Numerical Modeling of Sub-Scale Convective Combustion of M1 propellant

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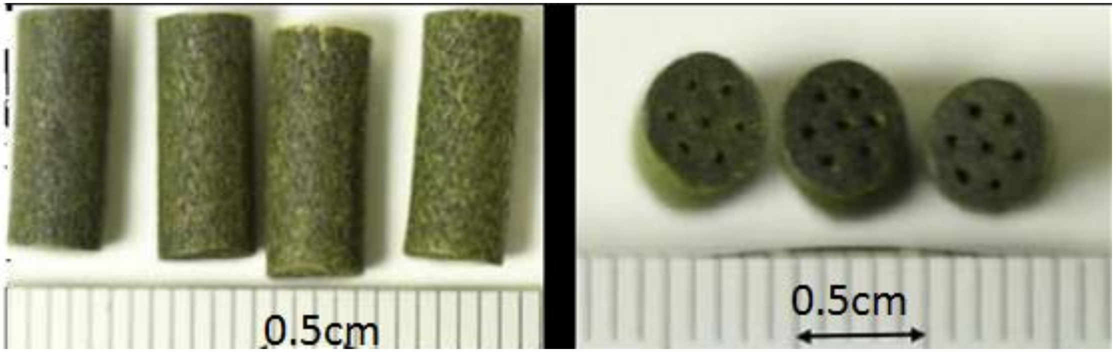
Back Ground

- DoD Explosive Safety Board (DDESB) began revising the siting methodologies for energetic ordnances other than Hazard Division (HD) 1.1
- HD 1.3 gun propellant (M1) combustion requires placement in confined storage configuration
- Naval Air Warfare Center Weapons Division (NAWCWD) has been conducting a series of experiments of bulk HD 1.3 gun propellant combustion within a confined polycarbonate tube

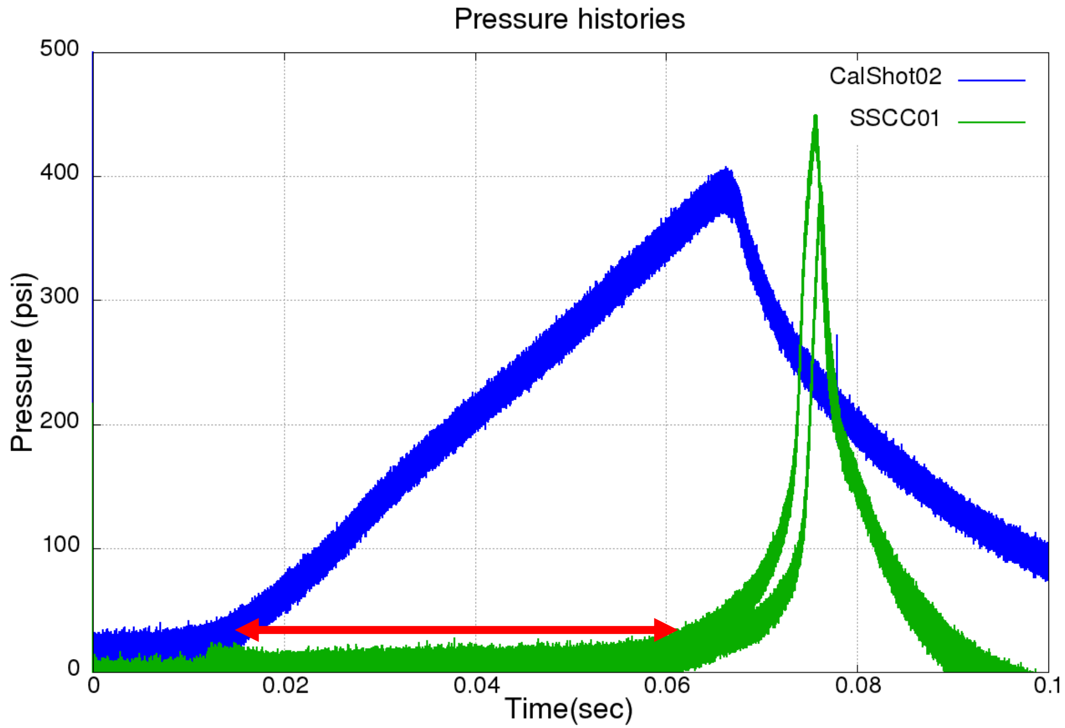
Experiments Conducted by NAWCWD



- 6” diameter, 13” height polycarbonate tube filled with 7lb M1 gun propellant
- density=1.569 g/cc, Length=1.0765cm, outer diameter=0.5cm, 7 perforations, each with a nominal diameter of 0.0451 cm
- 20g of Red Dot smokeless powder in the steel basket as an igniter

