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*Title:* Double Shock Experiments and Modeling in PBX 9502

*Author(s):* Tariq D. Aslam, Richard L. Gustavsen, Nathaniel J. Sanchez, Brian D. Bartram and Ralph Menikoff

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Title: Double Shock Experiments and Modeling in PBX 9502

Authors:
Tariq Aslam
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Nathaniel Sanchez
Brian Bartram
Ralph Menikoff

## Abstract

The multi-shock response of PBX 9502 is examined. In particular a set of experiments utilizing multi-component impactors of low density material (TPX) followed by high density material (Ta) are used to shock compress PBX 9502 to very high pressures without subsequent chemical reaction. Relevant modeling and computations will be presented for the PBX 9502 reactants equation of state.

# Double Shock Experiments and Modeling in PBX 9502

Tariq Aslam, WX-9

Richard Gustavsen, WX-9

Nathaniel Sanchez, WX-9

Brian Bartram, WX-9

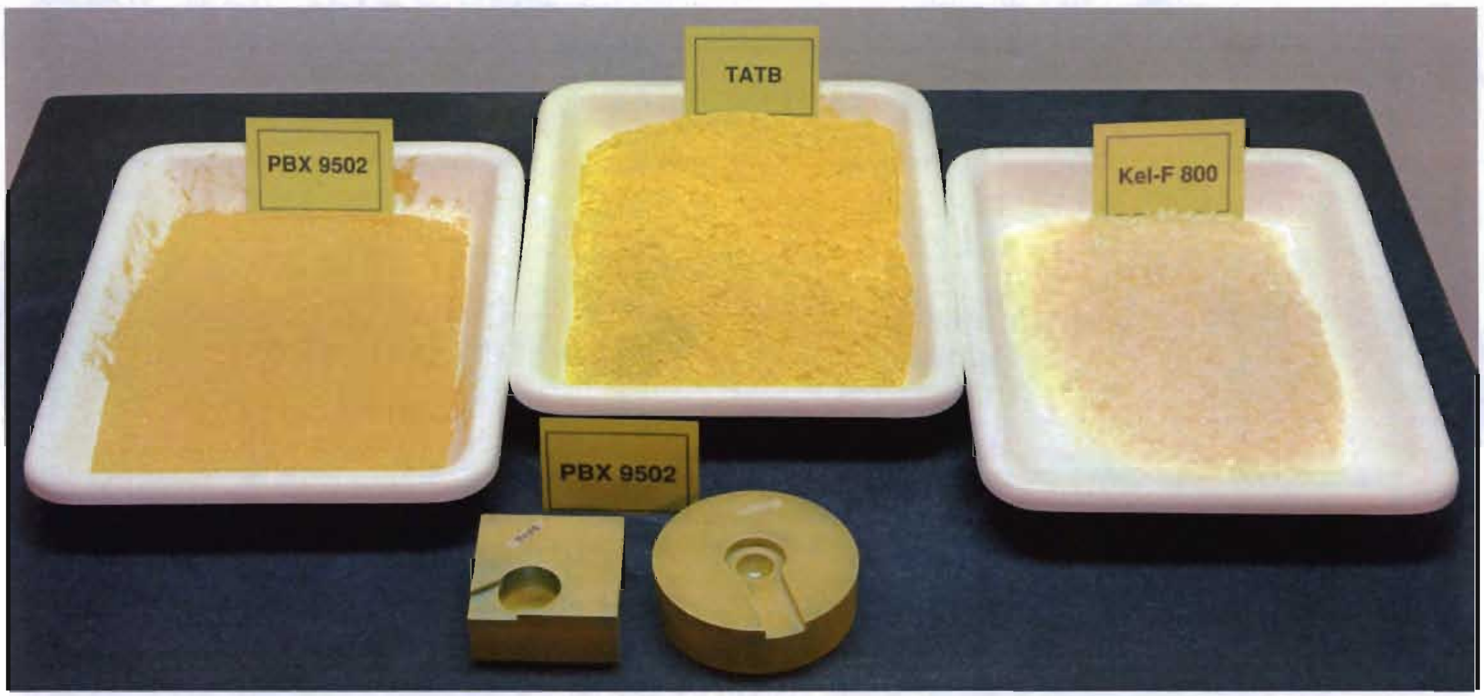
Ralph Menikoff, T-1

# OUTLINE

- Importance of Reactants Equation of State (EOS)
- Difficulty in Obtaining High Pressure Reactants EOS
- Experimental Approaches
- New Multi-Shock Gas Gun Experiments
- New Model for PBX 9502 Reactants at High Pressure

# Focus on PBX 9502:

95% TATB, 5% Kel-F 800



# Importance of Reactants EOS - Hugoniot:

## Reactive Flow Modeling:

### Ignition and Growth (I&G)

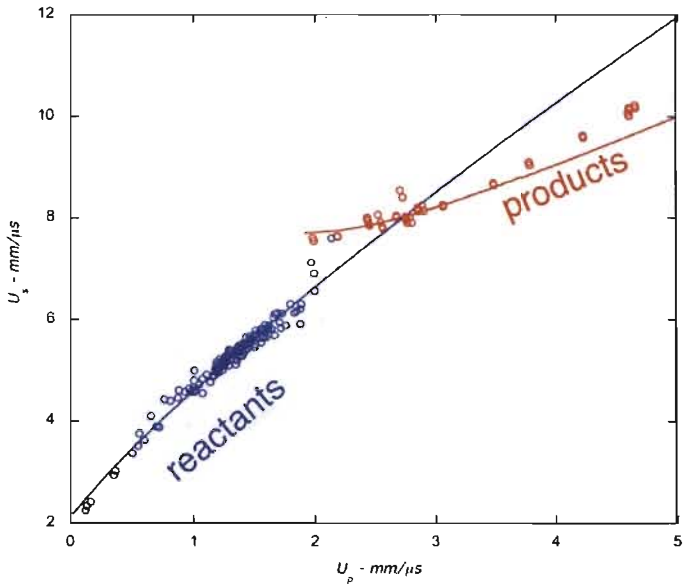



Figure 2: PBX 9502 unreacted Hugoniot data (blue ○), and reacted Hugoniot (red ○), and commensurate JWL IG unreacted (blue —) and reacted (red - ) Hugoniots.

