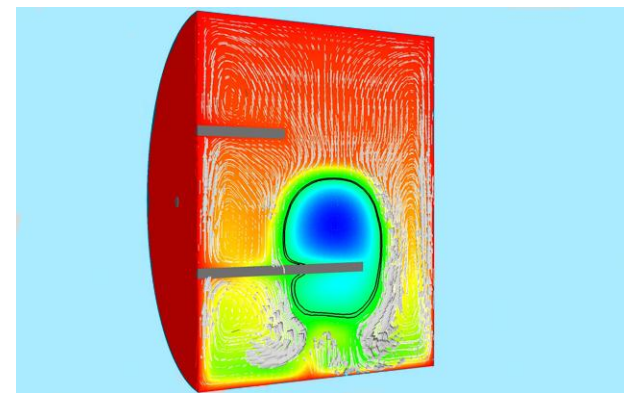
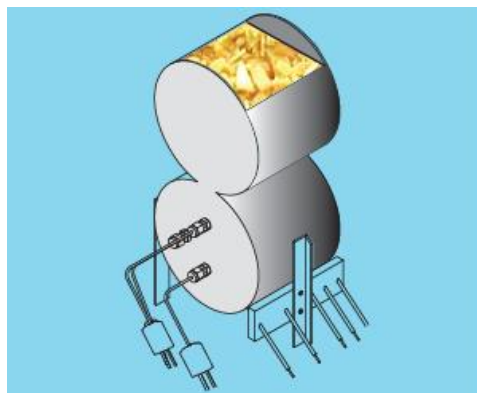
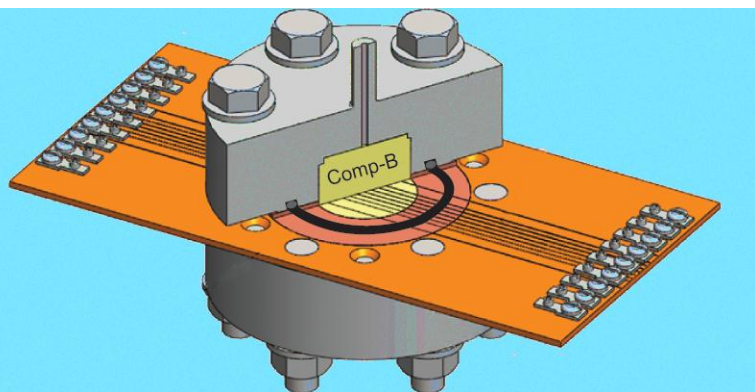
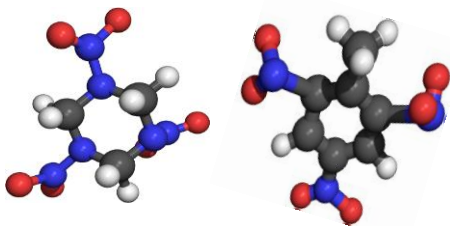


