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Solving a tricky heavy fragment effect : approach and corrective solutions

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Summary

1. BACKGROUND

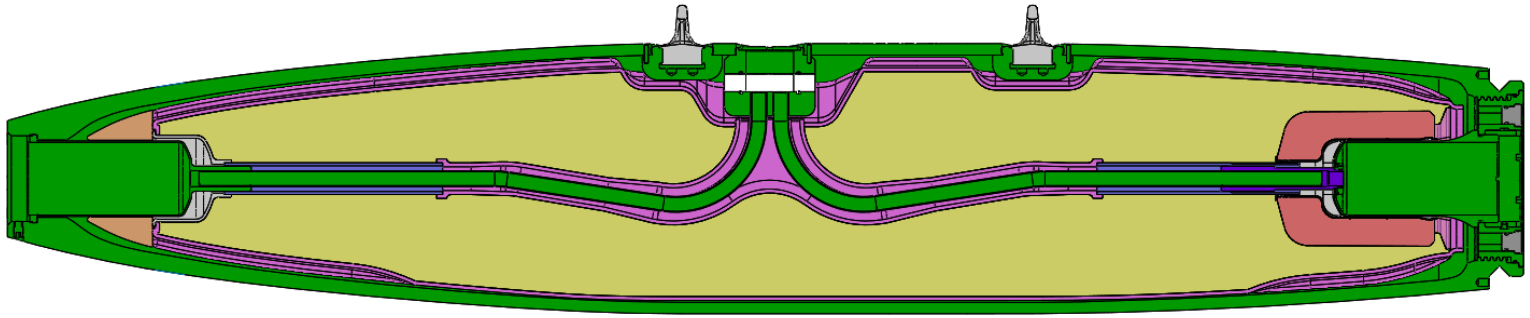
2. NUMERICAL MODELLING

3. DESIGN UPGRADE

4. CONCLUSION

CONTEXT

- Program development for DGA : bomb type MK82 (class 500 Lbs) design
- Specific insensitivity requirements :
  - **No Sympathetic Detonation (SD)**
  - **No Detonation after Heavy Fragment Impact (HFI)**
- ➔ Main charge of insensitive explosive B2268A (NTO based)
- ➔ Embedded Booster B2197A (HMX based)



BACKGROUND

- Heavy Fragment Impact requirement : Impact test on Main charge

➔ TYPE V reaction (Burn)

BACKGROUND

- Heavy Fragment Impact requirement : Impact test in booster area

➔ TYPE I reaction (Detonation)

- Test result not in accordance with tests on similar designs ➔ Numerical modeling

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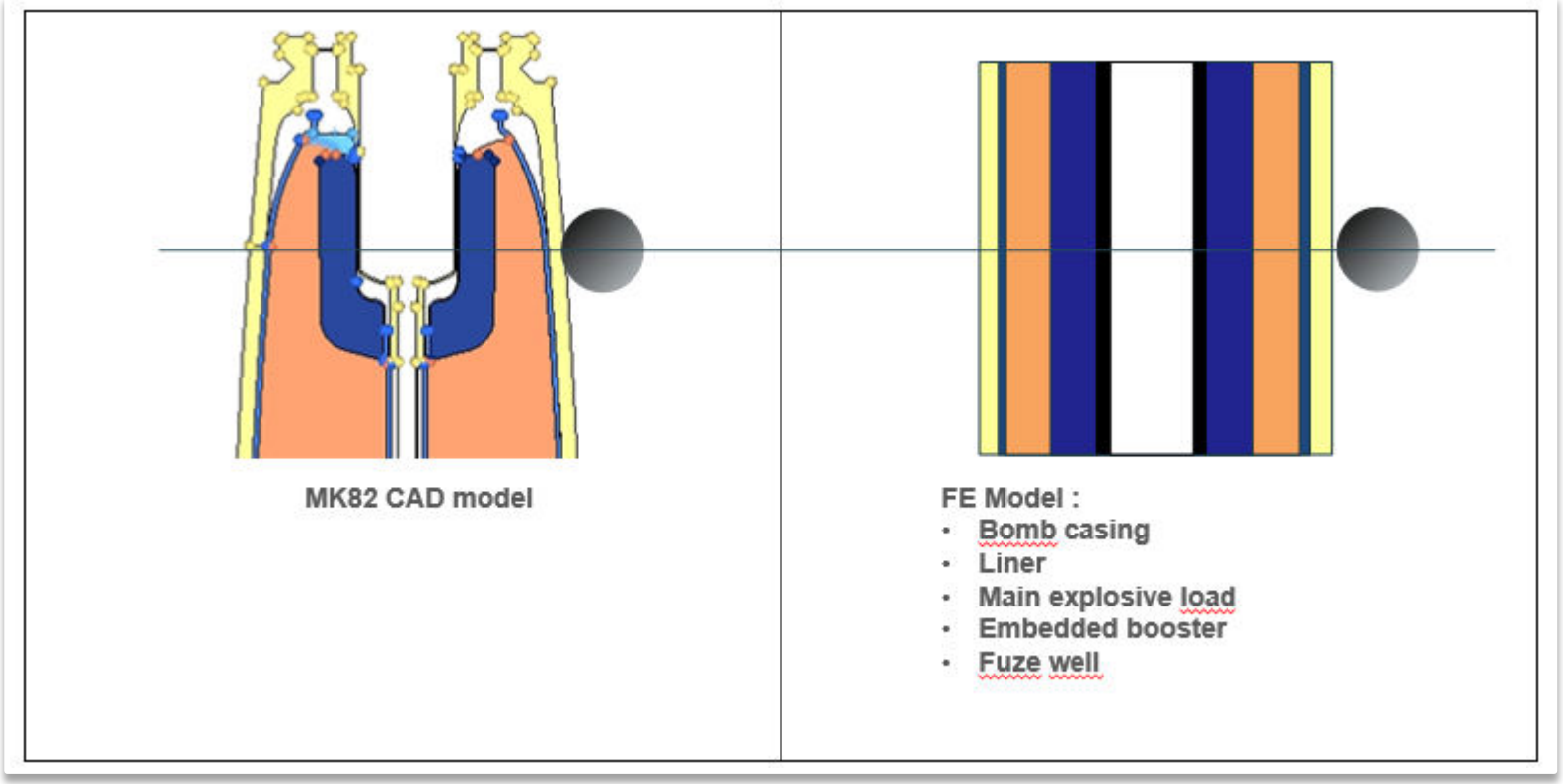
FE Modeling

