Use of CFD Modelling in the design of a IM Warhead to Cook-off Stimuli

Fernando Echeverría
Ing. Aerospace & Weapon

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Introduction

- Low vulnerability Sea Mine (MINEA-EXPAL).
- Novel insensitive energetic material (plastic bonded Expal PBXN-111) based on RDX, AP and binder.
- To be designed to fulfil the IM cook-off according to STANAG 4439: Fast cook-off (FCO) and slow cook-off (SCO).
- To develop a cook-off predictive CFD model together with future experimental tests.

Introduction

- MINEA warhead is composed of explosive, liner, GFRP casing, covers and Safety & Arming Device (SAD).

- The main dimensions of the warhead are Ø533 mm and L1200 mm. The warhead is filled with 350 kg of explosive.
- A passive cook-off mitigation device to be achieved through the design: venting device through the reaction in the surroundings of the covers.

Cook-off phenomena

- Energetic material, subjected to a thermal aggression, exhibits exothermic and endothermic reactions due to chemical decompositions.
- Self-heating process may induce self-ignition.
- The chemical degradation reactions generate also some gases by pyrolisis phenomena resulting in cracks.
- Typical time-to-ignition can range from seconds to several hours.
- Typical reactions can range from a low order (combustion) to a high order reaction (total detonation).

Kinetic model

- Thermal decomposition model of McGuire – Tarver of 3-steps:

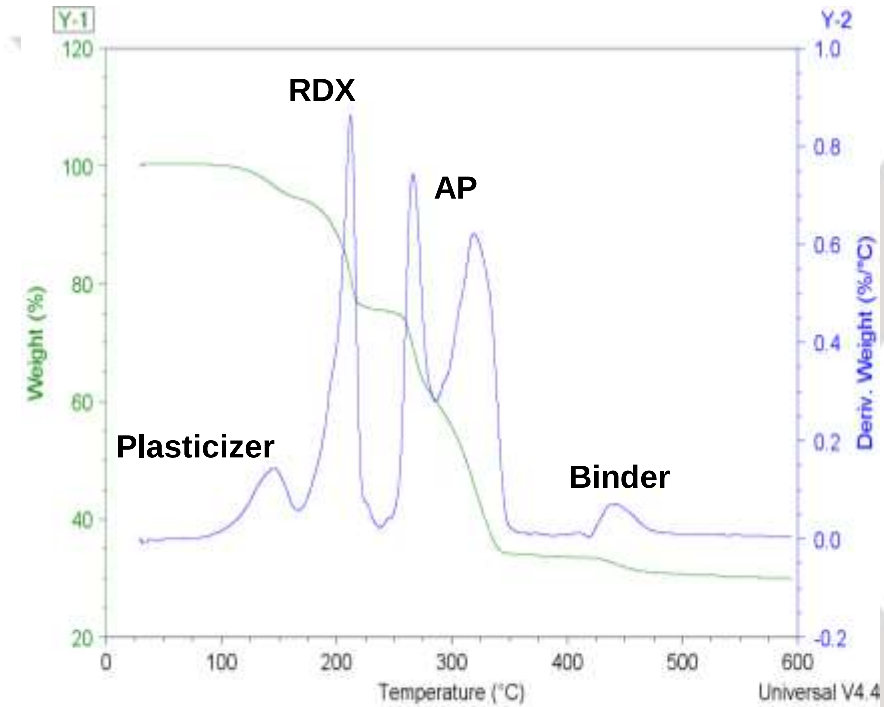
$$A^1 \rightarrow B^2 \rightarrow 2C^3 \rightarrow D \qquad -\lambda \cdot \nabla^2 T + \rho \cdot c_p \cdot \frac{dT}{dt} = S$$

A=RDX, B= H_2C, C=CH_2O+N_2O, D=final gaseous products

- Arrhenius equation:

