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Update on Energetic Material Studies

TCG-1 Technical Review

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Overview

- Successful modeling of explosives and explosives systems requires reliable unreacted EOS, initiation model, and detonation product EOS – this is valuable to both DoD and DOE
- Test EOS and initiation models against experimental data
- Shock and shockless experiments for unreacted EOS
- Developing a 1D experimental technique to probe the initiation model and detonation product EOS
- Developing 2D experimental diagnostics to examine mesoscale behavior
- Conducted experiments on Comp-B/Viton, IMX-101, IMX-104, and HNAB
- IMX results are directly shared with Phil Samuels of ARL
- Other results are shared with DoD partners on request

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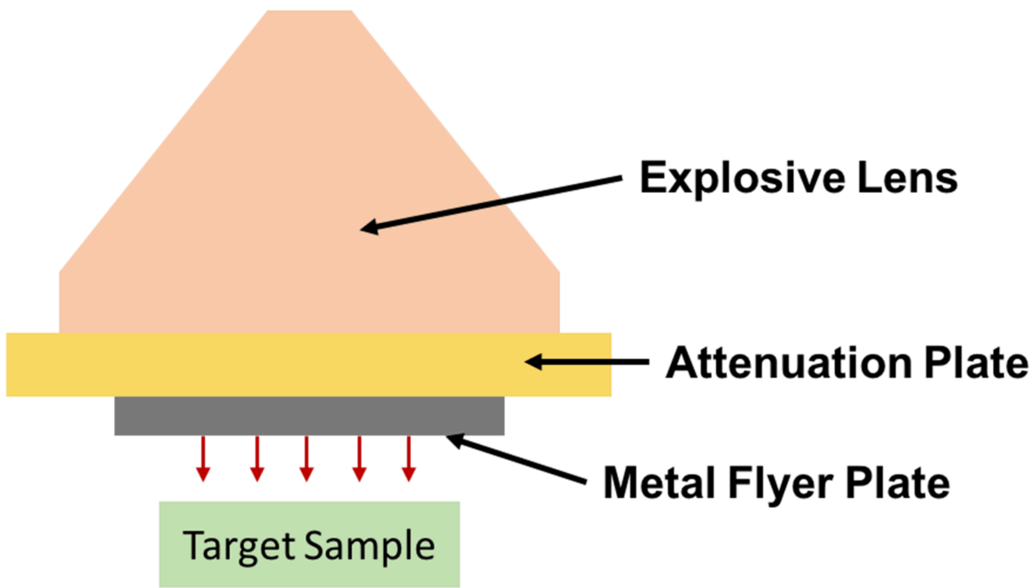
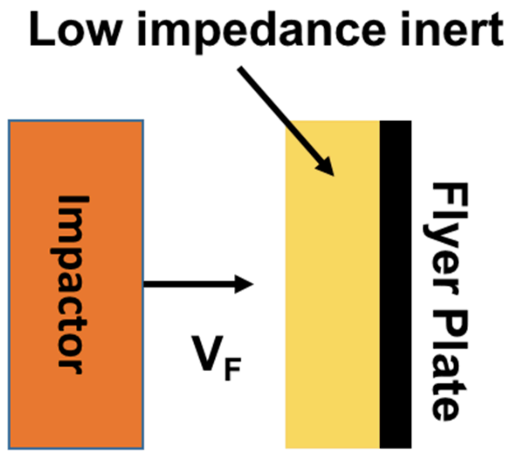
Interaction of Detonation Wave with Low Z Inerts

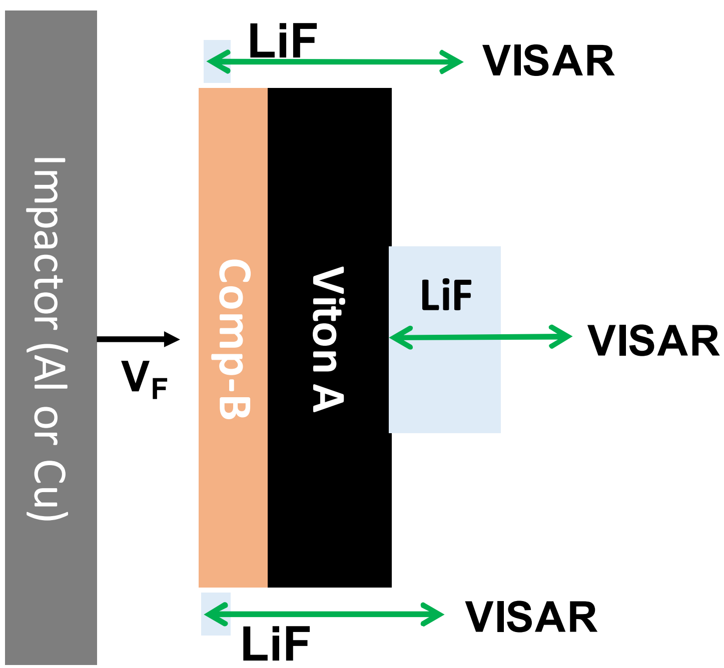
- Previous work looked at metal inerts: Al, Cu, and Ta
- Explosive lens systems use low Z inerts to tailor the input to flyer
- Layered flyer methods used to increase flyer velocity over 2-stage guns
- Perform a series of experiments on Comp-B backed by Viton A

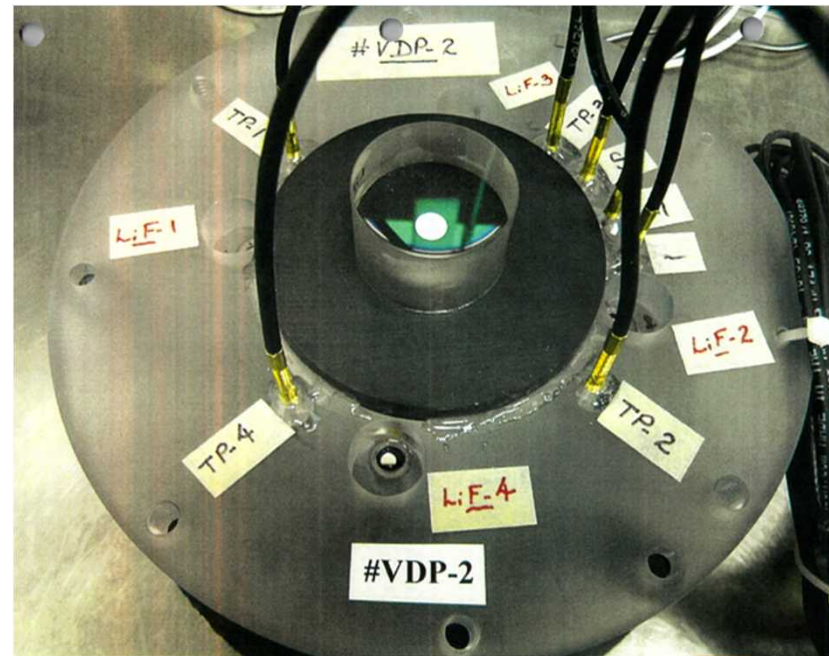




Experimental Configuration

- Impactor sets up a detonation wave in the Comp-B that propagates through the Viton A
  - Comp-B samples: 70 mm diameter X 7 mm with $\rho_0 = 1.70\ g/cm^3$
- VISAR measures the transmitted velocity profile at Viton A / LiF interface
- VISAR measures tilt and impact time at 4 LiF windows around the target





Experimental Parameters

Four experiments performed for 3 different comparisons

- **Comp-B impacted at same V_F with different impactor (VDP-01/VDP-02)**
- **Comp-B impacted with different impactor, but same run-to-detonation distance (VDP-03/VDP-04)**
- **Comp-B impacted with same impactor and run distance, but different Viton thickness (VDP-02/VDP-04)**

Shot	Impactor	V_F (km/s)	Input Stress (Gpa)	Run Distance (mm)
VDP-01	Cu	1.959	14.85	3.22
VDP-02	Al	2.002	11.39	4.57
VDP-03	Cu	1.622	11.29	4.62
VDP-04	Al	2.010	11.35	4.59

Shot	Viton A (mm)	Viton A Density (g/cm^3)
VDP-01	11.927	1.913
VDP-02	11.931	1.913
VDP-03	16.947	1.916
VDP-04	16.946	1.916

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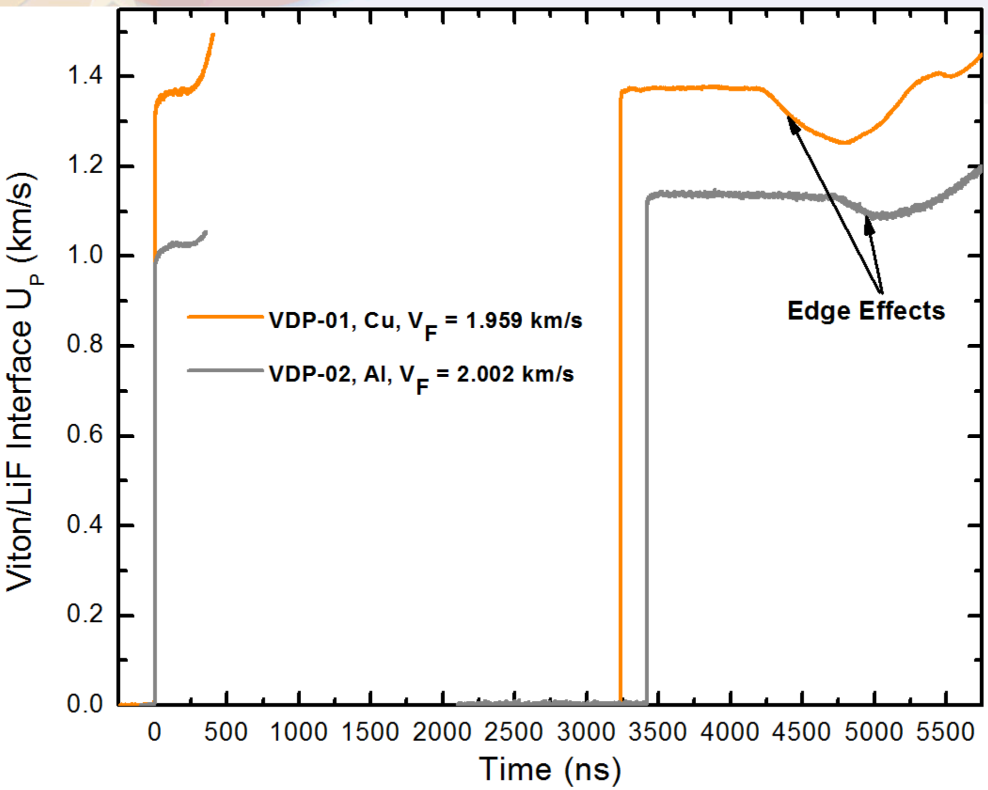
Experimental Results - 1



- VDP-01
  - VF = 1.959 km/s
  - Input Stress = 14.85 Gpa
  - Run Dist. = 3.22 mm
- VDP-02
  - VF = 2.002 km/s
  - Input Stress = 11.39 Gpa
  - Run Dist. = 4.57 mm

- Measured wave velocity higher for VDP-01
- VDP-01 shows an arrival time of 185ns before VDP-02
- Assuming constant shock velocity up to the detonation transition accounts for approximately 80 ns
- Remaining time difference caused the higher wave velocity in the Viton for VDP-01