*Exceptional service in the national interest*



# Cookoff of a Melt-castable Explosive

M. L. Hobbs, M. J. Kaneshige, M. U. Anderson

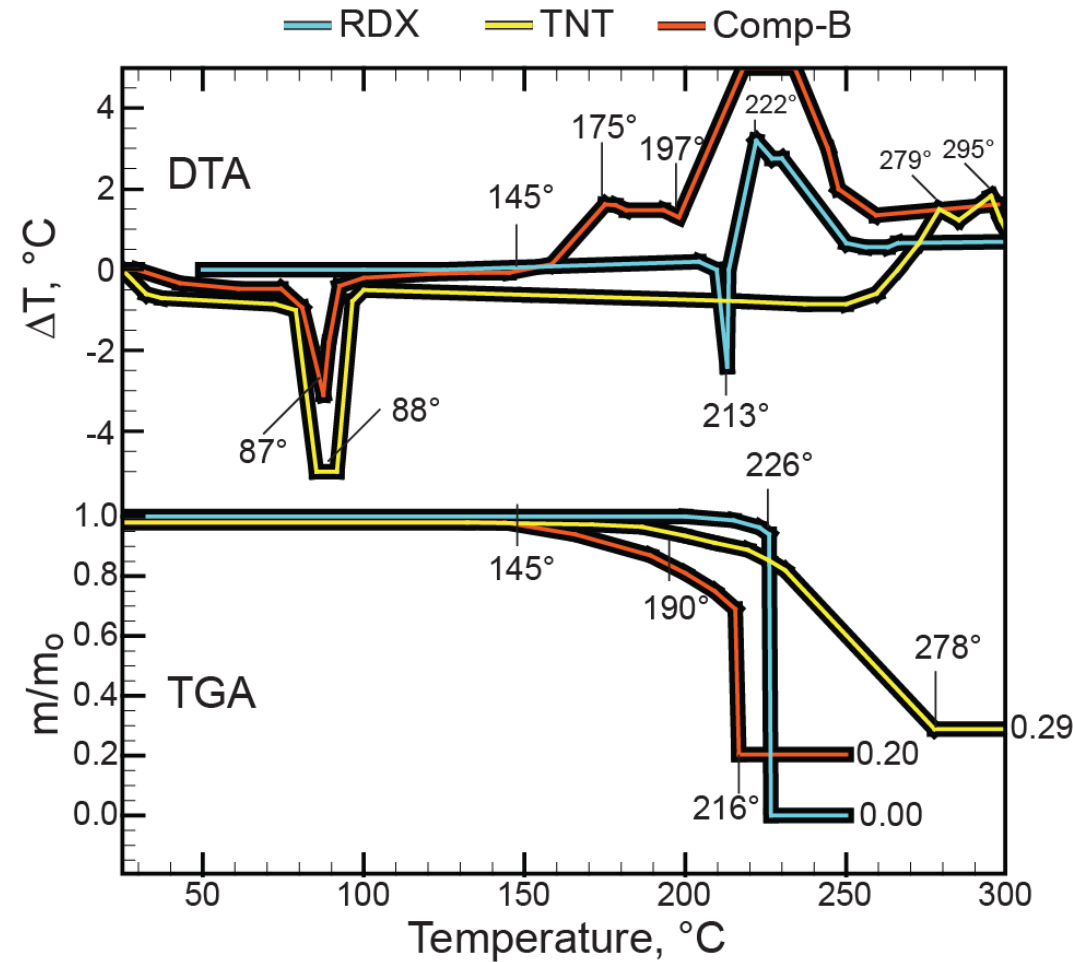


# Introduction



- Composition B (Comp-B) explosives consist of mixtures of RDX and TNT, and a desensitizing wax. In the current work, Comp-B is assumed to be composed of 60/40 RDX/TNT by weight.
- Developed prior to WWI and used in mortar shells, torpedoes, demolition charges, warheads, shaped charges, and bombs.
- Prepared by melting TNT in a steam-jacketed kettle, adding wet RDX slowly, heating and stirring until the water is evaporated. Comp-B is cast into desired shape and cooled.
- Comp-B is easy to process, has a high detonation pressure, but fails many insensitive munitions (IM) requirements.
- Comp-B does not pass slow and fast cookoff IM tests. Consequently, the response of Comp-B during an accident, such as a fire, is important for safety analysis.

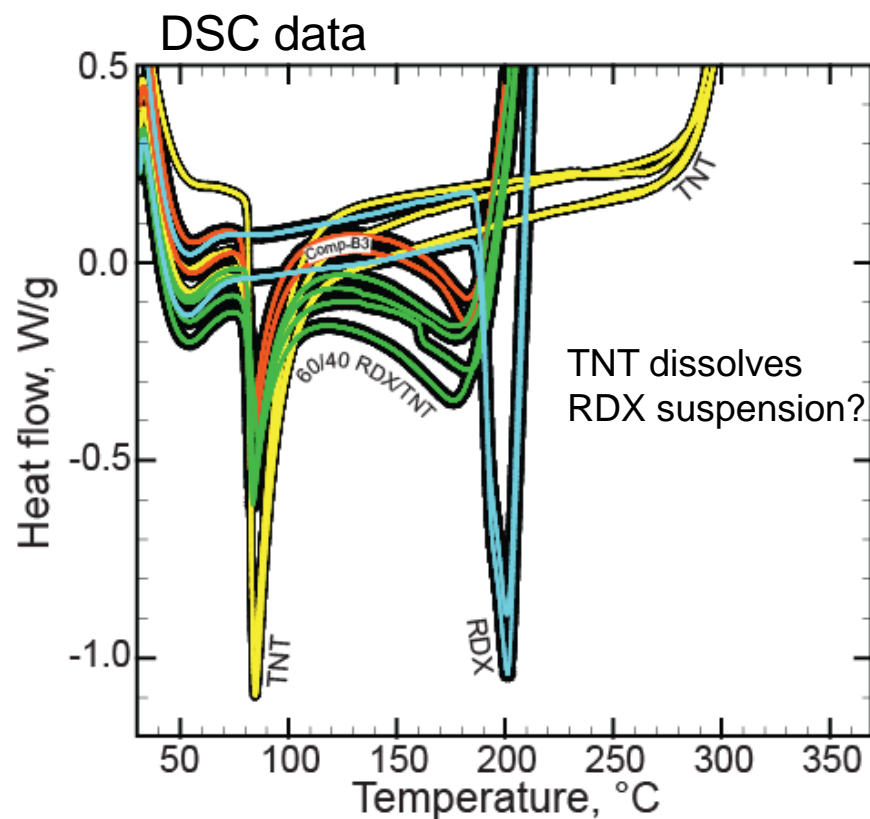
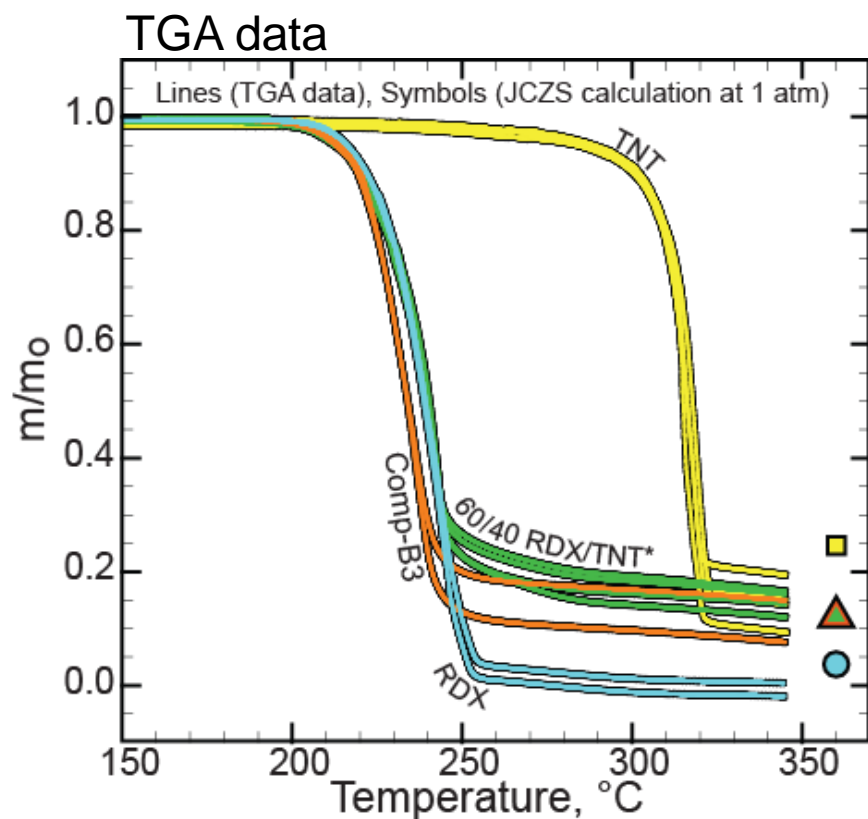
# Thermal Analysis by Others\*



