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An Approach to Simulate the Cook-off Response of Large Scale Munitions Using Small Scale Tests and Analysis

By

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Background

Small Business Technology Transfer Project (STTR)

- Topic N10A-T011
- Contract N68335-12-C-0006

Team

- STTR Lead: BlazeTech Corp.
- STTR Research Partner: Sandia National Laboratories
- China Lake: Sponsor

Scope:

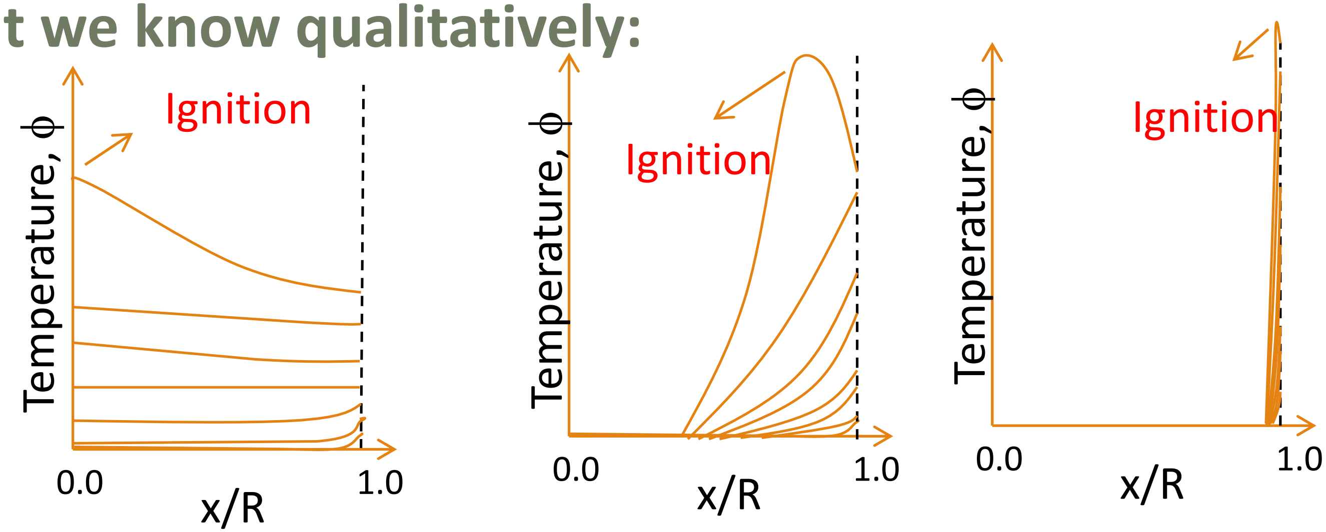
- Smalls-scale tests and modeling
- Focus on PBXN-109 for which there is data in literature at different scales
- Some work done on PBXN-5, but limited data at different scales

Effect of Scale and Heating Rate on Cook-off

What we know qualitatively:

SCO

FCO



Small Propellant
Slow Heating Rate

Large Propellant
Fast Heating Rate

More % material involved

Less % material involved

What is missing quantitatively:

1. Extent of thermal degradation prior to ignition
2. Effect of thermal degradation prior to ignition on burn rate and violence

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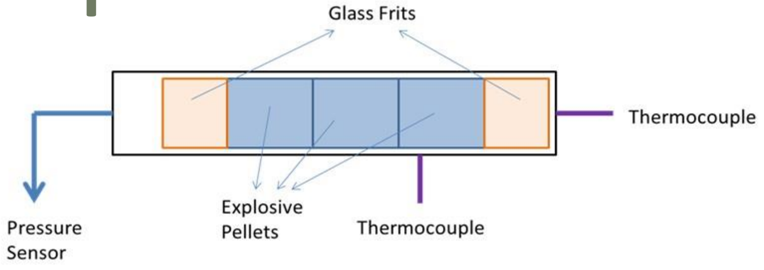
BlazeTech Approach/Talk Outline

1. Thermal degradation tests → kinetics rates as f(Temperature- time)
   - Confined and unconfined samples
   - Tracked pressure and its effects on degradation
2. Burn rate tests on pristine and degraded samples → $u_{burn} = A \times P^n$
   - Dependence of A and n on degraded state
3. Cook-off models using heat conduction + 1 and 2
4. Small scale cook-off tests and compare results to model predictions
5. Use data from literature to validate model and investigate tradeoffs between scale and heating rate
   - Compared wall temperature at ignition ($T_{wall@ignition}$) for both small and large scale tests

1. Thermal Degradation of Confined Samples



Three ¼”×¼” cylindrical pellets per test

Heat to T for finite duration to induce thermal degradation. Test stopped before cookoff.

Measurements

- P(t) and T(t) during the test
- Sample mass before and after test
- Account for amount of gas formation and condensation