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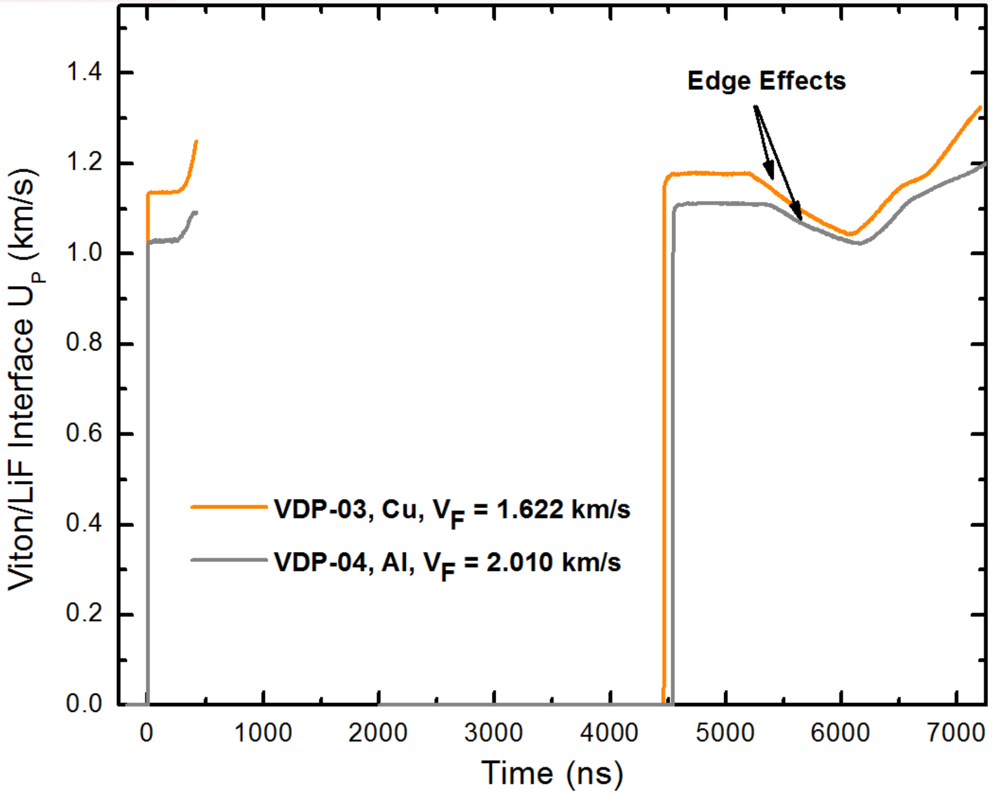
Experimental Results - 2



- VDP-03
  - VF = 1.622 km/s
  - Input Stress = 11.29 Gpa
  - Run Dist. = 4.62 mm
- VDP-04
  - VF = 2.010 km/s
  - Input Stress = 11.35 Gpa
  - Run Dist. = 4.59 mm

- Input stress and run distance are the same
- VDP-03 shows higher transmitted wave velocity than VDP-04
- Possible confinement effects from the Cu impactor

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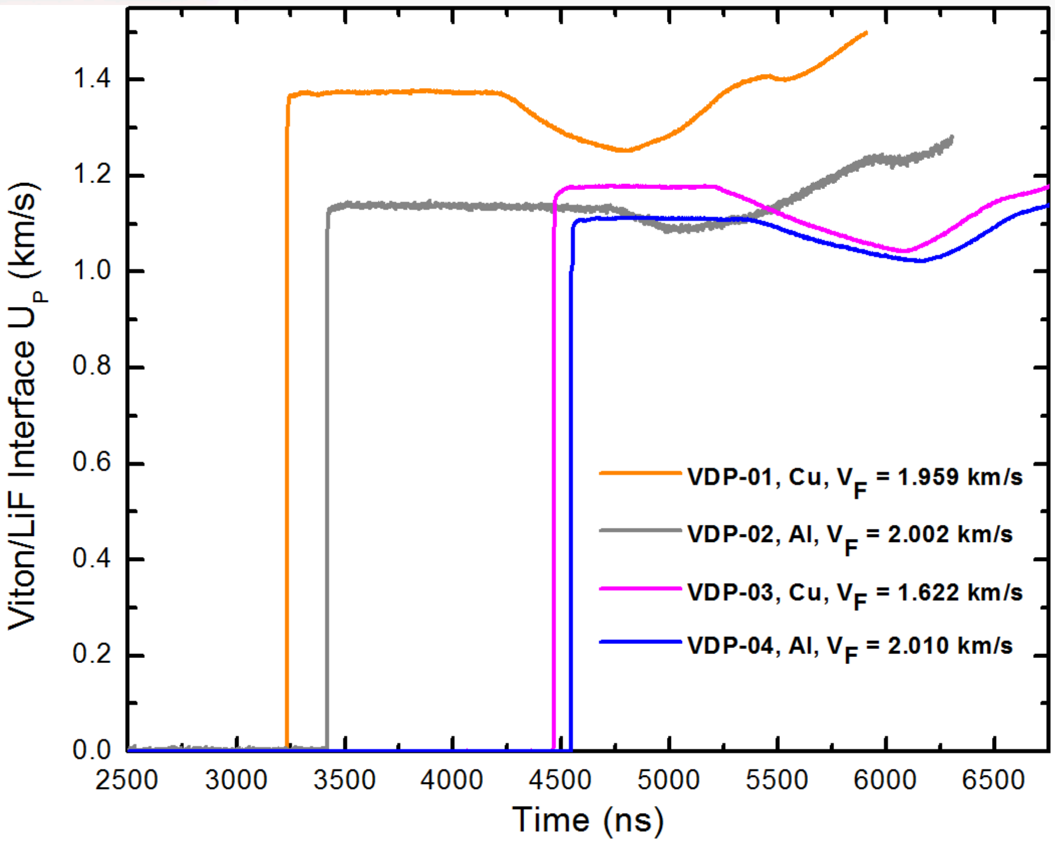
Experimental Results - 3



- VDP-01
  - VF = 1.959 km/s
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  - Run Dist. = 3.22 mm
- VDP-02
  - VF = 2.002 km/s
  - Input Stress = 11.39 Gpa
  - Run Dist. = 4.57 mm
- VDP-03
  - VF = 1.622 km/s
  - Input Stress = 11.29 Gpa
  - Run Dist. = 4.62 mm
- VDP-04
  - VF = 2.010 km/s
  - Input Stress = 11.35 Gpa
  - Run Dist. = 4.59 mm

- **VDP-04 shows lower velocity than VDP-02**
  - **Attenuation through Viton**
- **VDP-03 shows higher wave velocity than VDP-02 and VDP-04**
  - **Confinement effects because of the Cu impactor**

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Comparison to Simulations

- CTH Library version of HVRB Model for transition to detonation and Comp-B EOS
- Unreacted Comp-B: Mie-Gruneisen, US = $2.55+1.99U_P$, ρ_0=1.70 g/cm^3
- Comp-B Det. Products: SESAME 8311 (COMPB3_DP)
- Mie-Gruneisen for Al, Cu, LiF
- No EOS data for Viton A:
  - Viton B EOS US = $1.88 + 2.37U_P$ with r0 = Expt. Viton A density
  - Millett, Bourne, and Gray, *J. Appl. Phys.* 96, 5500, 2004
  - SESAME 7192 (PTFE_UR) Unreacted Teflon

Material Differences

- Viton A contains vinylidene fluoride (VF2) and hexafluoropropylene (HFP); (ρ_0=1.91 g/cm^3)
- Viton B contains VF2, HFP, and tetrafluoroethylene (TFE); (ρ_0=1.77 g/cm^3)
- Teflon – polytetrafluoroethylene (ρ_0=2.15 g/cm^3)

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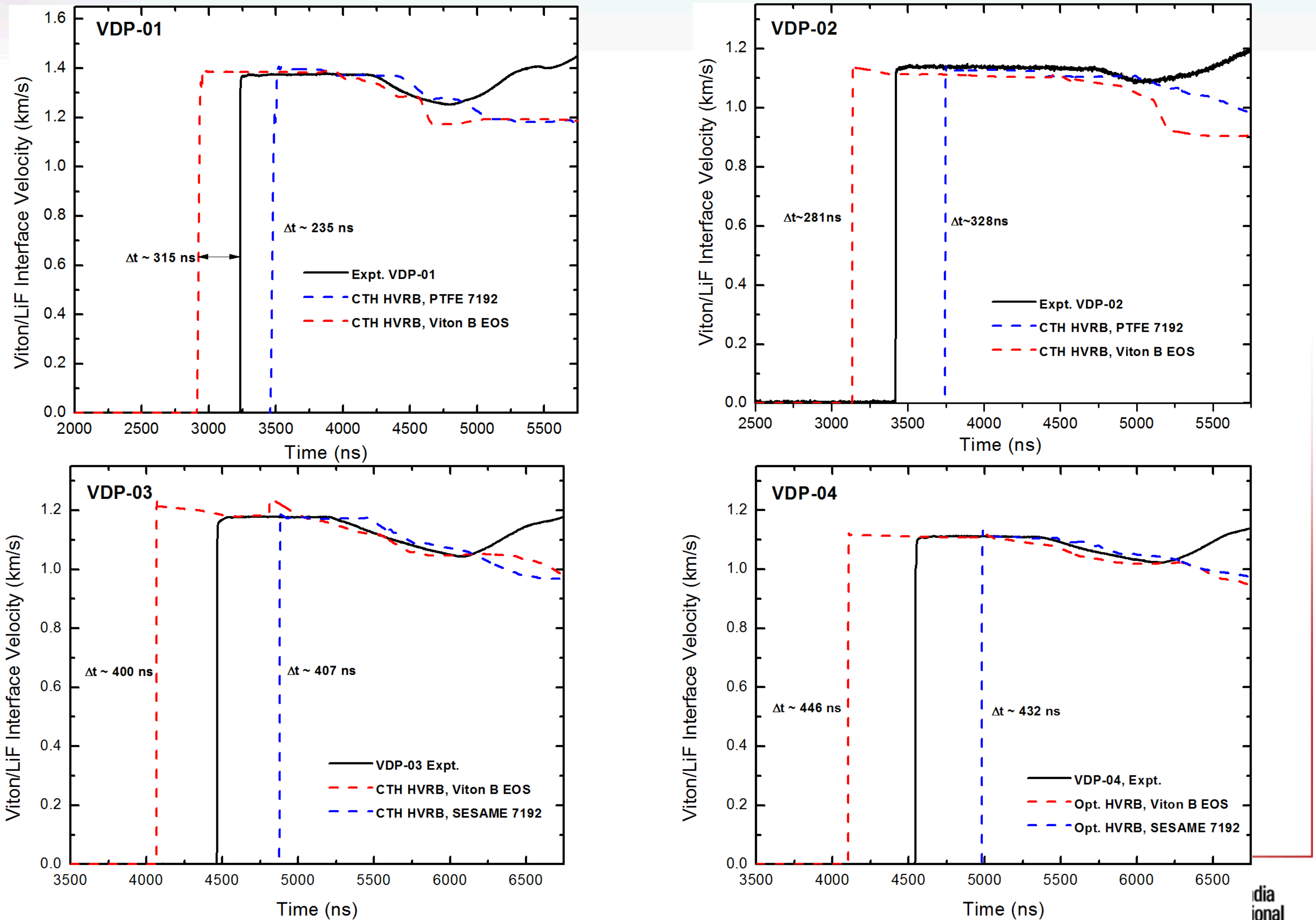
Comparison to Simulations



Comp-B / Viton Summary

- Completed a series of 4 experiments looking at detonation wave propagation through a low Z inert
- Results suggest that there is a confinement effect between using Cu or Al impactor
- Results also indicate a need for EOS data for Viton A
- Completed 3 experiments on Viton A Hugoniot – Under Analysis
- Completed 1 experiment on Viton A under ramp-loading – Under Analysis