- TNT in Comp-B melts at same temperature as in pure TNT.
- RDX melt is absent in the Comp-B DTA data.
- Early onset of Comp-B may be caused by hot Comp-B liquid dissolving the RDX suspension.
- Some discrepancy in data (e.g. DTA shows exotherm after TGA indicates no reaction)

\**LLNL Explosives Handbook*, LLNL report DE85-015961 (1981).

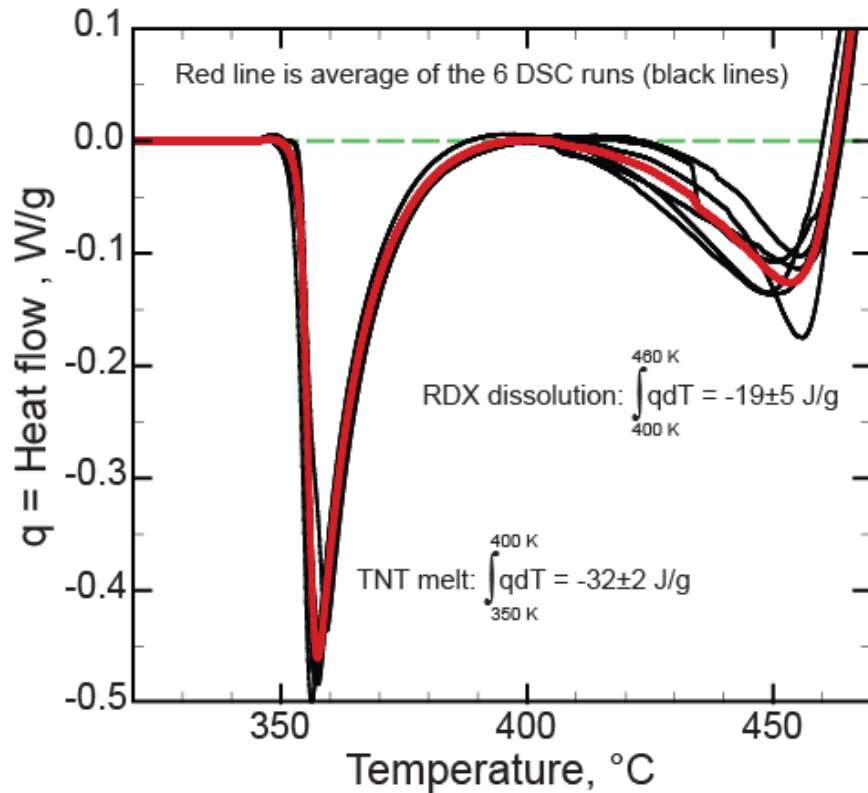