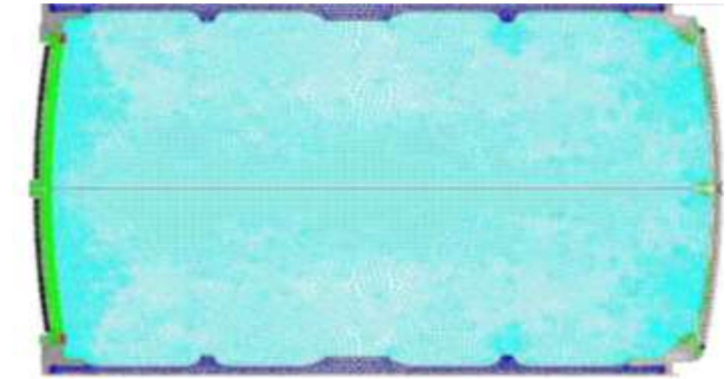
$$\frac{d\alpha}{dt} = -\frac{A}{\beta} \cdot \left(\alpha^N e^{\frac{-E}{RT}} \right)$$

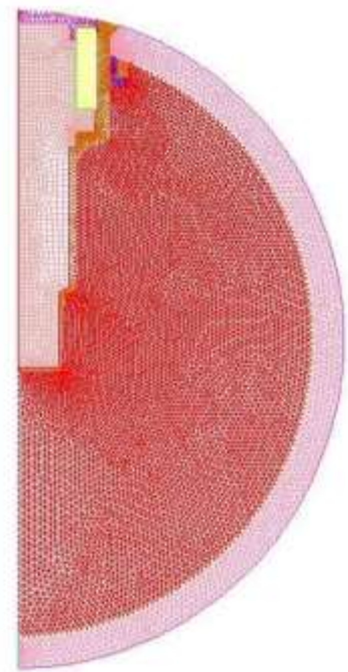
- Kinetic parameters were calculated with small-scaled tests of TGA.



CFD model

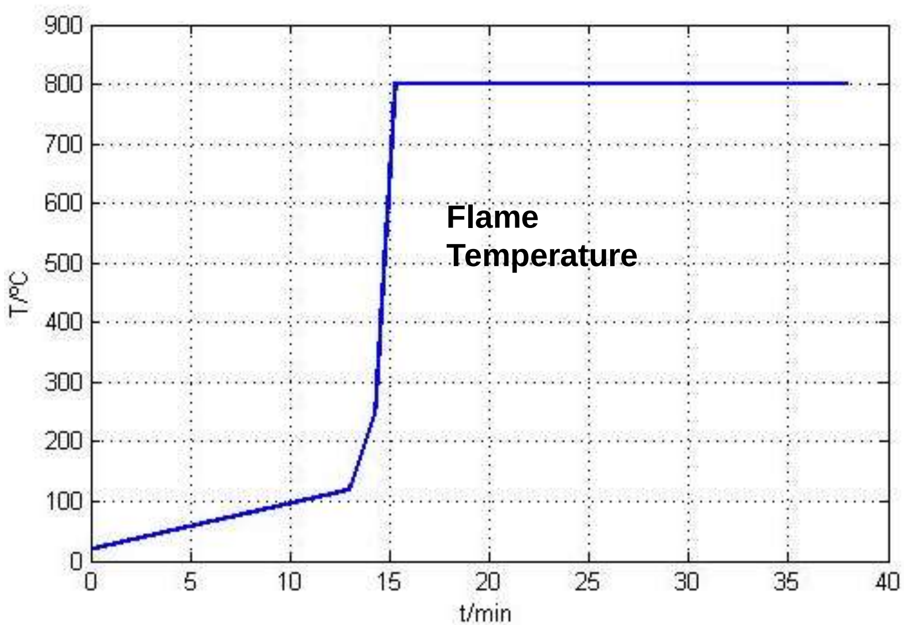
- Unsteady axisymmetric model grid composed of > 100,000 elements with a nodal point for each 1mm.
- Material properties were applied.
- A liner of Bitumen of 2mm thick between the explosive and the casing.
- Two area were analyzed: entire warhead and fuze cavity.
- Ignition points location, ignition temperature and time-to-ignition were given as results.



