



Fast Cook-Off Modeling and Simulation

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Paper No. 20259

*Gun and Electric Weapon
Systems (E)*



Introduction and Background

Modeling with experimental confirmation was the subject of our IMEMTS paper and poster presented in Nashville in 2016 [1]. We showed a very accurate time to reaction for a Navy rocket booster motor in a 25 x 25 inch square missile launcher canister made out of a carbon fiber composite material. A reaction time of 14 minutes was predicted *before the test*. The test showed the reaction to occur at 14 minutes. Since that time, the computer simulation was run for a 21-inch-diameter second stage rocket motor in an open fire. The prediction *before the test* was 244 seconds to reaction; the test showed 225 seconds to reaction. Calculations were then carried out for a very complicated third stage rocket motor with a composite case. The predicted time was 260 seconds; the experimental time was 240 seconds.

Finally, we had an opportunity to model the fast cook-off test of 110 rounds of 30-millimeter (mm) gun ammunition contained in an ammo can with a thermal protection system. We did not have accurate reaction rate chemistry data, so we used a generic values for an Arrhenius reaction rate for nitrocellulose/nitroglycerin propellant from a French paper, and computed a reaction time of 163 seconds, compared to 150 seconds from the experiment. We made no changes in the input or property data to converge the model on the experimental time.

In this problem, each cartridge case was modeled with its own propellant and primer. The thermal protection system consisted of fiberboard panels around the inner surface of the can. There also was a wide strip of canvas wound back and forth in the can separating the layers of cartridges. Having modeled the time to reaction, and realizing the model is likely to be predicting the evolution of decomposition products accurately, we are ready to start work on predicting the violence of the reactions. Results from the models will help our understanding of fast cook-off and lead to safer weapons.

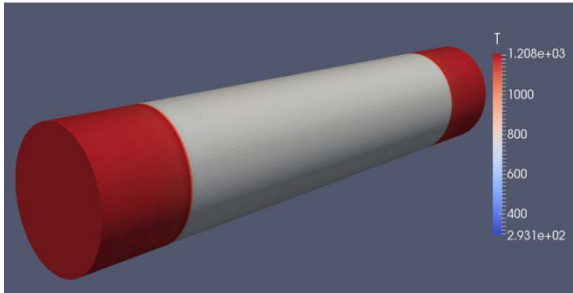
This paper reviews the rocket motor calculations, then shows the work done on the ammunition can. A concept for how the method can be extended to the computation of reaction violence is shown.



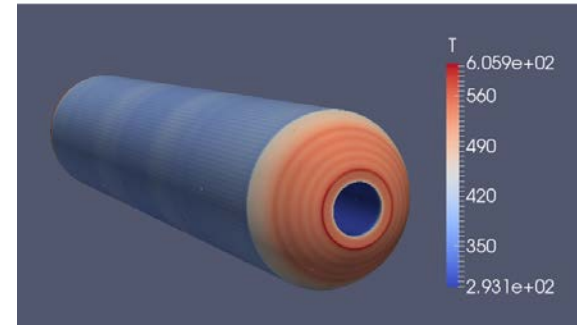
Second Stage Rocket Motor

Predicted Reaction Time: 244 seconds, 20 seconds more than the test data time of 225 seconds

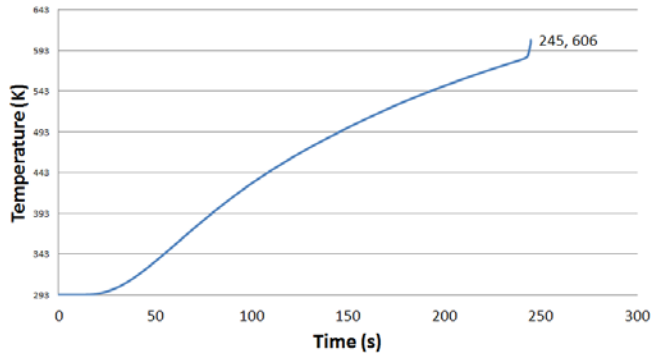
COMPOSITE CASE TEMPERATURE (K)
AT REACTION TIME



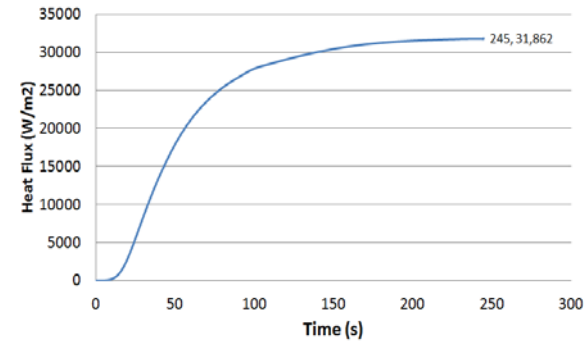
Propellant Temperature (K) at
Reaction Time