# Simultaneous TGA/DSC Data



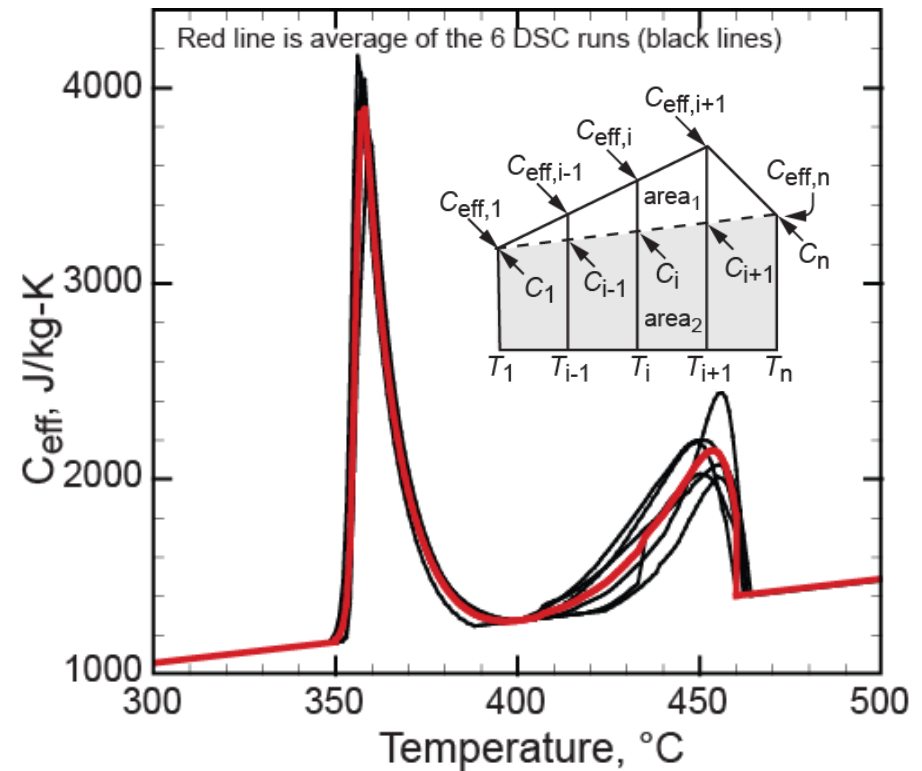
*\*RDX and TNT are from the same lot used to make the 60/40 mixtures.*

# TNT Melt & RDX Dissolution

Baseline corrected DSC



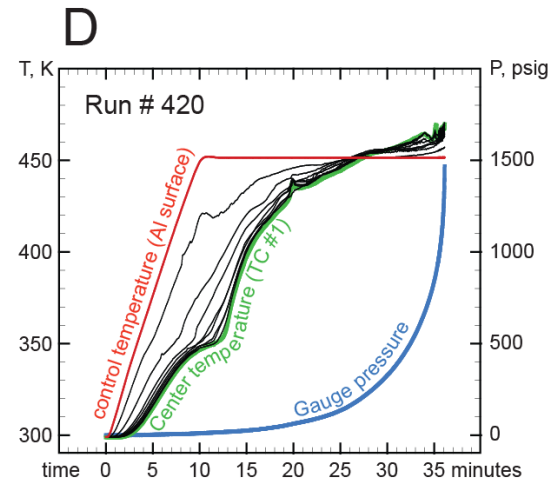
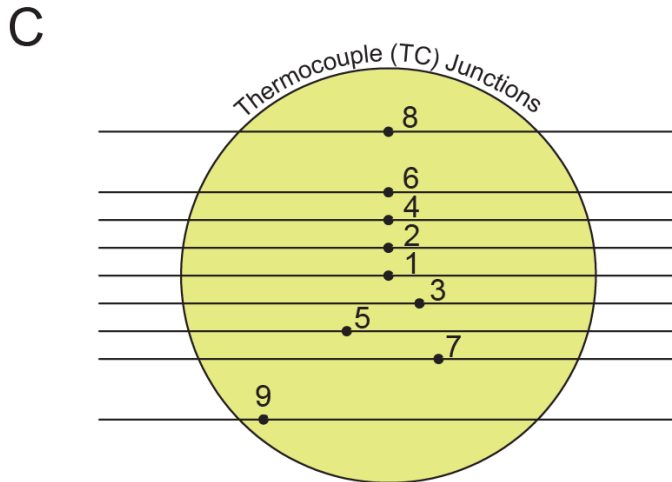
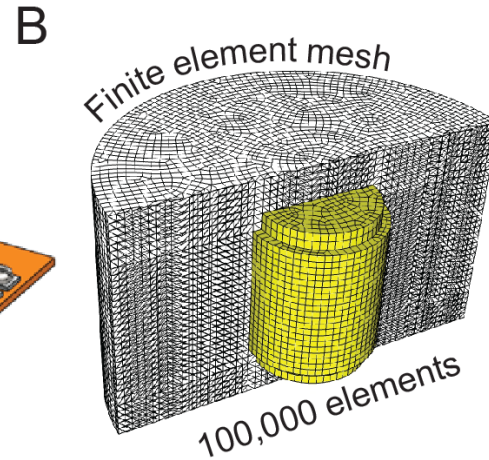
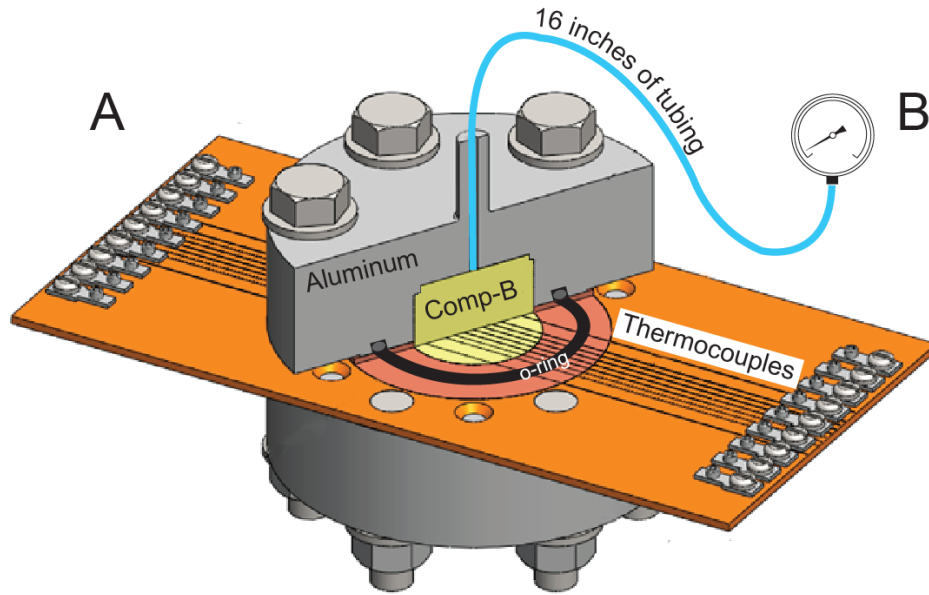
Effective capacitance model