Model development for thermal degradation kinetics

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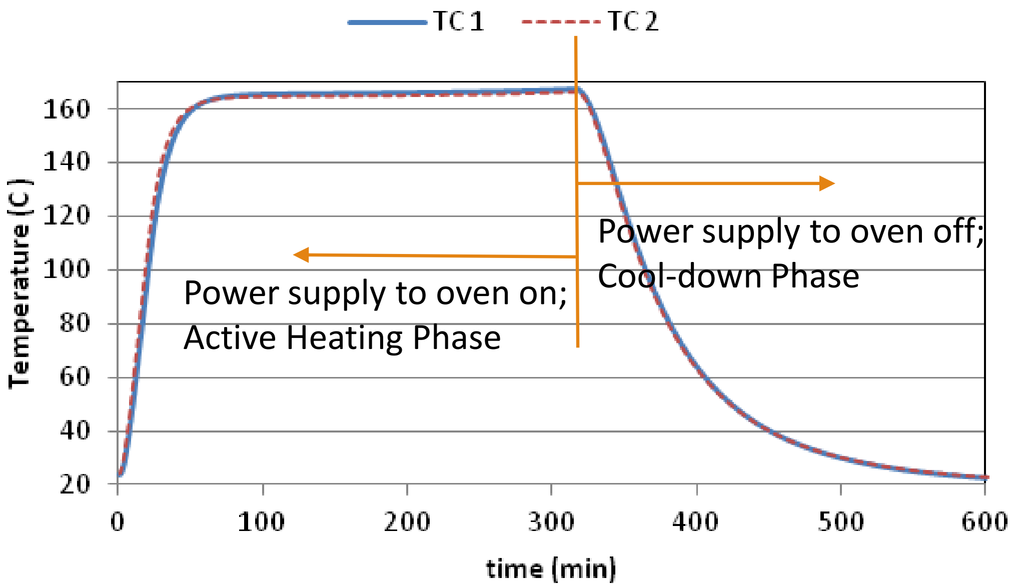
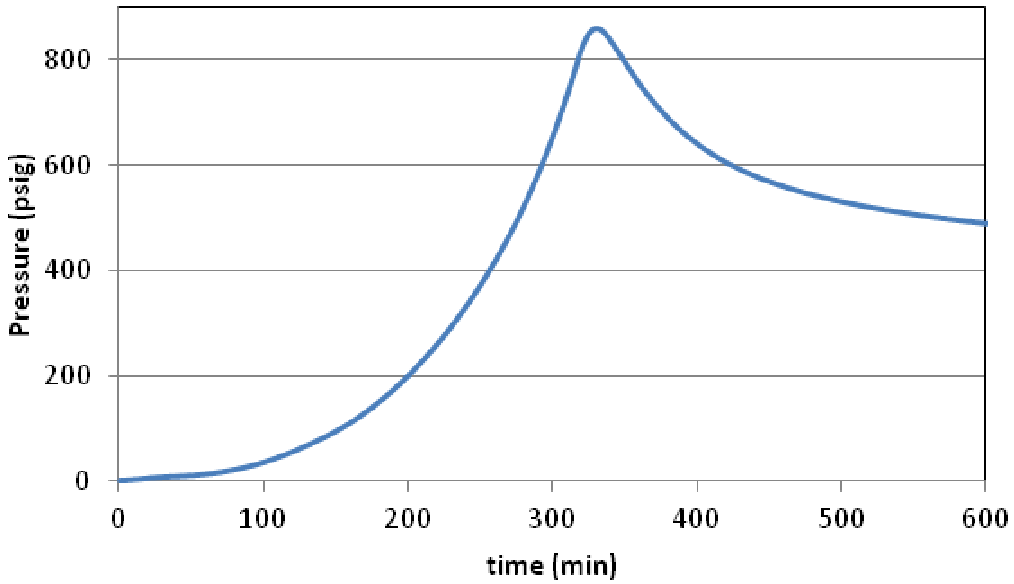
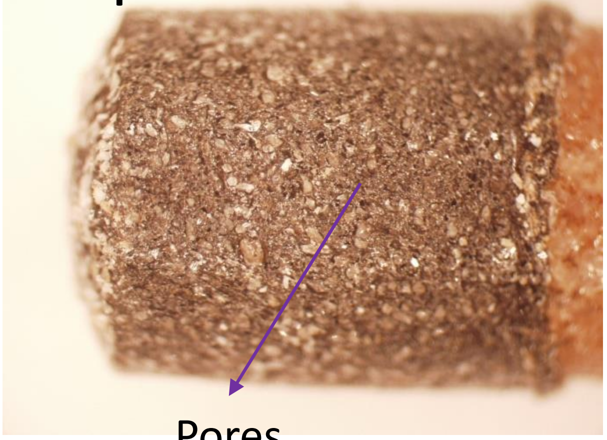
Sample Test with PBXN-109

- Duration for which the sample remains above 130°C ~ 317 min
- Mean Temp. for the above duration ~ 163.4 °C