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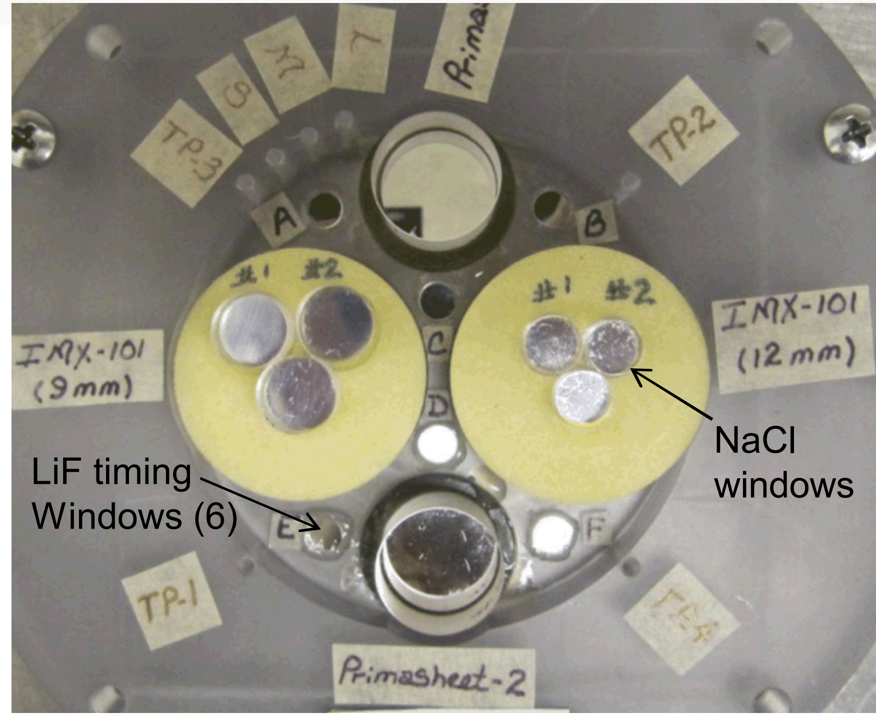
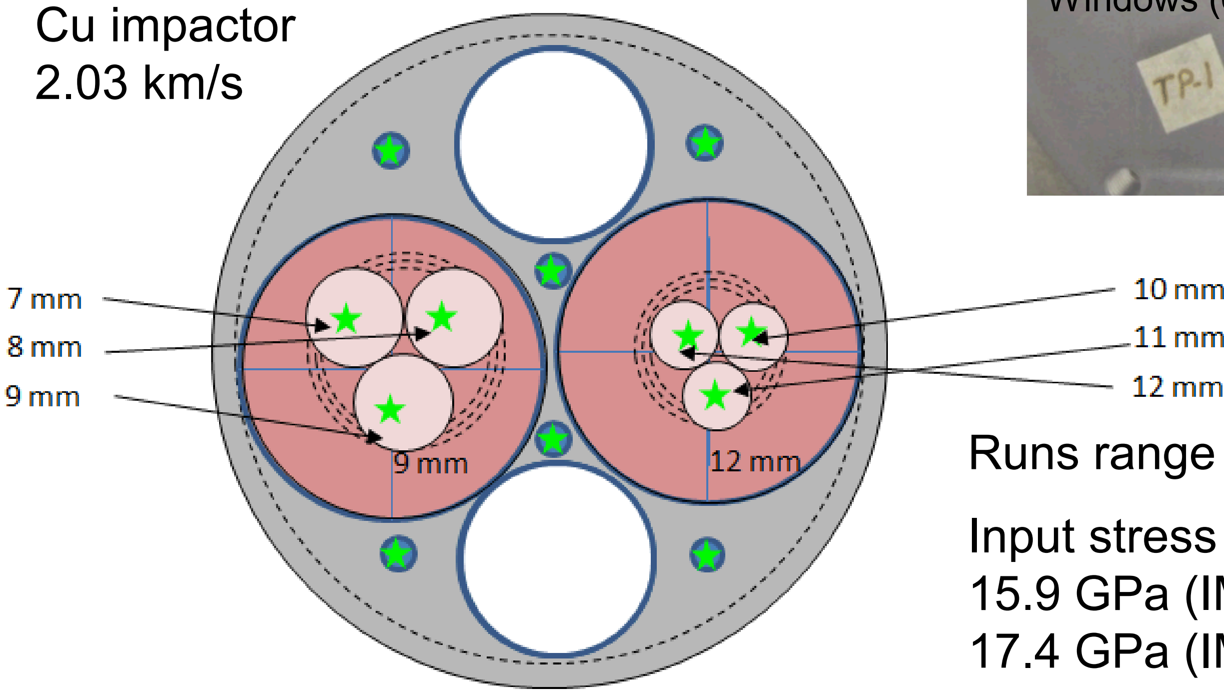
IMX Shock Compression Experiments

IMX-101 & 104 Run-to-Det experiment used NaCl windows and counterbored samples



Cu impactor
2.03 km/s



Runs range from 7 – 12 mm.

Input stress levels are:
15.9 GPa (IMX-101)
17.4 GPa (IMX-104)

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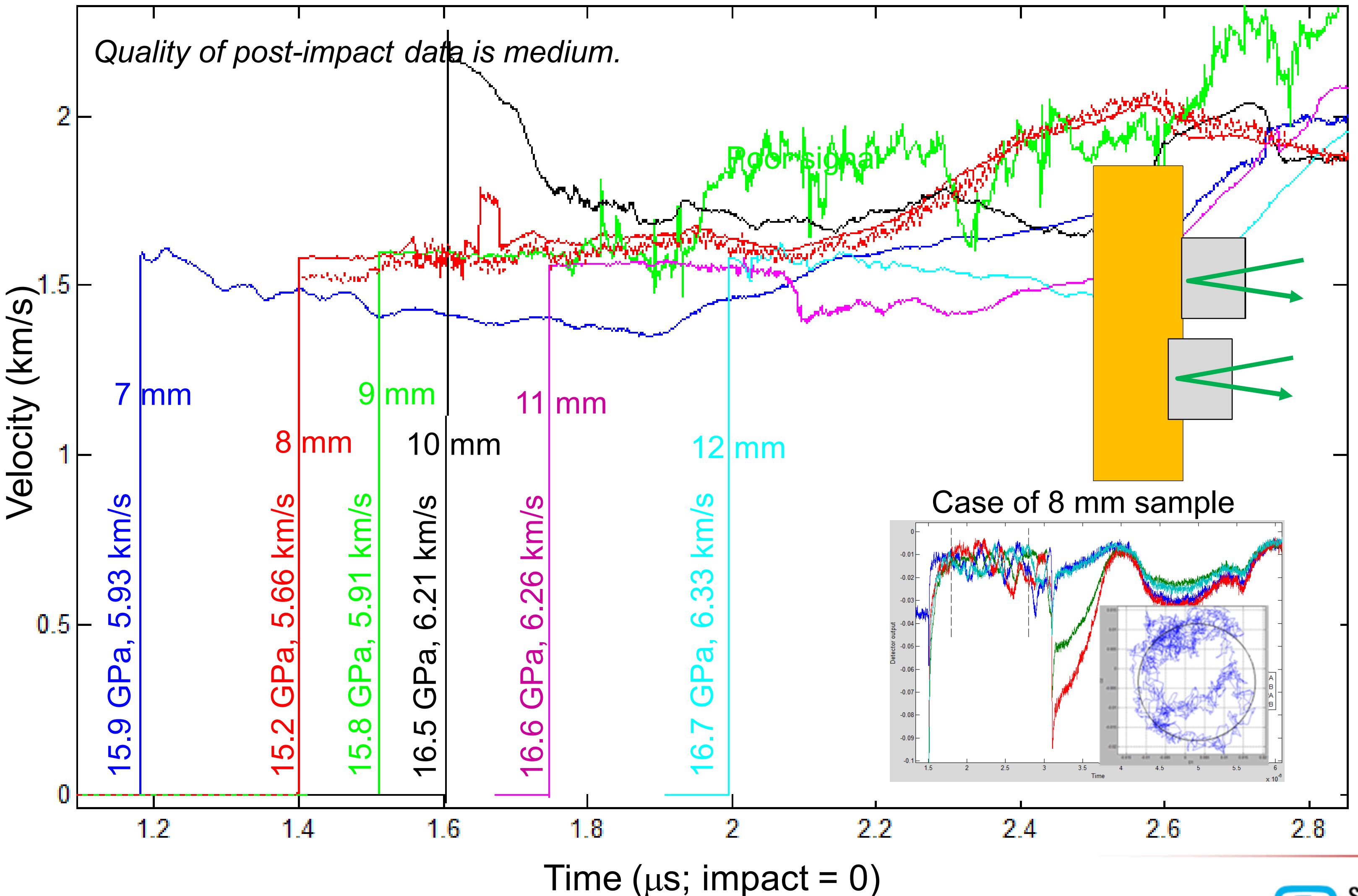
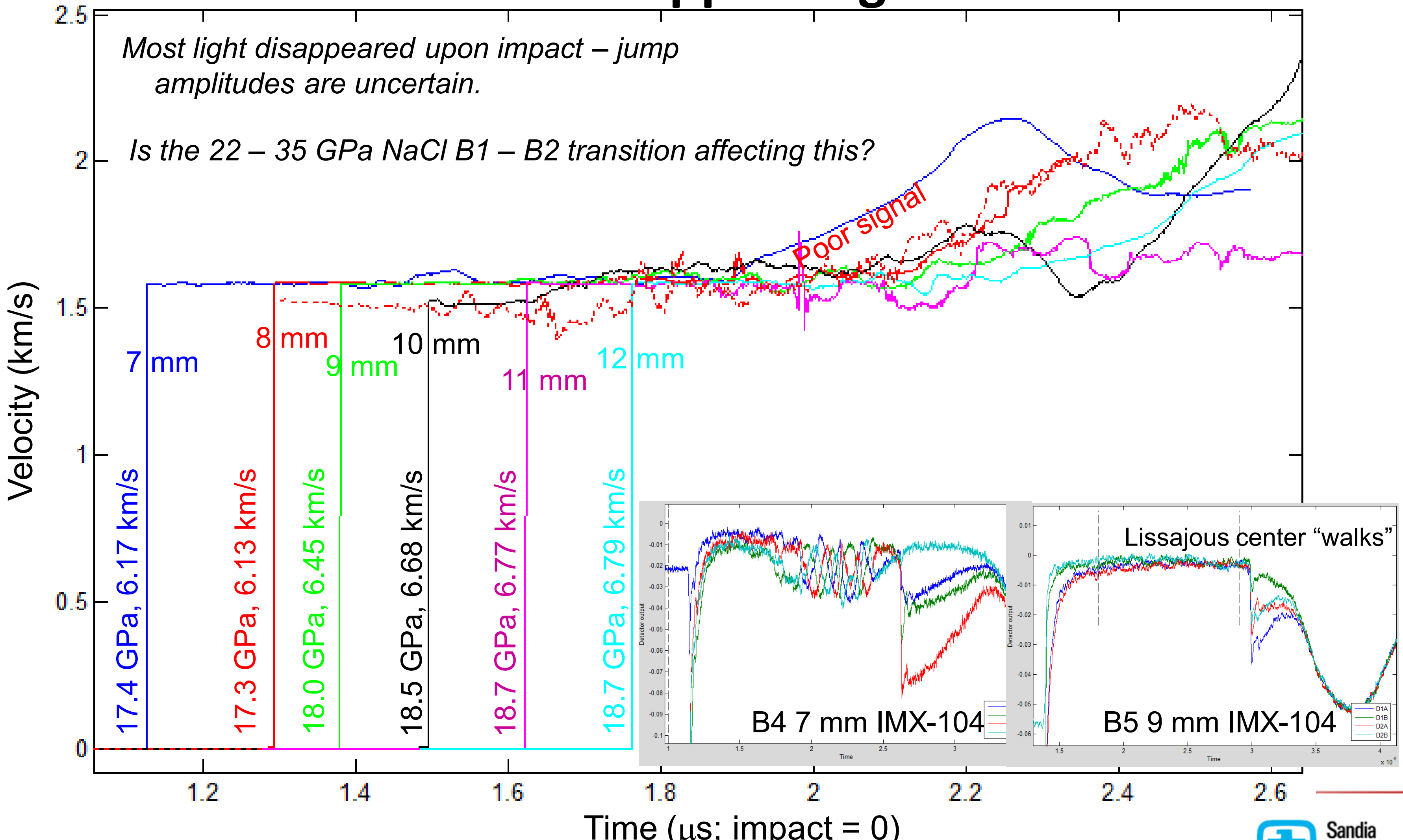
The IMX-101 case showed no evidence of detonation, but very noisy signals.



The IMX-104 case showed no evidence of detonation, with returned light almost disappearing.



