NUMERICAL SIMULATION OF REACTION VIOLENCE TO COOK-OFF EXPERIMENTS

David DESAILLY - Yves GUENGANT

SNPE Matériaux Energétiques - France

CONTENTS

WHAT ARE THE STAKES ?

BURNING

DETONATION

THERMAL SOURCE ACCIDENTS

Forestall aircraft carrier

DOHA camp

- Many research programs have been investigated at SME to reduce vulnerability of systems to accidental and hostile environments

FINANCIAL SUPPORT

- Sponsored by D.G.A. of the French Ministry of Defence
- Supported by the European consortium EUCLID CEPA14 RTP2

« Develop and evaluate test methods and computer models for predicting the response of generic explosive-loaded munitions »

SME METHODOLOGY

KEY STEPS - MAIN IDEAS

Predict the mechanical behaviour of systems subjected to thermal threats

- Characterisation tests on energetic material samples :

SELF-HEATING ⇔ LOSS OF MASS (POROSITY) ⇔ REACTIVITY

- Physical model establishment - Fitting of numerical parameters

- Implementation of this physical model within Finite Elements code

HYPOTHESES - NUMERICAL TOOLS

- Simulating the response of systems subjected to a thermal conditioning requires thermo-chemical and structural analyses

- **MODEL FEATURES :**

  - *Accelerated combustion regimes*

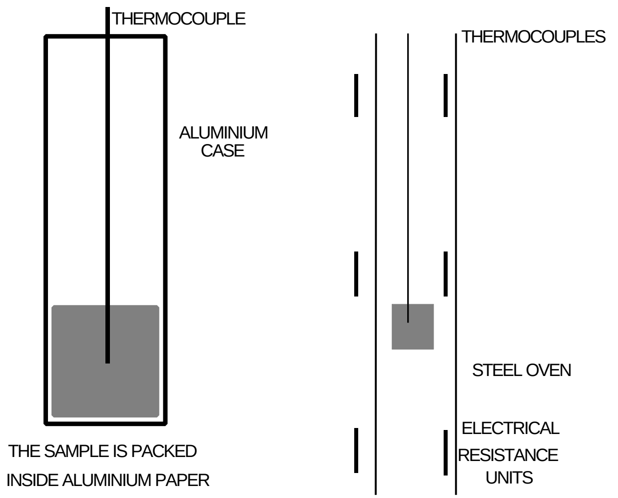
  - *Thermal damage prior ignition is a key parameter to reaction violence level*

ABAQUS / LS-DYNA

WEAK COUPLING

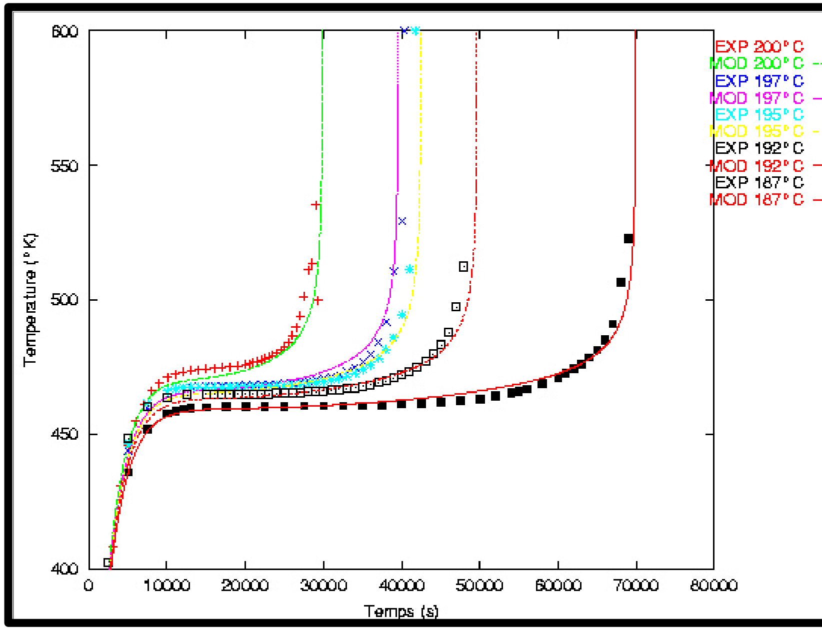
COOK-OFF EXPERIMENTS FOR MODELS

SELF- HEATING / THERMO- IGNITION (1)



SNPE n°41/ GEMO SEN307-00

Temperature history



Energetic materials can exhibit endothermic and exothermic decomposition processes