*Latent enthalpy taken directly from DSC data. TNT latent enthalpy matches literature. Energy of RDX dissolution is less than RDX melt.*

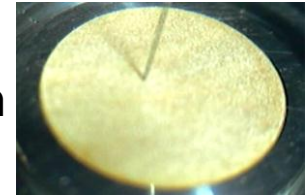


# Sandia's Instrumented Thermal Ignition (SITI)



Open half shell

4 m



8 m



12 m

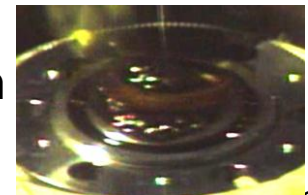


16 m

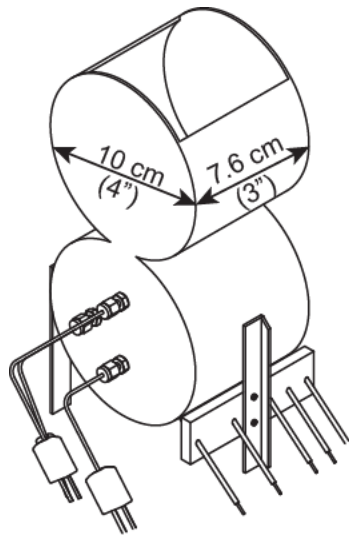


36 m

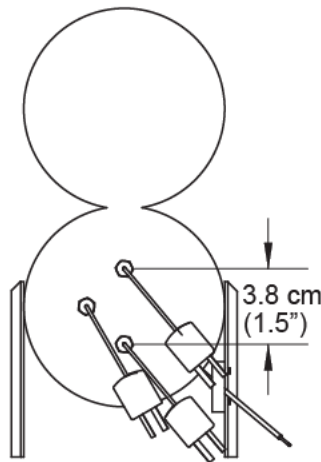
22 s



# Oven Test (a.k.a. snowman)



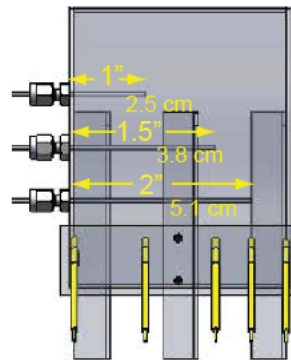
45 minutes



135 minutes



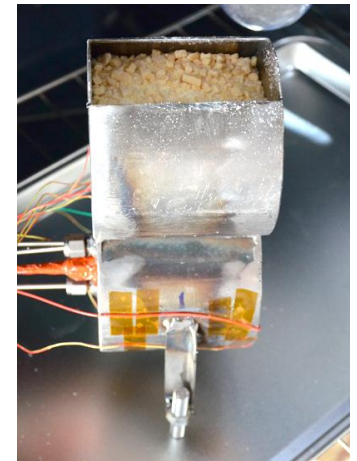
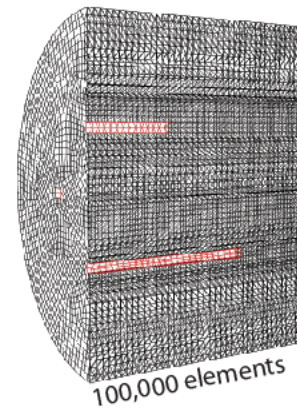
Lower cylinder  
fills with liquid



270 minutes



Mesh

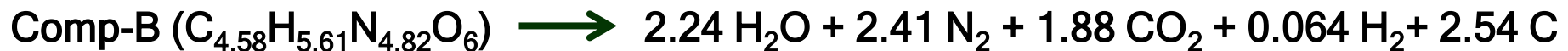


Post test oven



# Model Features

- One-step, first-order mechanism
- Distributed Arrhenius rates modified by  $(P/P^0)^n$
- Product hierarchy from equilibrium calculations
- Liquefaction modeled thermodynamically
- Liquid rates are 15 times larger than solid rates
- Thermal expansion, TNT phase change, RDX dissolution
- One energy equation, one momentum equation, three continuity equations (Comp-B, Gas, Carbon), various auxiliary equations for gas volume fraction, pressure, etc.



