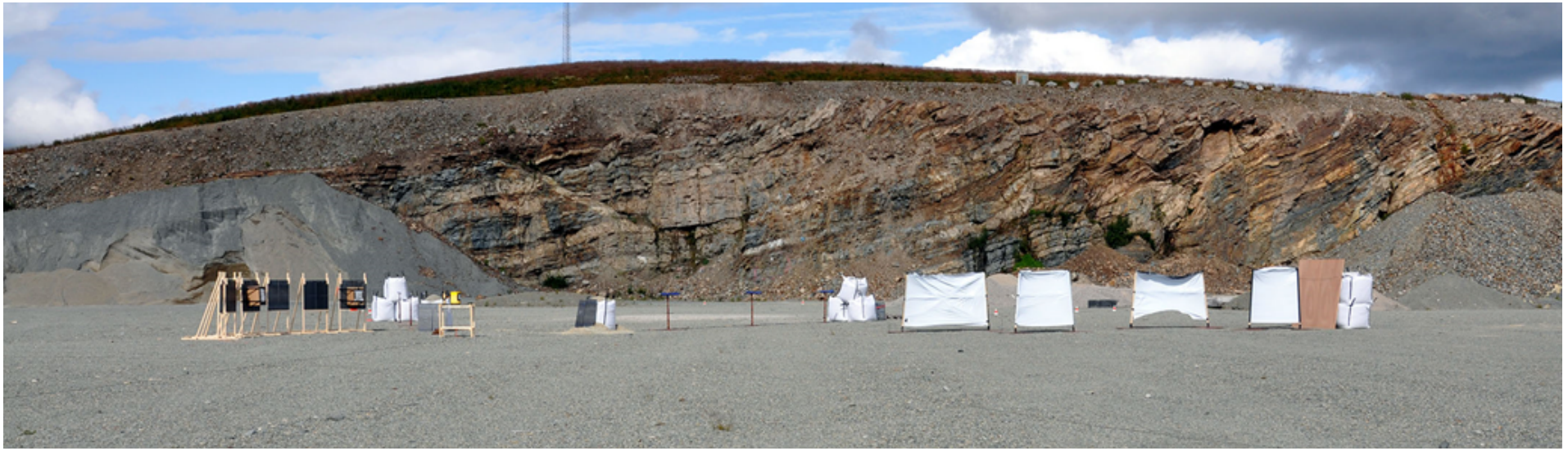
4 TNO employees

4 Norwegian MOD employees

Terabytes of data

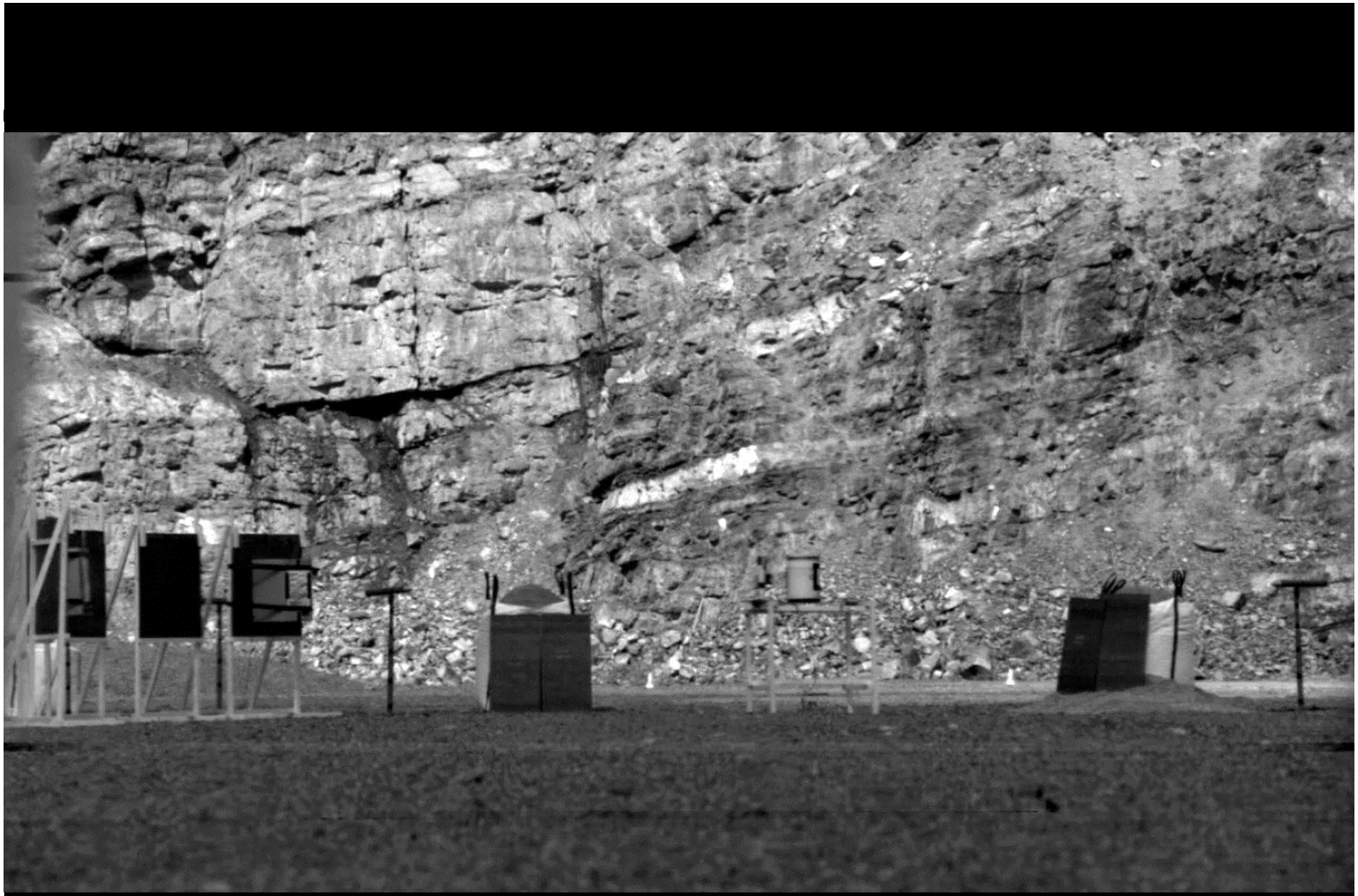
CHARACTERISATION OF A SINGLE WARHEAD

- Assessment of effect by means of steel plates
- Fragment velocity measurement with triggering foils
- HS video of fragments at distance of 15-30 meters
- HS video overview and close-up of warhead
- Normal speed video
- Pressure measurement in 2 lines at 3 positions



IMPRESSIONS

IMPRESSIONS



SYMPATHETIC REACTION

- Warheads set-up simulating storage situation
- HS video overview and close-up of warheads
- Normal video
- Pressure measurement

LESSONS LEARNED

- Not all instrumentation needs to be expensive
- Protect your expensive camera's and data acquisition well
- Some unexpected results in current storage situations → need for mitigation
- Also a type III reaction can result in a sympathetic reaction giving a type III reaction or more severe !
- Smaller caliber bullets sometimes give a more violent reaction!
- A large SCJ does not always give a detonation! (non IM WH)
- These type of tests can give more than just vulnerability results:
  - Performance of warhead (fragment speed, perforation performance, fragmentation patterns, actual size of fragments)
  - Effects of the detonation to the surrounding of the ship and personnel

SCJ impact on warhead

CONCLUSIONS

- Shock model works quite good and will be implemented in platform vuln. codes
- Experiments:
  - Obtained several types of reaction
  - Results led to preliminary advise for safe storage of munitions on board a ship
  - Analyses still in progress but Terabyte of data available for validation of data for:
    - Munition vulnerability toolbox
    - Fragmentation codes (SPLIT-X, TARVAC of RESIST)
    - RESIST: effect of certain reactions on board of ship
- Very good co-operation between DMO (Naval vulnerability), DMO Centre of Excellence, Norwegian MOD and TNO.

Results will contribute to reduction of risks in general and of munitions storage and more balanced ship design.