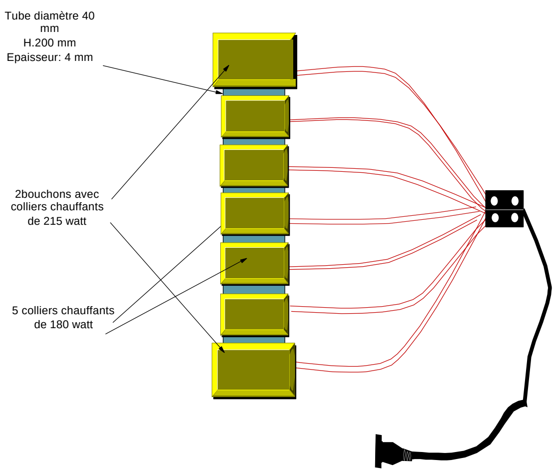
SELF- HEATING SIMULATION via ABAQUS

- Reactional scheme : three steps Arrhénius law

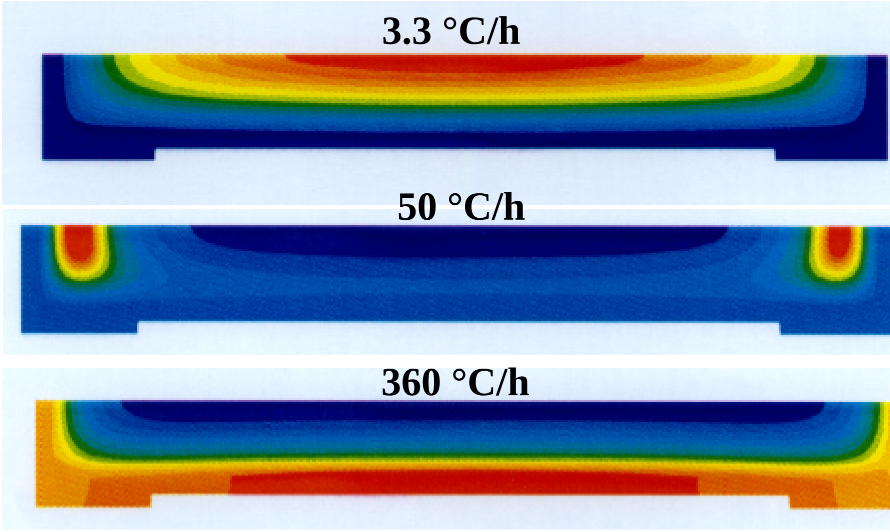
$$A \xrightarrow{REACTION\quad 1} B \xrightarrow{REACTION\quad 2} C \xrightarrow{REACTION\quad 3} D$$