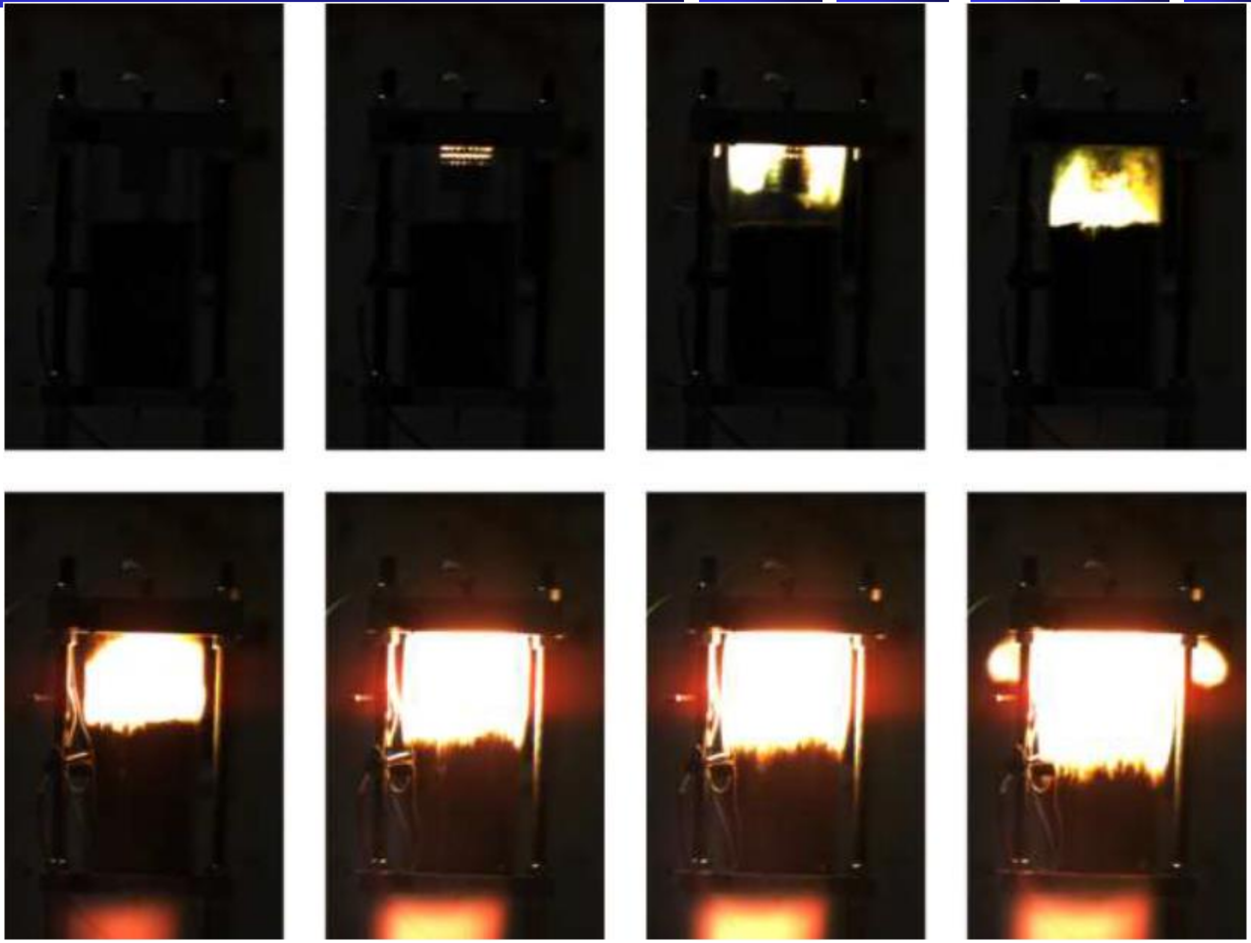
Pressure Histories Measured

- **Empty tube : blue line**
- **With M1 pellets : green line**



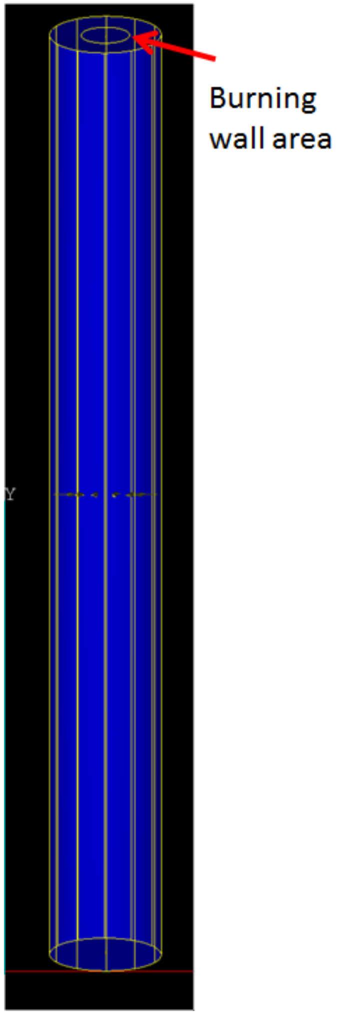
Significant difference in pressure rise time (!)