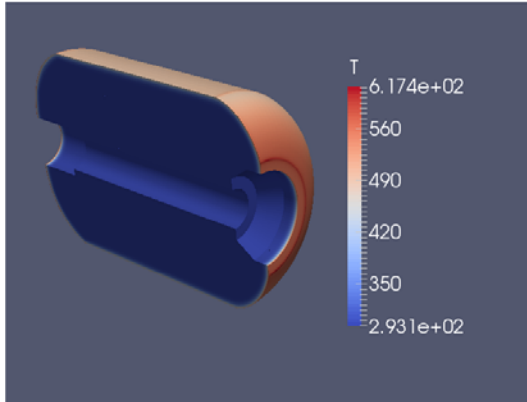
Propellant Maximum Temperature



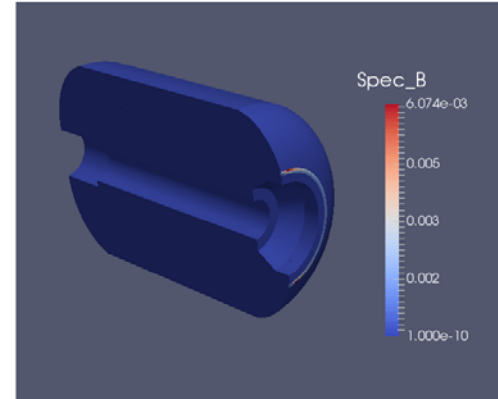
Heat Flux Reaching the Propellant



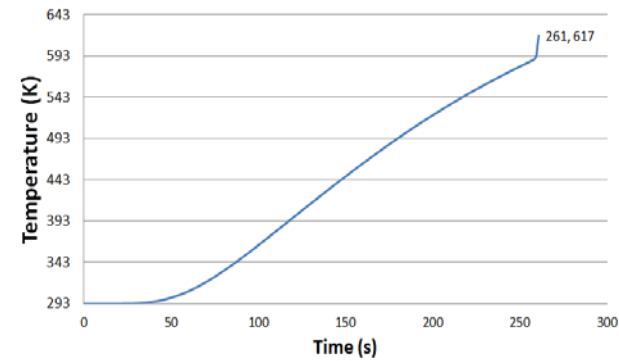
Propellant Temperature



Gas Phase Concentration

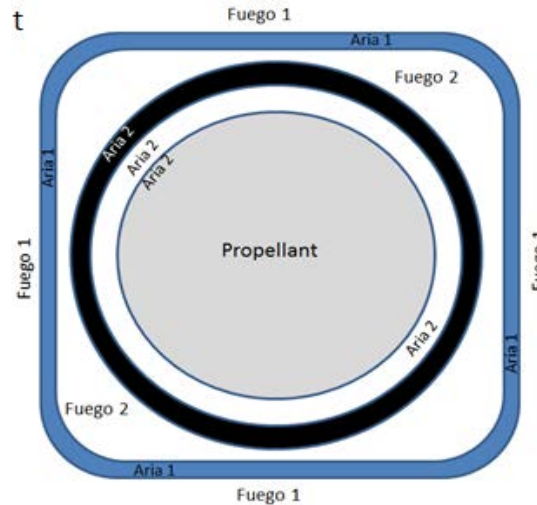


Propellant Maximum Temperature



Predicted Reaction Time for TSRM :
260 seconds, 20 seconds more than
the test data time of 240 seconds

Modeling Strategy



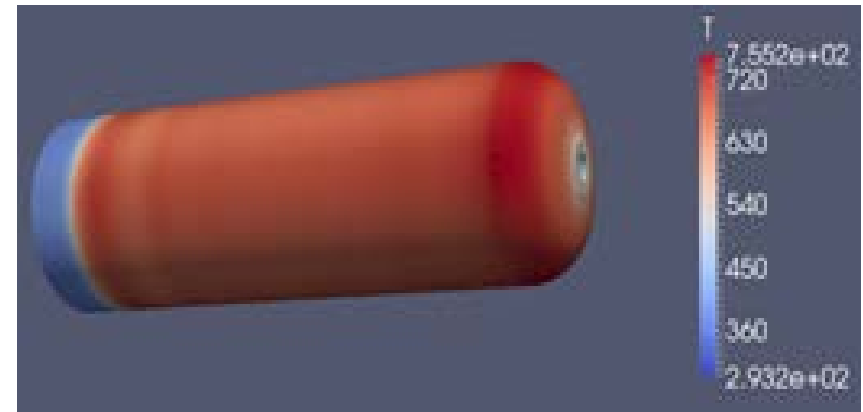
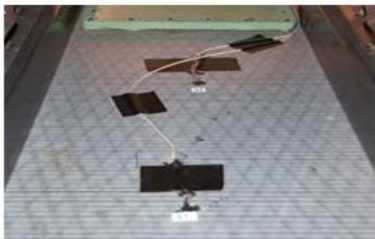
No one computer model is available to solve the problem of heat flow from the fire, through a container, into the rocket motor, and finally the response of the propellant. Our model consists of four sub models using the Sandia Fuego and Aria computer codes. Fuego is a reactive flow gas dynamics code that was used to model the fire with one application, and natural convection in the space between the container, or launcher canister, and the motor with a second application. These are both flows where the fluid motion is caused by buoyancy. The conduction of heat and pyrolysis of epoxy is converted to gaseous products and char. This process was modeled with Aria. The radiative heat input to the rocket motor was calculated using Aria inner-surface temperatures of the canister walls. Convective heating inside was computed using heat transfer coefficients determined from the second Fuego model. The heat flow through the chamber, insulation, and on into the propellant was computed with a second Aria model. The heat flow into the propellant causes self-heating of the propellant, which suddenly greatly exceeds the material's ability to conduct heat to the outside, resulting in an explosion.