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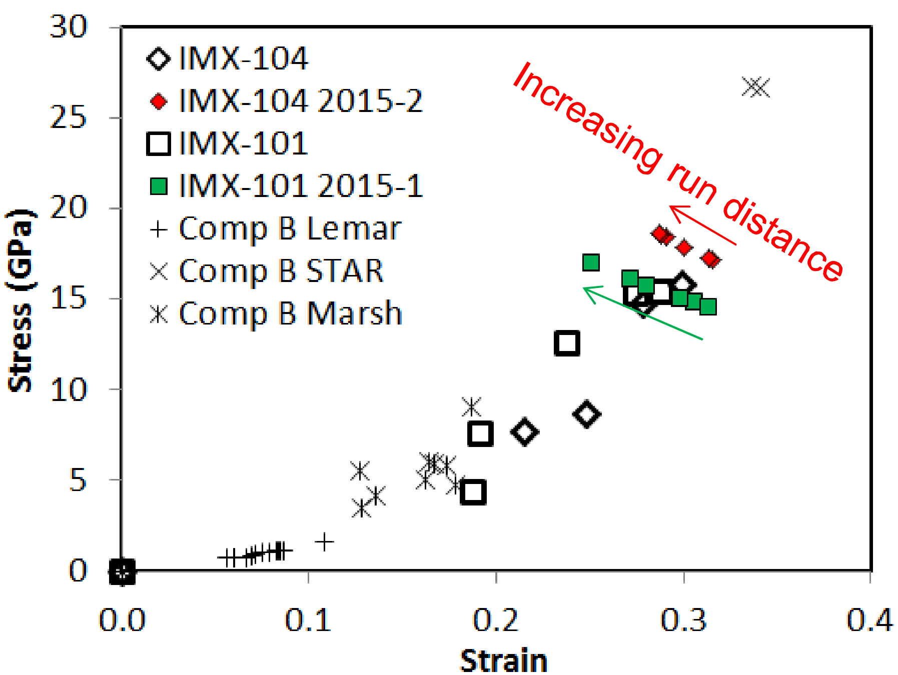
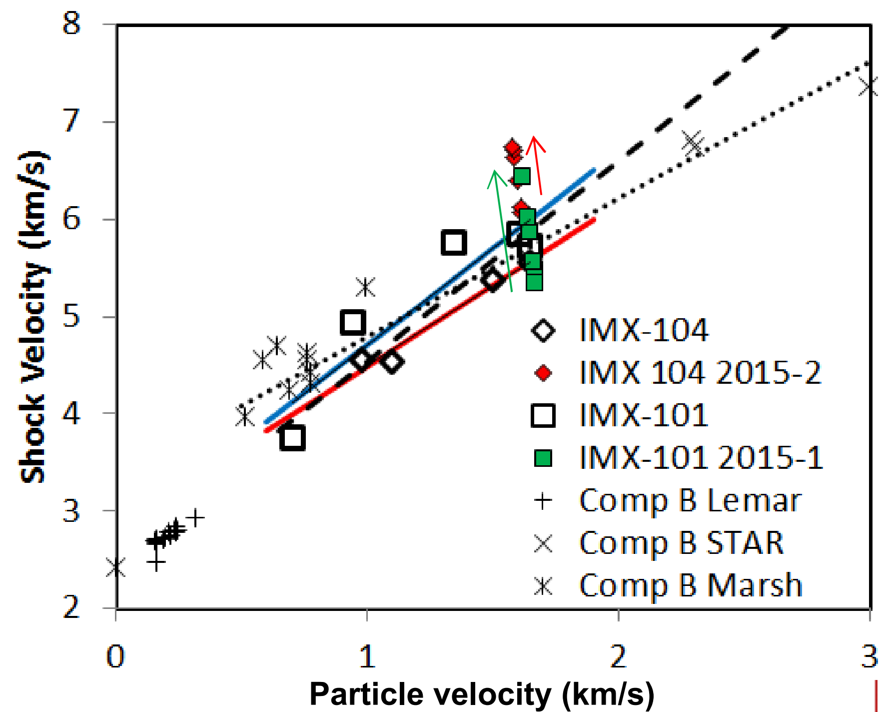
Both experiments showed a trend toward increasing wavespeed with distance, possibly related to detonation

Wavespeed increases as thickness increases from 7 to 12 mm





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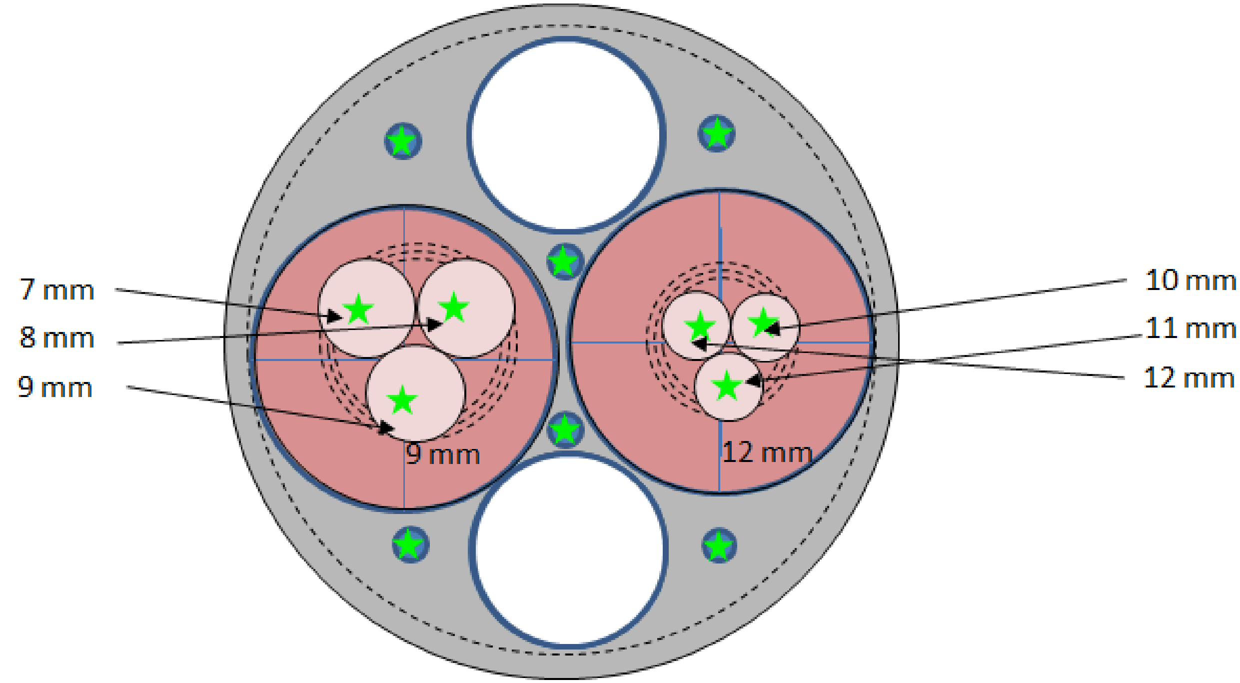
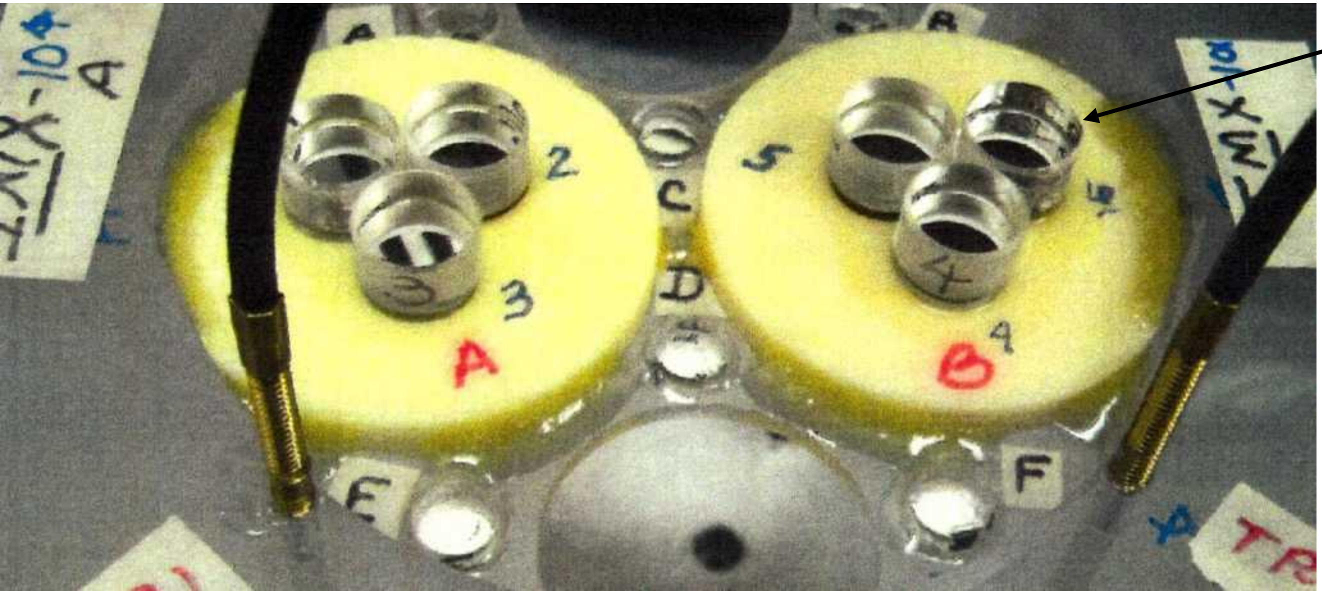
We re-did these tests with LiF buffers and windows



Input stress levels are:
16 GPa (IMX-101)
17.5 GPa (IMX-104)



Recent shots used 1 mm LiF buffers and 6 mm LiF windows instead of NaCl.

(Rationale: Avoid effects of 22 – 35 GPa B1 – B2 transition in NaCl)