Flame Propagation

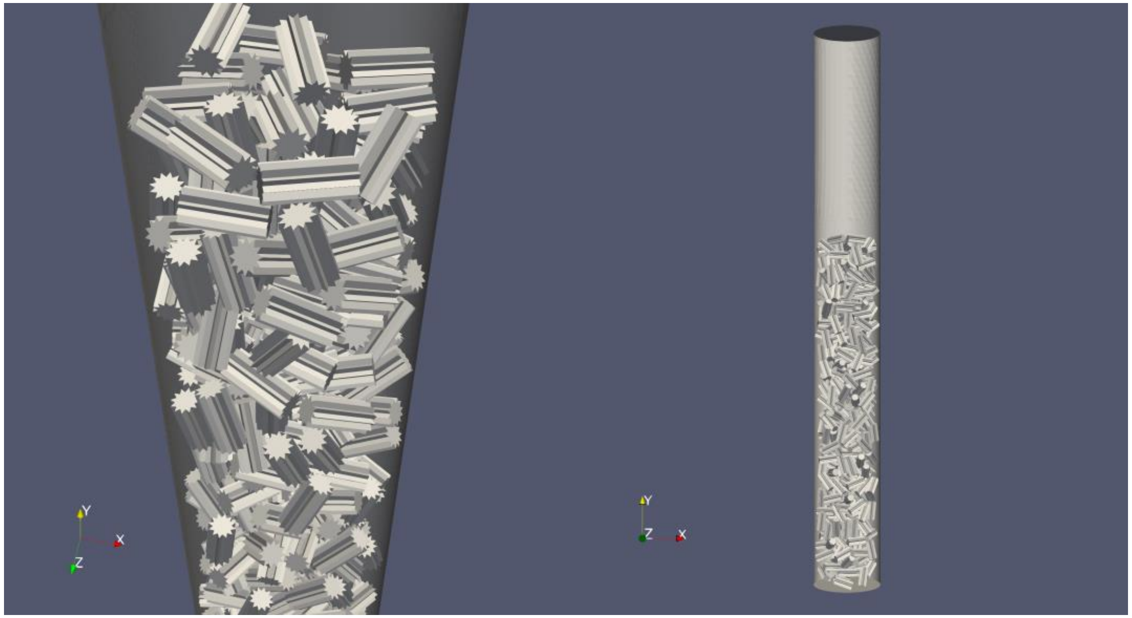


Flame did not reach the bottom at the tube failure

Numerical Modeling

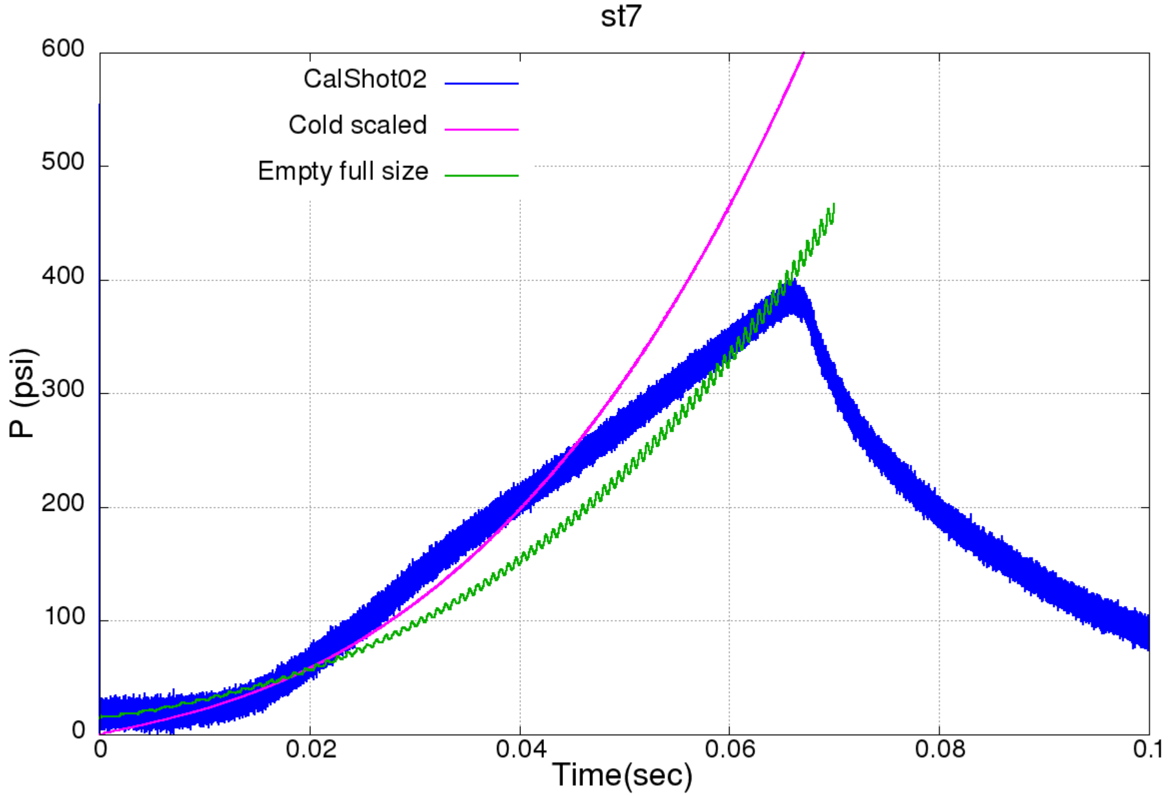


Scaled diameter, same igniter conditions



Pellets have the same wetted area to avoid the difficulty of numerically modeling the 0.45 mm perforation

Calibration Test (Empty Tube)



- **Burning rates were obtained from "*Introduction to the Technology of Explosives*" *Cooper Et. Al.***
- **Burning rate of Red Dot was calibrated based on measurement**

Where Did The Energy Go ?

- Coupling code CFD/ CTD to handle heat transfer
  - The pressure rise was delayed by the turbulent heat transfer
  - However, not enough

- Questions
  - The heat loss into M1 is not enough ➔ What is missing?
  - Heat Absorbed by Heating Up Pellets
  - Heating By: Conduction, Convection, Radiation: Too Slow

