GENERAL DYNAMICS
Ordnance and Tactical Systems–Canada

Modeling of Variable Confinement Cook-Off Test (VCCT)

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Ordnance and Tactical Systems–Canada

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Outline

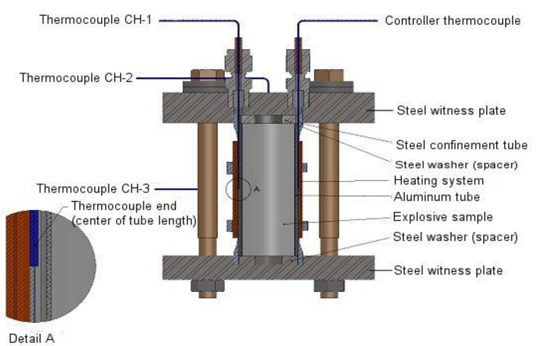
- Introduction
- Variable Confinement Cook-Off Test
- Multiphysics and Simulation software
- Simulation Model
- Tests and results
- Conclusions
- On-going and future work

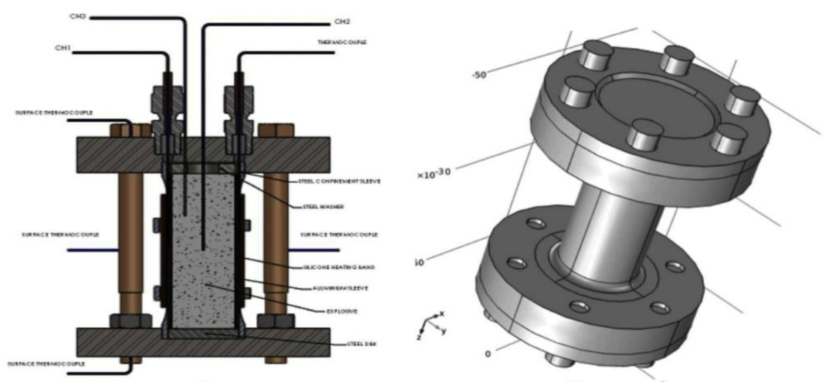
Introduction

- Cook-off is a major stimuli for insensitive munitions testing
  - Threat present in all the parts of munitions life cycle as observed in different thread hazard analyses
- Difficult to obtain actual data of temperature inside the tested object (Mainly for fast cook-off)
- Testing is expensive
  - Cost of fuel for fast cook-off
  - Long test for slow cook cook-off
- Small scale tests
- Computer simulation
  - Additional data for better understanding
  - Mulitiphysics code: Coupled heat transfer and solid mechanics
- Ultimate goal: Simulation of cook-off in full munitions

Variable Confinement Cook-off Test (VCCT)

- **Defined in STANAG 4491**
- **Small sample (Typically 50 grams of explosive)**
- **Two configurations were simulated with two heating rates**
  - **Standard STANAG 4491**
  - **Modified design to be presented in paper #16080**
  - **Fast cook-off and intermediate cook-off (25°C/hr) after soaking at 108°C**
  - **Different melt-pour and cast-cure explosives**





a) b)

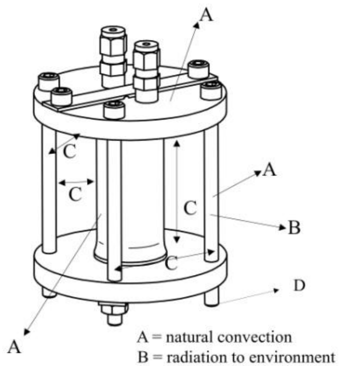
Multiphysics and Simulation software

- **Multiphysics**
  - **Capabilities to conduct joint study /simulation of multiple physical phenomena: heat transfer, solid mechanics, chemical reactions**
  - **No need to transfer data between software**
- **COMSOL Multiphysics:**
  - **Finite element analysis, solver and simulation software/FEA package with preprocessing and postprocessing capabilities**
  - **Personal definition of the equations /models to be used by entering coupled systems of partial differential equations**
  - **Toolboxes available for various physical phenomenon**
  - **Interface to MATLAB**
  - **Previously known as FEMLAB**