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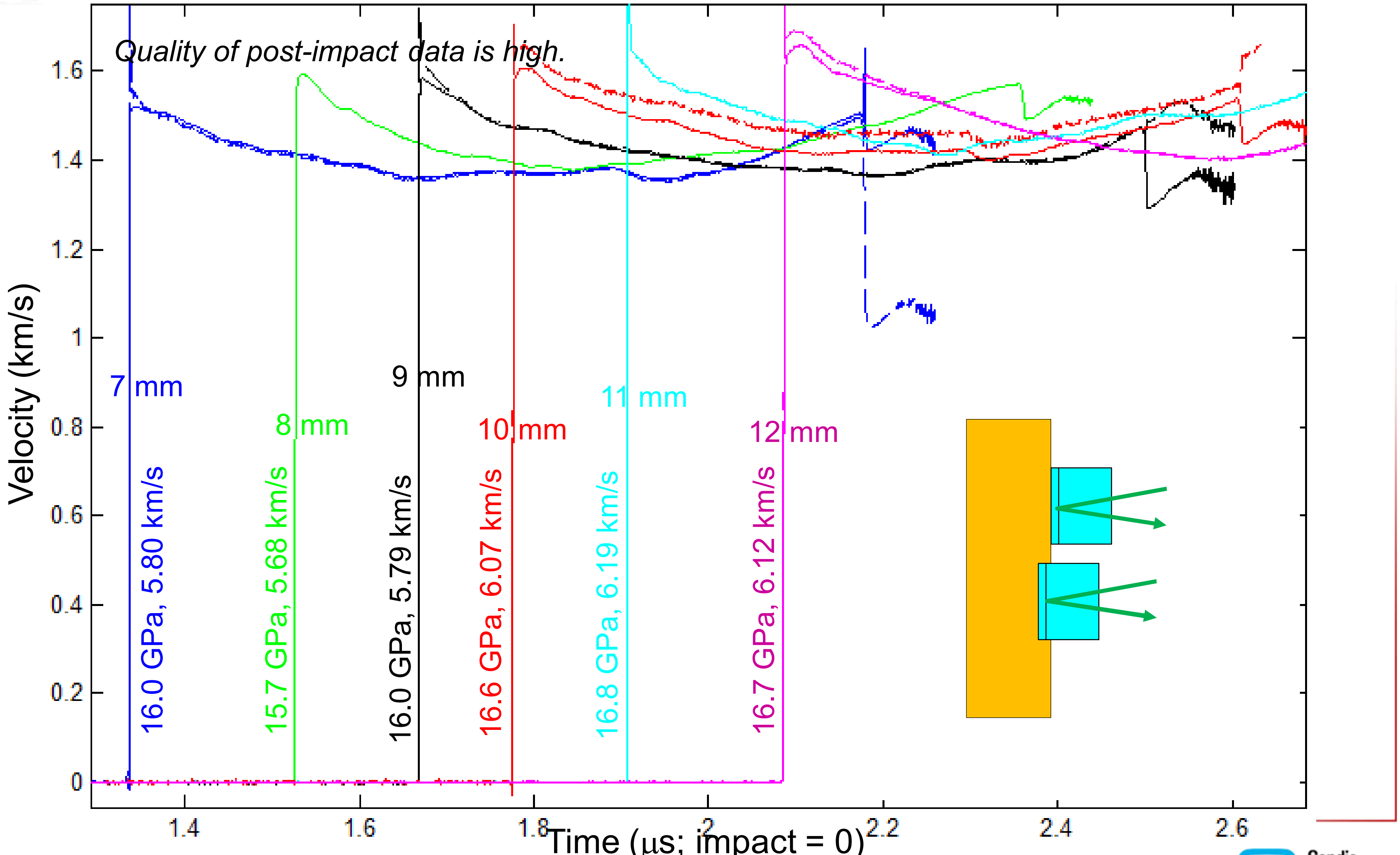
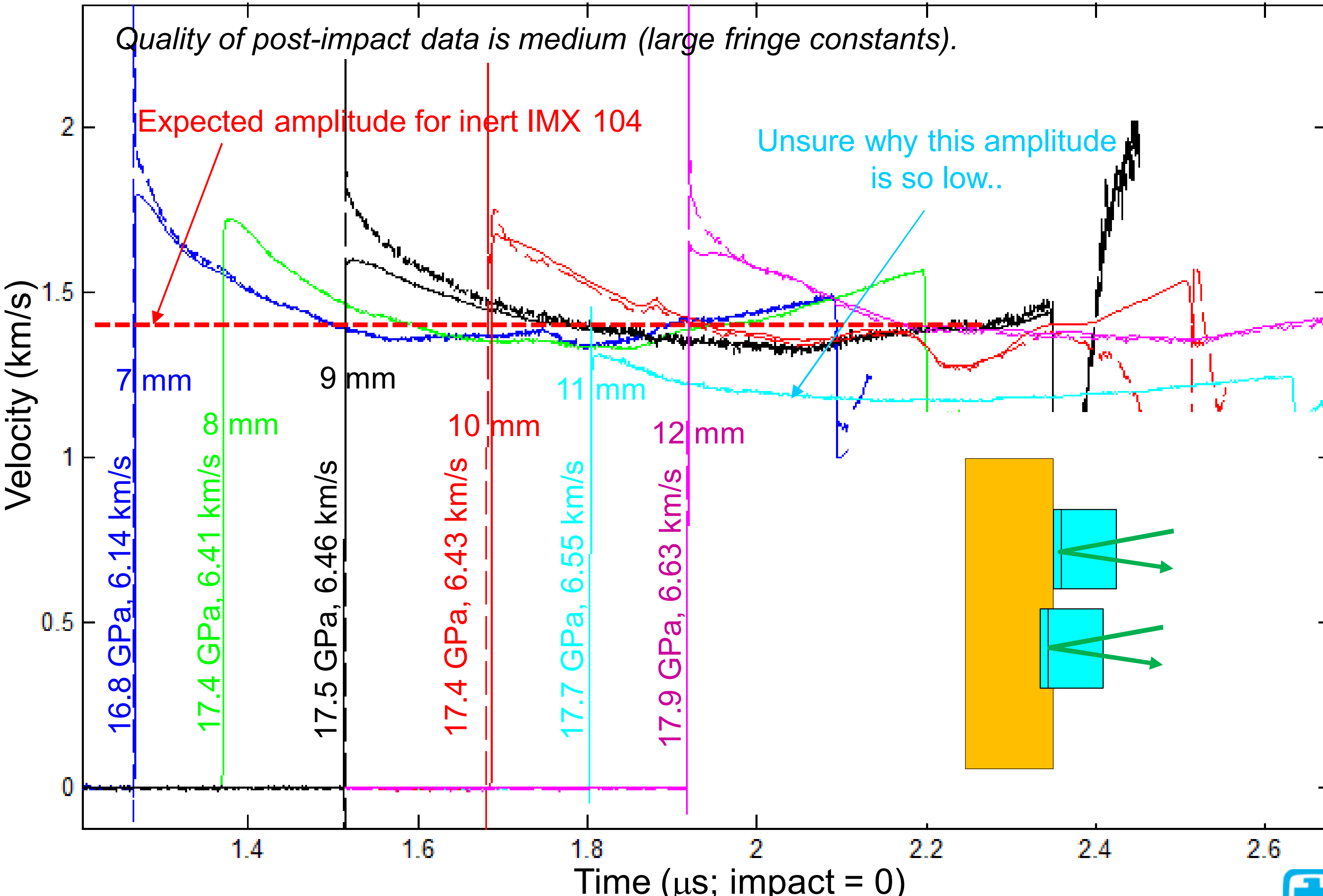
The waveforms in the IMX 101 were very suggestive of detonation at ~16.5 GPa.



The waveforms in the IMX 104 were also very suggestive of detonation at ~16.5 GPa.



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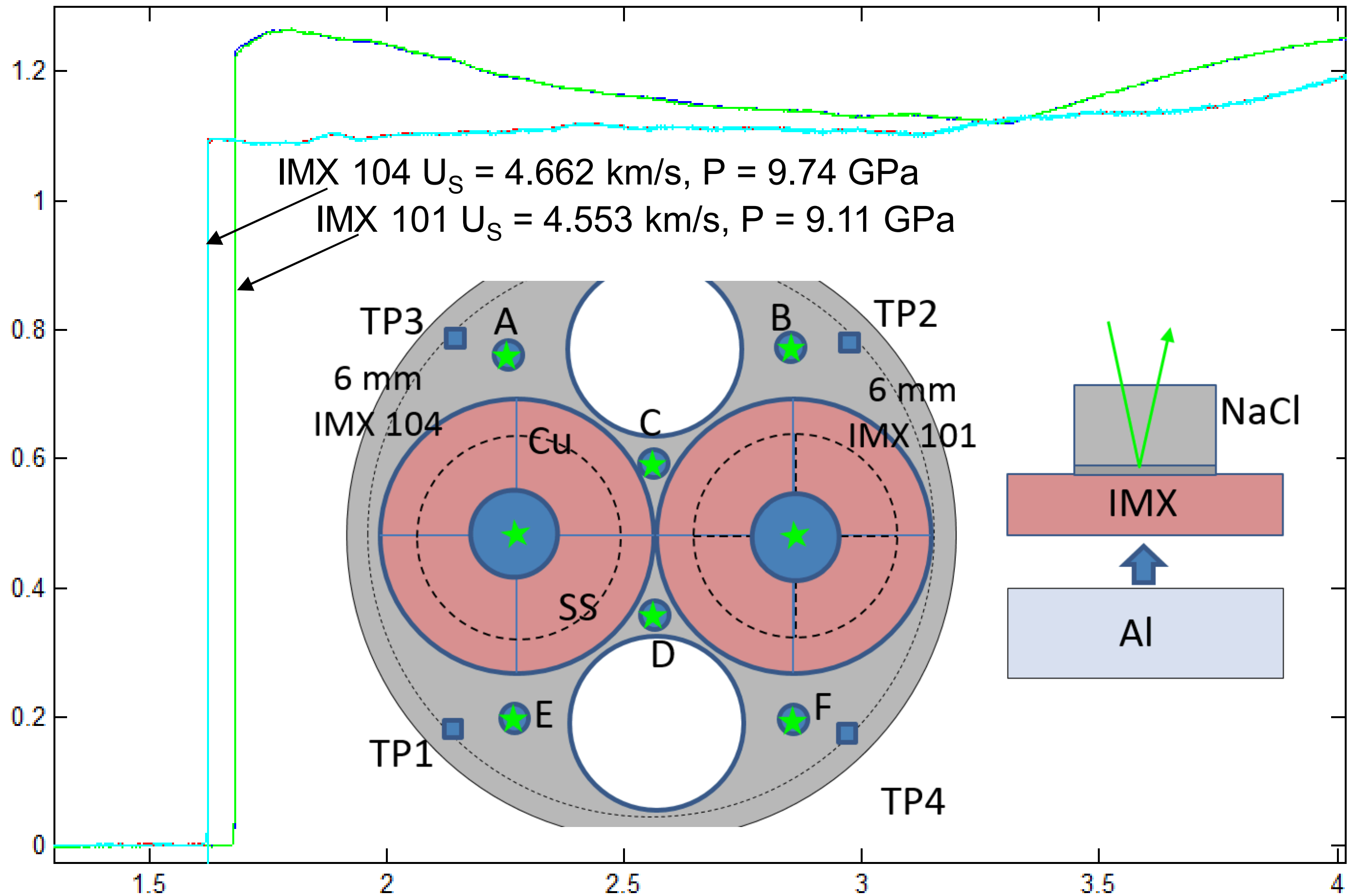
A lower-amplitude shot (9.5 GPa) with both materials showed smooth profiles and no detonation



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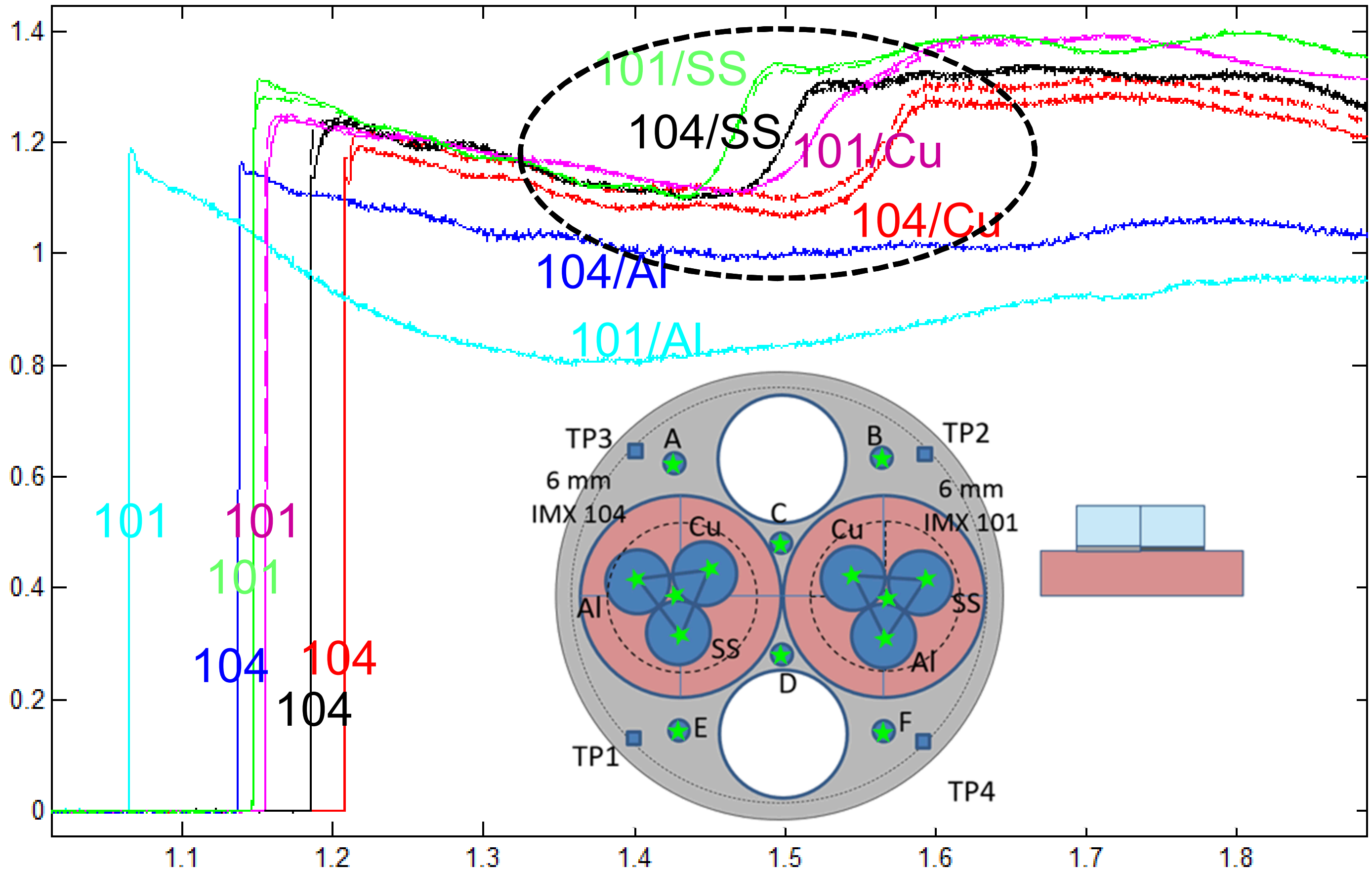
A shot at ~17.5 GPa with both materials showed possible post shock (0.4 ms) processes for higher-impedance witness plates (Cu, SS, not Al).