$$r = A \left( \frac{P}{P^0} \right)^{n_p} \lambda \exp \left[ - (E + \xi \sigma_E) / RT \right] [\text{compb}] \quad r_{\text{gas}} = \frac{d}{dt} [\text{gas}] = +6.845r \quad r_{\text{carbon}} = \frac{d}{dt} [\text{carbon}] = +2.450r$$



# Model Features (continued)

- Single energy equation with convection and reaction source.

$$\rho C_p \frac{\partial T}{\partial t} + \rho C_p \vec{v} \cdot \nabla T = \nabla \cdot (k \nabla T) + q_r$$

- Single momentum equation with Boussinesq volume force.

$$\rho \frac{d\vec{v}}{dt} + \rho \vec{v} \cdot \nabla \vec{v} = -\nabla P + \mu \nabla^2 \vec{v} + (\rho - \rho_o) gh$$

- All wetted surfaces assumed to have a no-slip boundary.

$$\vec{v}_{\text{wetted surfaces}} = 0$$

- Local gas/solid velocities/temperatures equal.

$$T_c = T_g = T(x, y, z, t) \quad \text{and} \quad \vec{v}_c = \vec{v}_g = \vec{v}(x, y, z, t)$$

- Low Mach flow (velocities much less than sound speeds).

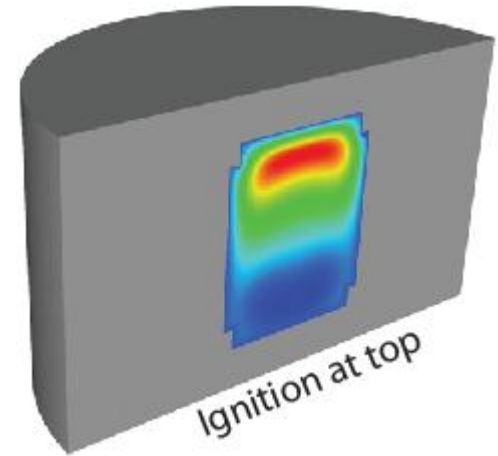
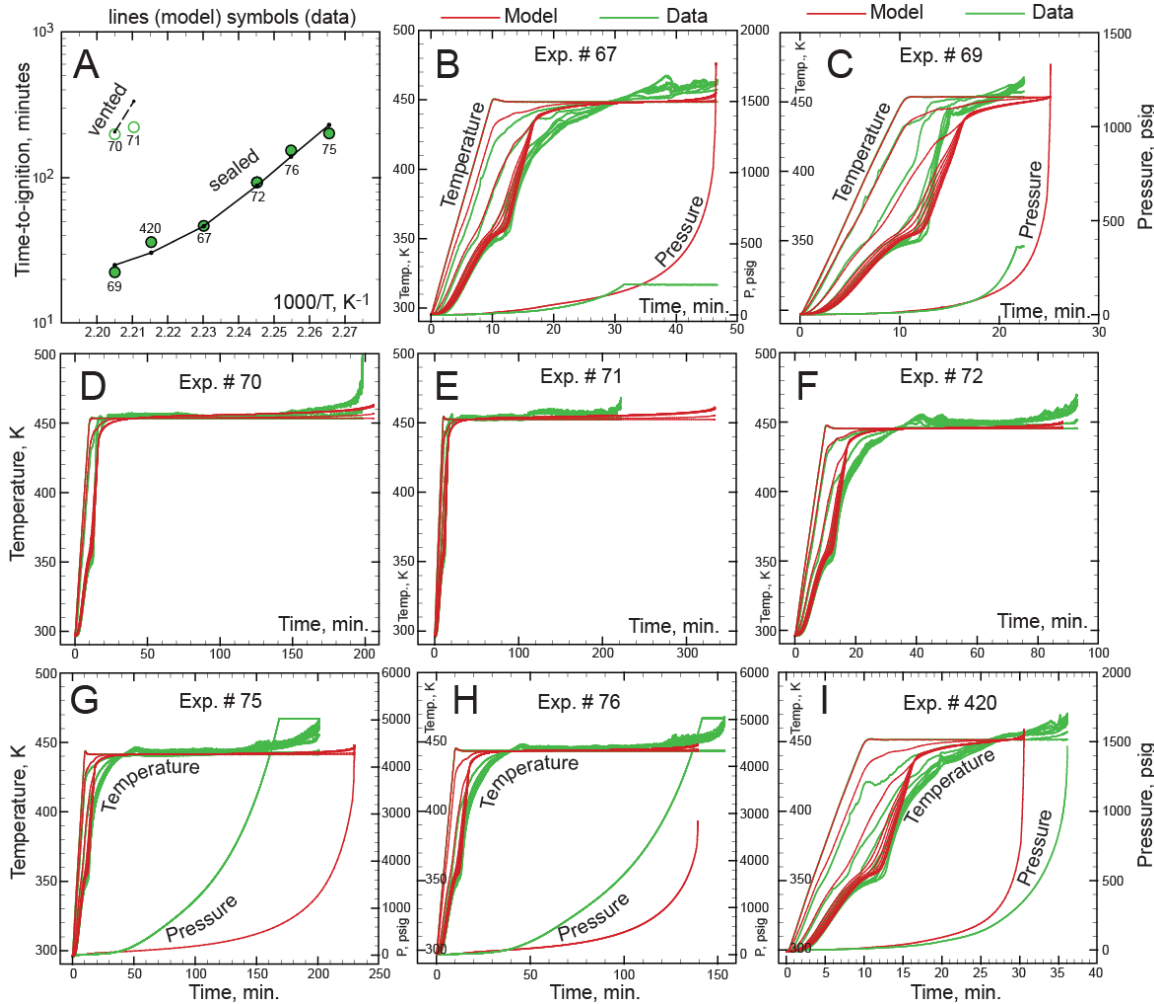
$$P(x, y, z, t) = P(t)$$