High Resolution Image of Explosive Pellet after Test



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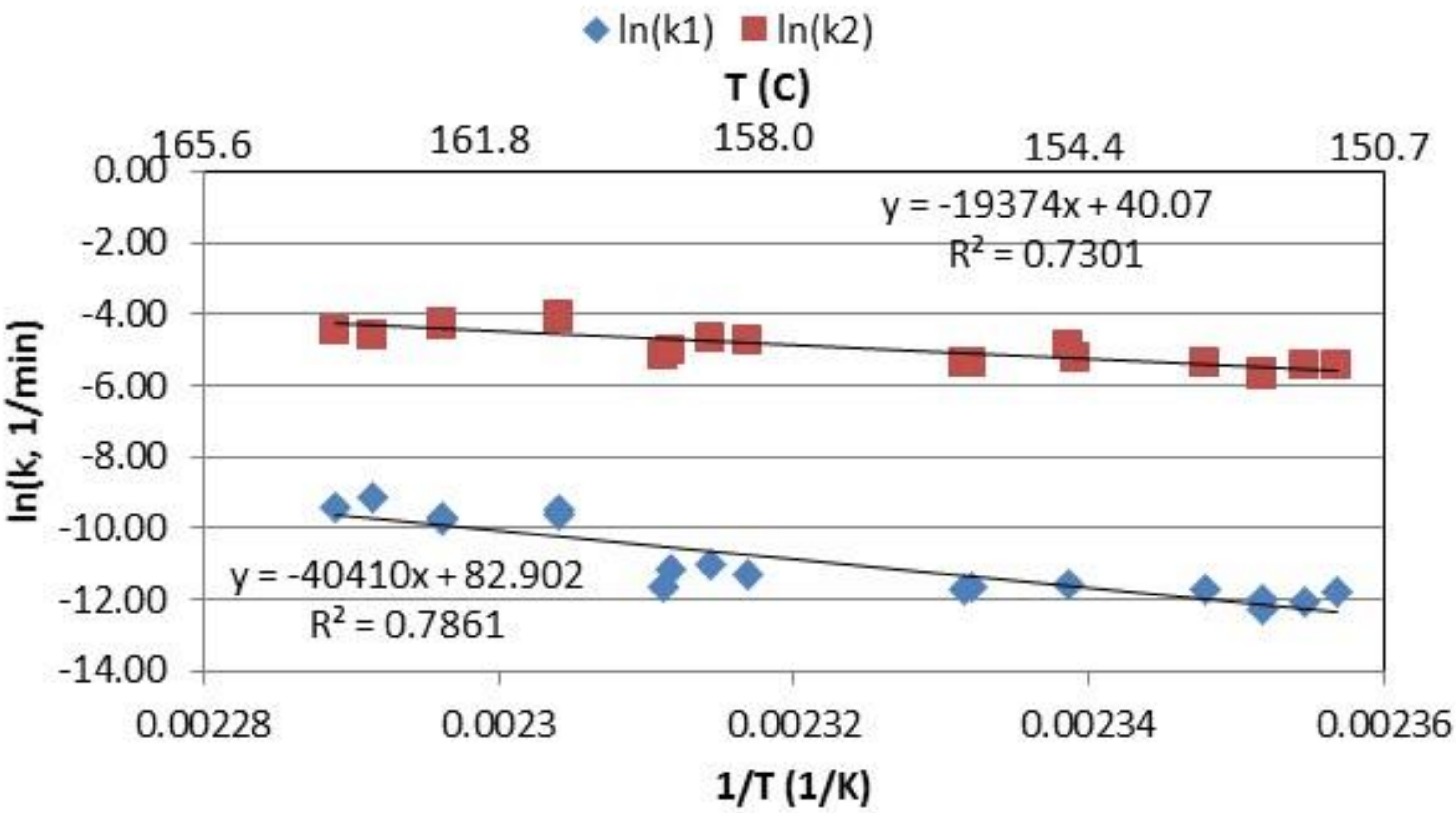
PBXN-109 Thermal Degradation Kinetics



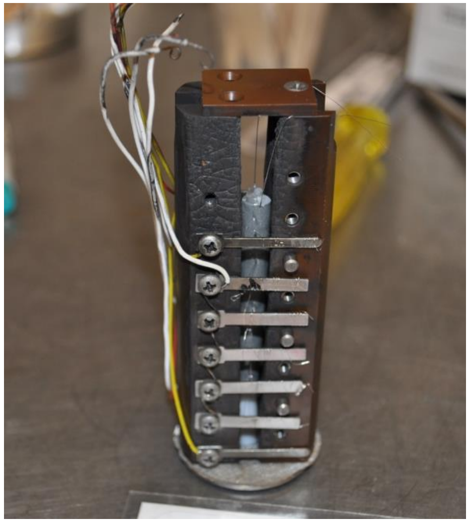
- Fitted a two-step first order reaction model to the test data
- Reaction rate constants (k_1 and k_2) depend only on T

2. Burn Rate of Thermally Degraded Explosives in a Confined Strand Burner

- TC & break-wires between pellets
- Pressure adjusted to the target level
- Expose strand to desired T(t)
- Then ignite top end of strand
- Measure P(t), T(t), u_{burn}(t)
- Fit data to classical power law:

$$u_{burn} = A \times P^n$$

- A depends on extent of thermal degradation prior to ignition; n=constant



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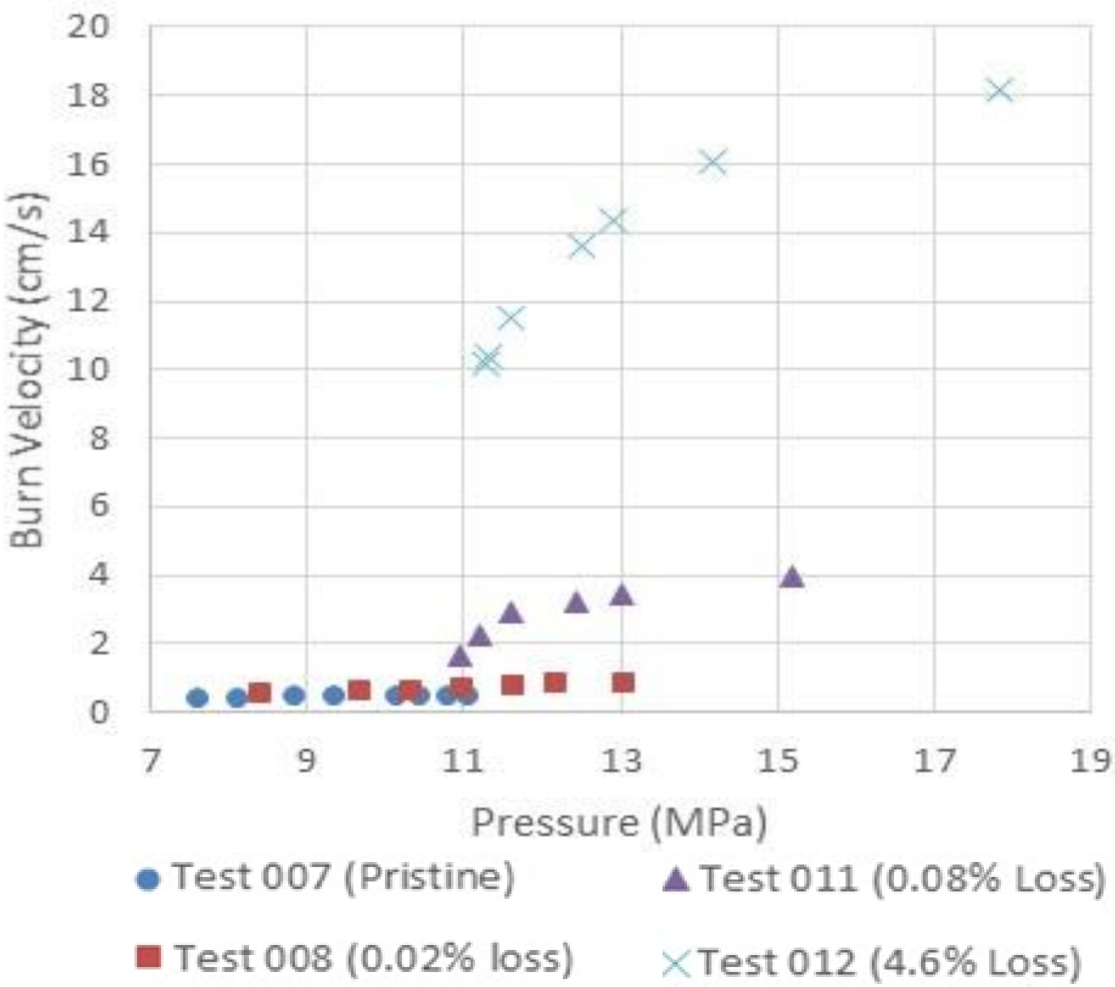
Measured Burn Velocities vs. Pressure and Extent of Thermal Degradation



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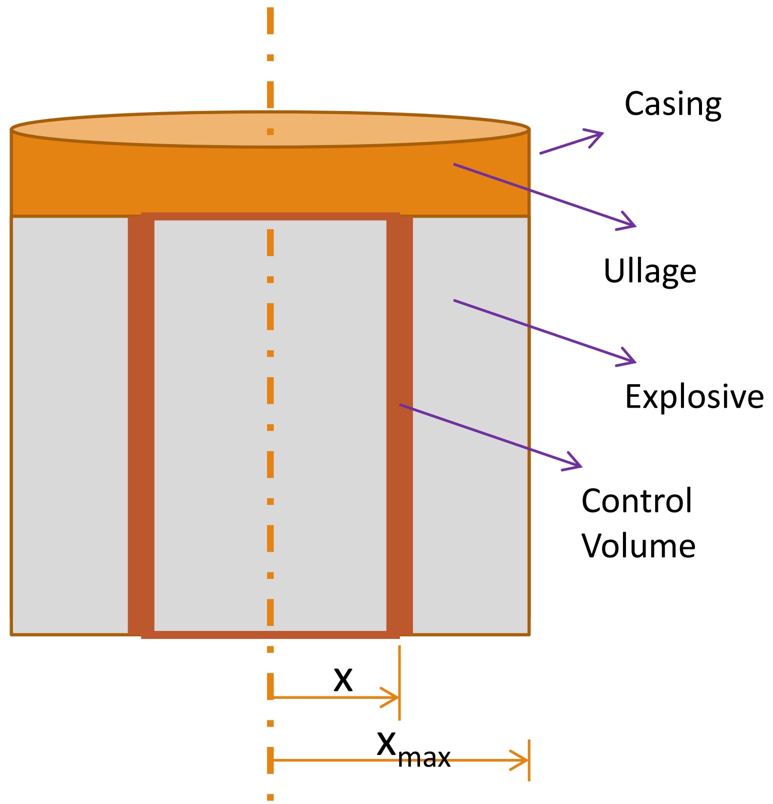
3. BlazeTech Cook-off Model

Fast running 1-d model, includes
- Rapid heating from $T_{ambient}$ to T_{soak}
- Soak for finite duration T_{soak}
- Slow heating from T_{soak} to ignition

Model tracks
- Heat conduction, thermal expansion and phase change
- Chemical reactions
  - Pressure rise due to heat and gas release
  - Mass loss and increase in porosity
- Ignition when temp. inside the explosive >> wall temp.

Model outputs:
- T(x), residual explosive mass, reaction conversion, specific surface area vs. time
- Occurrence of ignition and its location
- Burn rate
- Casing pressure time history (which is indicative of violence)