Simulation model

- Transport phenomena
  - Three modes of heat transfer considered
  - Heat diffusion through a solid (3D generalized Fourier law)

$$\rho C_p \frac{\partial T}{\partial t} = k \nabla^2 T$$



A = natural convection
B = radiation to environment
C = surface to surface radiation
D = thermal conduction

  - Density, heat capacity and conductivity functions of temperature
  - Thermal boundaries definitions:
    - Solid to solid with negligible thermal resistance
    - Solid to solid with thermal resistance
    - Solid to fluid
  - Z-component equation of motion

$$\frac{\partial v_z}{\partial t} + \underbrace{v_r \frac{\partial v_z}{\partial r} + \frac{v_\theta}{r}\frac{\partial v_z}{\theta} + v_z \frac{\partial v_z}{\partial z}}_{inertia} = \underbrace{g\beta\left(T - T_\infty\right)}_{buoyancy} + \underbrace{\frac{\mu}{\rho}\frac{\partial^2 u}{\partial y^2}}_{viscous\ forces}$$

  - Energy equation

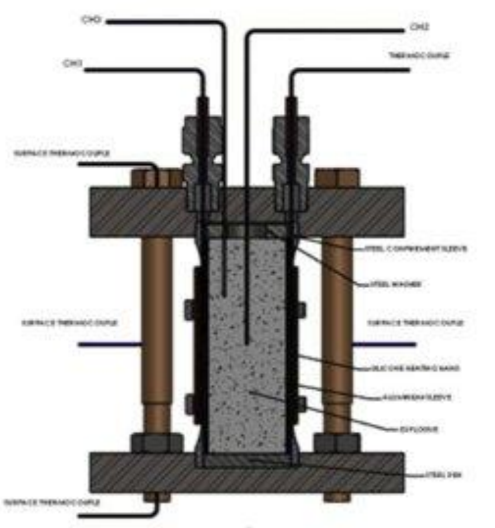
$$\frac{\partial T}{\partial t} + \underbrace{v_r \frac{\partial T}{\partial r} + \frac{v_\theta}{r}\frac{\partial T}{\partial \theta} + v_z \frac{\partial T}{\partial z}}_{convection} = \underbrace{\frac{k}{\rho C_p}\left[\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial T}{\partial r}\right) + \frac{1}{r^2}\frac{\partial^2 T}{\partial \theta^2} + \frac{\partial^2 T}{\partial z^2}\right]}_{conduction}$$