$$Q_1 > 0 \qquad Q_2 < 0 \qquad Q_3 > 0$$

un tube ONU résistance 750 bars
et 2 bouchons résistance 450 bars

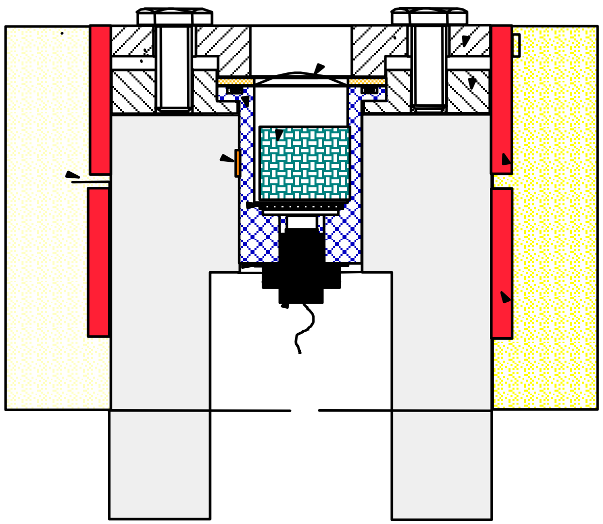


Ignited region prediction



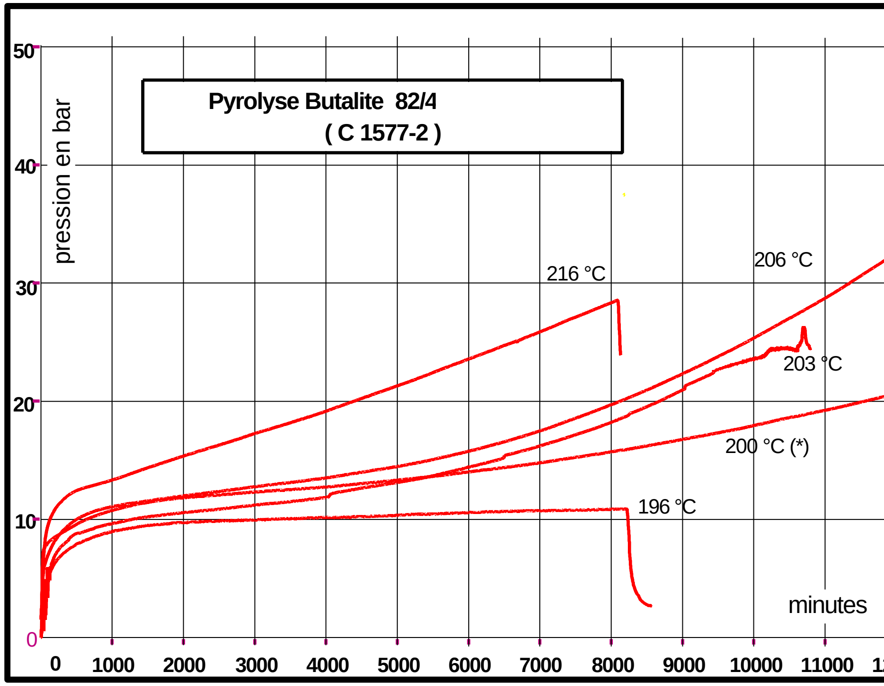
UNDER CONFINEMENT PYROLYSIS TEST (2)

- Quantify loss of mass and increase of pressure



SNPE pyrolysis set-up

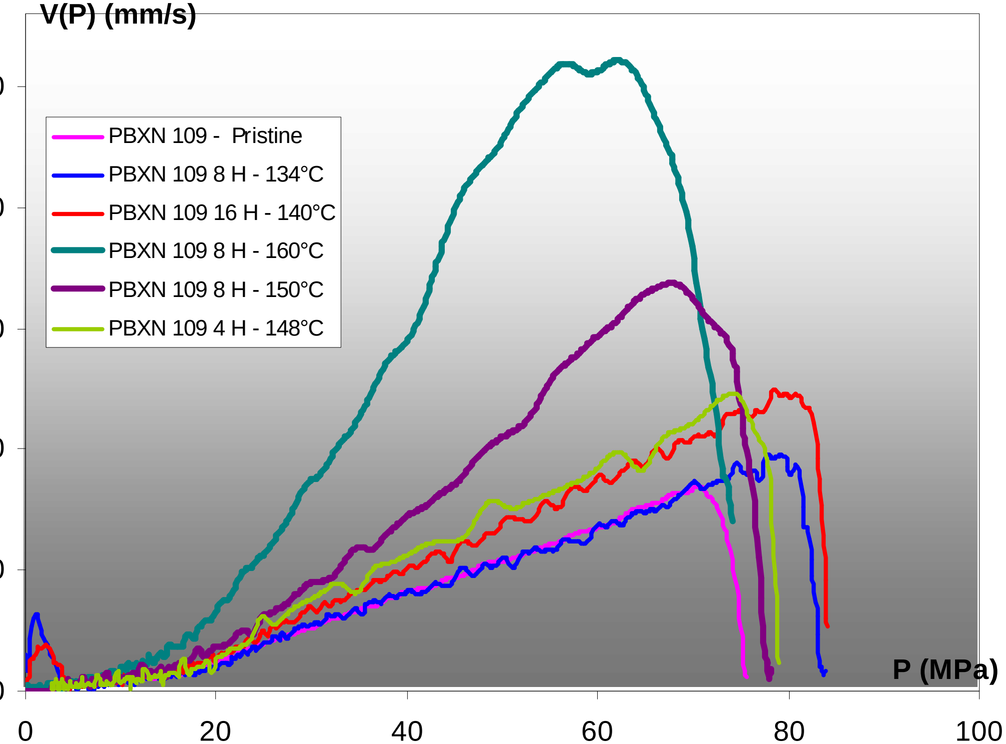
Pressure increase



- Fit the kinetic parameters

HIGH PRESSURE CLOSED VESSEL BOMB (3)

- Trials are performed in a HPCV Bomb under temperature control
- Effect of thermal damage γ on an explosive composition reactivity :



$$V_r(g) = a(g)P^{n(}$$

porosity Û reactivity

COUPLED STRUCTURAL/BURNING MODEL V.R.E.M.E.