### Wescott, Stewart & Davis (WSD)

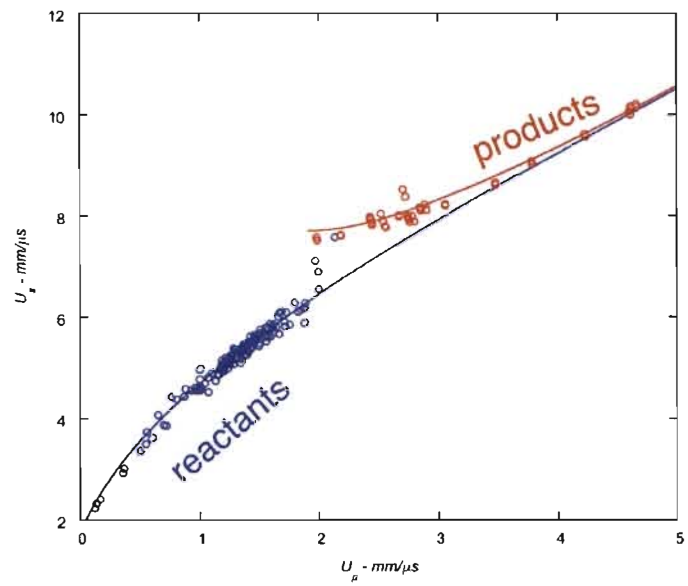


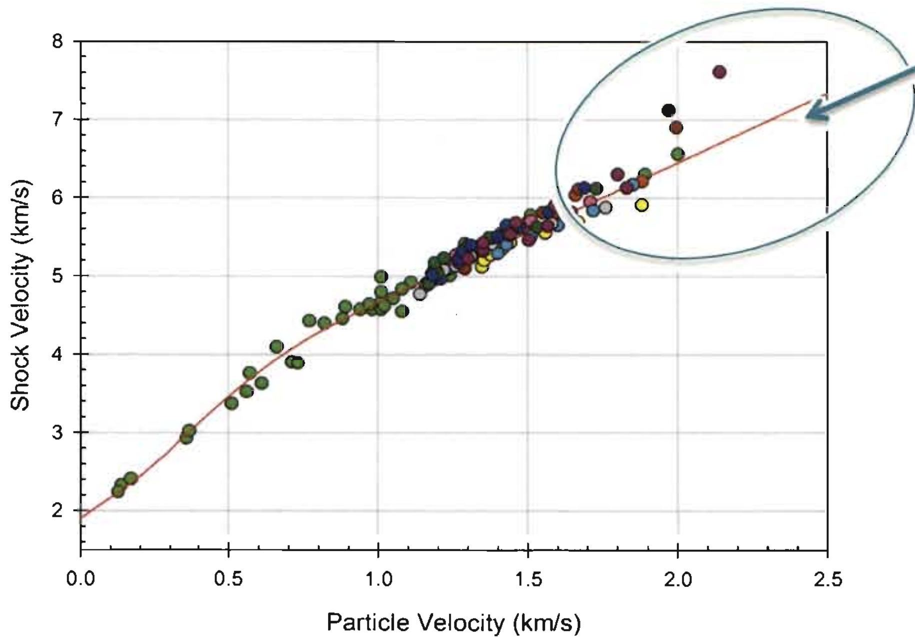

Figure 3: PBX 9502 unreacted Hugoniot data (blue ○), and reacted Hugoniot (red ○), and commensurate WSD unreacted (blue —) and reacted (red —) Hugoniots.

**The ZND pressure is ~6GPa different between 2 models (~36GPa and ~42GPa)**

# Importance of Reactants EOS:

## Reactive Flow Modeling:

PBX 9502 Hugoniot




We need EOS data in this range on the Reactants i.e. p > 20GPa

# Importance of Reactants EOS:

## Detonation Confinement Angles

Shock Polar is used to Determine DSD Shock Angle at end of HE Charge

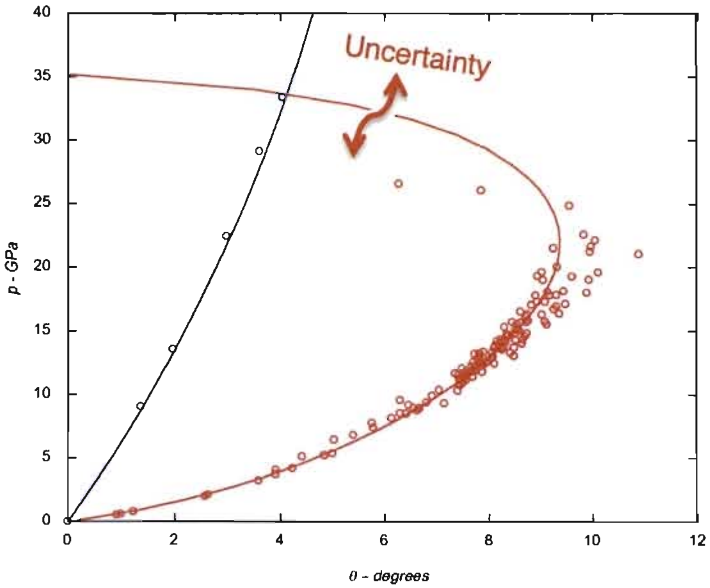
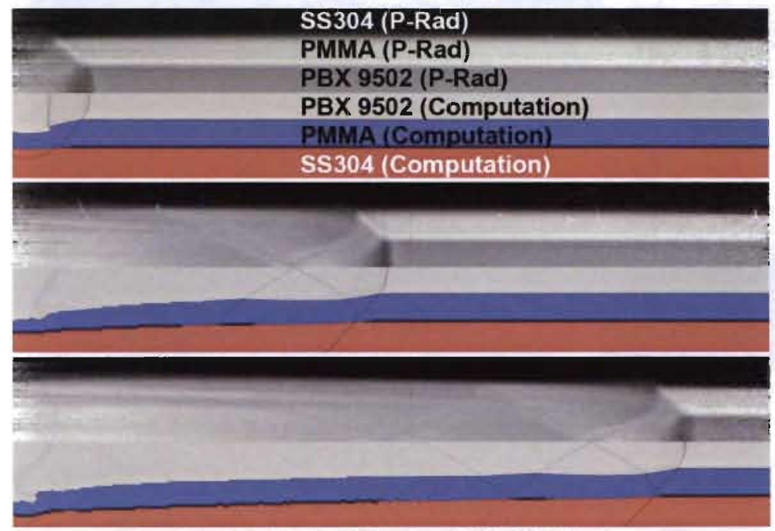



Figure 4: Shock Polars for PBX 9502 data (red o) and IG (red —) and SS304 data (blue o) and linear $U_s - U_p$ (blue —) ; SS304 linear fit $U_s = 4.48 + 1.51U_p$, $\rho_0$=7.926gm/cc.