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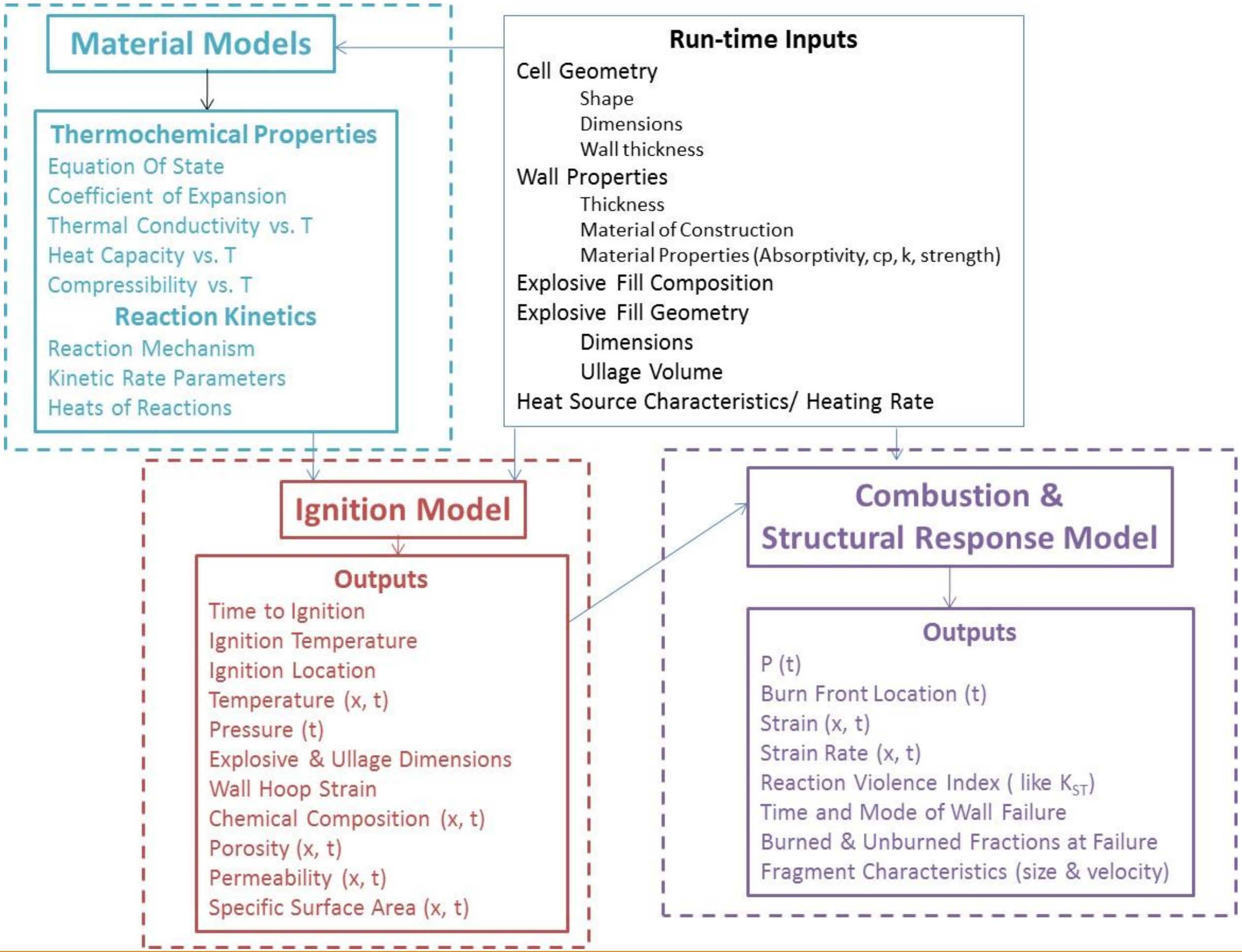
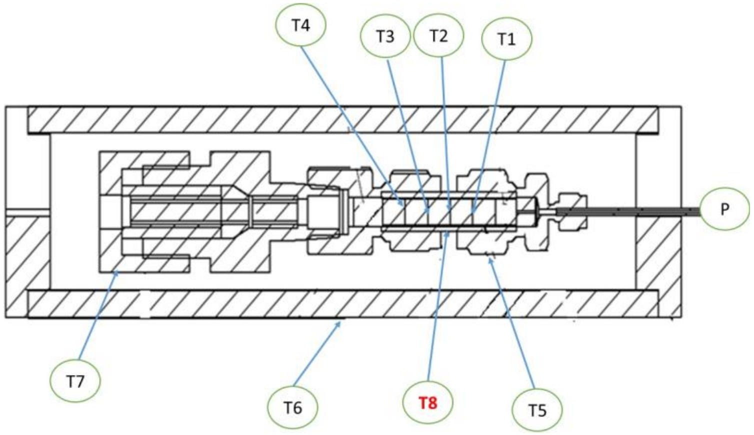
Unified Model for SCO and FCO