Missile Launching Canister in Fast Cook Off Pit Ready for Test



Instruments Inside Canister

Instruments on Rocket Motor

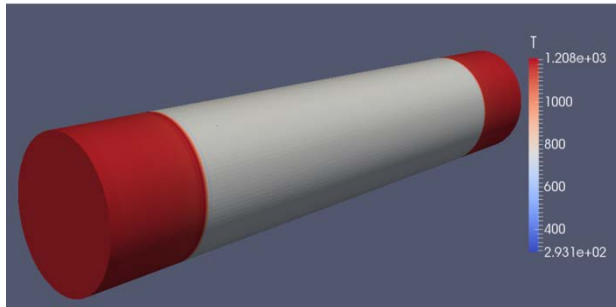


Pre-test model predictions and the test both showed cook-off at 15 minutes after ignition of the fire

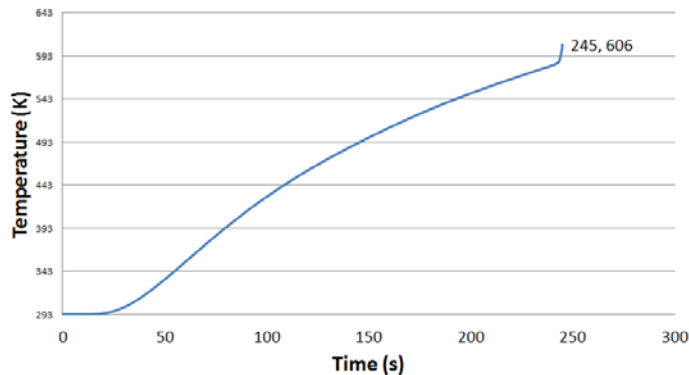
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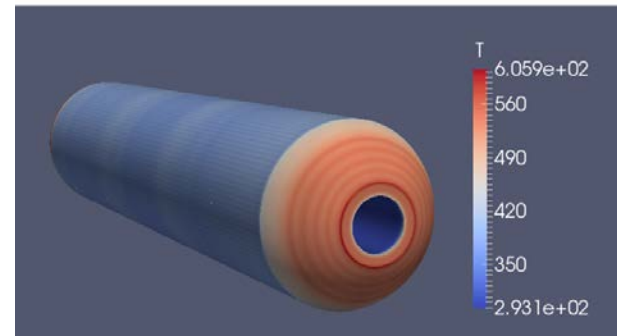
COMPOSITE CASE TEMPERATURE (K)
AT REACTION TIME