IMX 101: U_S = 6.3 – 6.4 km/s, P = 17.2 – 17.5 GPa

IMX 104: U_S = 5.8 – 6.0 km/s, P = 17.2 – 17.6 GPa

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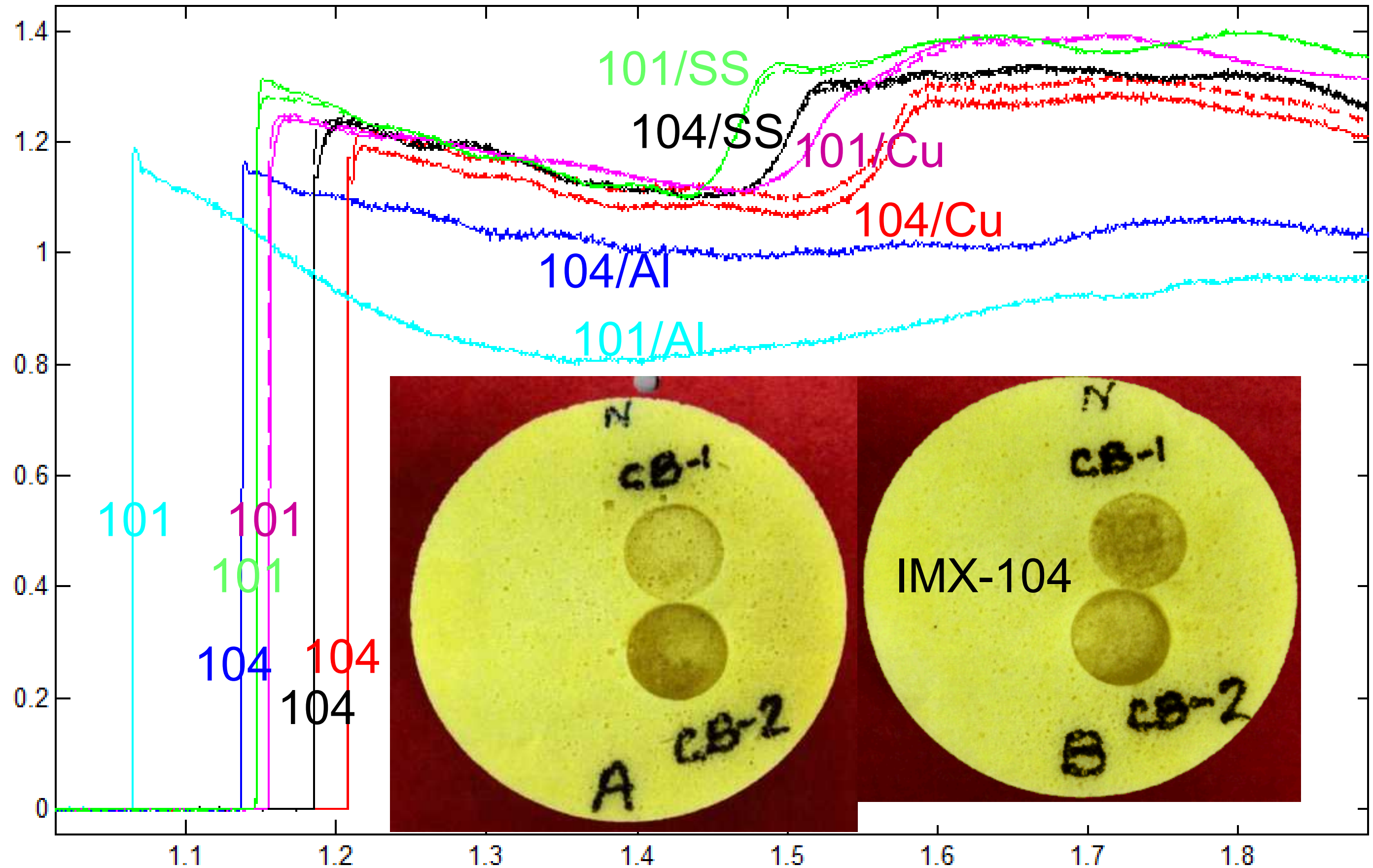
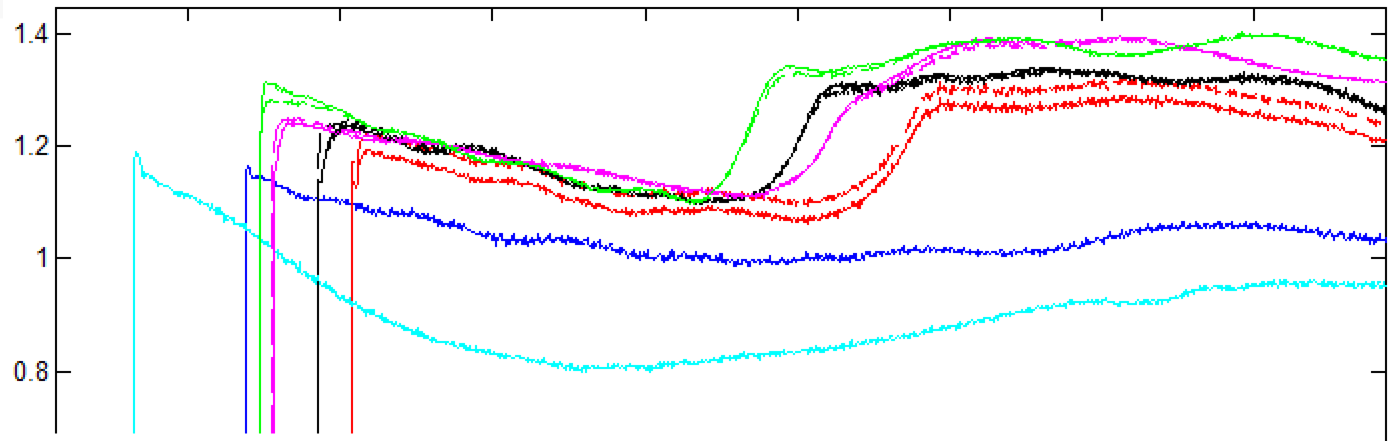
This shot again shows the relatively noisy profiles associated with VISAR and IMX, probably due to voids and heterogeneities

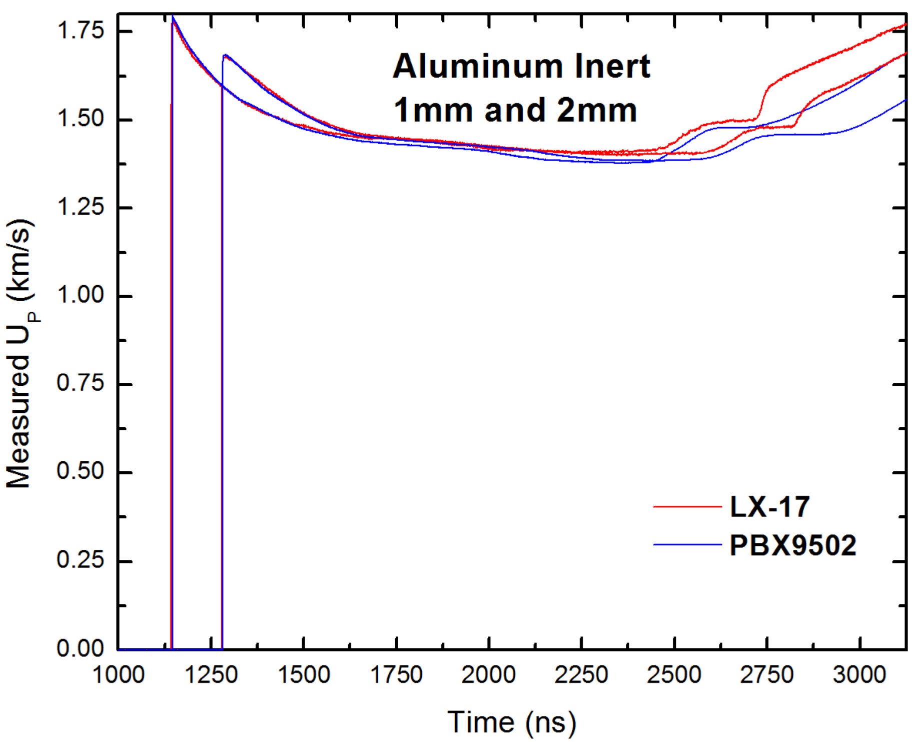


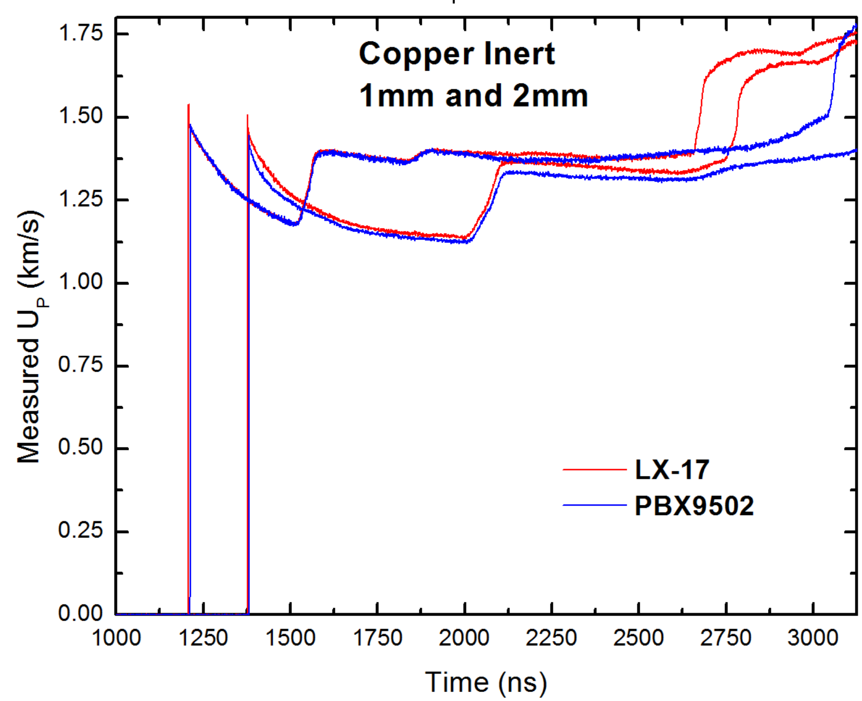
IMX 101: U_S = 6.3 – 6.4 km/s, P = 17.2 – 17.5 GPa

IMX 104: U_S = 5.8 – 6.0 km/s, P = 17.2 – 17.6 GPa

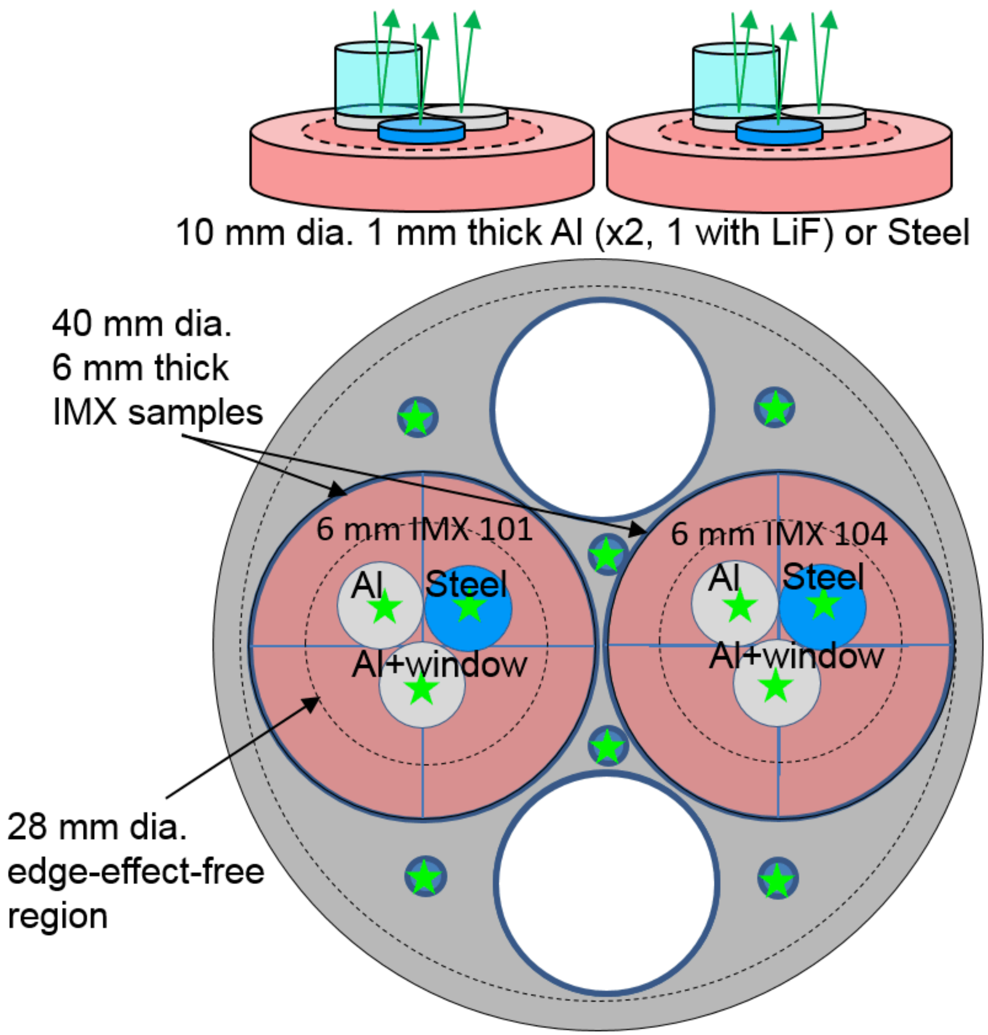
The IMX velocity profiles show more noise compared to similar experiments on PBX9502 and LX-17







Repeat experiments with unwindowed metal inerts (the original Bancroft-Goranson method) at ~18 GPa.