Physical representation :

- Two-phases flow model with compressible solid and gas phases

$$p = A\left(1-\frac{w}{R_1V}\right)e^{-R_1v} + B\left(1-\frac{w}{R_2V}\right)e^{-R_2V} + \frac{we}{v}$$

- Laws of mixture : pressure equilibrium - additivity of volumes and internal energ

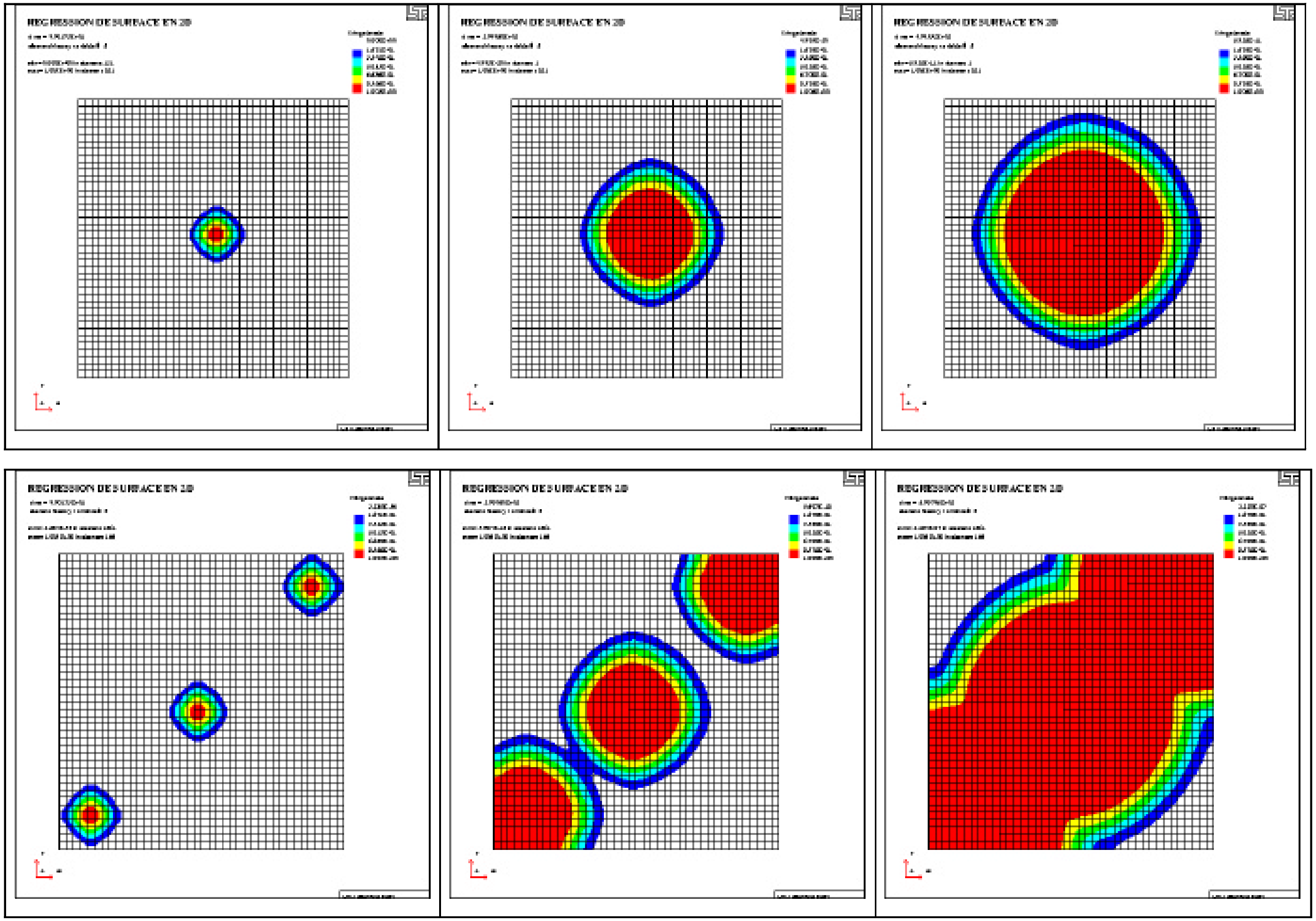
$$v = \sum x_i v_i = (1-F)v_1 + Fv_2$$
$$e = \sum x_i e_i = (1-F)e_1 + Fe_2$$

- Burning : surface regression model

- FOG method : $\frac{dF}{dt} = aV_r(g)$

- « Level - Set » method (front « capturing » approach) : $\frac{\partial F}{\partial t} + \vec{u}.\vec{\nabla} F = V_r(g)\left\|\vec{\nabla} F\right\|$

SURFACE REGRESSION (HAMILTON - JACOBI)