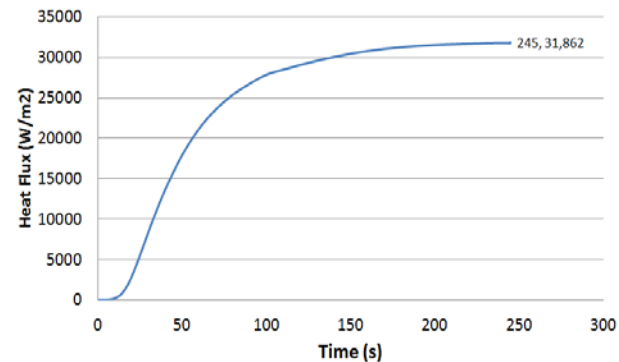
Propellant Maximum Temperature



Propellant Temperature (K) at
Reaction Time

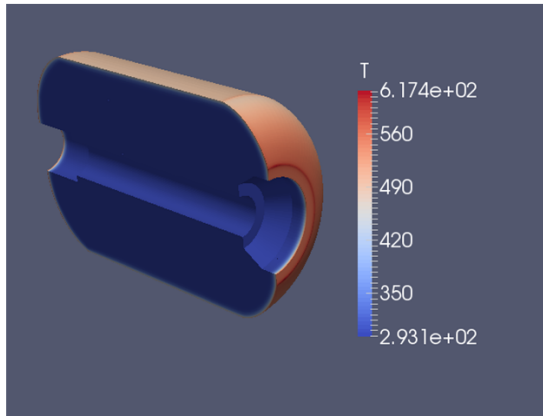


Heat Flux Reaching the Propellant

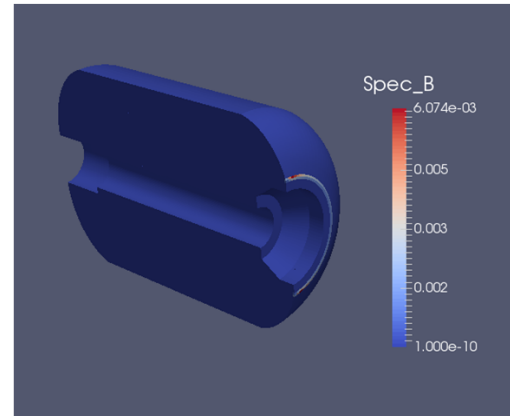


Third Stage Rocket Motor

Propellant Temperature

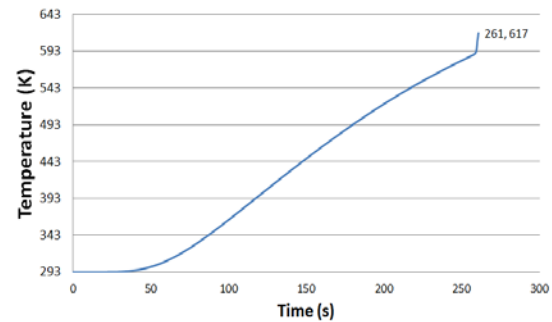


Gas Phase Concentration



Predicted Reaction Time for TSRM :
260 seconds, 20 seconds more than
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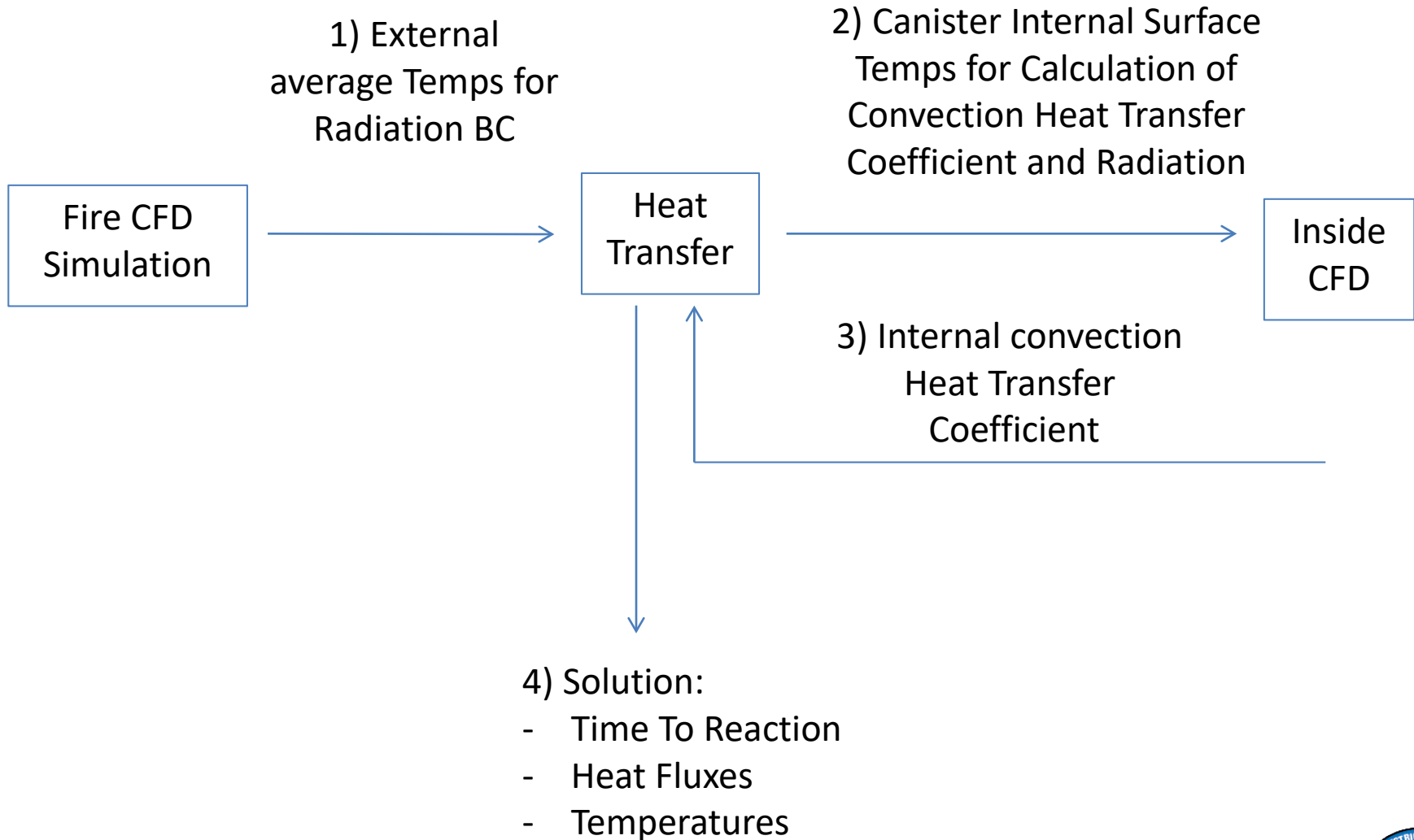
Propellant Maximum Temperature



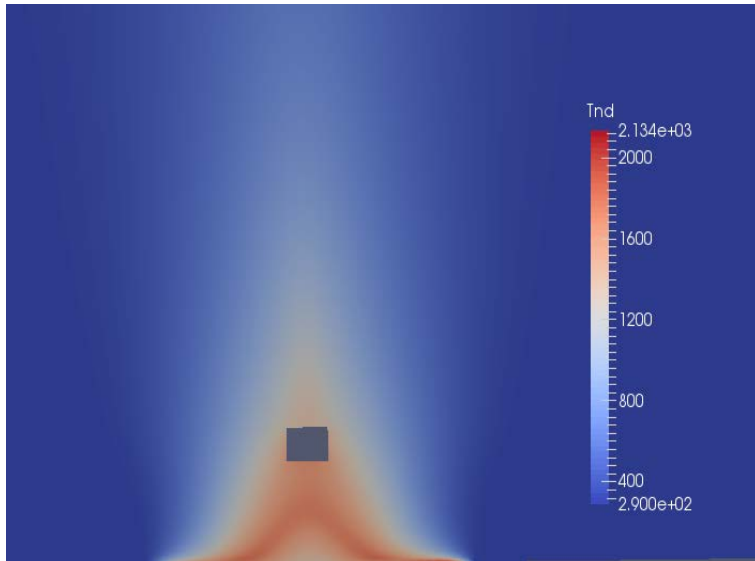
Fast Cook-Off of 110 30 mm Cartridges in an Ammo Can in a Propane Fire