- Geometry simplified with representatives thickness

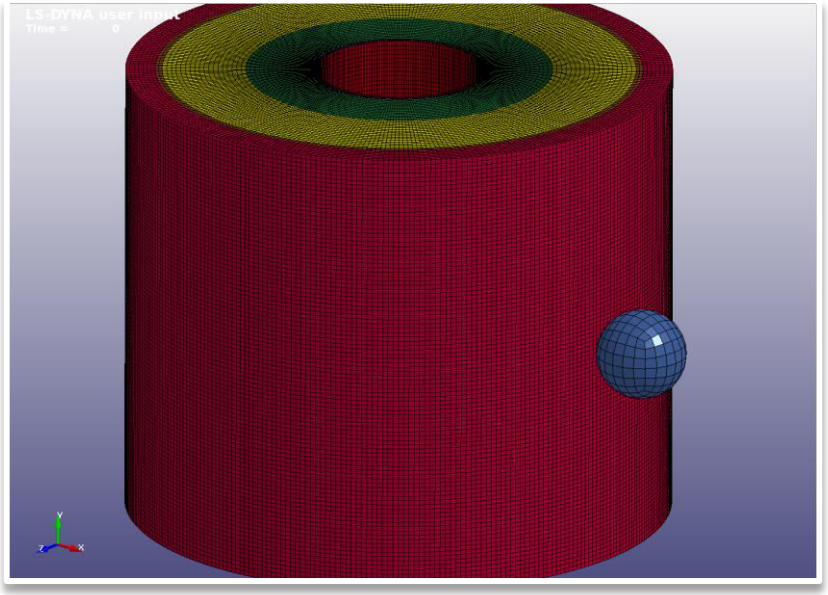


FE Modeling

- Simulation run under 3D lagrangian assumptions : the model is a 360° cylinder with a spherical steel « heavy fragment ».

	Material	Behavior law	Equation of state
Casing	Steel 4340 model	Johnson-Cook	Mie-Gruneisen
Thermal insulator	Rubber PBHT model	Elastic-plastic without hardening	
Main charge	B2268A		
Booster	B2197A (ORA86B)		
Anti-friction	Rubber type PBHT model		
Gap between fuze wall of the well and anti-friction sheet	Void		
Fuze well	Steel 4340 model	Johnson-Cook	Mie-Gruneisen
Inside of the well	Void		

Behavior laws : elastic-plastic with equation of state



FE Mesh 2mm×2mm×2mm

FE Modeling

- Behavior laws and material parameters

Steel 4340 :

Johnsonn-Cook behavior law and parameters

Mie-Gruneisen equation of state

ρ (kg/m³)	C0 (m/s)	S1	A (MPa)
7810	4578	1,33	792

$$\sigma_y = \left(A + B\varepsilon^{p^n}\right)\left(1 + Cln\dot{\varepsilon}^*\right)\left(1 - T^{*^m}\right)$$

Ruber - Santoprene : PBHT assimilated

Elastic-plastic bahavior and Mie-Gruneisen equation of state

FE erosive algorithm activated beyond ε = 500 %

ρ (kg/m³)	C0 (m/s)	S1	G (Mpa)	σ_y
920	1885	2,144	10	1

$$p = \frac{\rho_0 C^2 \mu \left[1 + \left(1 - \frac{\Gamma}{2}\right)\mu\right]}{\left[1 - (S_1 - 1)\mu\right]^2} + \Gamma e$$

B2268A- B2197A(ORA86B)

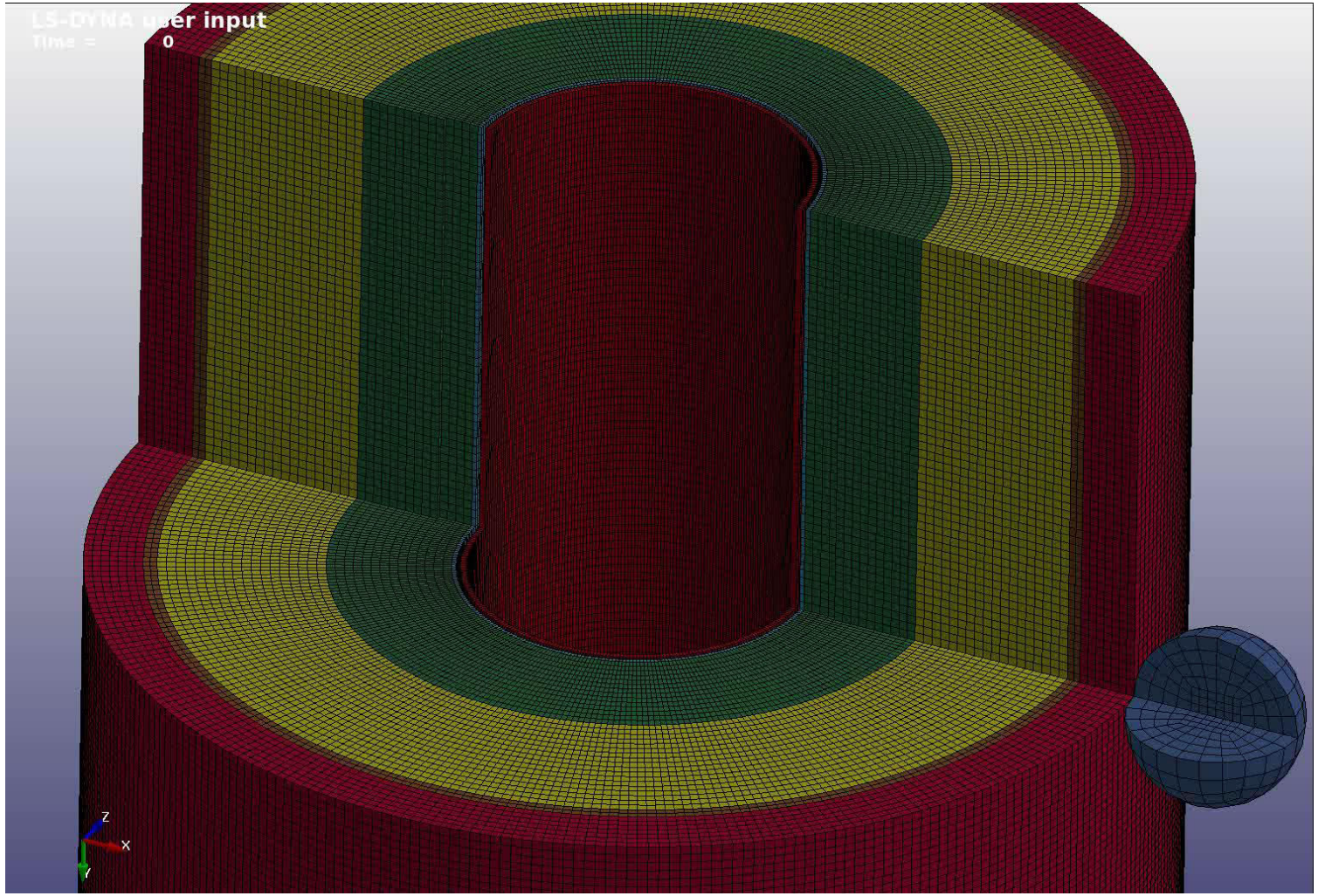
Elastic-plastic bahavior and Mie-Gruneisen equation of state