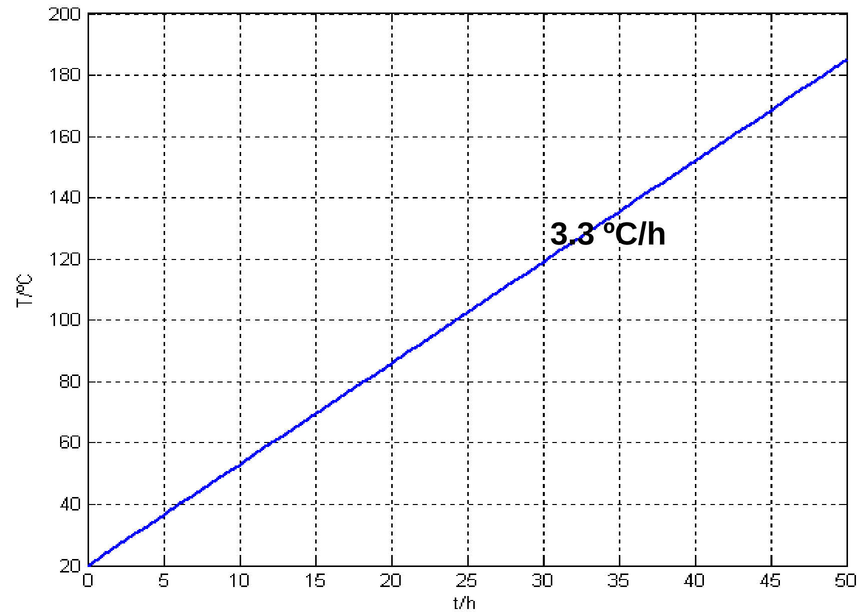


Boundary conditions

Validated with experimental results in a FCO and SCO facilities:



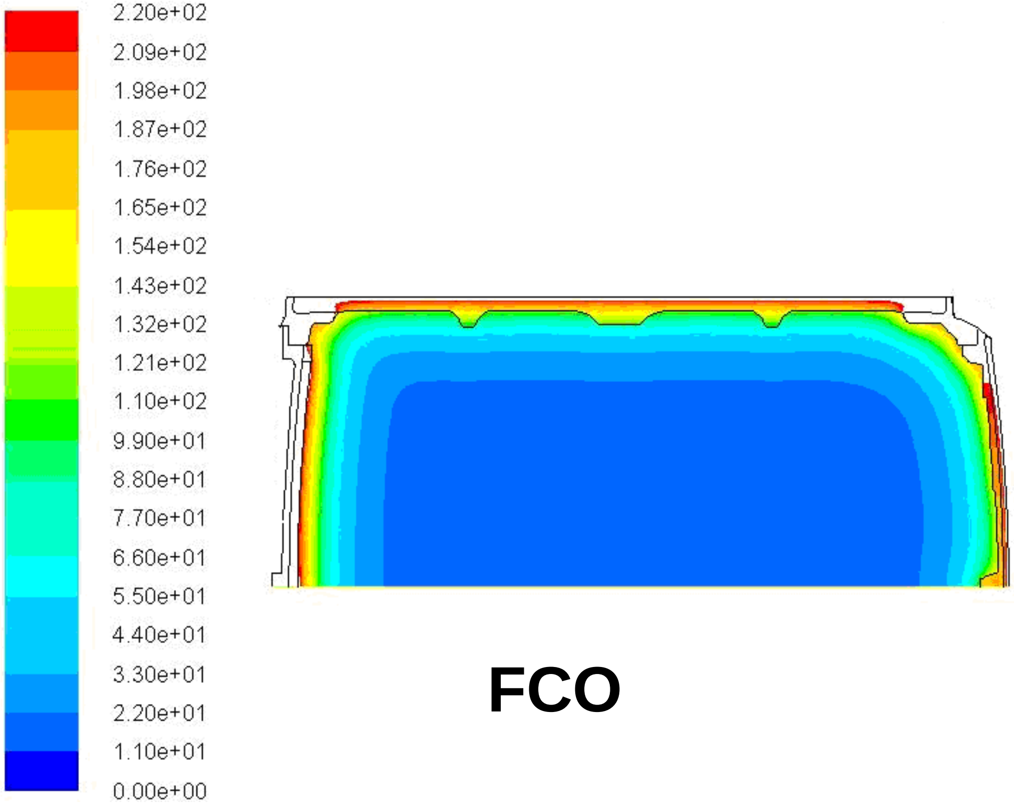
FCO



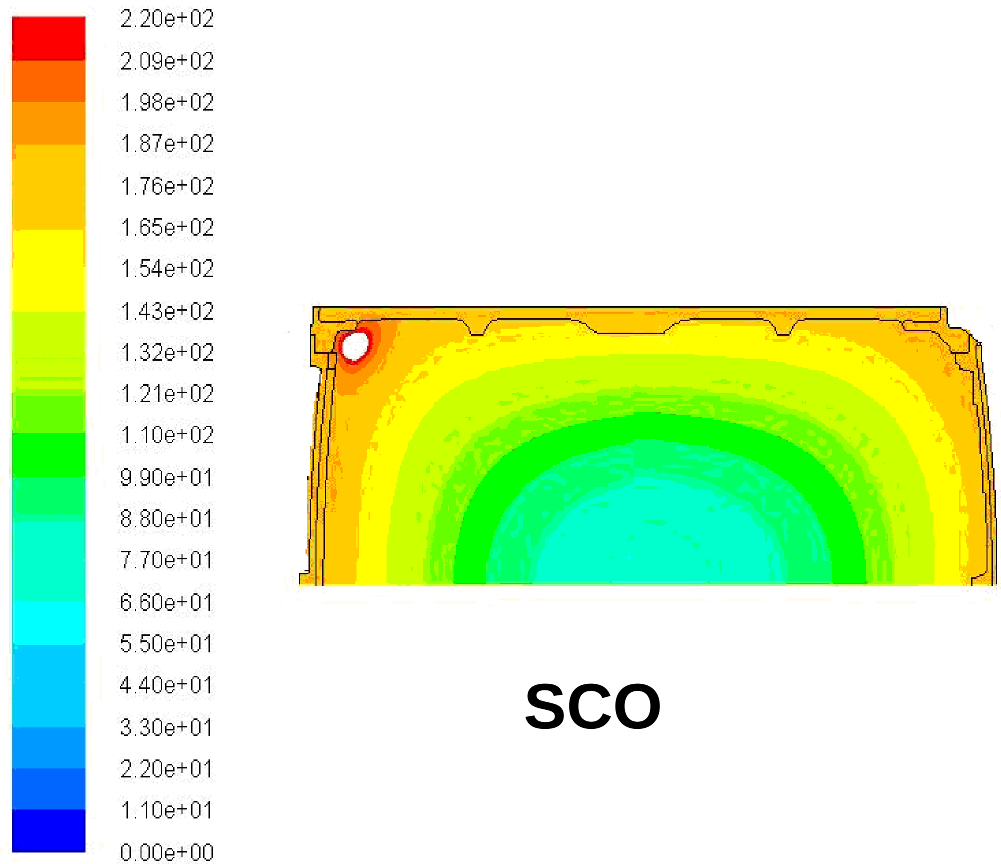
SCO

CFD results

Temperature plot and ignition point:



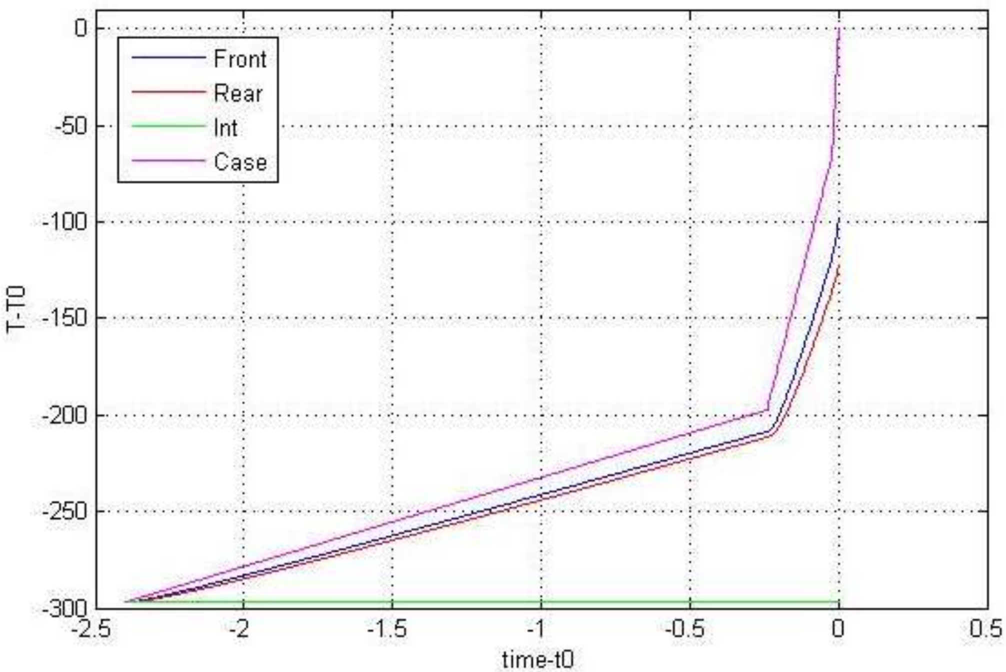
FCO



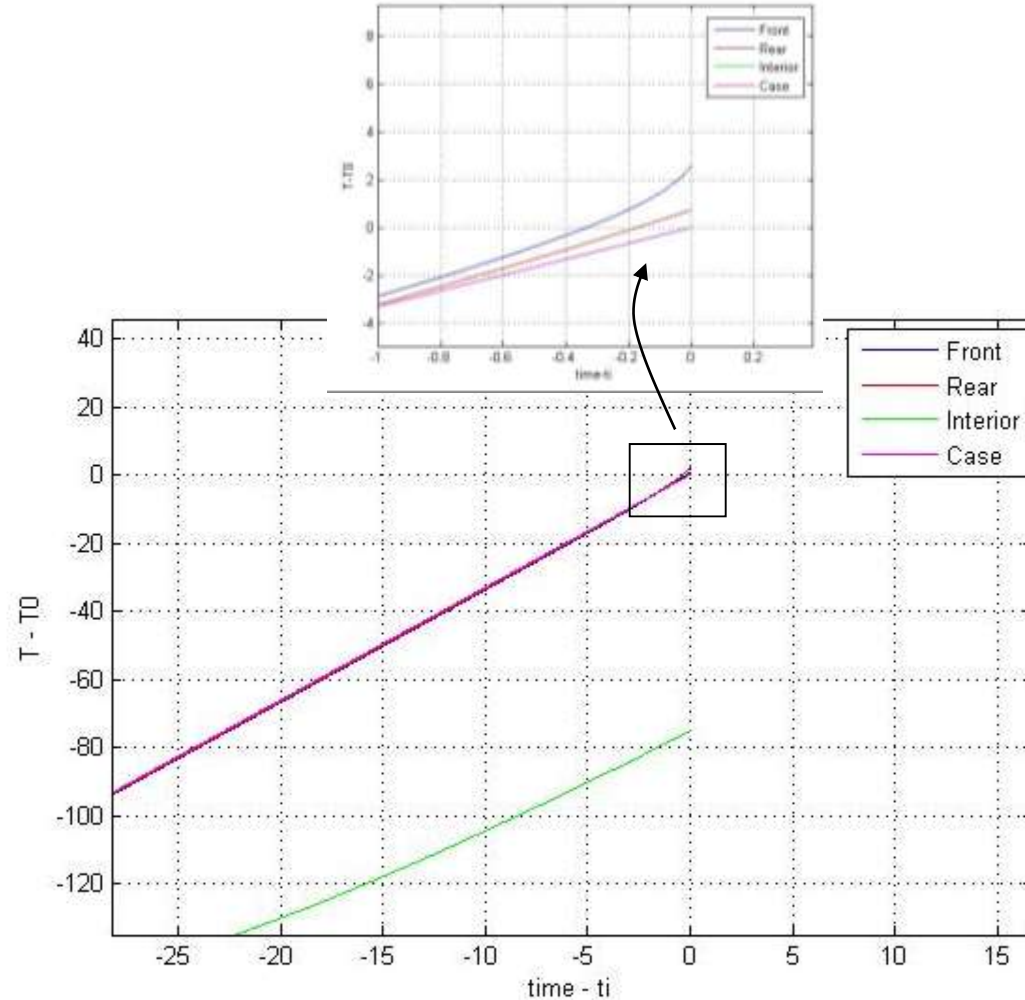
SCO

CFD results

Time-to-ignition and ignition point:



FCO



SCO

Parametric analysis

- Configuration A: entire warhead with liner0 at four different thicknesses ranging from -2, -1, 0, to +1mm. An alternative liner material (linerX) was also analyzed.