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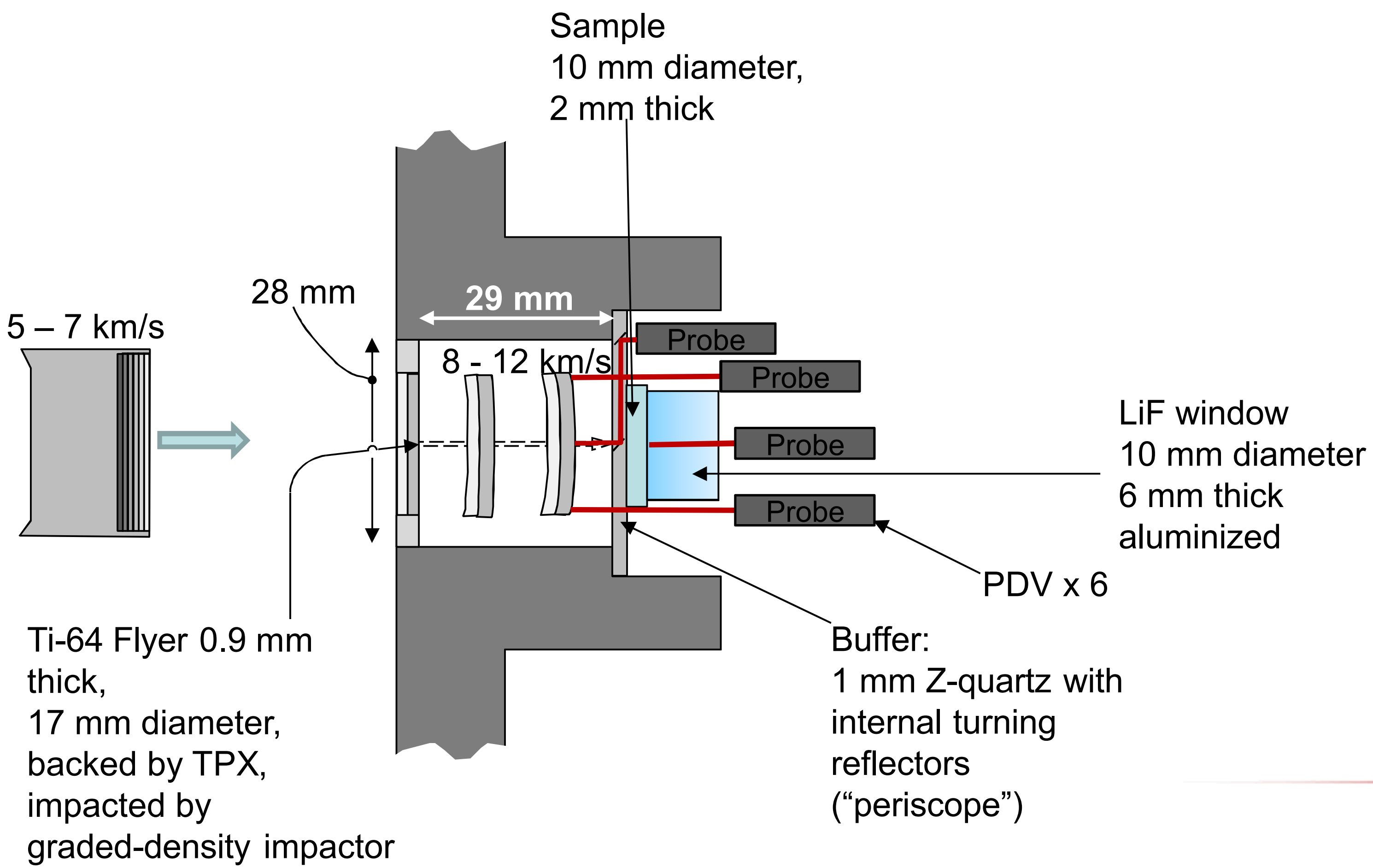
Detonation product EOS shots with highly-overdriven conditions are scheduled soon.

Overdriven detonation EOS with very fast impacts (8 – 12 kms)



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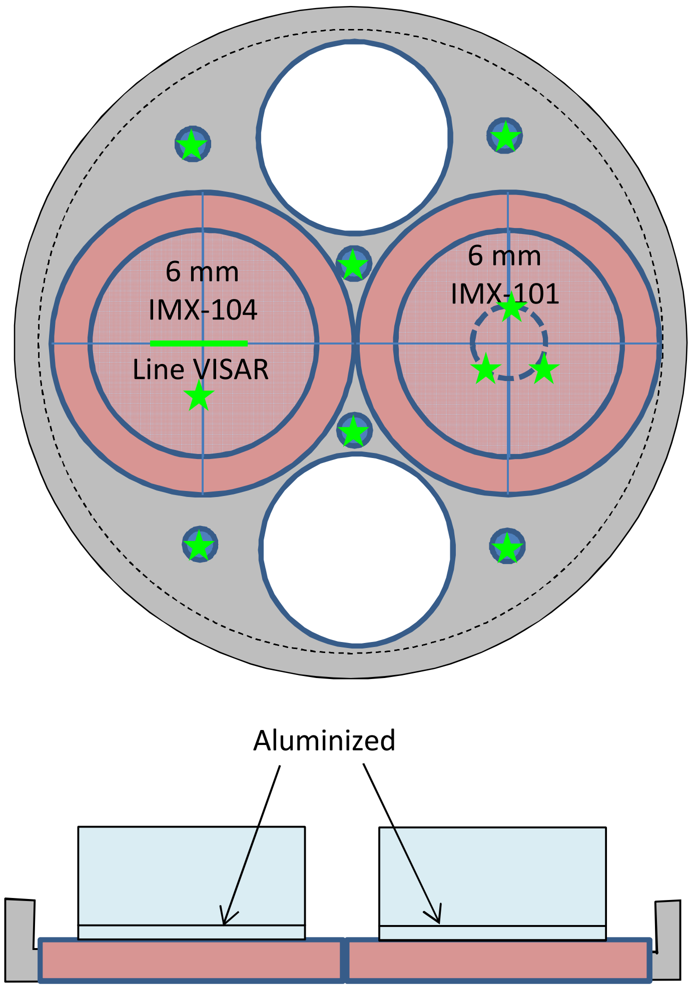
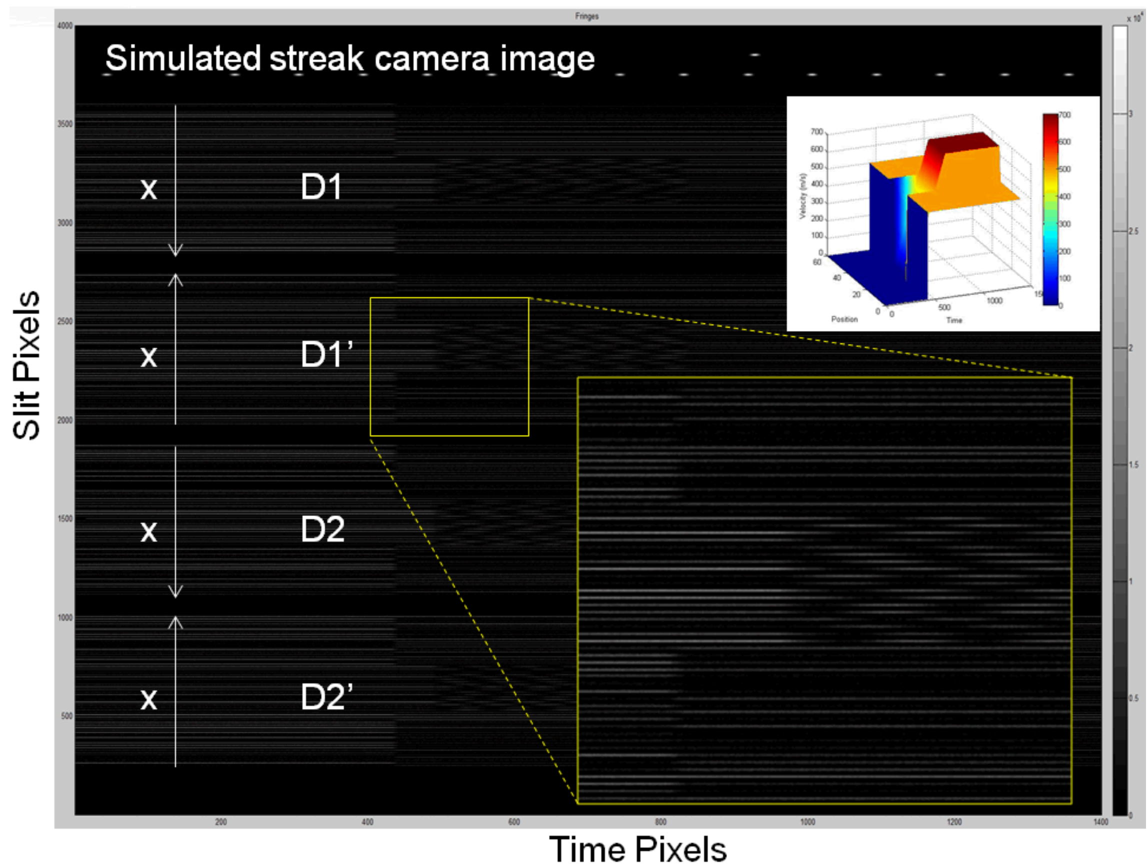
Also on the board are shots to analyze the shock heterogeneity more quantitatively with spatial resolution.

Sample variability using new 60-point "line-imaging" VISAR (which has been demonstrated)





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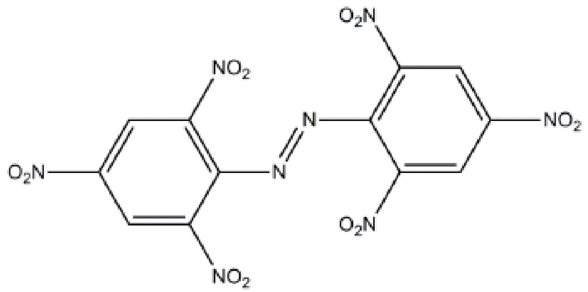
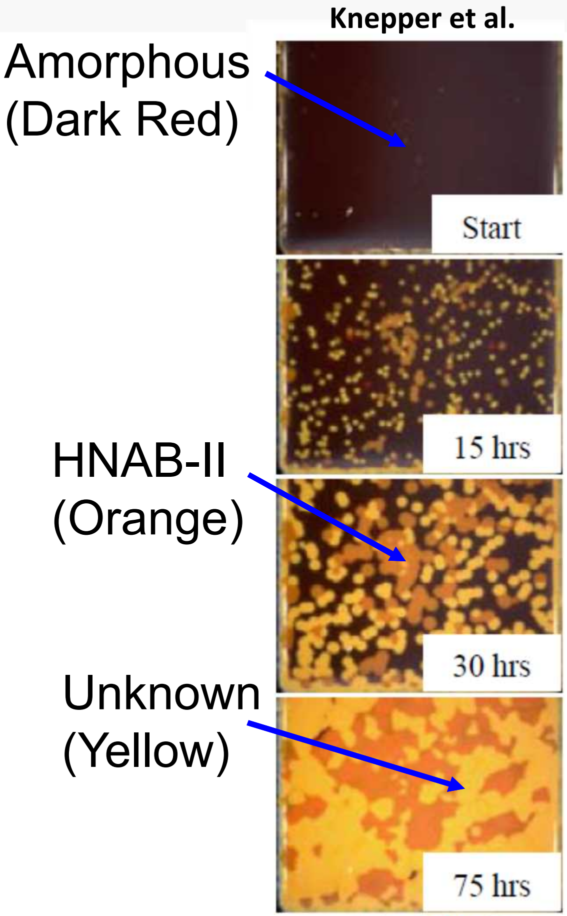
HNAB Equation of State

Hexanitroazobenzene (HNAB)

- **Alex Tappan (SNL) and Rob Knepper (SNL) can generate vapor deposited thin films of HNAB [1]**
- **The HNAB is deposited as an amorphous phase**
- **The HNAB then undergoes a thermally dependent crystallization to HNAB-II**
- **Under certain conditions HNAB transforms unidentified crystalline phase [1]**
  - **HNAB has 5 known polymorphs [2]**
- **Thermal aging process produces high purity, low porosity, polycrystalline HNAB-II layers**





(a) 40° C

[1] R. Knepper, et al., AIP Conf. Proc. 1426, 1589 (2012).
[2] W. McCrone, SAND75-7087 (1967).