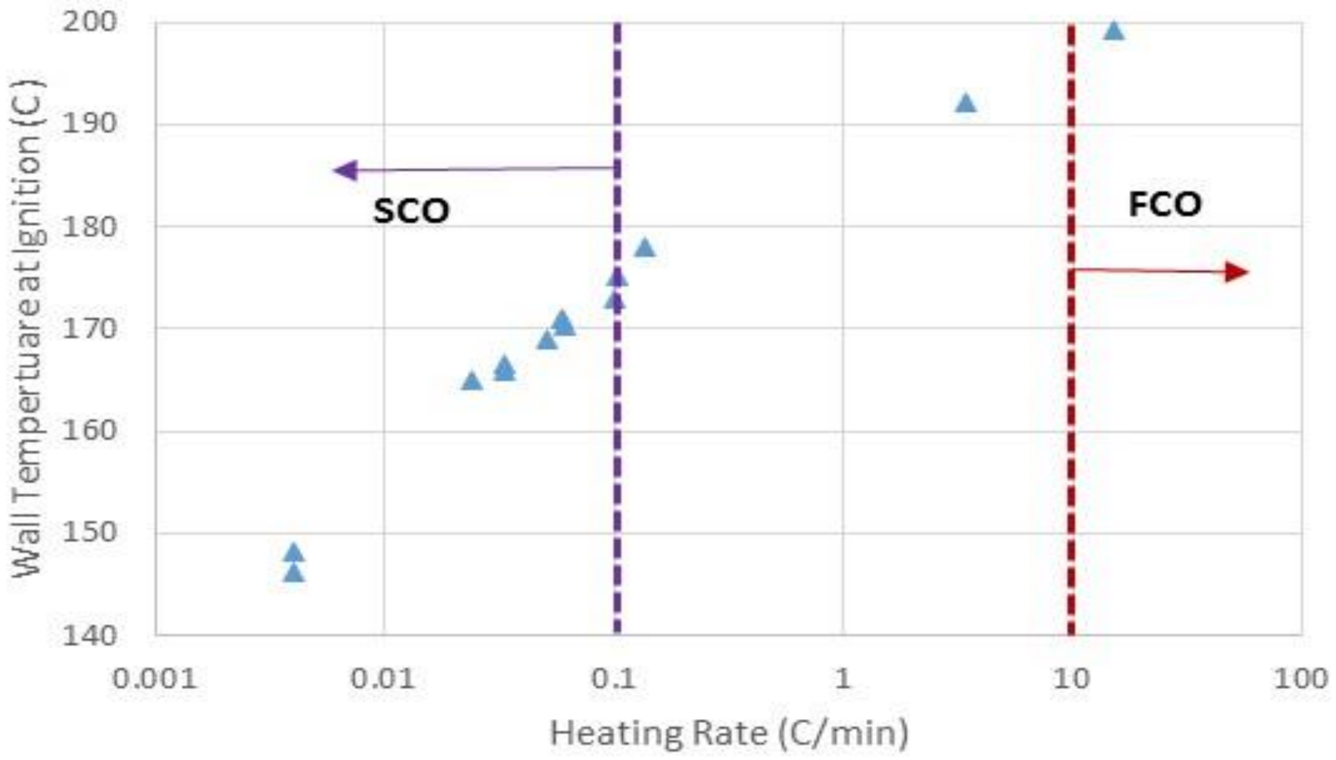


4. Small-scale Cook-off Tests



5 pellets, ¼ inch, 1.7 grams
16 SCO tests on confined PBXN-109 pellets varying heating rate from 0.004 C/min to 15 C/min