- BKWS-EOS used for pressure  $P_g(x, y, z, t) = P_g(t) = \frac{\bar{z} n R \bar{T}}{V_g}$

$$\bar{z} = 1 + X \exp(0.298X)$$

$$X = \left( \frac{n}{V_g} \right) \left( \frac{0.0105 \times Covol}{\sqrt{\bar{T}} + 6620} \right)$$

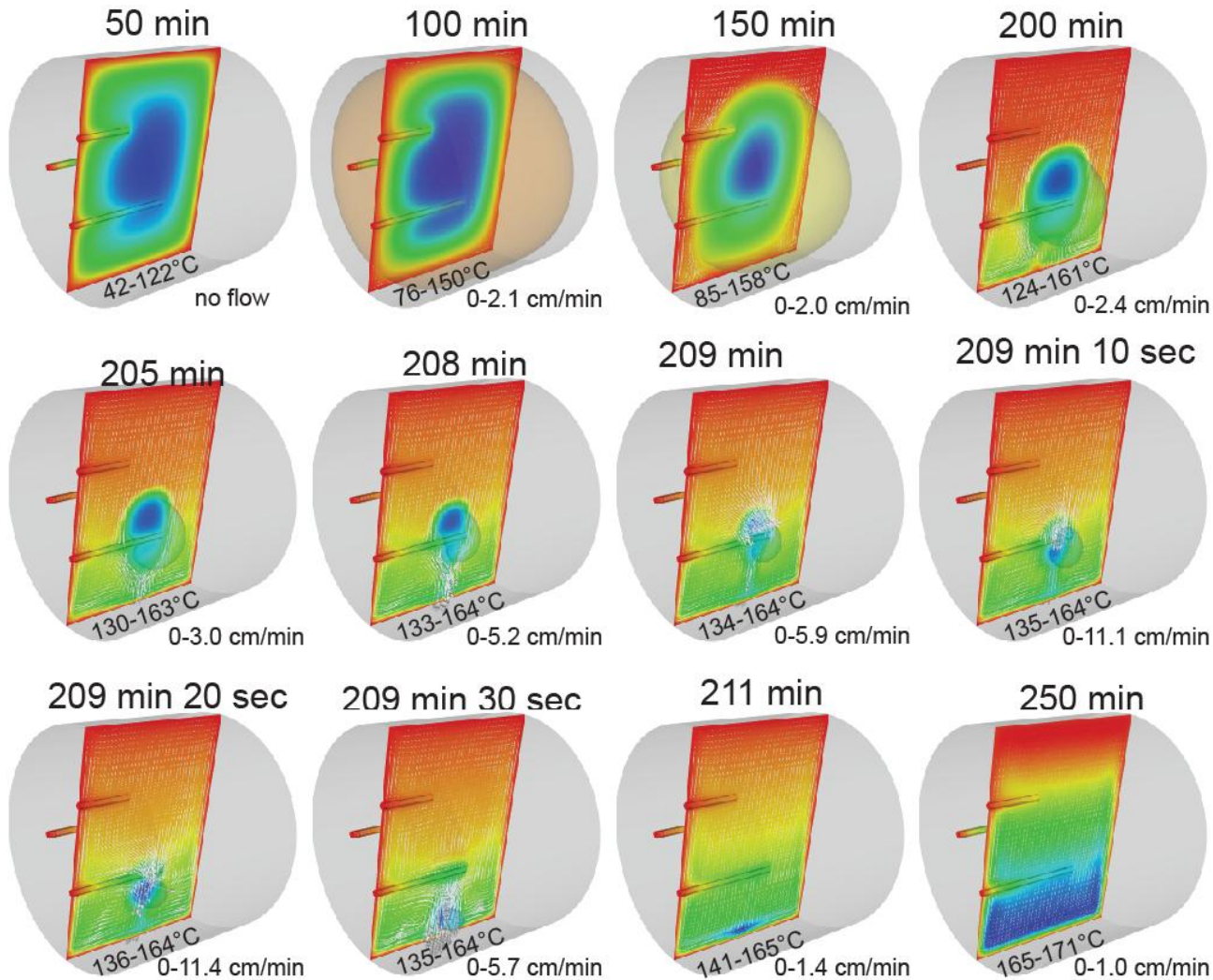
# SITI Test Results



- #71 ignited faster than predicted. Possible plug?
- Good temperature match to 430 K, then model transition from solid to liquid is too fast.