Confinement angles are a function of HE Reactants and Confiner EOSs

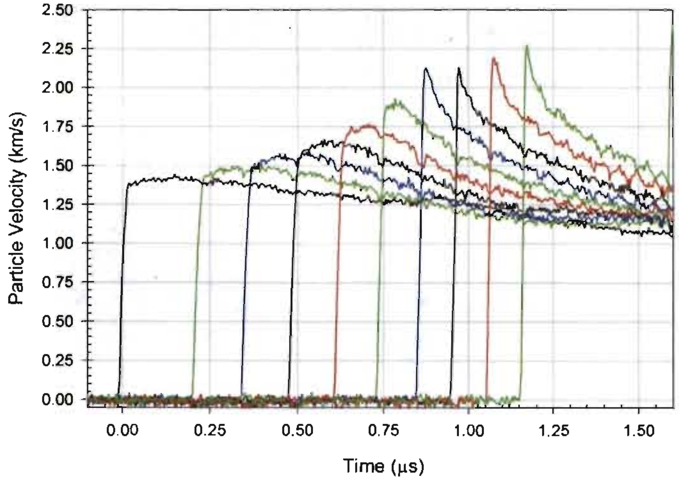



Aslam, Jackson, Morris, APS-SCCM, 2009

# Inherent Difficulty at High Pressures:

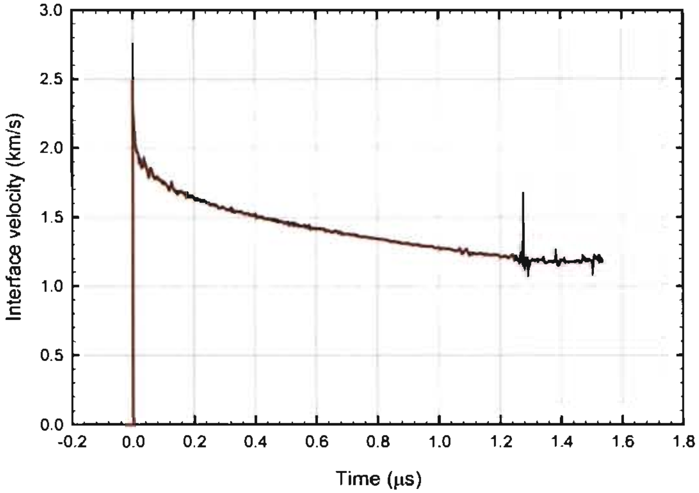
- At high Shock Pressures, Reaction is very fast

Embedded Magnetic Gauge




At detonation pressures, embedded gauges are too slow ~ 25ns rise time

Photon Doppler Velocimetry (PDV)

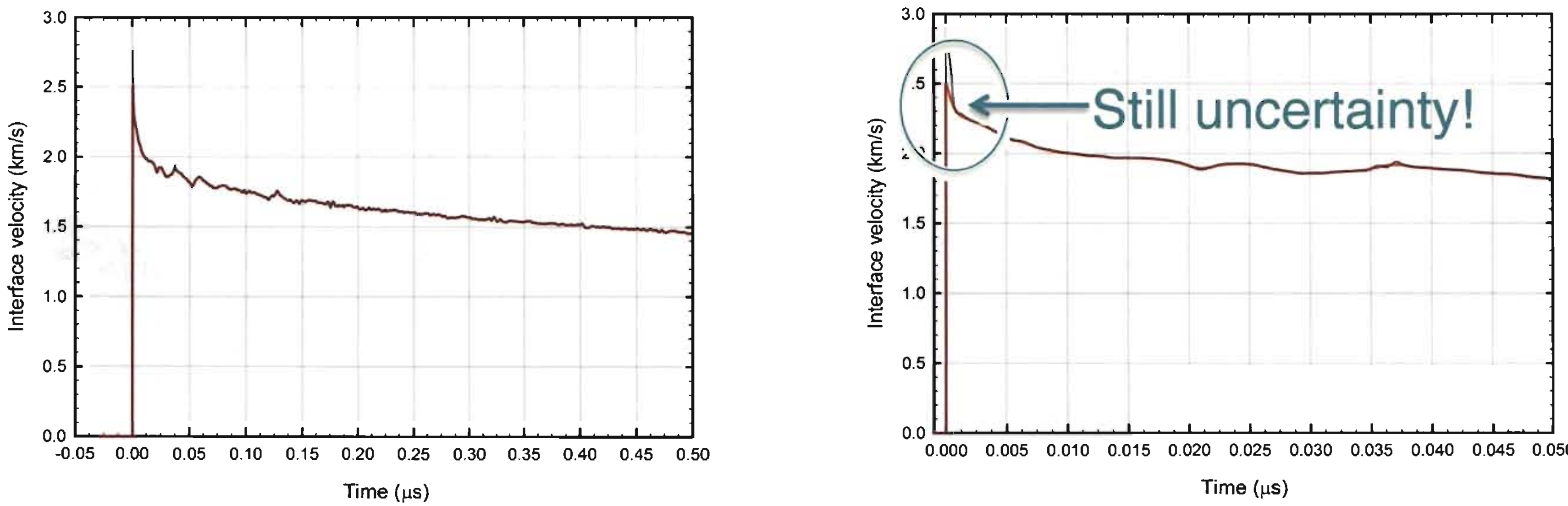



At detonation pressures, PDV is much faster ~ 1ns rise time

# Inherent Difficulty at High Pressures:

- Zooming in near t=0 reveals fine-scale structure

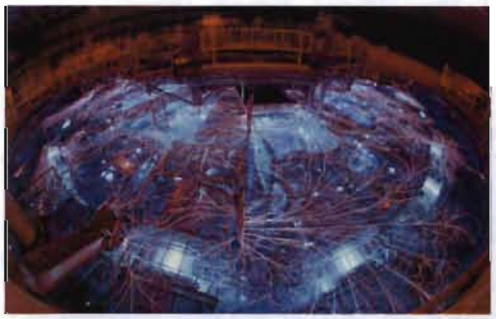
Photon Doppler Velocimetry (PDV)