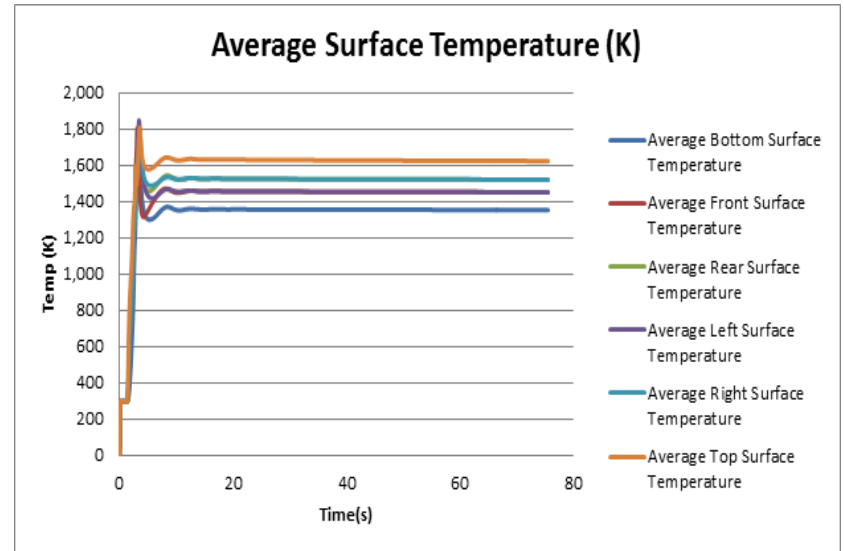
Modeling Flow Chart for Ammunition Can



Surface and Steady State Temperature for the Ammo Can

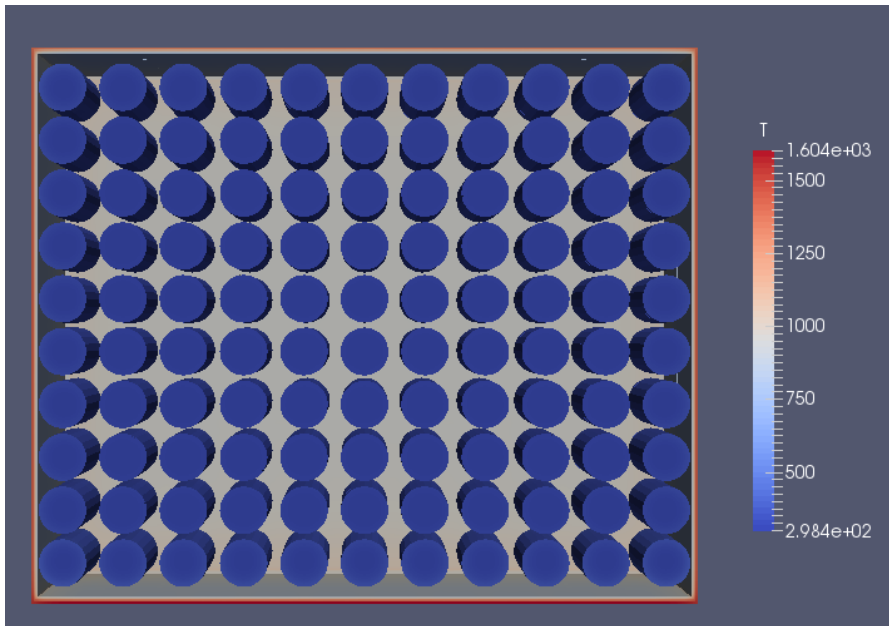


Steady state temperature field around ammo can at 75 seconds

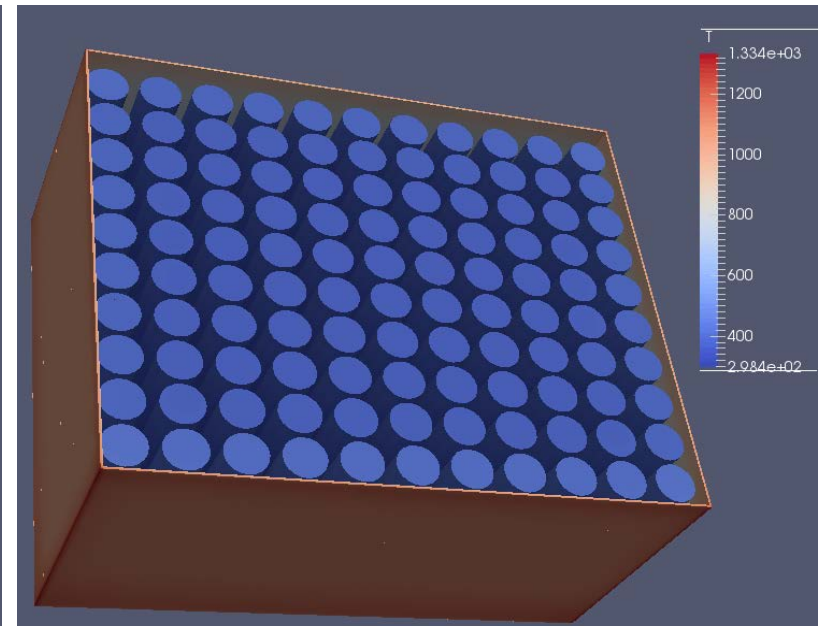