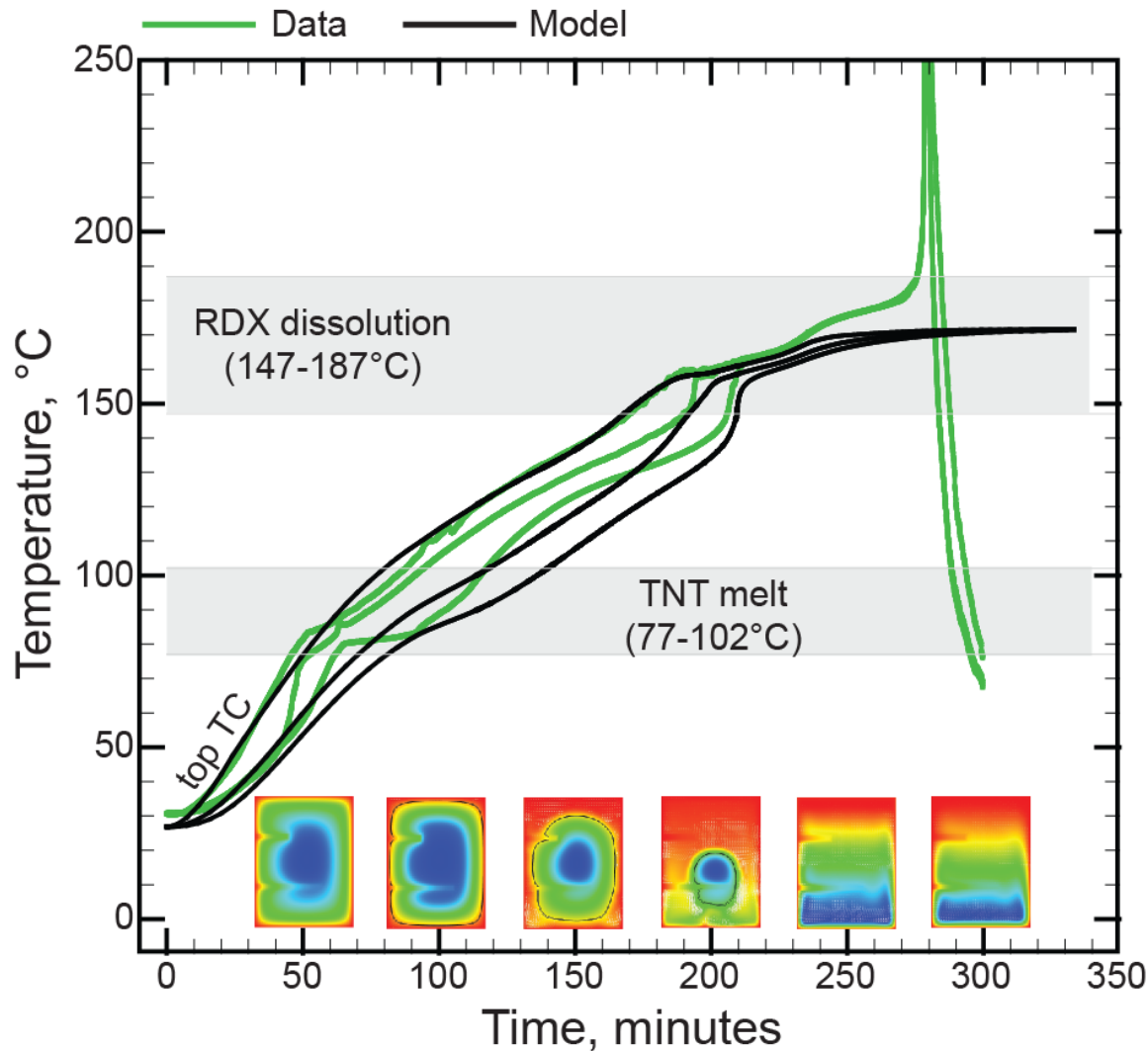
$$\begin{aligned}
 T < 412.5K & \quad \mu = 0.25 \times 10^6 \text{ Pa} \cdot \text{s} \\
 T > 413.5K & \quad \mu = 0.2 \text{ Pa} \cdot \text{s}
 \end{aligned}$$

# Oven Test Results



- Melts from outside to the inside.
- Solid plug gets smaller and starts to fall toward the bottom of the can.
- Liquid heats up and eventually self-heats and ignites at the top of the can.

# Oven Test Results



- Temperature pinch occurs in middle of RDX dissolution range.
- Model predicts slightly longer ignition times.
- Discrepancy in ignition time could be related to the method of melting the Comp-B flakes.
- In the experiment, the flakes were melted in the combined system.

# Summary and Conclusions

- Decomposition of Comp-B decomposes differently as a mixture than the individual components RDX and HMX.
- TNT melts between 77-102°C in Comp-B.
- The RDX suspension in hot TNT dissolves between 147-187°C
- The dissolution of RDX is not as sharp as a phase change and favors a distributed activation energy model.
- The model captures the time-to-ignition for the SITI experiments.
- The modeled SITI internal temperatures are good until about 157°C and then the temperatures pinch together faster than the measured temperatures.
- Temperature dependent volumetric expansion data is needed at elevated temperatures.
- Viscosity data above 157°C is needed.
- More data is needed for both open and closed systems using melt-cast Comp-B as well as flaked Comp-B.