FE erosive algorithm activated beyond ε = 300 %

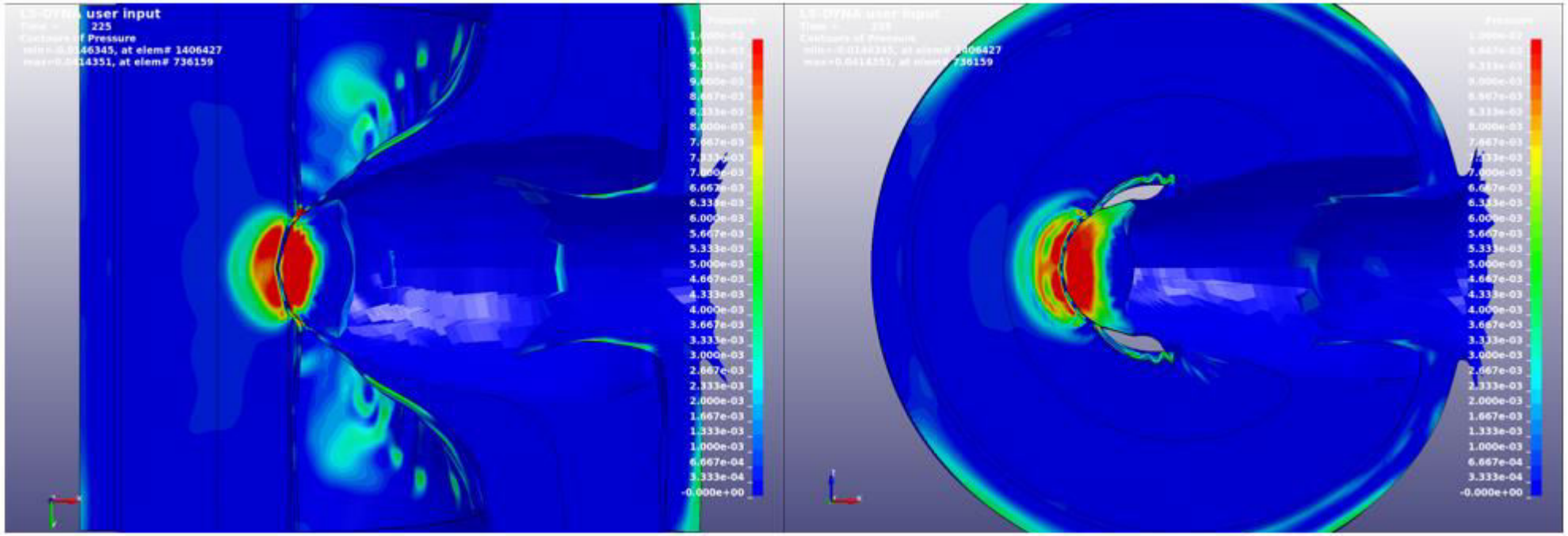
	ρ (kg/m³)	C0 (m/s)	S1	G (Mpa)	σ_y
B2268	1766	2042	2,336	10	1
B2197	1700	2211	2,715	10	1