After about 10 seconds steady state temperatures are attained



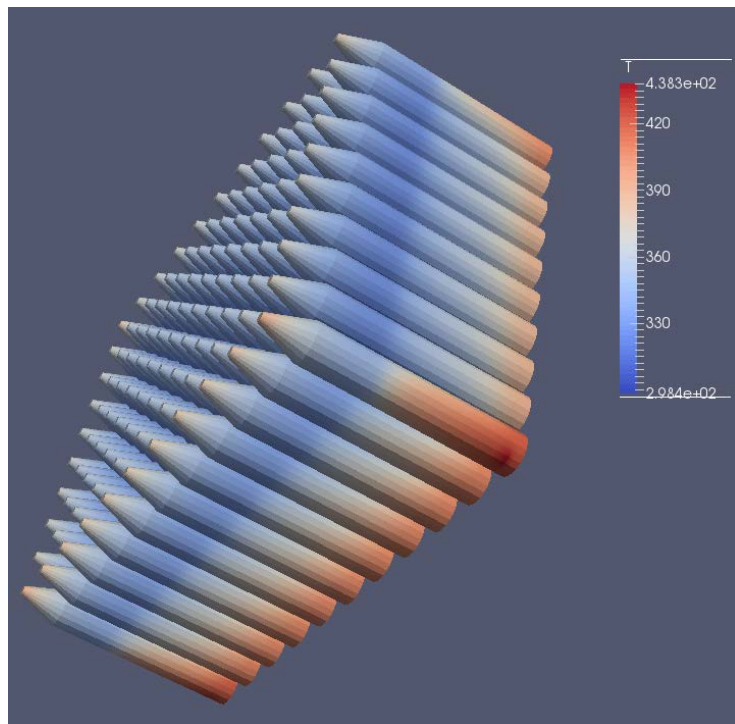


Metal, fiber board, and canvas

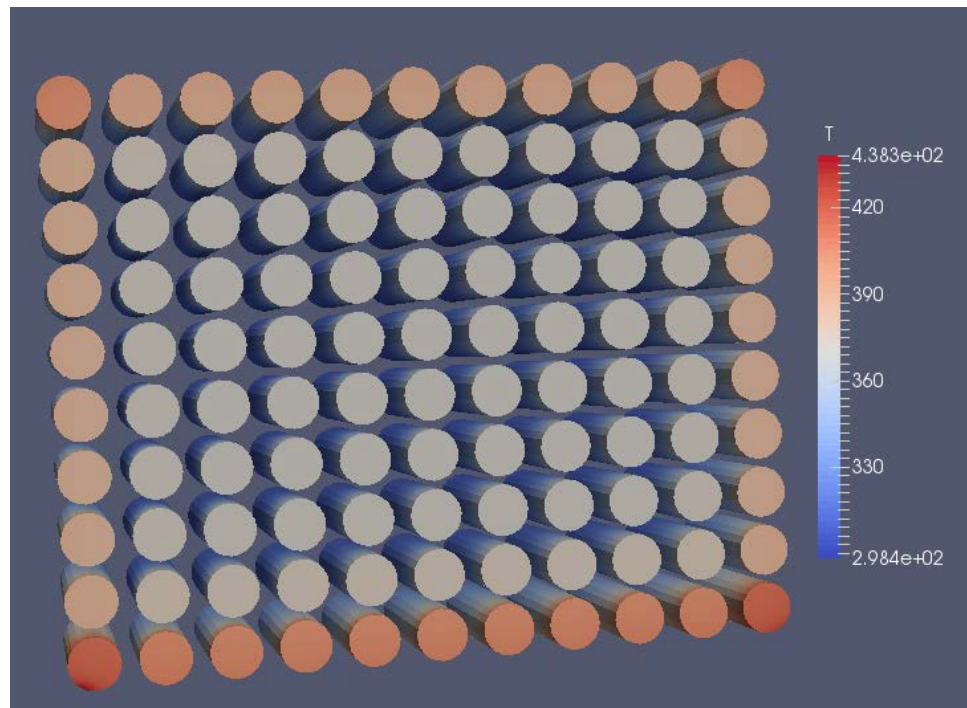


Fiberboard, canvas and packed rounds

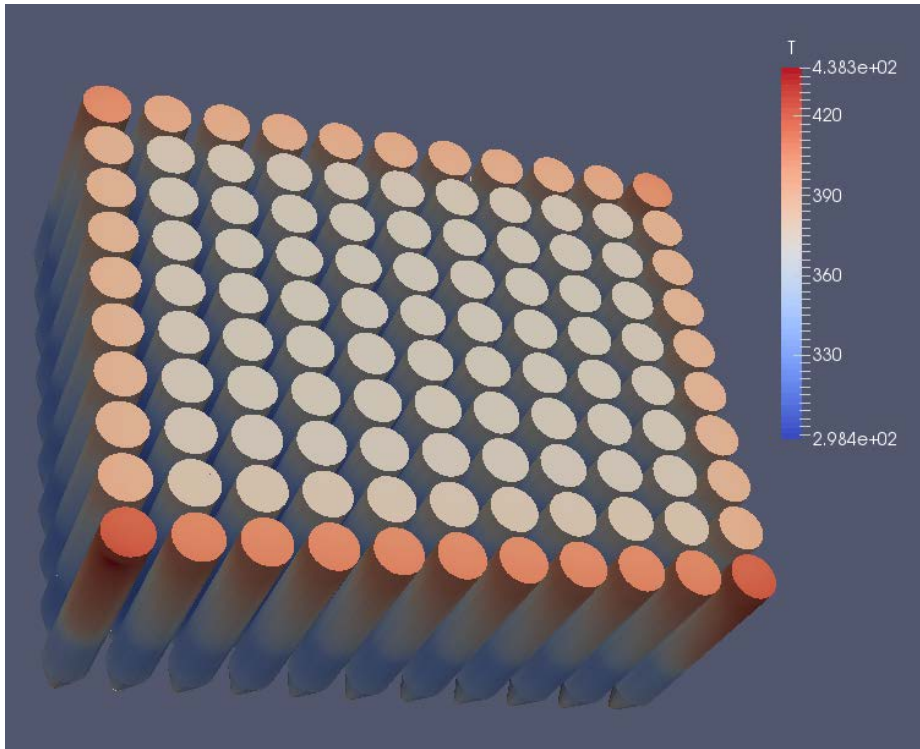
Temperatures of Cartridge Cases Shortly After the Reaction Began in the Lower Corners