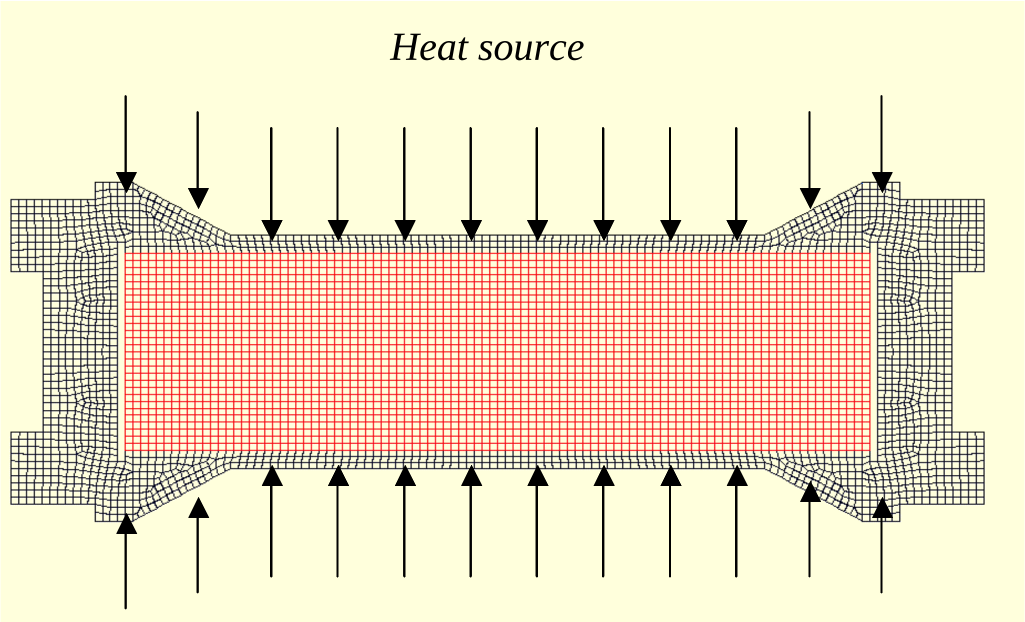


SIGNIFICANT RESULTS

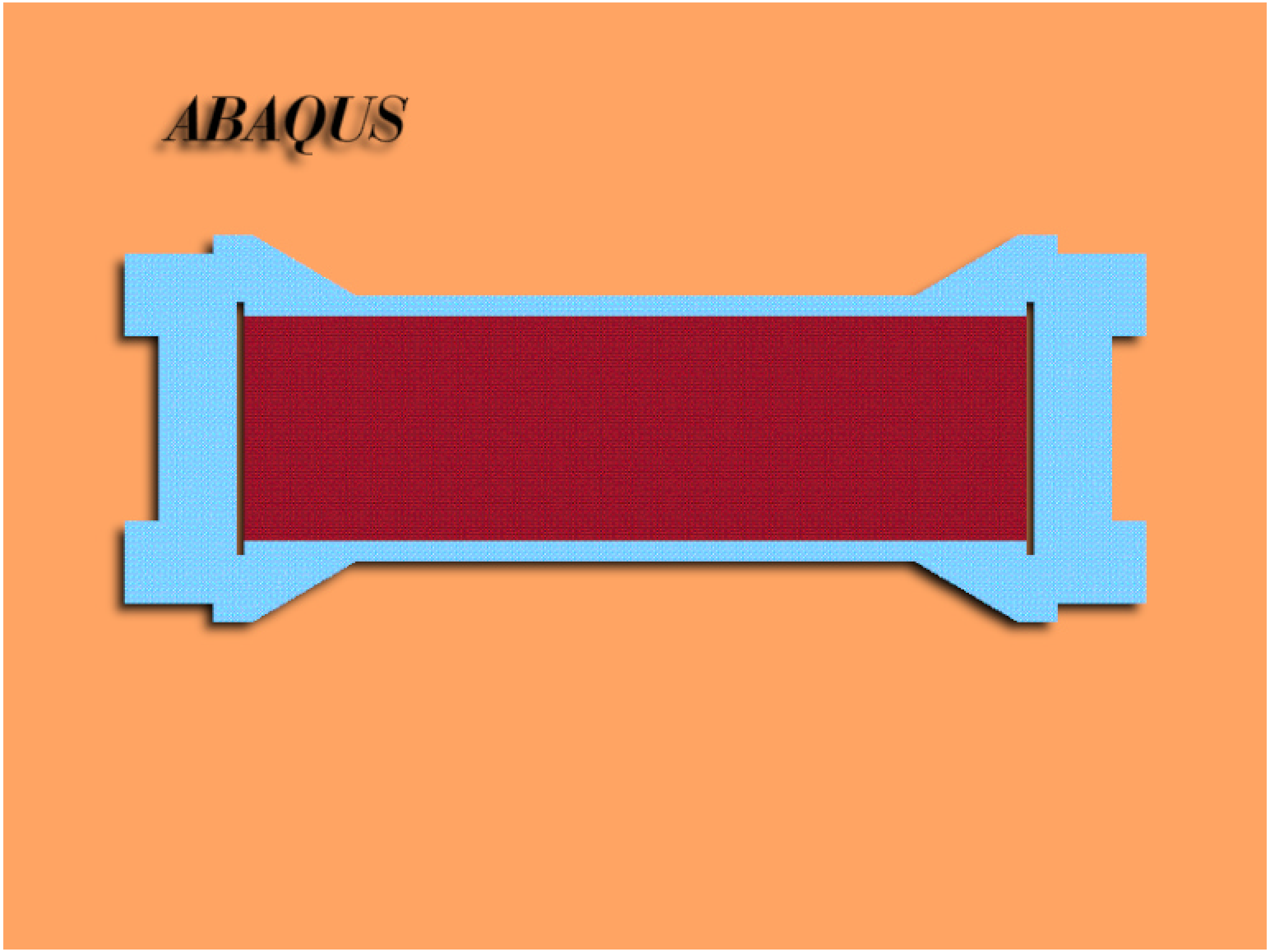
(Application to large scale tests)