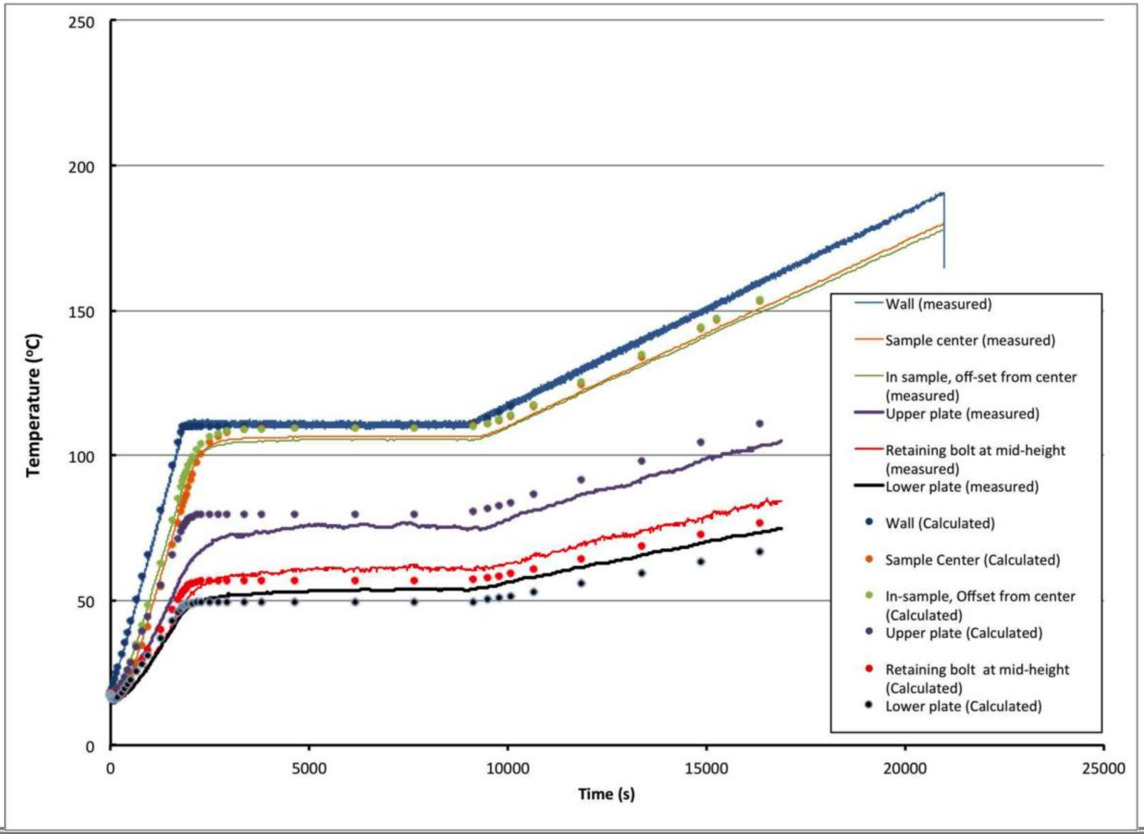
Simulation model

- Melt-Pour explosives
  - Smoothed time function for viscosity to approximate melting process with discontinuity in specific heat to account for large amount of energy
- Decomposition process
  - Cast-cure explosive: Data based on paper on PBXN-109 decomposition (McClelland et al.)
  - Melt-pour explosives: Kinetic information based on DSC test
    - Applicability and limitations still under study
    - Subject of a future presentation

Tests and results

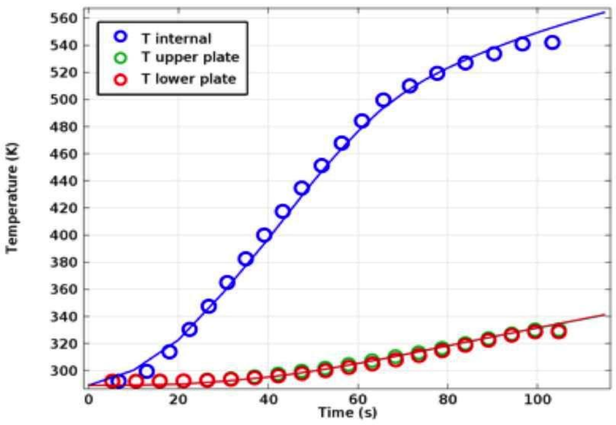
- Model assessment
  - Inert Teflon sample
  - Additional thermocouples