NUMERICAL MODELING

- Impact simulation

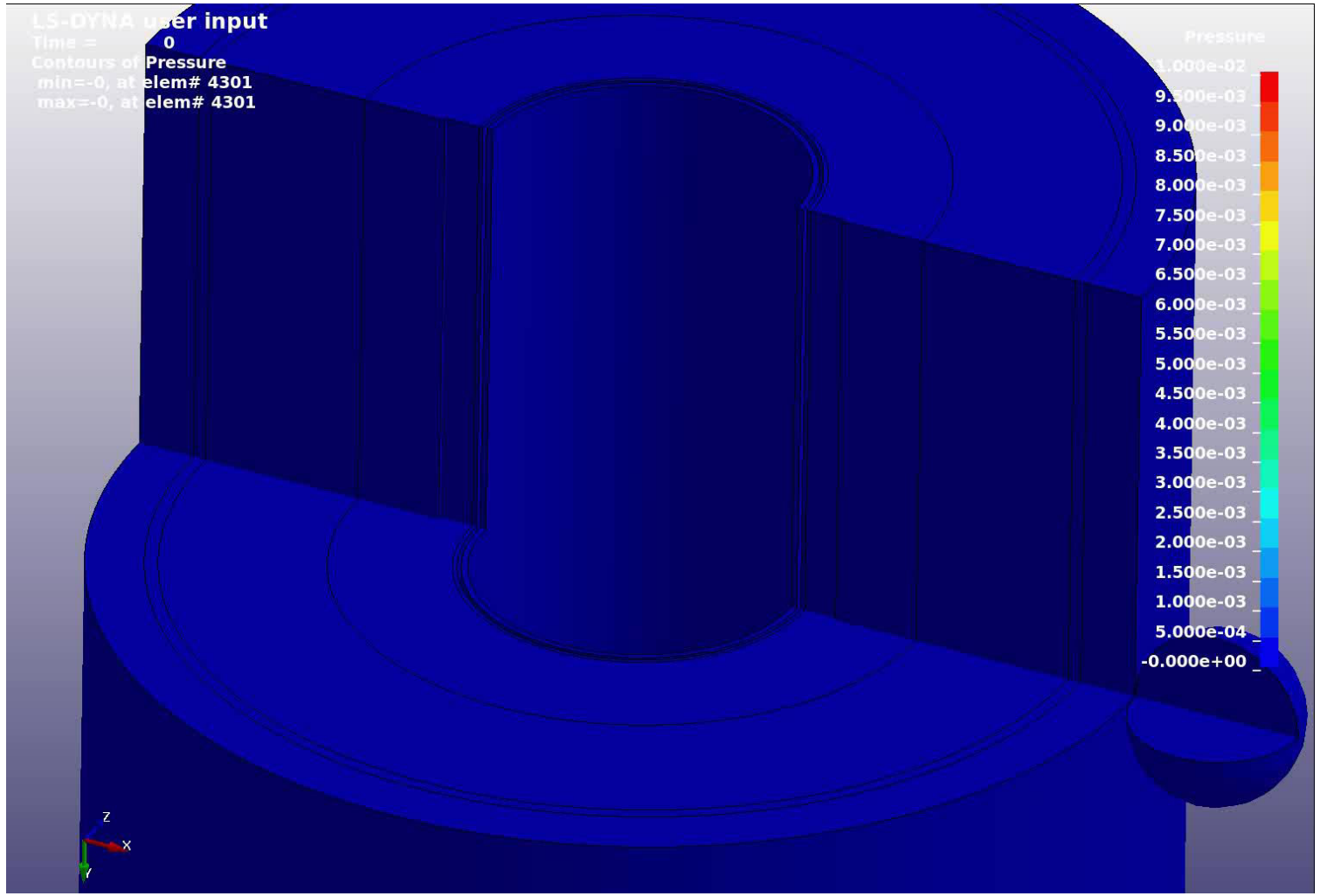


- Pressure field



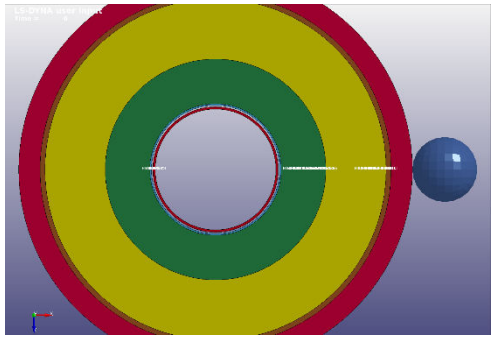
NUMERICAL MODELING

- Pressure field



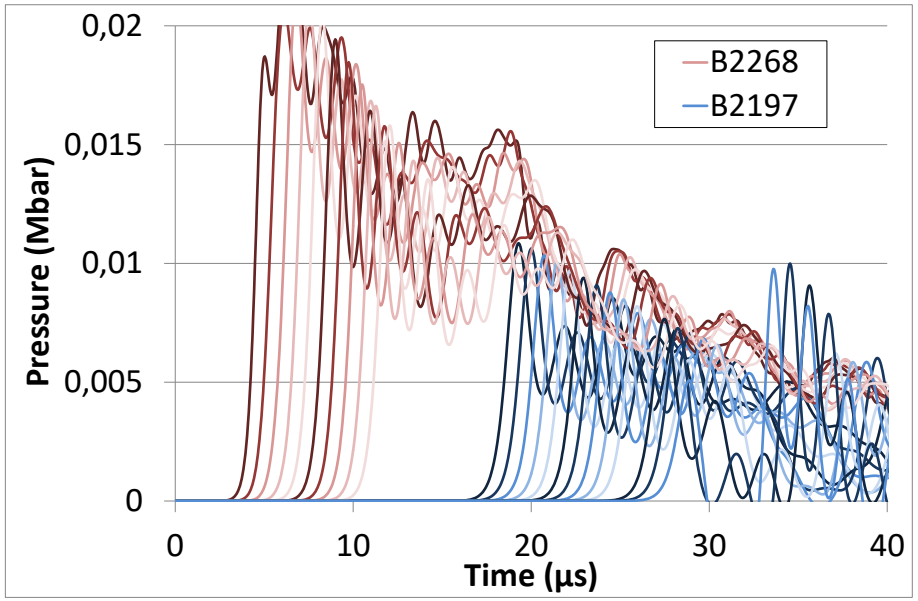
- Pressure

Monitored under the casing and at the B2268A/B2197A interface
Compared to the « Gap Test » detonation pressure criterion:

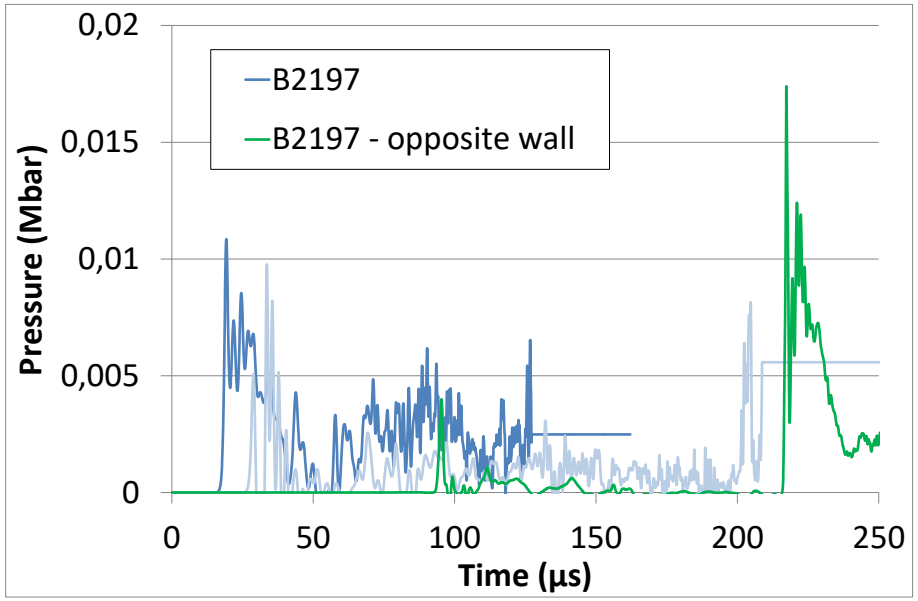


Locations of pressure probes

- **B2268A**
  - Gap Test ∅40 : 50 cards ⇔ 125kb
  - Gap Test ∅75 : 45mm ⇔ 70kb
- **B2197A**
  - Gap Test ∅40 : 160 cards ⇔ 45kb
  - Gap Test ∅75 : 90mm ⇔ 27kb



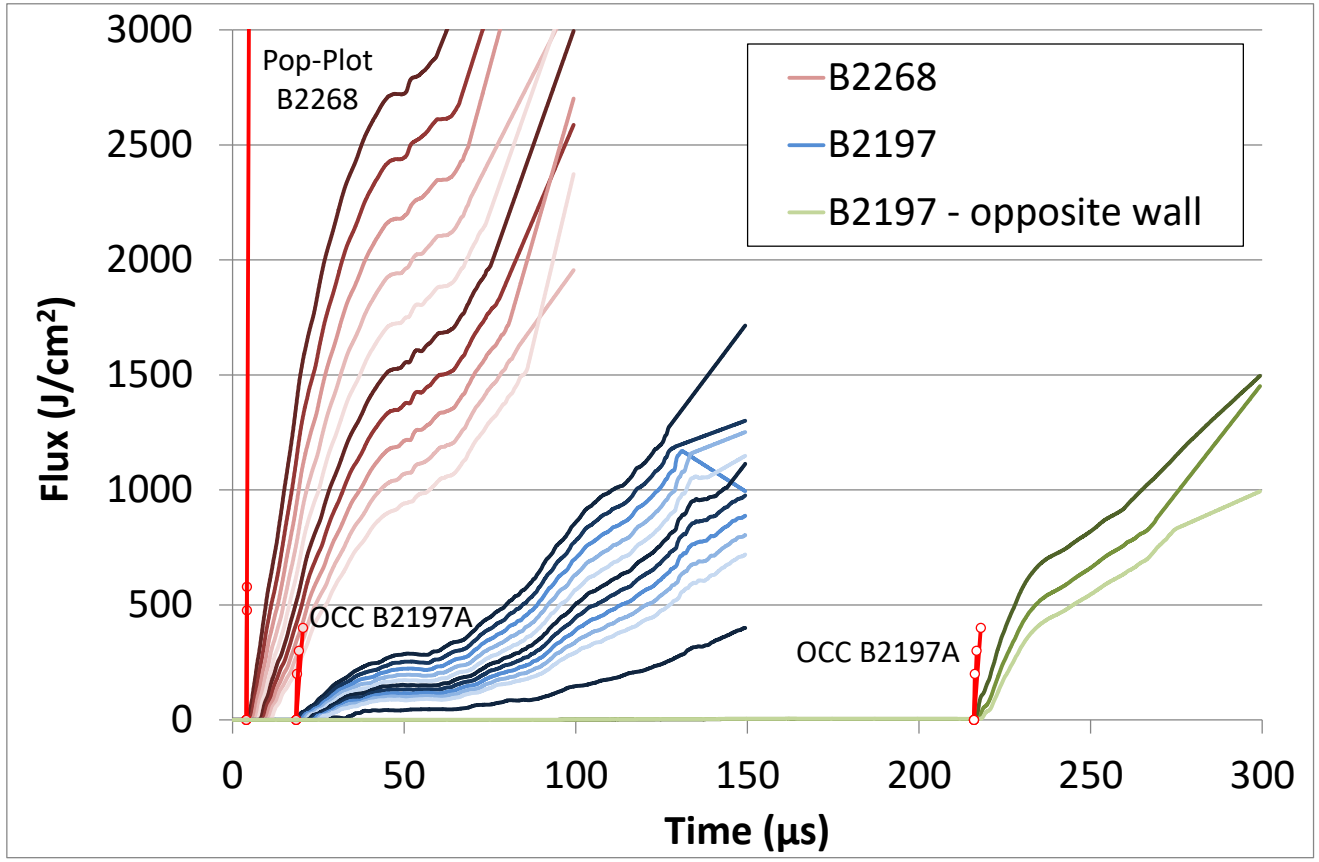
Pressure signals under casing



Pressure signals completed with the one taken on the opposite wall

- Energy flow rate

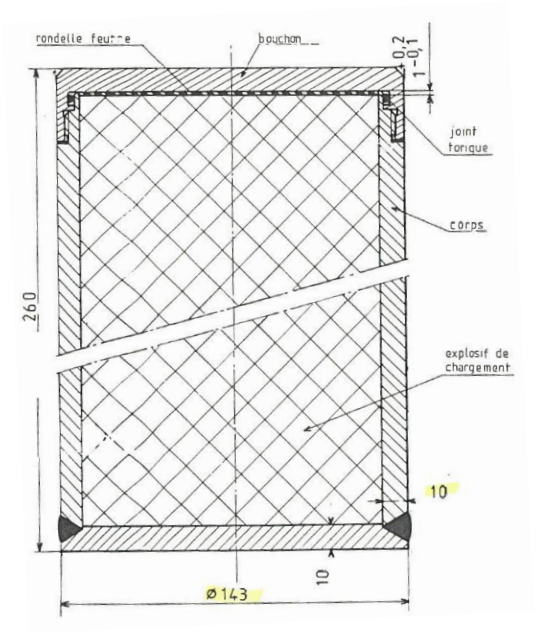
Monitored under the casing and at the B2268A/B2197A interface
Compared to the « Calibrated Shock Wave Test » and the « Wedge Test » energy criteria:

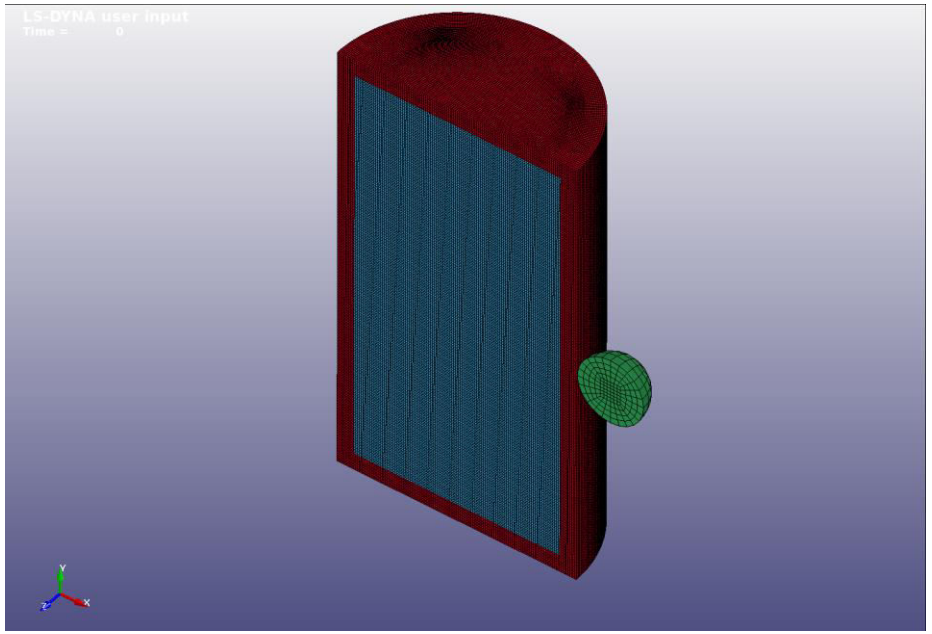


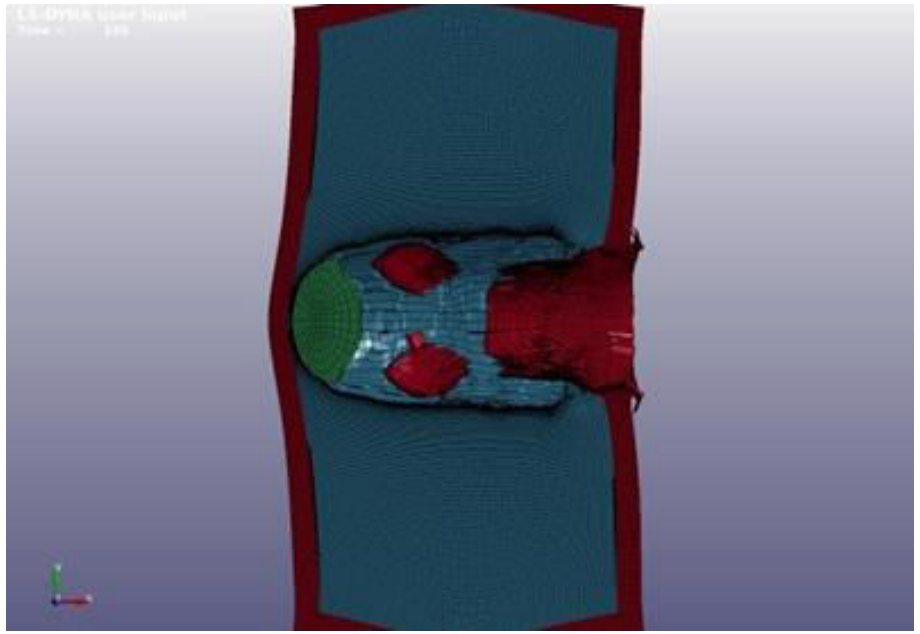
A strong energy flow rate towards the B2197A when the fuze well is collapsing around 215µs, but a significant margin compared to the required amplitude for a Shock to Detonation Transition

NUMERICAL MODELING

- Modeling validation : B2197A response under heavy fragment loading on the 3 liters mock-up