Measured $T_{wall@ignition}$ in BlazeTech Tests



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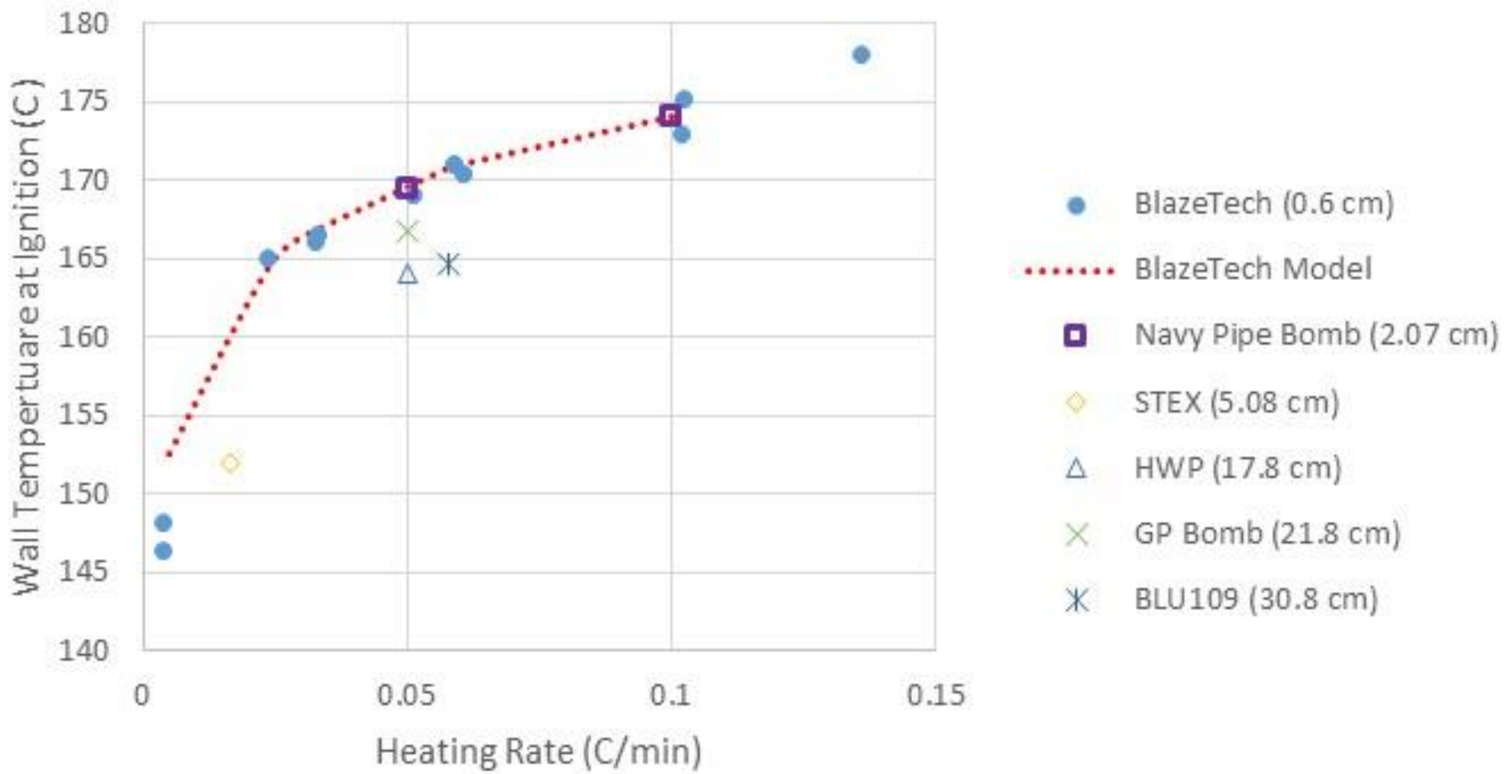
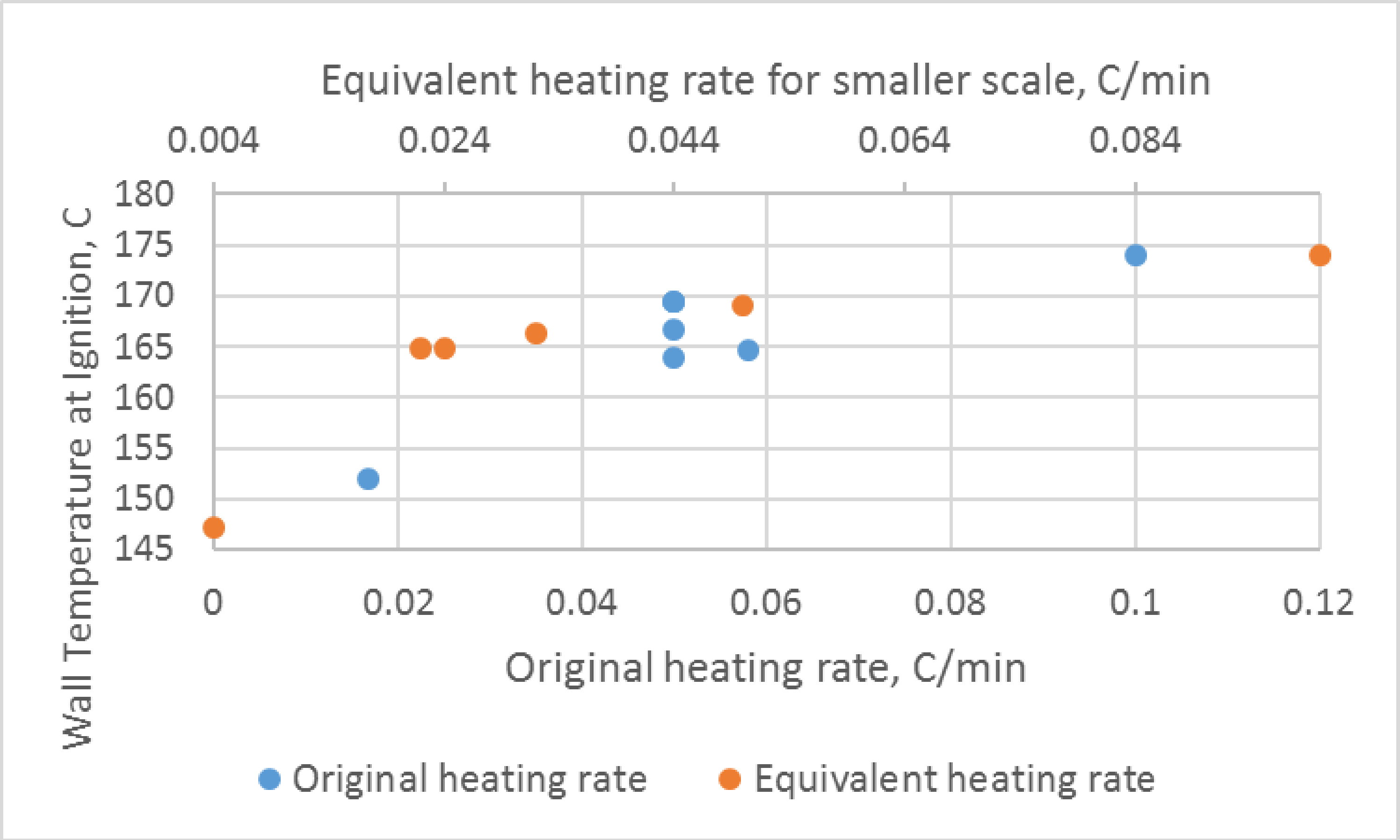
5. Literature data for Model Comparison

Parameter	Description	NAWC-5	NAWC-6	STEX	HWP	GP Bomb
Container Dimensions	Length (cm)	12.10	12.12	21.37	45.21	155
	Inner Diameter (cm)	2.06	2.07	5.08	17.78	25.5*
	Wall Thickness (cm)	0.22	0.22	0.4	1.25	1.2*
Explosive	Mass (g)	57.38	58.44	679	15150	84,000
	Volume (cm^3)	34.36	34.99	407	9072	50,250
	Length (cm)	10.3	10.35	20.3	42.95	137*
	Diameter (cm)	2.06	2.07	5.08	17.78	25.5*
	Ullage Volume (%)	14.9	14.6	5	5	10*
Heating Profile	Initial Heating Rate (°C/min)	10	15	10	3.3	NA
	Soak Temperature (°C)	130	155	130	147.2	42*
	Soak Duration (min)	20	30	300	300	NA
	Final Ramp Rate (°C/min)	0.1	0.05	0.0167	0.05	0.056
Results	$T_{wall@Ignition}$ (°C)	174±1	169.5±1	152	164	~ 166.7
	Time to Ignition After Soak (min)	442	295	1320	354	2244

Our Measured and Predicted $T_{wall@ignition}$ (Plus Literature data at various scales)



$T_{wall@ignition}$ from Various Sources vs. Original and "Equivalent" Heating Rates