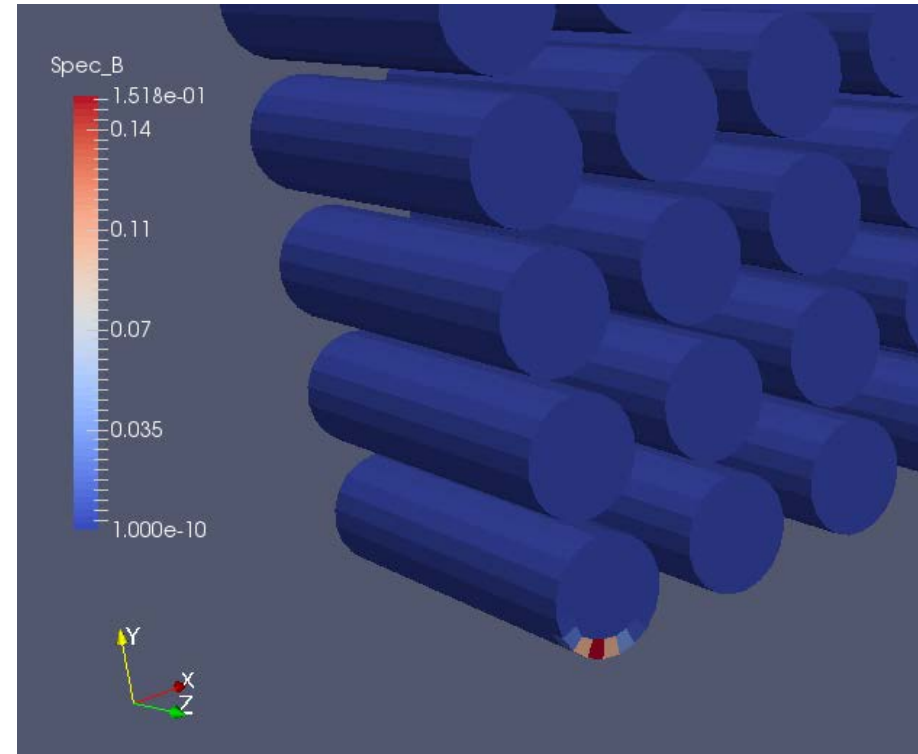
Cartridge case temperatures during ramp up to the reaction. The bottom corner projectiles are starting to show more heating.



Case head temperatures during the ramp up. Temperatures are rising in the lower corner case heads at a higher rate.