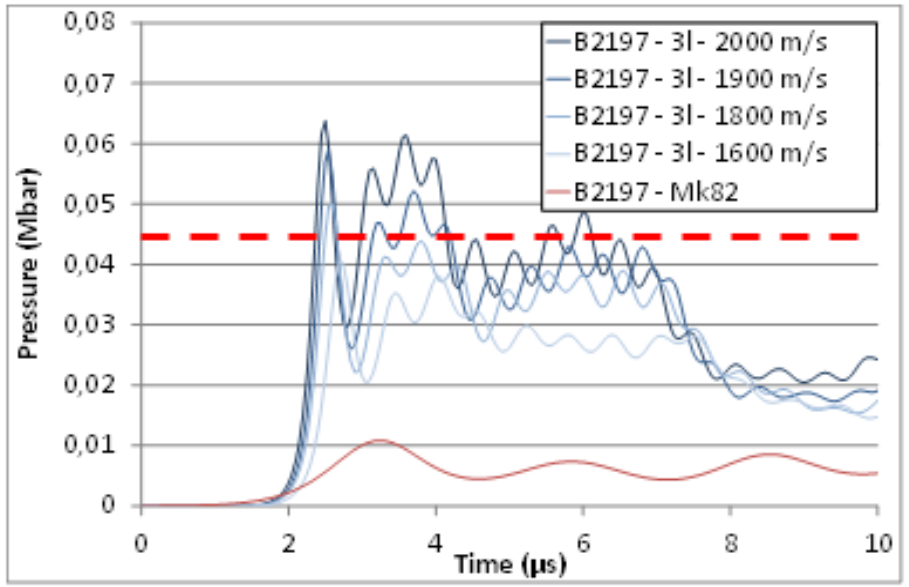


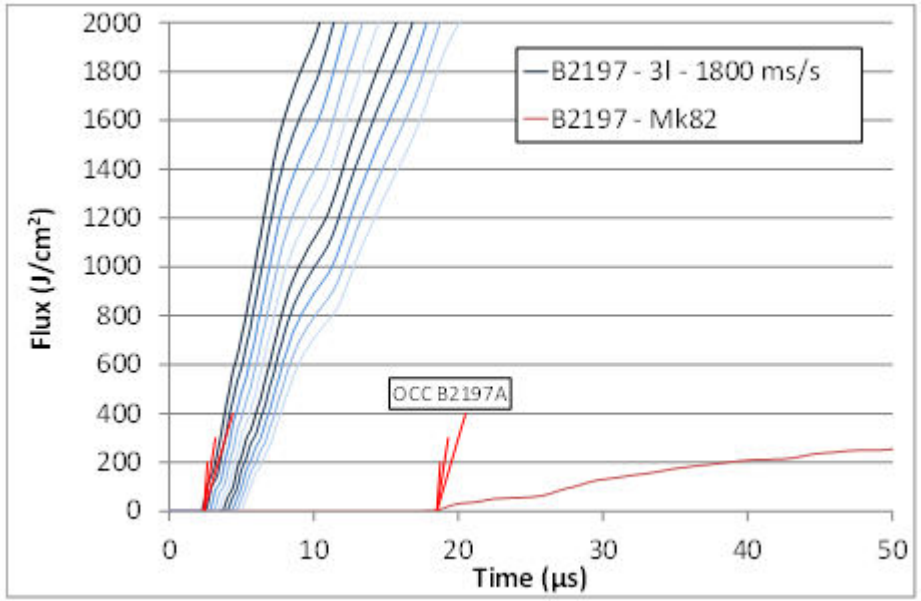




NUMERICAL MODELING

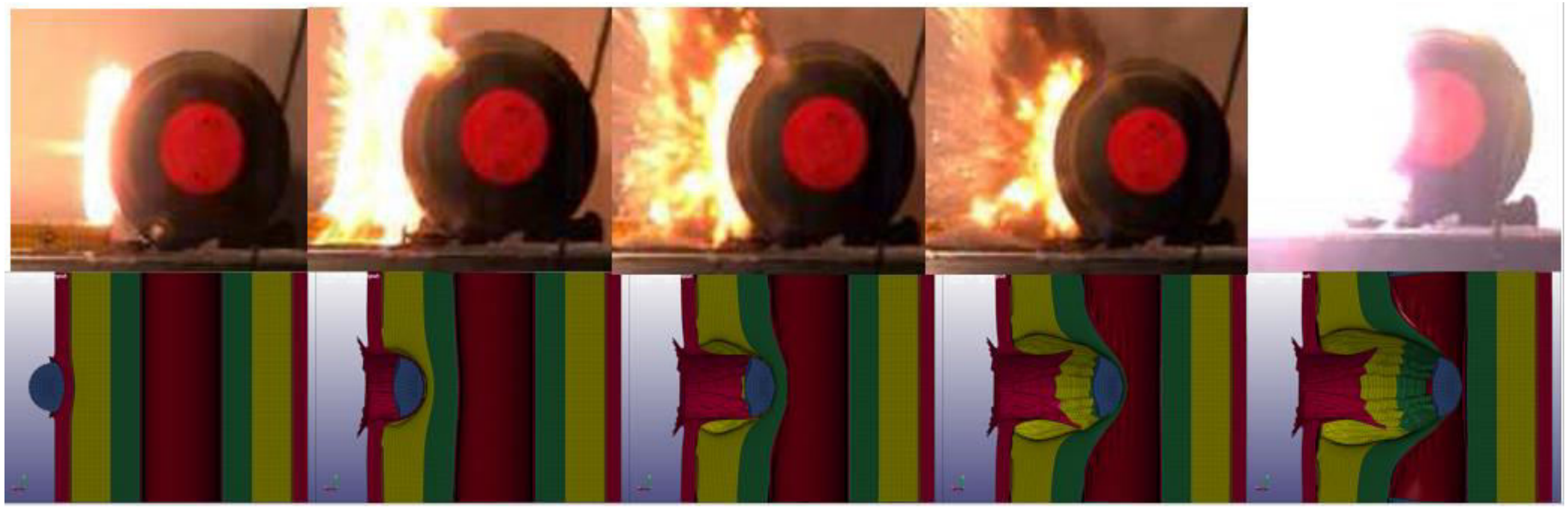
- The model predicts the impact velocity leading to B2197A detonation observed on 3 liters mock-up heavy fragment impact tests, around 1900 m/s





NUMERICAL MODELING

- Intermediate conclusion :
  - **Shock levels below the SDT criteria of the two PBXs**
  - **Detonation likely due to the second shock on the opposite fuze well wall on a damaged B2197A explosive**