Black and red curves use 1/2ns and 1ns FWHM Wavelet smoothing

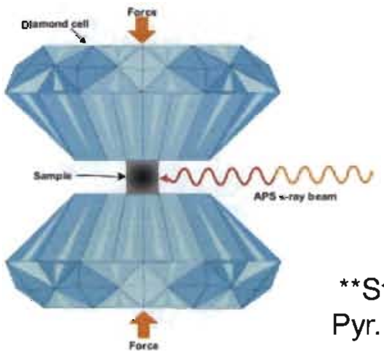
# Other Approaches to Measuring Reactants EOS:

- Isentropic Compression, e.g. Z-machine experiments
  - only up to ~15GPa in literature for LX-17*
- Isothermal Compression, e.g. Diamond Anvil Cell
  - only up to ~13GPa in literature for TATB**



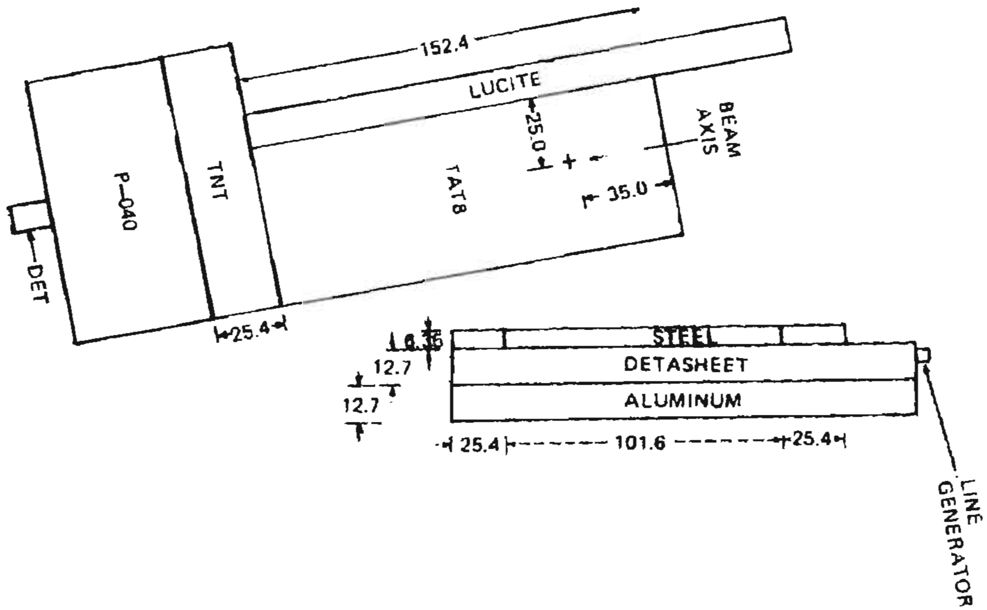
*Springer et al,
14th Int. Det. Symp., 2010

And more recently up to ~25 GPa
on PBX 9502 from Seth Root

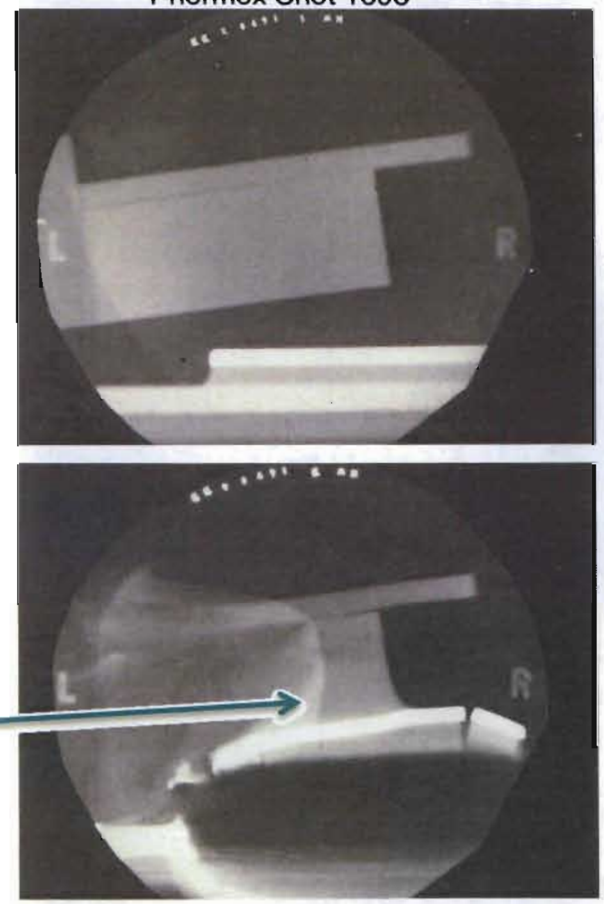



**Stevens et al,
Pyr. Exp. Prop., 2008

# Can we "Magically" Turn Off Reaction?



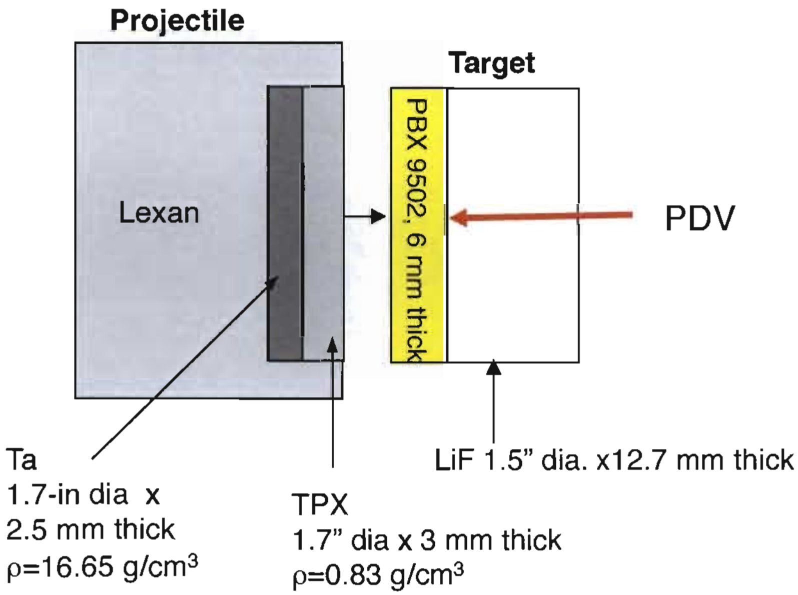

Phermex Shot 1698




~5GPa shock from steel impact causes detonation to go out (squeezes out voids – no hotspots)