VIOLENCE PREDICTION TO FAST HEATING RATES

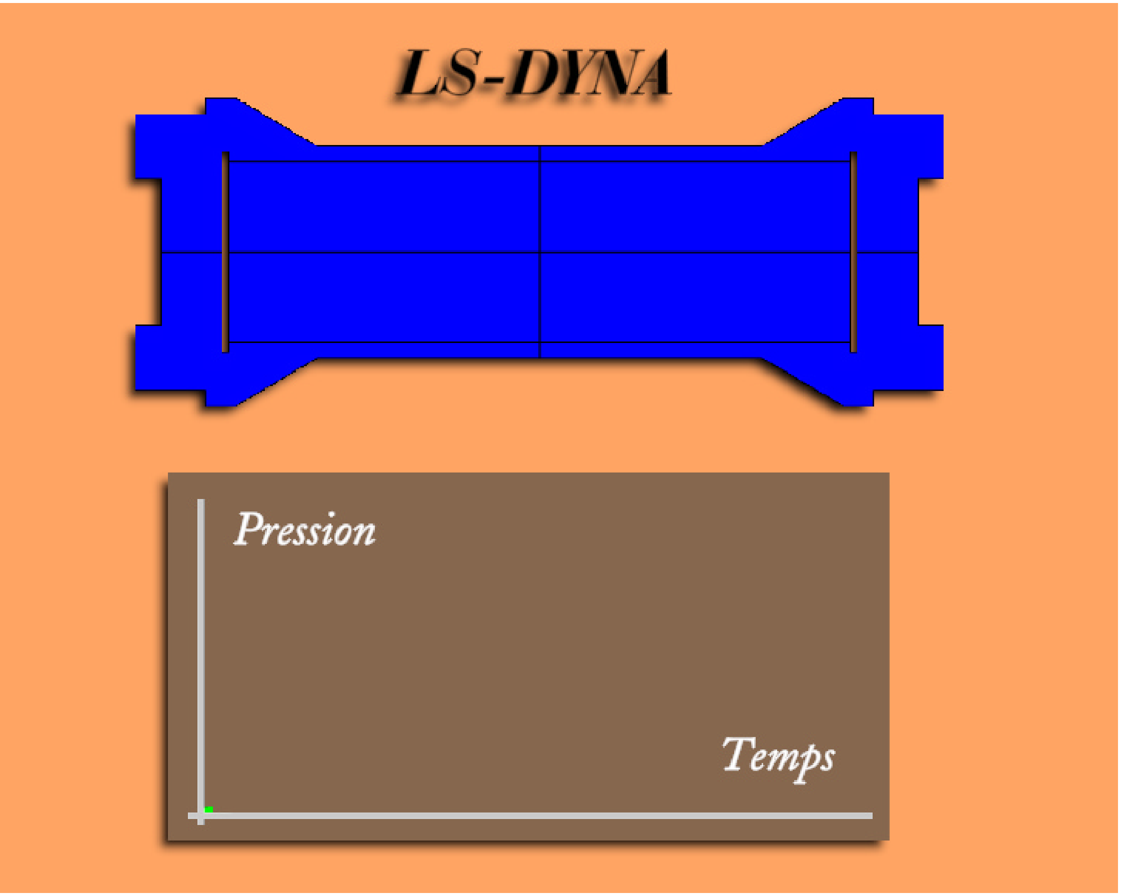
- Description - boundary conditions
  - Energetic material : B2238 explosive (RDX, PBHT binder)
  - Thermal conditioning : fast cook-off conditions (heating profile 360 °C/h)