- ➔ There Must Be Something Else Going On

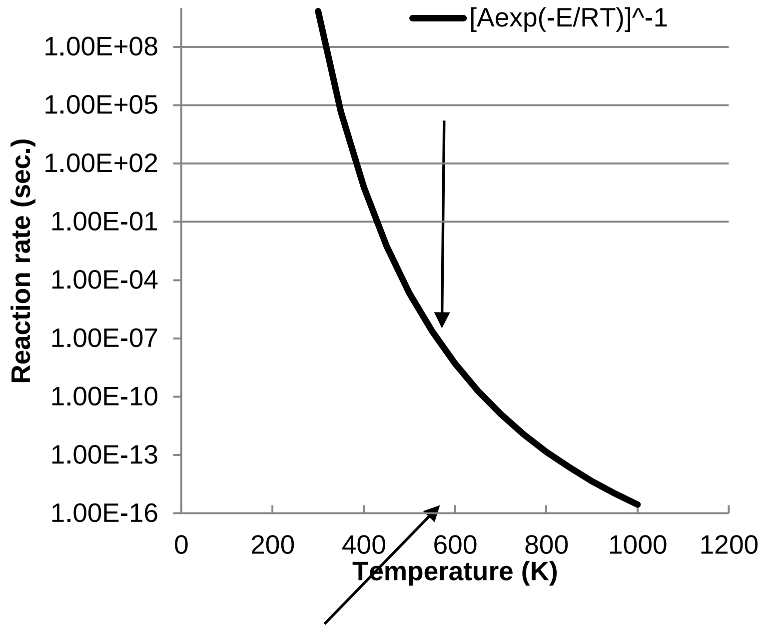
Detailed Study of Videos

- 2gr of Air, 20/60 gr of Red Dot
- ➔ Almost All of the Gas Surrounding the Pellets Was Generated by the Red Dot Combustion
- Very Hot Gas
- And Yet, Pressure Did Not Increase…
- Other Possible Mechanism ? See if Pyrolysis Possible

Pyrolysis Data for Nitrocellulose

- **Rate Formula:** $r = Ae^{\frac{-E}{RT}}$

- **Coefficients:**
  - **A=2.72e+27 1/sec**
  - **B=49.80 kcal/mol**
  - **R=1.99e-03 kcal/K/mol**



Almost Instantaneous !

- **M1 Density: 1.569 gr/cc**
- **Enthalpy of Pyrolysis: 2.23e+09 erg/gr**
- **A. I. Atwood et. al. - Burning Rate, Radiant Ignition, and Global Kinetics of a Nitrocellulose Propellant; Proc. 25th JANNAF Subcommittee Meeting CPIA Publication 498, Vol 1, pp. 69-81 (1988).**

Pyrolysis Data for Nitrocellulose

- **Regression Velocity:** $$v = v_0 \left(\frac{p}{p_0} \right)^n$$
- **Coefficients**
  - v_0=0.0356 cm/sec
  - p_0=1ATM
  - n=0.7

  "*Introduction to the Technology of Explosives" Cooper Et. Al.*

Pyrolysis Data for Nitrocellulose

- Flammability Limits (from NIST Tables/Documents):
  - Lower Limit 1.9% of Volume at 1 ATM, Ambient Conditions
  - Upper Limit 48% of Volume at 1 ATM, Ambient Conditions
- Back of Envelope Calculation
  - Assuming Similar Masses/Densities
  - 1.9% of 60 gr ➔ 1.1gr for Ignition
- Estimated Time for Pyrolysis of Sufficient Nitrocellulose for Ignition: About 60-80 msec

Implementation of Pyrolysis Model in FEFLO

- Check Surface Faces
- If Proper Material/Pyrolysis Possible:
  - Compute Temperature and Pressure
  - Compute Reaction/Pyrolysis Rate
  - Compute Regression Velocity
  - Multiply by Timestep ➔ Amount of Mass Pyrolysized
  - Obtain Energy Required for Pyrolysis
  - Add Mass Pyrolysized to Densities
  - Subtract Energy Required from Flow Energy
- Implemented and Working in FEFLO

Example

- Pellets Modeled Via Simple Shapes
  - Similar Surface Area As Real Pellets
- Inflow:
  - p=2ATM
  - T=3000K
  - V=235m/sec