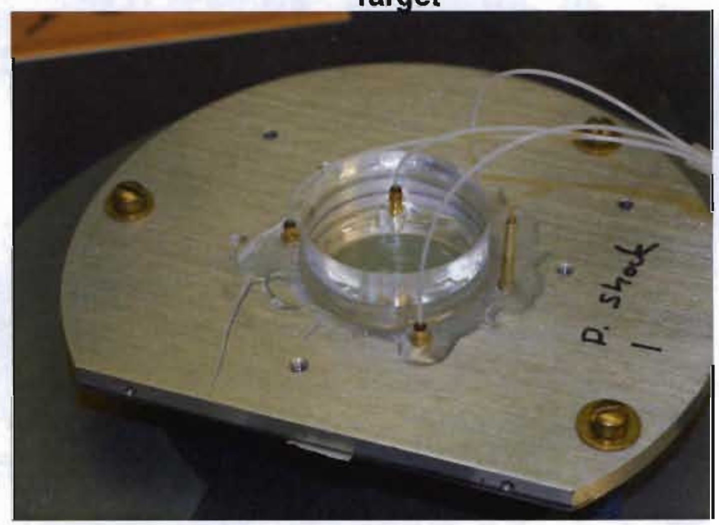
# Design Multi-Shock Experiment to Explore High Pressure Reactants EOS:

2 Stage Gas Gun Experiment, with Dual-Layer Impactor




Projectile

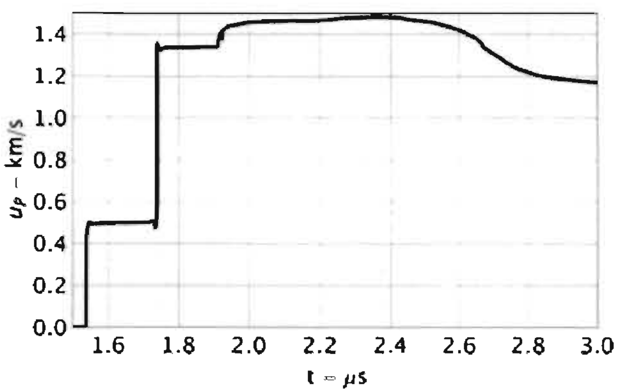
Target



# Results of Multi-Shock Experiments:

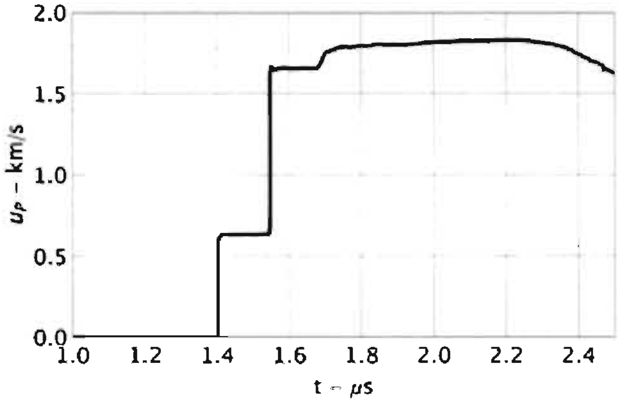
Shot 2s-450

$u_{impactor}$ = 2.139 mm/μs



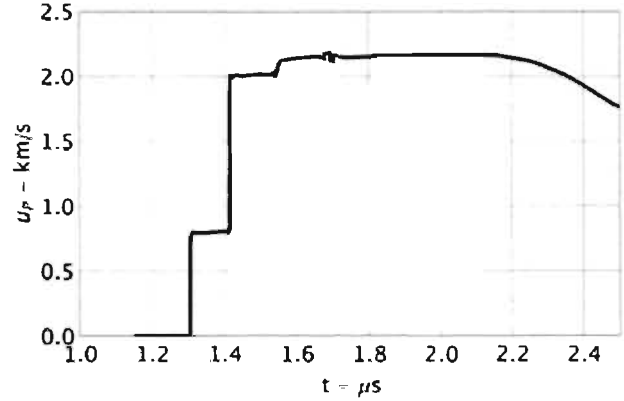

Shot 2s-463

$u_{impactor}$ = 2.585 mm/μs




Shot 2s-465

$u_{impactor}$ = 3.025 mm/μs



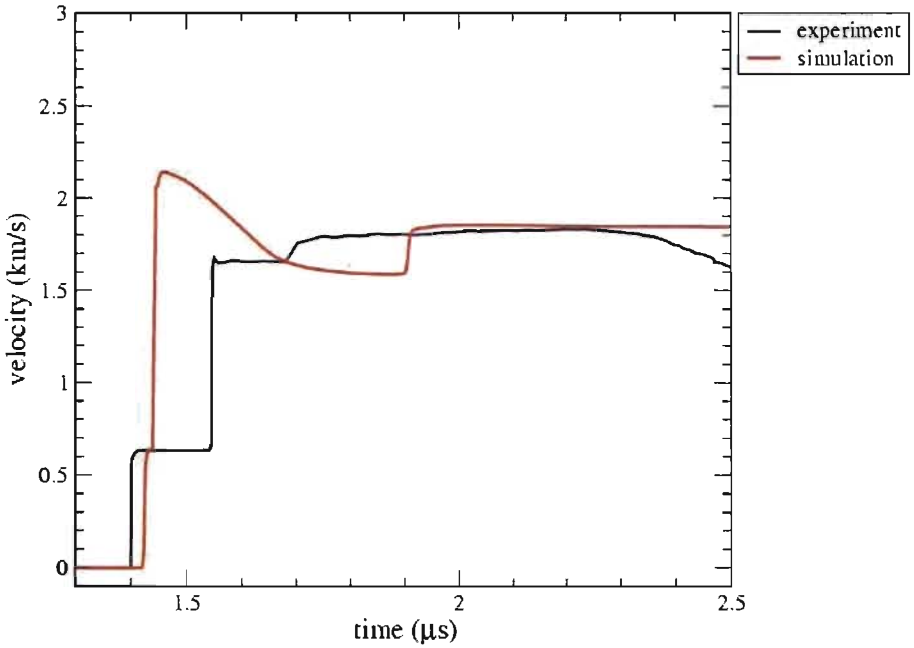

- Little or no apparent reaction
- First shock 5.4 GPa < p < 9 GPa
- Later pressures up to ~45GPa