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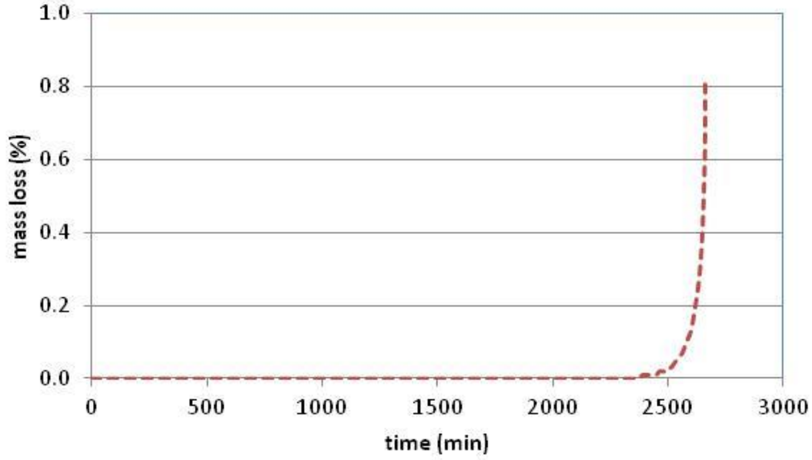
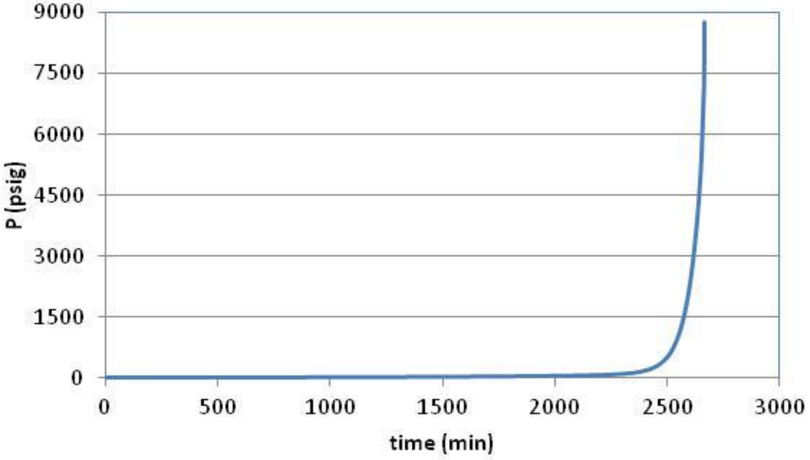
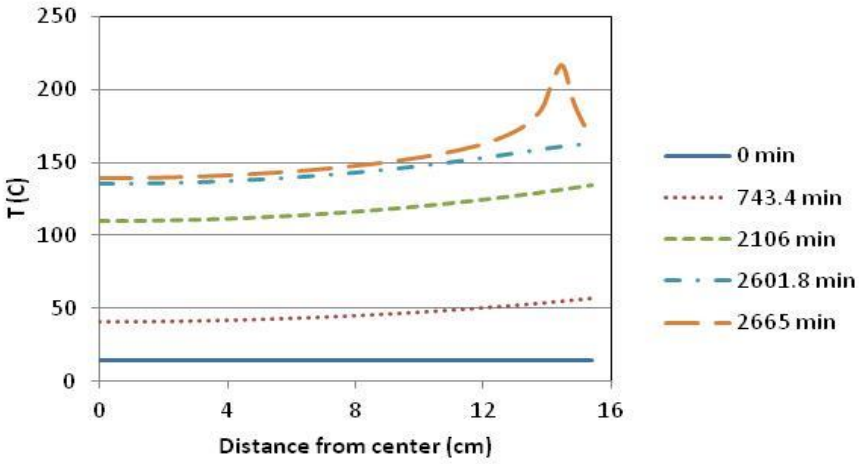
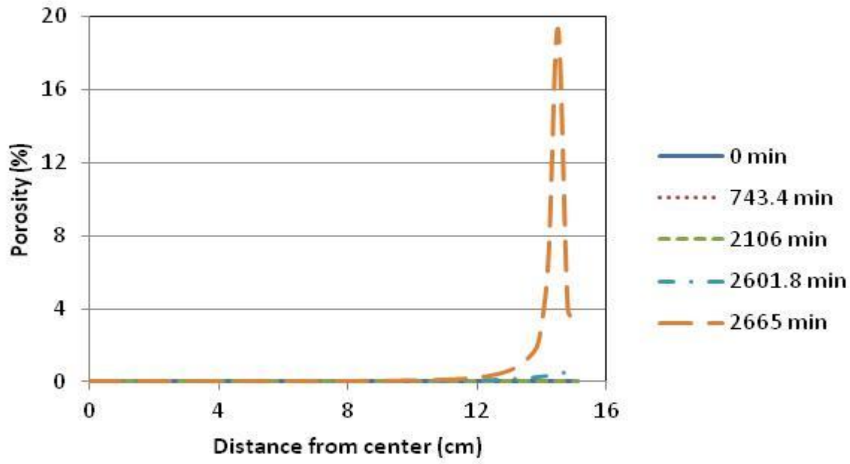
Other Model Predictions for BLU109 Loaded with PBXN-109









Key Findings Related to Scaling

We focus on $T_{wall@ignition}$ – reported by others:

1. Predicted $T_{wall@ignition}$ agrees well with SCO data for various scales in literature
2. At a given scale, $T_{wall@ignition}$ increases with increasing heating rate
3. At a given heating rate, $T_{wall@ignition}$ increases with decreasing scale
4. Choice of scale and heating rate are interrelated and can be given by our model in test design
5. SCO and FCO can be handled by our model given that kinetic rates are coupled with heat transfer

Closure

To scale violence one needs to match:

1. Thermal degradation state of explosive prior to ignition
2. Casing pressure

Both predicted by our model

Our model can be used :

1. To adjust the heating protocol to match 1 and 2 between different scales.
2. To develop better scaling tests
3. To develop methods to mitigate cook-off

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Key References

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