Significant resu



Significant resu

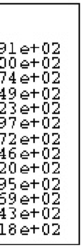


FRACTURE
IN THE MIDDLE PLANE

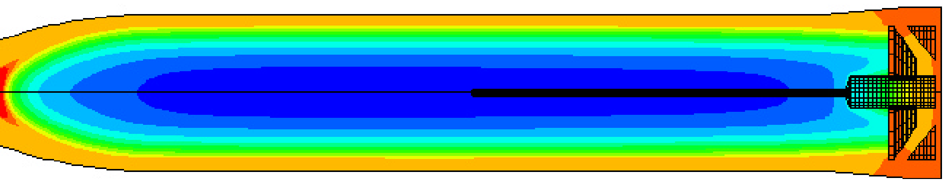
WARHEADS BEHAVIOUR TO SLOW HEATING RATES

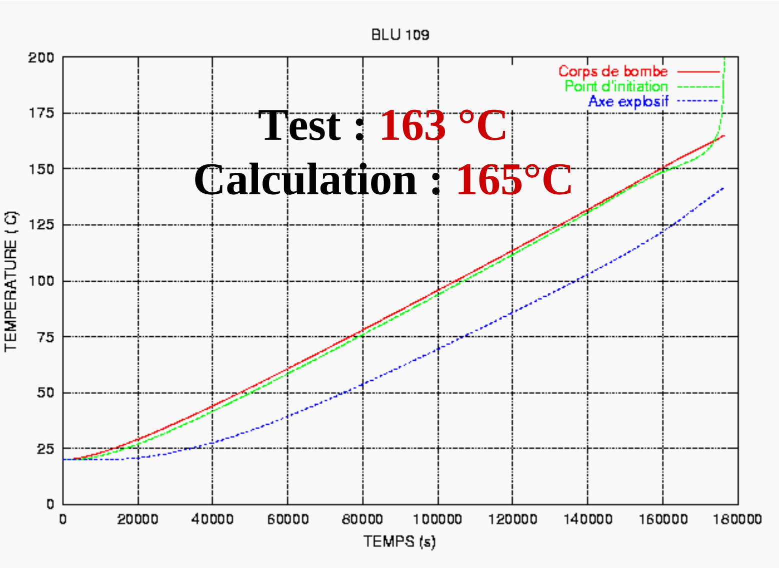
- Full-scale warhead - Strong confinement
- Energetic material : PBXN109/SNPE explosive (I-RDX® based)
- Thermal conditioning : slow cook-off conditions (heating profile 3.3 °C/h)