# Examination of 2s-463 with Pressure Sensitive Reactive Flow Models:

## Ignition & Growth

Velocity Data

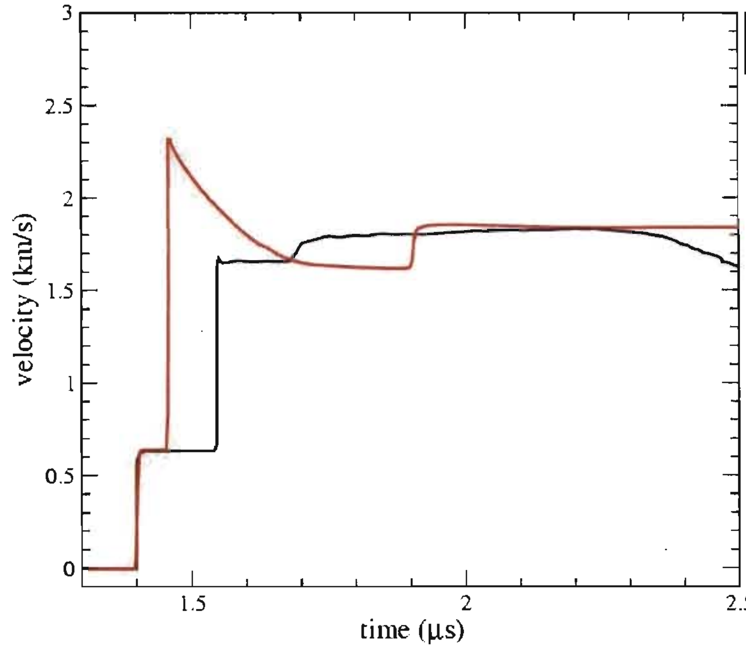
(shot SHOT.1G/2s463)




## WSD

Velocity Data

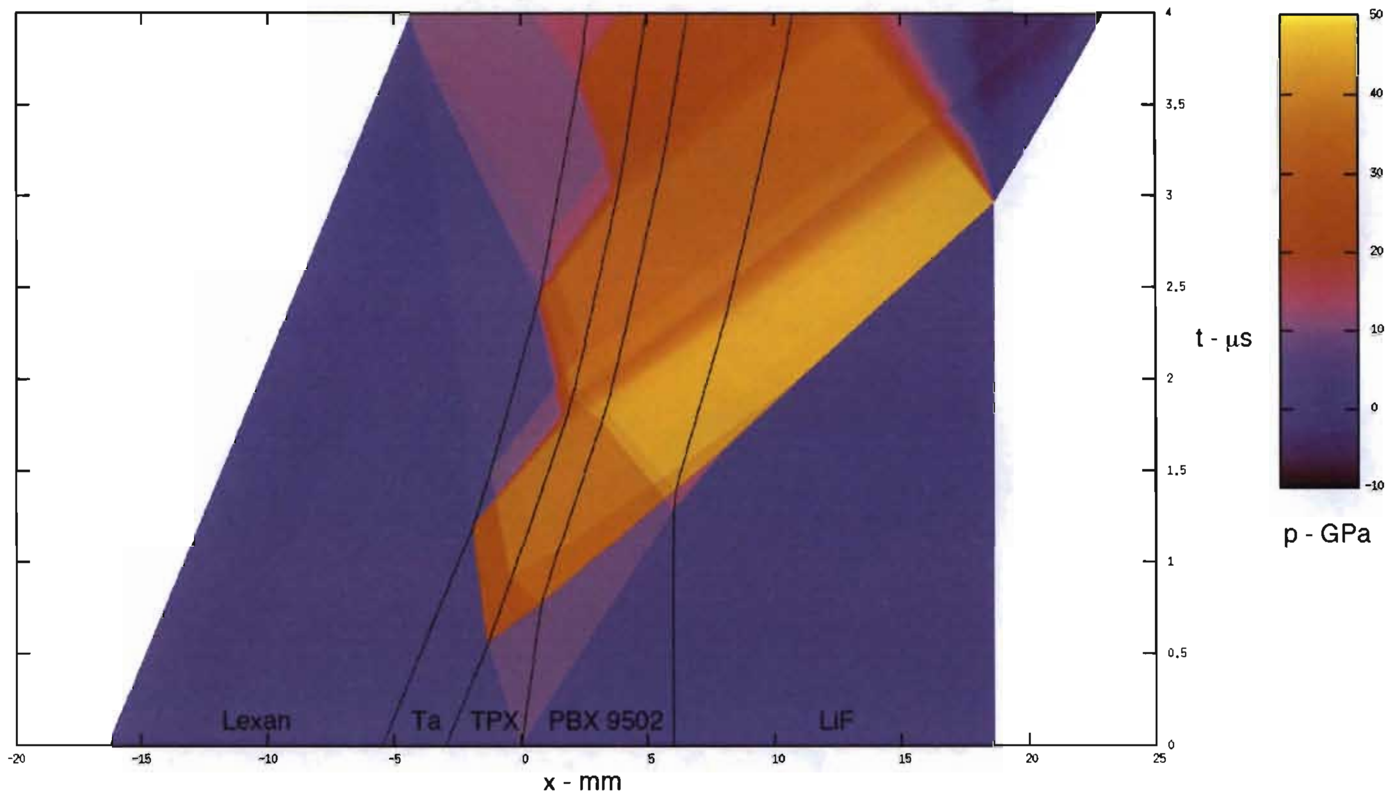
(shot SHOT.1G/2s463)




Other $p^n$ rates, such as Cheetah/ALE, probably also predict detonation.