DESIGN UPGRADE

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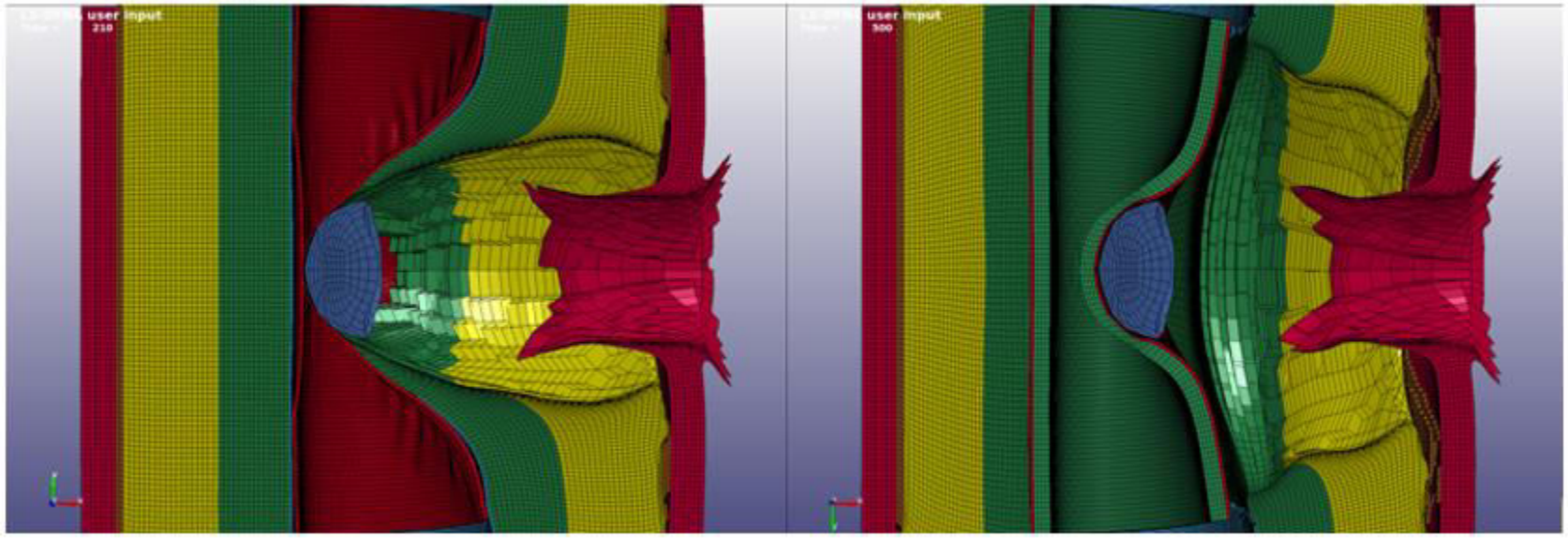
DESIGN UPGRADE

Design upgrade objective :

- Avoid the heavy fragment second sock on the fuze well opposite wall

Design upgrade mean:

- Steel hollow stiffener

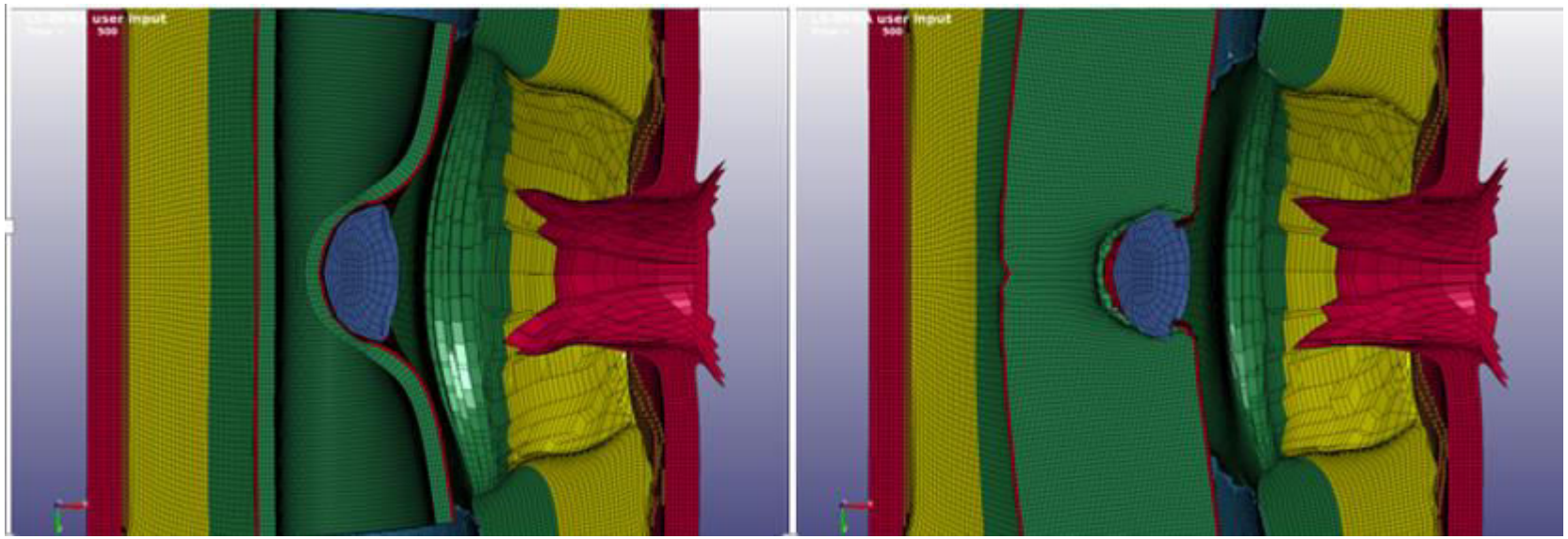


empty fuze well vs fuze well with steel stiffener

DESIGN UPGRADE

Design upgrade mean:

- Steel hollow stiffener
- Full plastic plug



fuze well with steel stiffener vs plastic plug

Design upgrade test validation :

Steel stiffener + plastic plug

Design upgrade test validation :

CONCLUSION

Numerical modeling has permitted to :

- Understand the 1rst test result and identify the root causes
- Validate the Shock to Detonation Transition (SDT) criteria
- Assess the reliability of different solutions for final choice and experimental validation

CONCLUSION : expected EG VR IM signature

Threat	Result
Fast Cook-Off	V
Slow Cook-Off	IV / V
Bullet Impact	V
Sympathetic Detonation	III
Light Fragment Impact	V
Heavy Fragment Impact	V
Shaped Charge	V

ACKOWLEDGEMENTS

- **Works performed under DGA Contract**
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A MEMBER OF

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