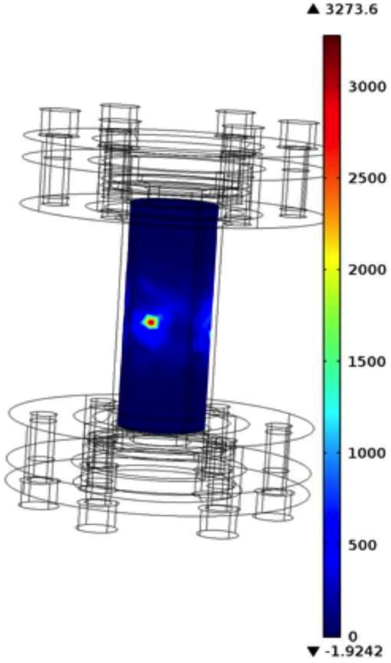




Tests and results

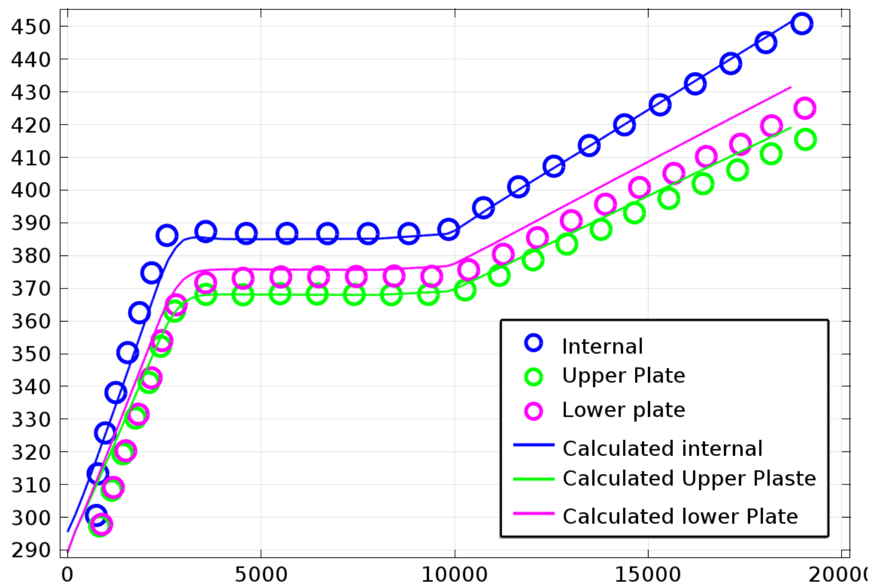
- Multiphysics simulation: Composition B fast cook-off confinement T45
  - Situation after 115 seconds (Calculated onset) – overestimation by about 15%
  - Circles = experimental data – Lines = computed data
  - Decomposition product concentration surface plot

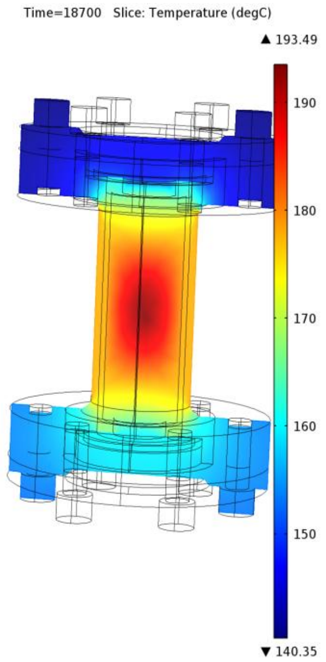




Tests and results

- Multiphysics simulation IMX-104 Intermediate cook-off (25°C/hr) after soaking at 108°C - Confinement T45
  - Situation after 18700 seconds (Onset time) – Overestimation by about 18%
    - Temperatures in K
  - Temperature in the middle plane surface plot (in °C)





Conclusions

- Simulation of Variable Confinement Cook-off Test (VCCT) shows good potential to match experimental results
  - COMSOL simulation environment software with built-in coefficient library and dedicated heat transfer module was adequate
  - This environment has capabilities to simulate heat and momentum transport found during heating and melting of melt-pour explosives
- The modelling process was successful in predicting the time-dependent temperature profiles in the VCCT assembly when used with a Teflon sample
  - Results confirmed from experimental data for intermediate and fast heating rate cycle.
- Similar calculations conducted on a virtual Composition B and IMX-104 samples indicated
  - Adequate simulation of temperature profiles around the system
  - A mathematical model representing the melting process as a pulse in the heat capacity of the sample material is believed to provide a physically sound approximation of the phase change.
  - The model provided a description of the transient melting process along with internal motion due to internal convection.
  - Limitation: No experimental temperature values inside the explosive sample were available to validate the numerical results.

On-going and future work

- Additional work is currently on-going to meet our goals of simulation of cook-off in a projectile
  - Inclusion the chemical reactions associated to the thermal degradation. This is being applied to both melt-pour and cast cure explosive and we have good preliminary results
  - Heat of reaction to be included as a source term in the equation energy
  - Mechanical effect of the gas produced by the decomposition process will be considered in a solid mechanics structural analysis of the sample confinement in the VCCT set-up.
  - Preliminary simulation of the intermediate cook-off in a shell to compare where with experimental data provided by DRDC Valcartier to see where we are at this point towards goal showed good results.