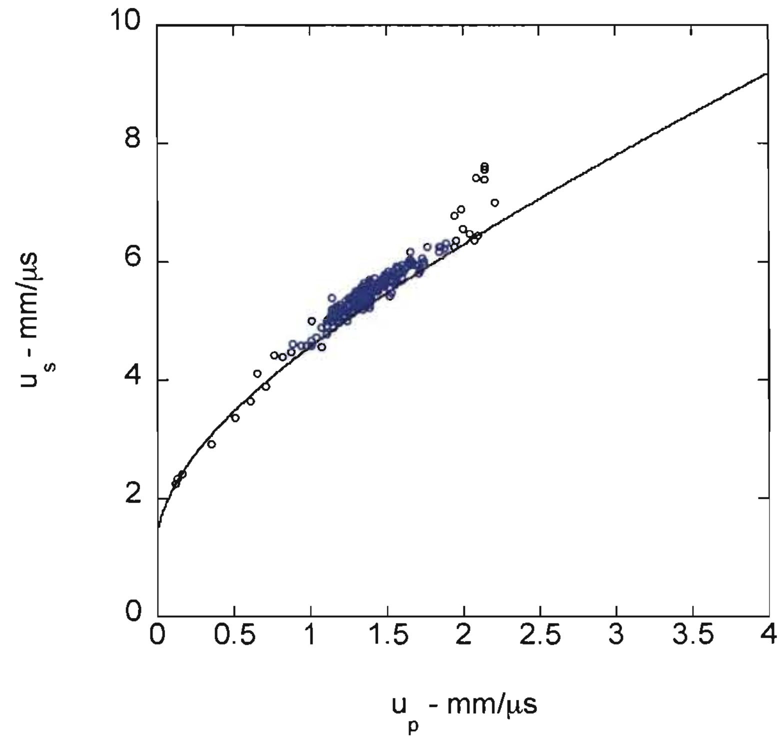
# Modeling of Multi-Shock Experiments:

- 1D Lagrangian Hydrodynamics Code, Δx=10μm
- Keane based Mie-Gruneisen EOS for Lexan, TPX and PBX 9502 (no chemistry)
- Linear Us-Up Mie-Gruneisen EOS for Ta and LiF



# Modeling of Multi-Shock Experiments:

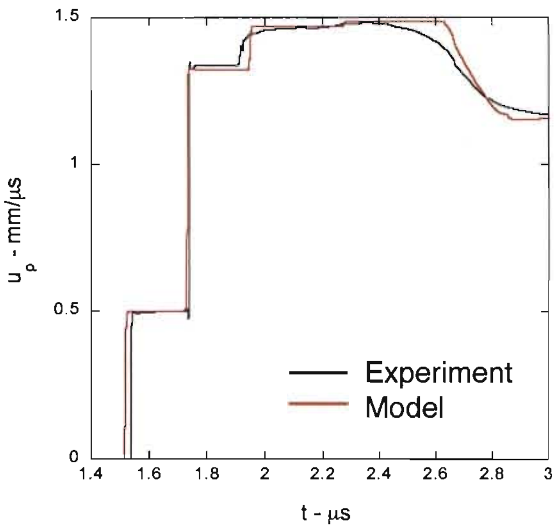
## Hugoniot of New PBX 9502 Reactants Model



# Modeling of Multi-Shock Experiments:

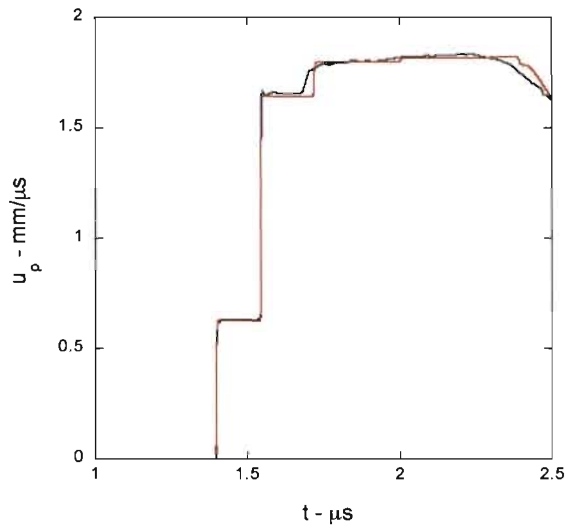
Shot 2s-450

$u_{impactor}$ = 2.139 mm/μs



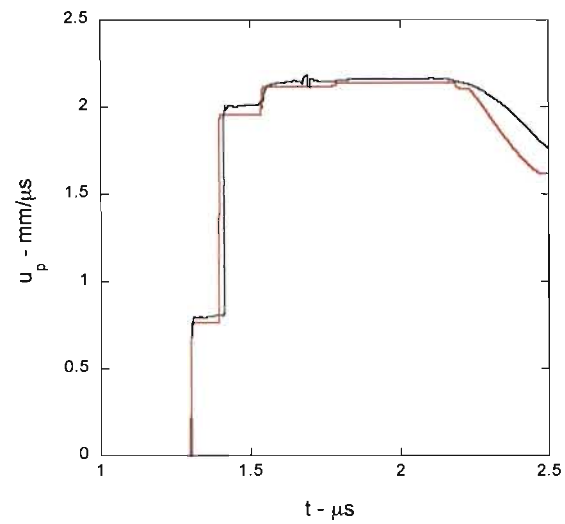

Shot 2s-463

$u_{impactor}$ = 2.585 mm/μs




Shot 2s-465

$u_{impactor}$ = 3.025 mm/μs



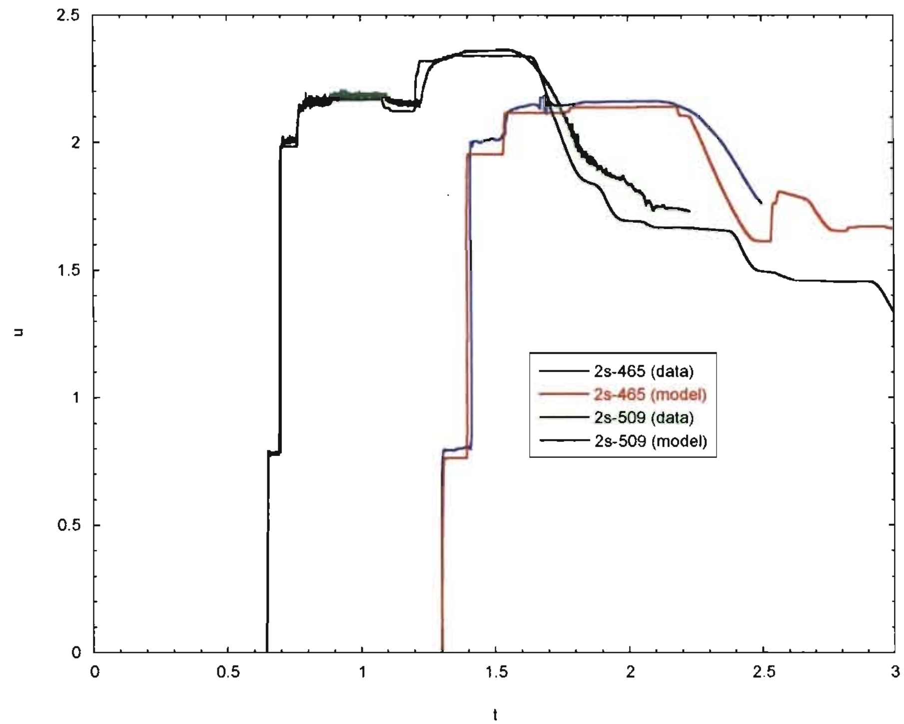

All Shock Speeds and Particle Speeds are in agreement to < 3% error.
Suspect a small amount of reaction from initial shock in 2s-465.