I-RDX BASED WARHEAD – THERMO-CHEMICAL ANALYSIS

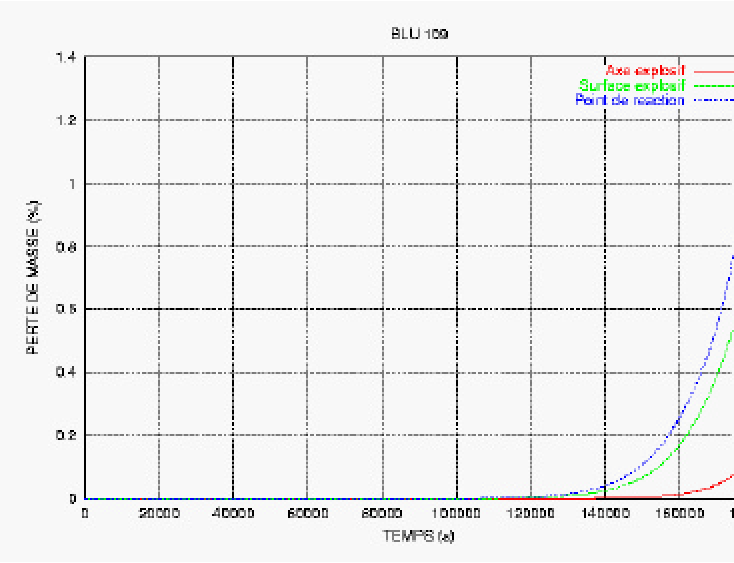


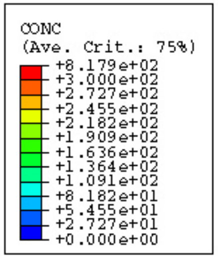
Temperature

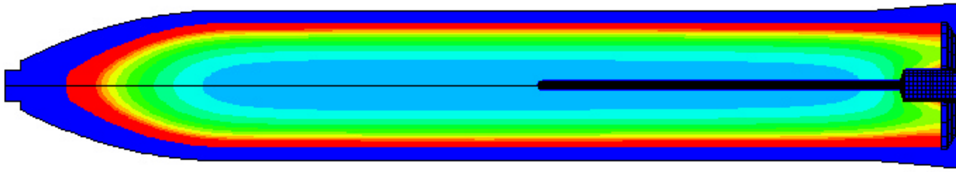




Mass loss



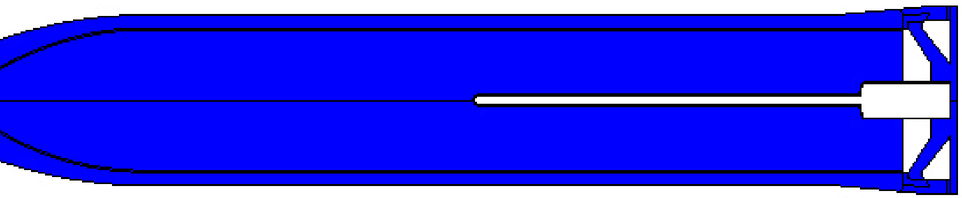


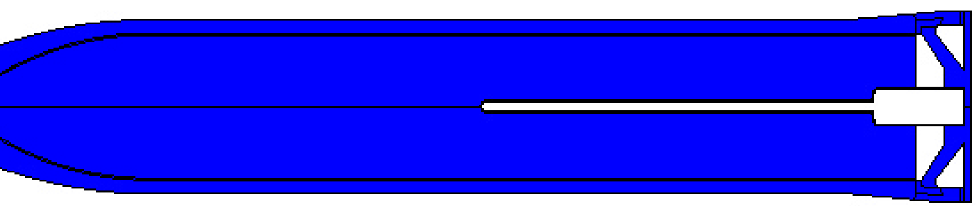


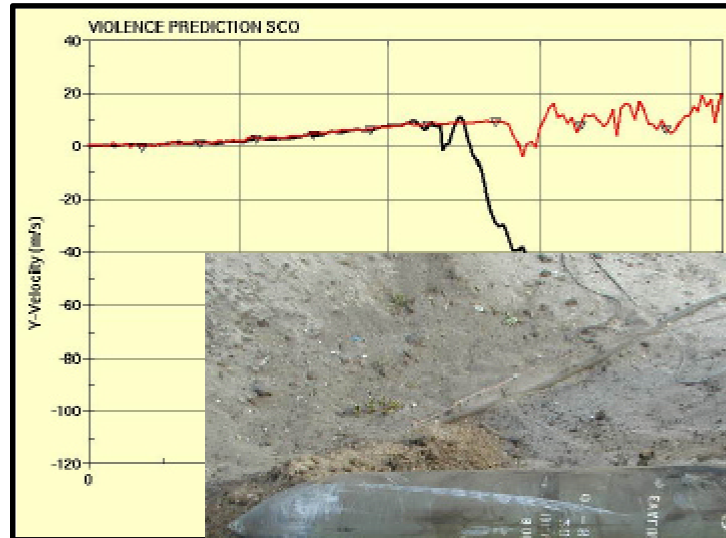
Step: Step-1
Increment 1805: Step Time = 1.7650E+05
Primary Var: CONC

E – SCO – BLU109
0

I-RDX BASED WARHEAD - VIOLENCE LEVEL







NON -VIOLENT EVENT

TYPE IV REACTION

CONCLUSIONS

FUTURE PLANS

ACHIEVEMENTS

➪ SNPE developed a methodolgy for predicting the violence level of systems submitted to a thermal threat :

- Characterisation tests on samples of energetic material
- Fitting of the numerical model parameters
- Prediction of the reaction violence of multi-dimensionnal systems (ABAQUS / LS-DYNA)

In combustion modes, we can estimate :

PRESSURISATION & EXPANSION VELOCITY ⇨ ***REACTION TYPES III, IV, V***

RESULTS ACCURACY

- Thermochemical processes : good agreement with tests (< 5 % variations) for explosive and propellant
- Violence level prediction : need a validation phase by precise measurement

Moderate reaction due to good microstructural and morphological properties of PBXN109/SNPE explosive (I-RDXÒ based)

FURTHER WORK

- Improve the model by incorporating physical components for simulating more violent events (DDT for instance)

REACTION TYPES
I, II, III, IV, V