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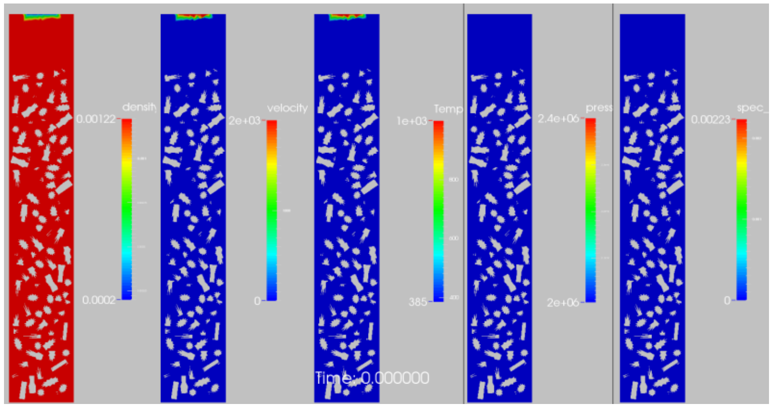
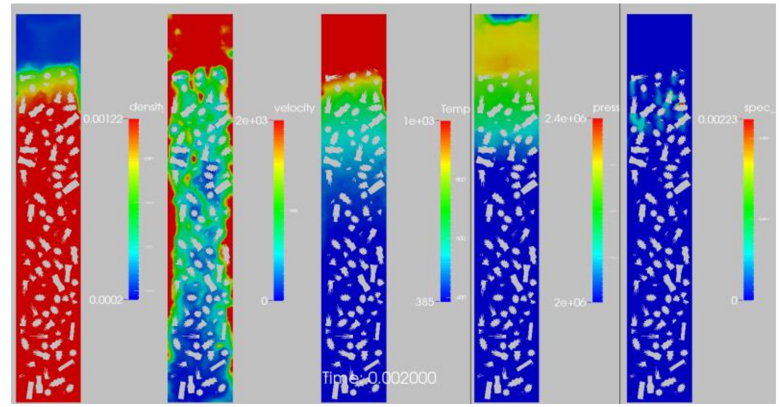
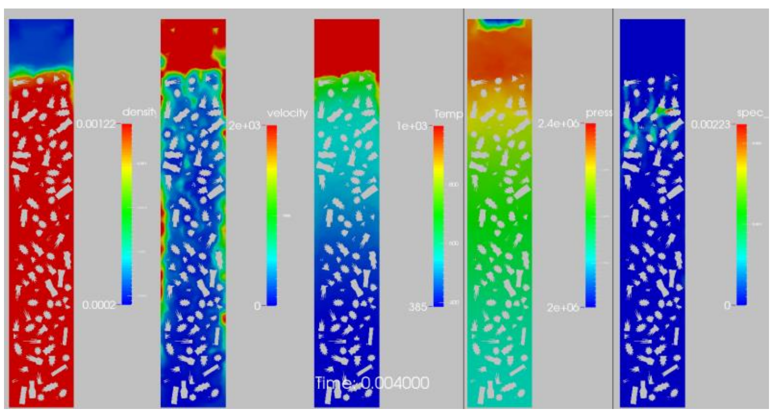
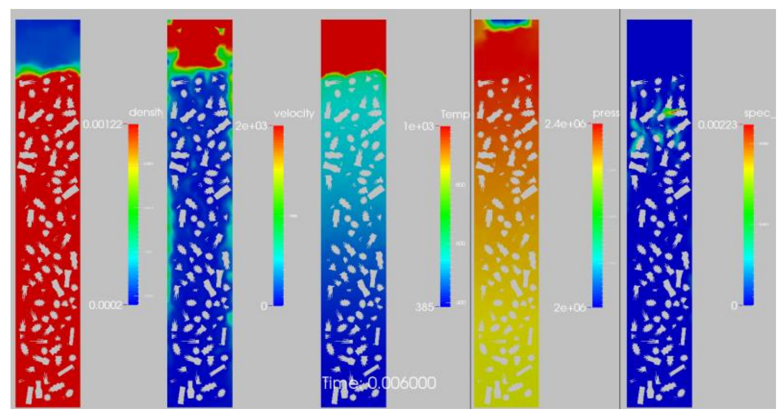
State Variables at 0,2,4 and 6 ms (about 10% done)









Induction Model for Chem React

- **Reaction Rate:** $$r = A \cdot \exp\left(-\frac{E}{RT}\right)$$

- **Energy Release:** $$\Delta e = \Delta t \; r \; Q$$

Conclusions and Future Work (1)

- Developed numerical methodology capable of modeling HD 1.3 gun propellant combustion
- Model is based on observations of several tests conducted by NAWCWD
- Systematic sequence of tests clearly indicated significant role of pellet gasification in the accidental ignition of propellants
- Developed new algorithms to model heat transfer from the igniter combustion products to the gun propellant, pellet gasification, propellant pyrolysis and combustion of the generated gasses and the propellant
- Development and validation of these models has been guided by the experimental NAWCWD data

Conclusions and Future Work (2)

- Numerical simulations of several tests demonstrated that the model accurately predicts the Red Dot ignition under ambient conditions, and that pellet gasification under high temperature flux will absorb enough energy to prevent pressure rise in a closed chamber

- Future work will focus on modeling of the flame propagation in the tested configuration, and the modeling of ignited propellant barrels in the Kasun facility