- Configuration B1: fuze cavity with a metallic cover.
- Configuration B2: fuze cavity without metallic cover.
- Configuration B3: fuze cavity with a ceramic cover.

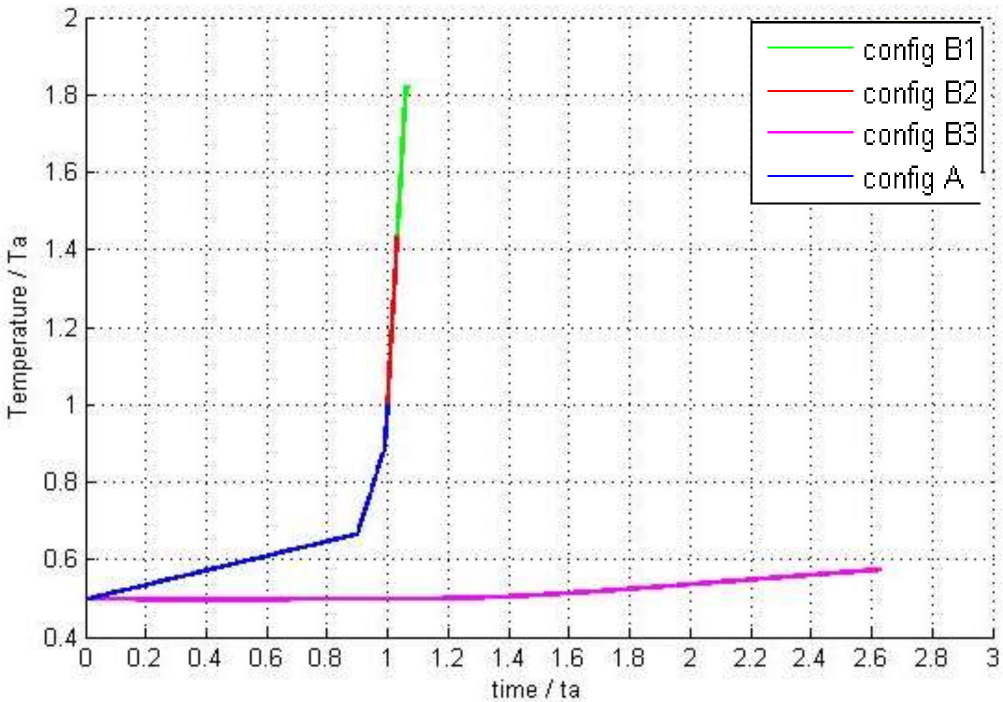
Parametric analysis results

Difference in time-to-ignition:

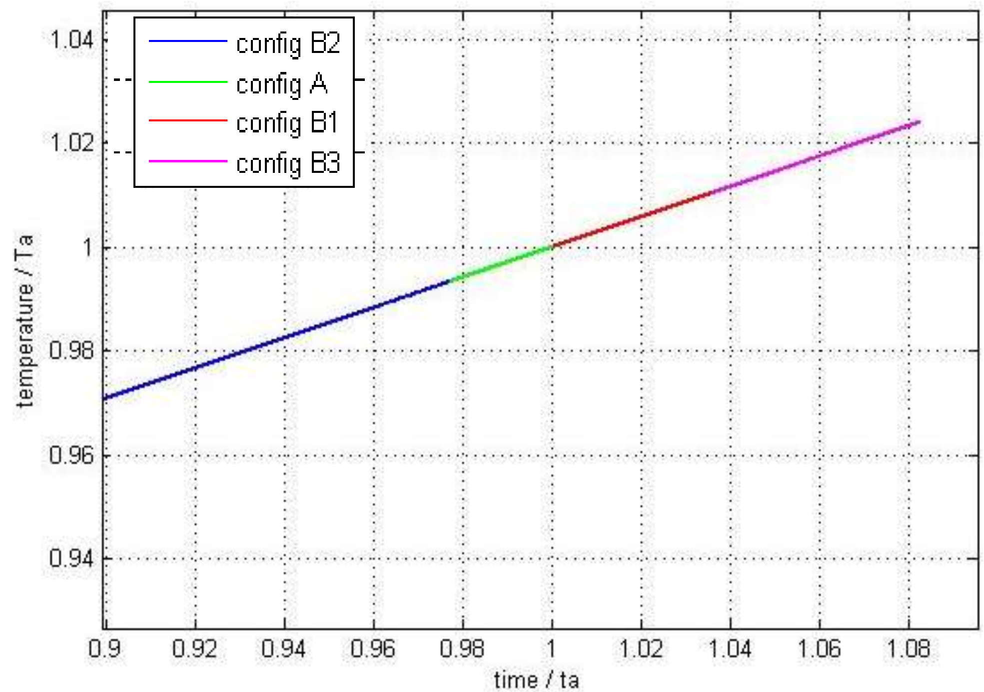
Design	Time - ta FCO	time - ta SCO
A (liner0)	0	0
liner0 +1mm	~ 0	+3.5 min
liner0 □1mm	~ 0	-2.8 min
liner0 □ 2mm	~ 0	-5.2 min
linerX	~ 0	-5.8 min
B1	+1 min	+1.4 h
B2	+0.5 min	-0.9 h
B3	+23.5 min	+3.3 h

Parametric analysis results

Difference in time-to-ignition:

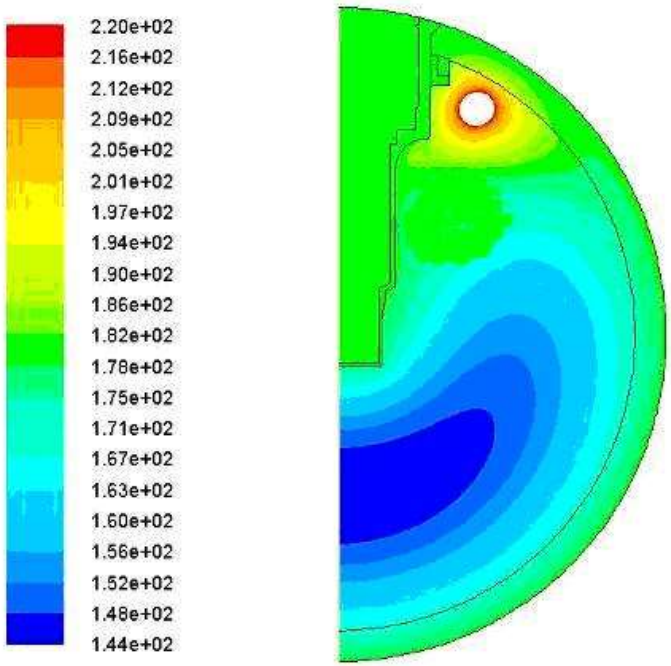


FCO

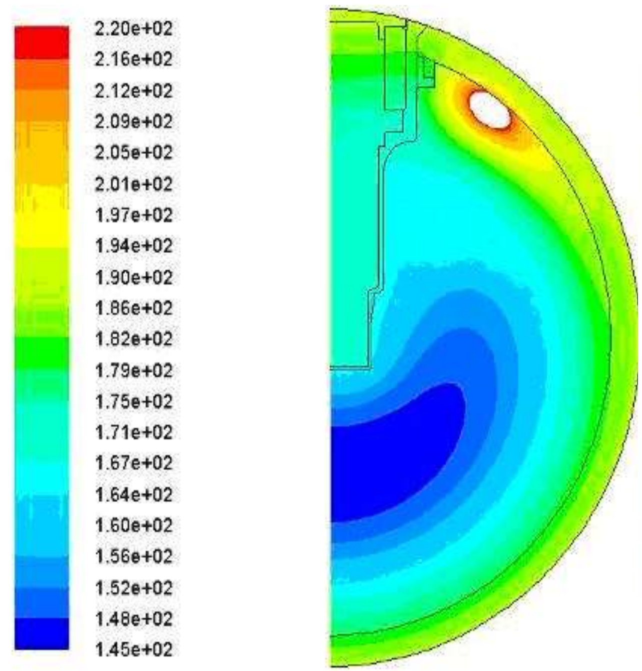


SCO

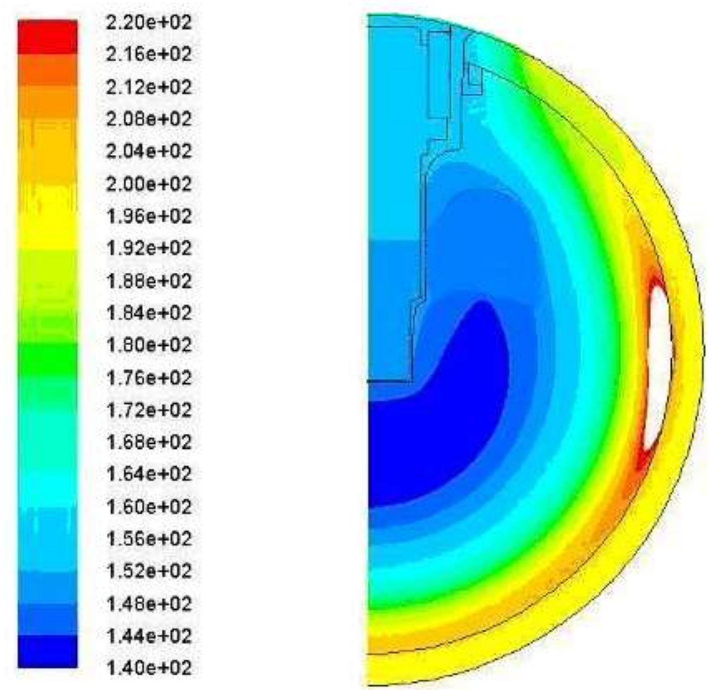
Parametric analysis results



B2



B1



B3

Conclusions

- The use of CFD models can be very helpful in the design of an IM warhead under slow and fast heating. It allows reducing costs during the testing phase.
- A sea-mine warhead (MINEA) when subjected to SCO & FCO stimuli was simulated.
- Explosive decomposition model is based in laboratory TGA on real explosive samples.
- A passive mitigation device was achieved through the design. A venting device was done through the covers.

Conclusions

- A parametric study was undertaken with different configurations to improve the IM cook-off signature.
- At the fuze cavity, the replacement of the metallic cover by a ceramic one improved the time-to-ignition safe margin.
- CFD modelling shall be validated with future experimental tests.