# Modeling of Multi-Shock Experiments:

Shot 2s-509:
Half scale repeat of 2s-465

TPX and PBX 9502 thicknesses are ½ of 2s-465

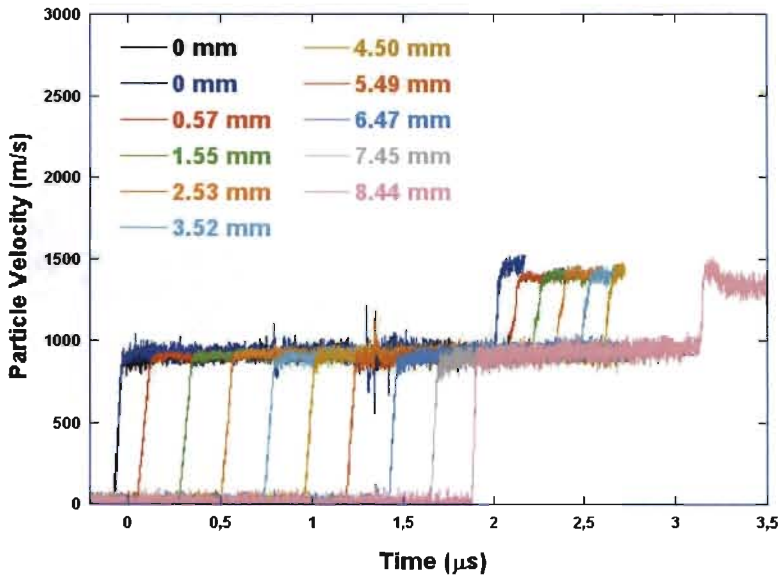
Ta, LiF are same as 2s-465



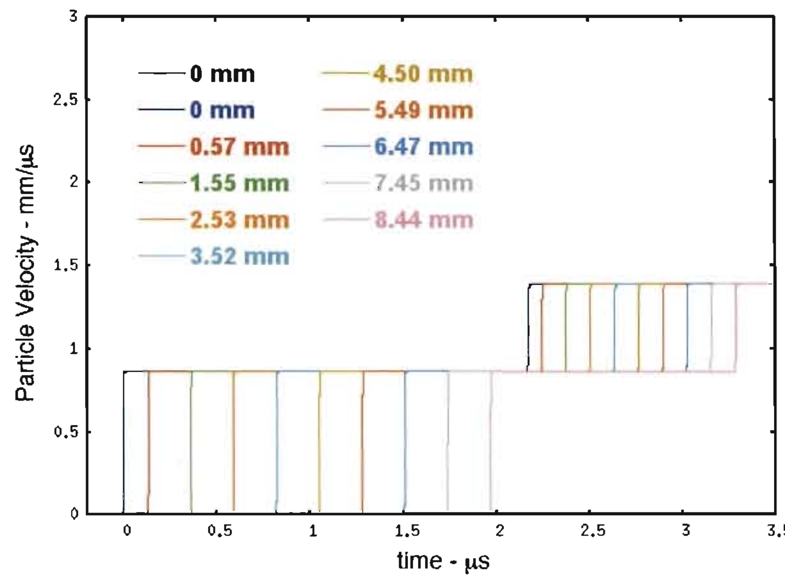

Shock Speeds and Particle Speeds are in better agreement in 2s-509.
Highest pressures in PBX 9502: 51GPa

# Comparison with CEA Double Shock Expt:

## Reasonable Agreement between T2 experiment and PBX 9502 Keane Mie-Gruneisen Model




Sollier, et al, 14th Int. Det. Symp., 2010




Mie-Gruneisen Keane Model

# CONCLUSIONS

- New Experiments to Examine High-Pressure EOS
- New Model of PBX 9502 Reactants

# FUTURE WORK

- Examine other HEs with this technique
  - HMX based HEs require lower impedance impactor
- Extend Model to Complete EOS include Porosity*
- Incorporate into a New Reactive Flow Model**

* Ongoing work

** Shaw and Menikoff, 14th Int. Det. Symp., 2010

# Appendix: Keane Form of Isentrope:

$$p(\rho) = \frac{K_0' K_0}{K_\infty'^{\,2}}\left(\left(\frac{\rho}{\rho_0}\right)^{K_\infty'} - 1\right) - \frac{(K_0' - K_\infty')K_0}{K_\infty'}\ln\left(\frac{\rho}{\rho_0}\right)$$

# Material Parameters for Simulations:

| material | $\rho_0$-g/cm$^3$ | $c_0$−mm/$\mu$s | $s$ | $\Gamma_0$ |
|---|---|---|---|---|
| LiF | 2.638 | 5.15 | 1.35 | 1.5 |
| Ta | 16.654 | 3.402 | 1.2196 | 1.8196 |

Table 1: Mie-Gruneisen parameters for $U_S = c_0 + sU_P$ and $\Gamma = \Gamma_0\rho_0/\rho$.

| material | $\rho_0$-g/cm$^3$ | $K_0$- GPa | $K_0'$ | $K_\infty'$ | $\Gamma_0$ | $q$ |
|---|---|---|---|---|---|---|
| Lexan | 1.193 | 4.44 | 11. | 4.1 | 0.6 | 1 |
| TPX | 0.831 | 2.7 | 7.9 | 5.2 | 0.57 | 0 |
| PBX 9502 | 1.890 | 4 | 45 | 3.4 | 0.5 | 1 |

Table 2: Mie-Gruneisen Keane EOS parameters with $\Gamma = \Gamma_0(\rho_0/\rho)^q$.