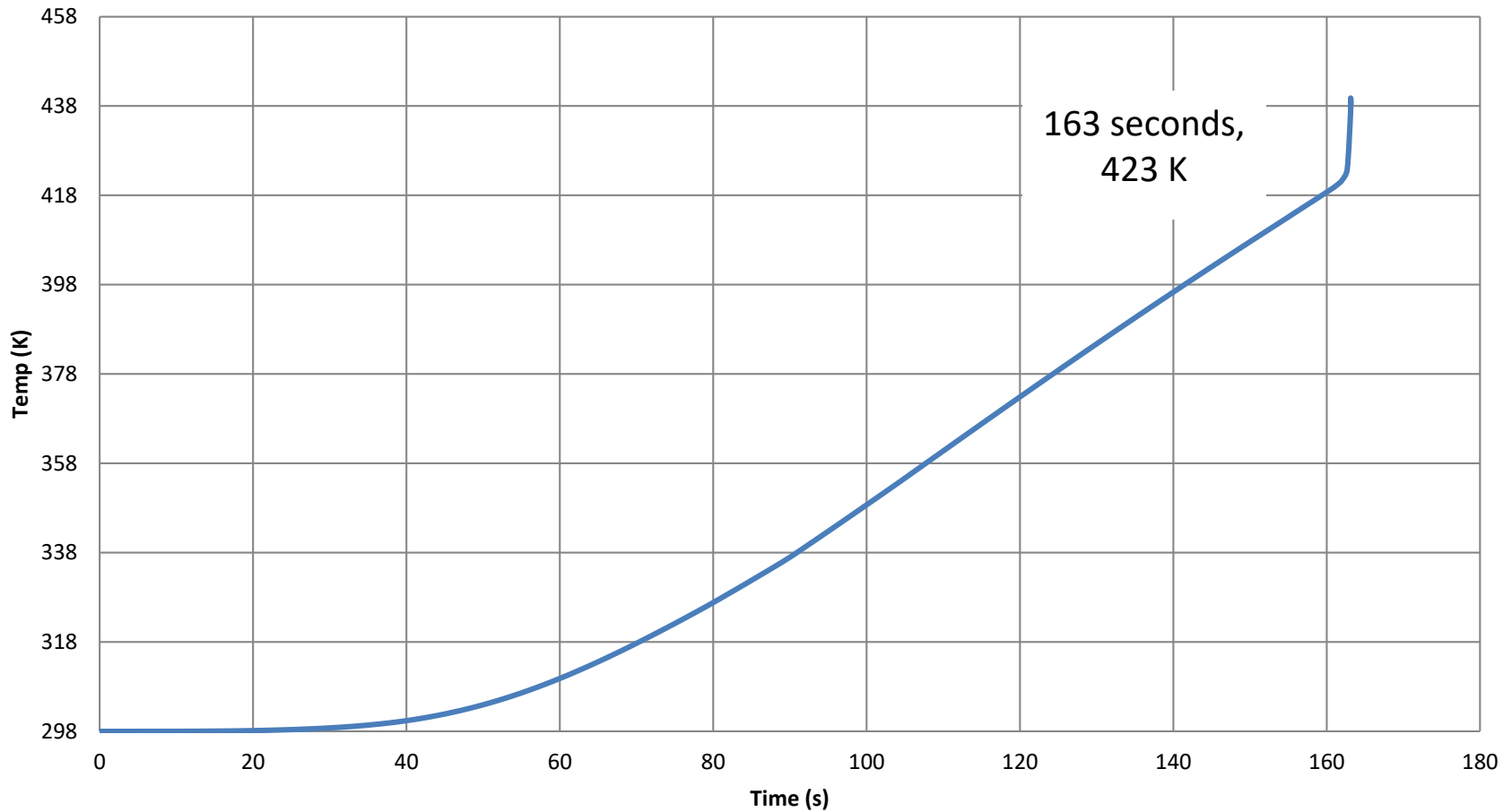


Cartridge Cases

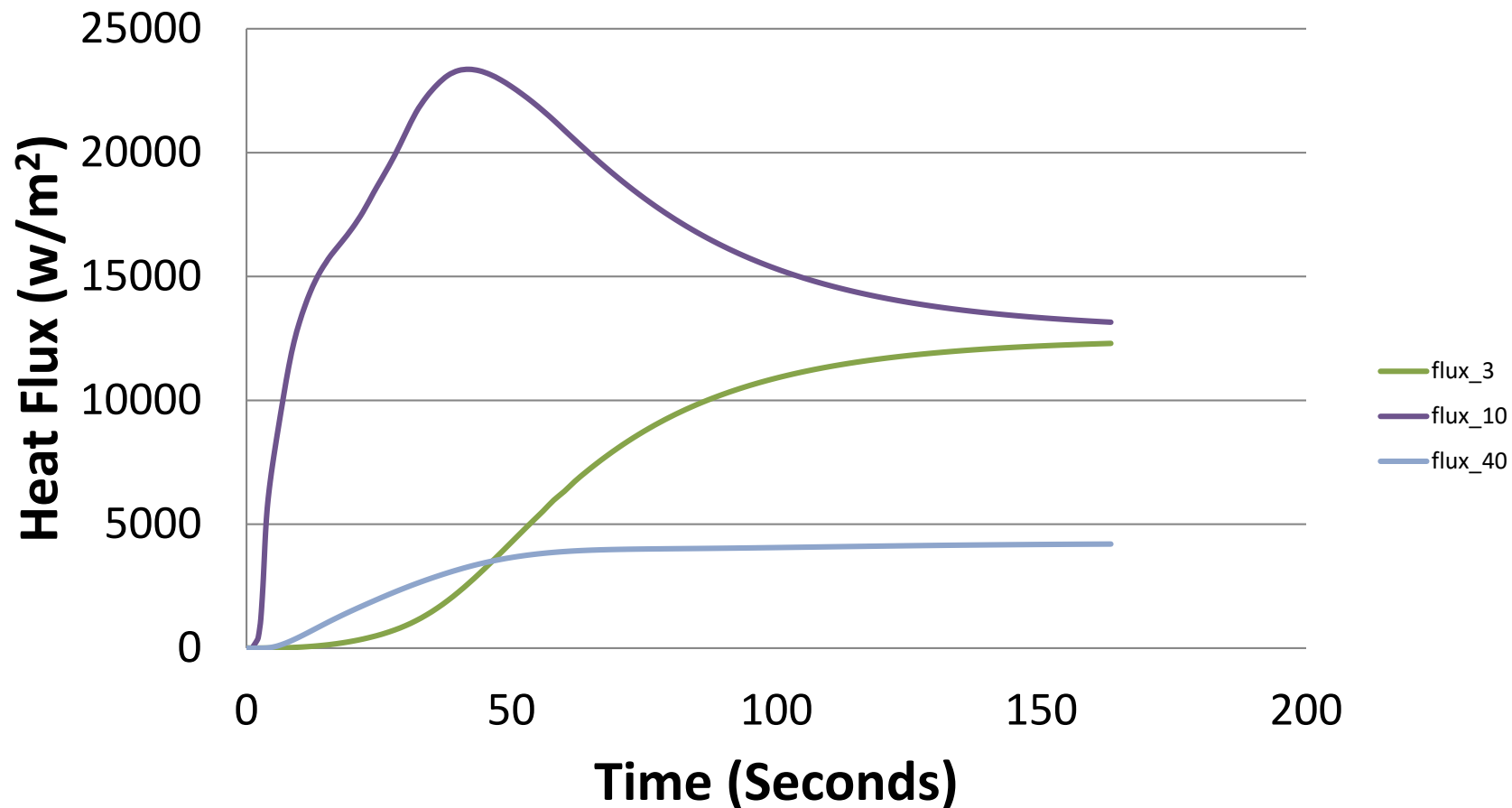


Propellant inside of cartridge cases. The charge in the corner is evolving gaseous decomposition products (species B), 0.151 moles per liter.

Propellant Temperature in First Round to React



Heat Fluxes Along Thermal Path to Propellant



Debris from Reaction

Exited Burner
but <50 ft

Remained inside
burner

Greater
than 50 ft



Summary and Conclusions

Fast cook-off models have produced very good agreement with experiments for the time to reaction. The models also produce very useful data that could not be obtained otherwise, especial heat flux along the path from the fire to the reactive material. The models have been validated with data from three different rocket motors in conditions varying from a bare motor in the fire to a motor inside of missile launching canister made out of carbon fiber composite material. The models also predicted the explosion of an ammunition can full of live cartridges. The model showed the heating to be most severe in the lower corners of can. The model also included mitigation materials and could be used to further improve similar systems. The evolution of pyrolysis products was also calculated.

The next logical step in development of the technology is to augment the present models with another code we have experience with to calculate reaction violence.

The computer models could also be used to predict the reaction time for slow cook-off. The heating is mainly free and forced convection in ovens. Some of the fast cook-offs we have calculated for encanistered munitions start at the point of maximum natural convection. It would not be difficult to simulate all the heat flow paths in slow cook-off, including source and sink elements to simulate internal blowers.