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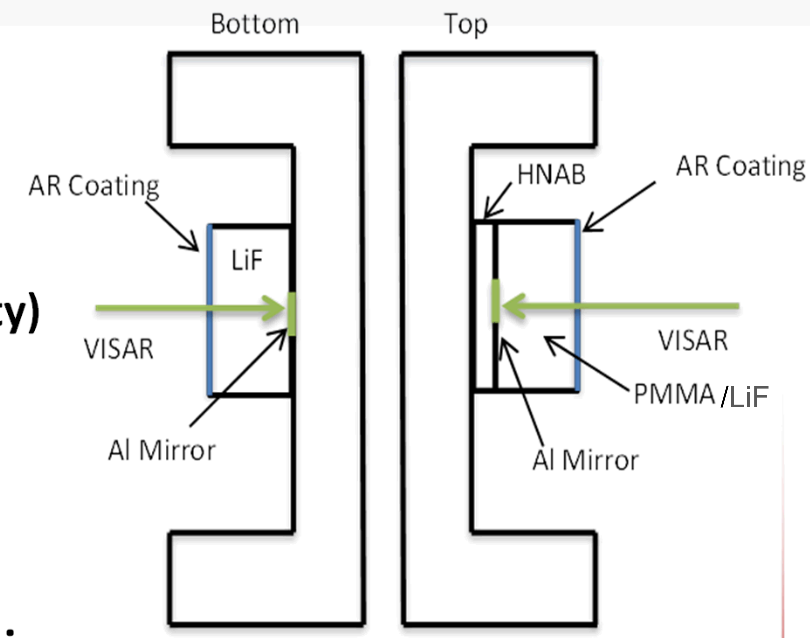
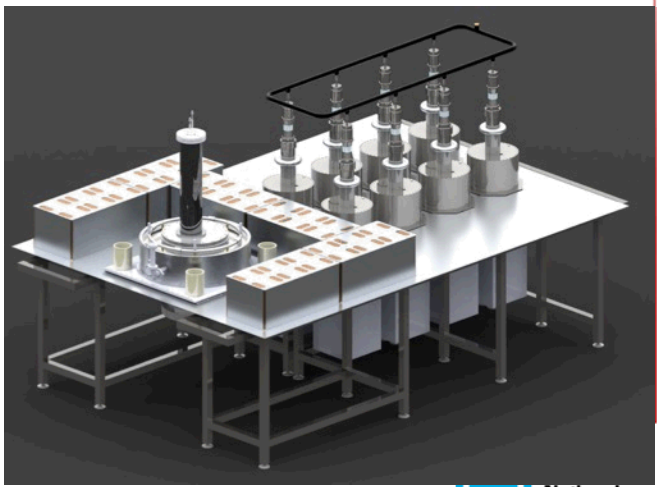
Experimental Objective and Approach

- **Generating EOS data for HNAB**
- **Quasi-isentropically load HNAB-II thin films using VELOCE**
  - **200 µm thick and 3 mm in diameter**
  - **HNAB-II density was 1.735 g/cc (~1% porosity)**
- **Two experiments:**
  1. **HNAB-II deposited on a LiF window**
  2. **HANB-II deposited on a PMMA window**
- **The quasi-isentrope was obtained using forward optimization and the transfer function method developed by Justin Brown, et al. [3]**

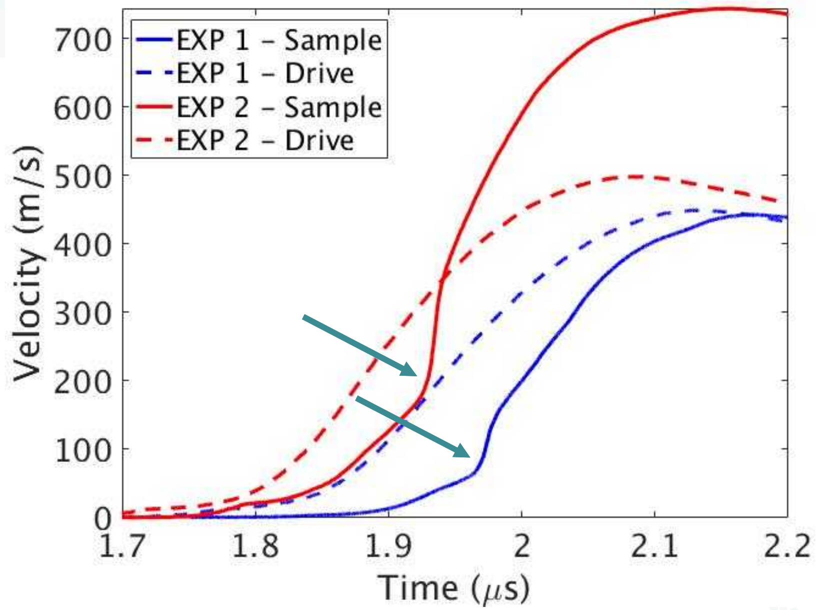


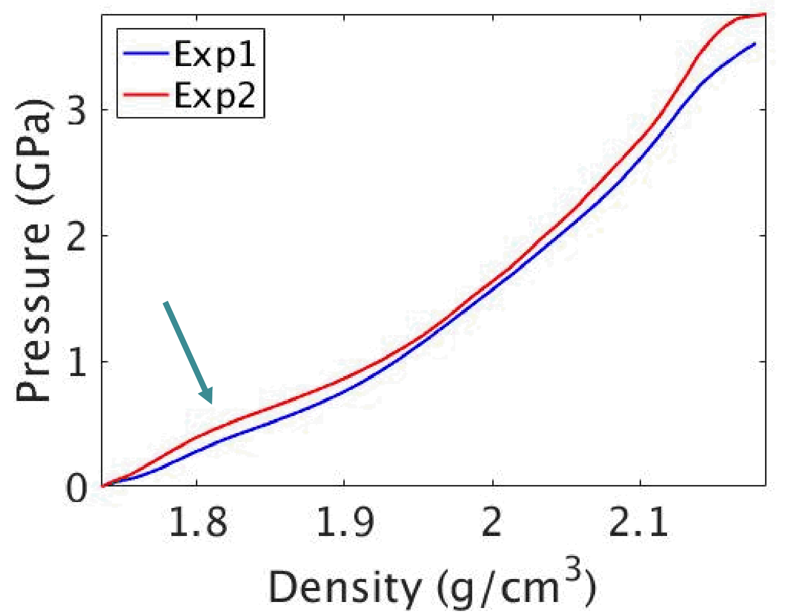


[3] J.L. Brown, et al., J. Appl. Phys. **114**, 223518 (2013).

Experimental Results

- **Interface velocity records from both experiments showed evidence of a low pressure (~ 0.6 GPa) phase transition in HNAB**
- **The phase transition cast doubt on the extracted quasi-isentrope**
  - **Invalidates the steady, isentropic flow conditions assumed**
  - **Current efforts are underway to extend the analysis technique through phase transitions**

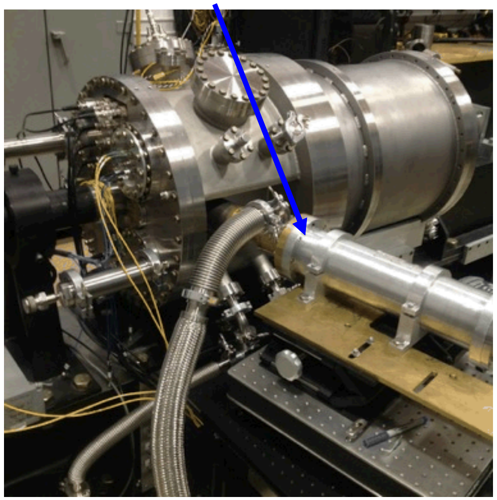




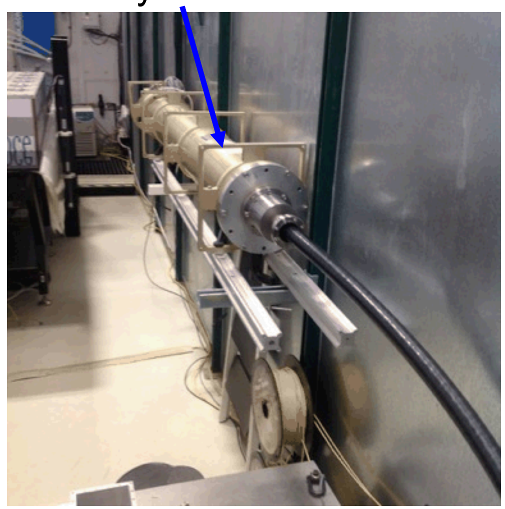
Future Efforts

- **Experiments are in preparation to use in-situ XRD measurements to identify the high pressure phase**
- **Single stage gas gun at the DICE facility has a NSTec Supersaver x-ray diode capable of generating a single pulse of line emission from metal anodes (e.g. Mo-K-a: 17.48 keV) [4]**

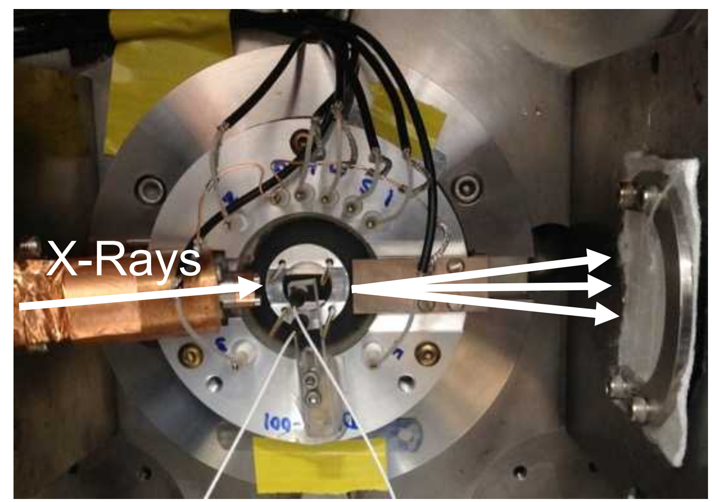
NSTec
x-ray diode head



NSTec
x-ray source Marx



XRD Target



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[4] D.V. Morgan, et al., Powder Diffraction **25**, 138 (2010).

Extra Slides

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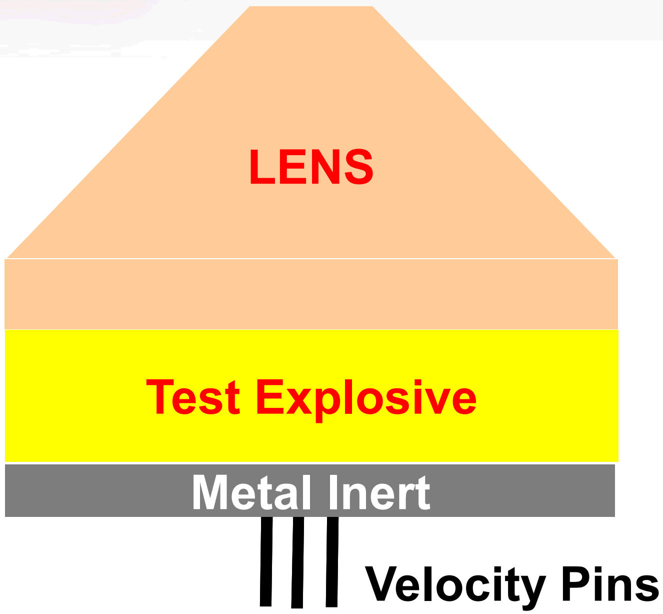
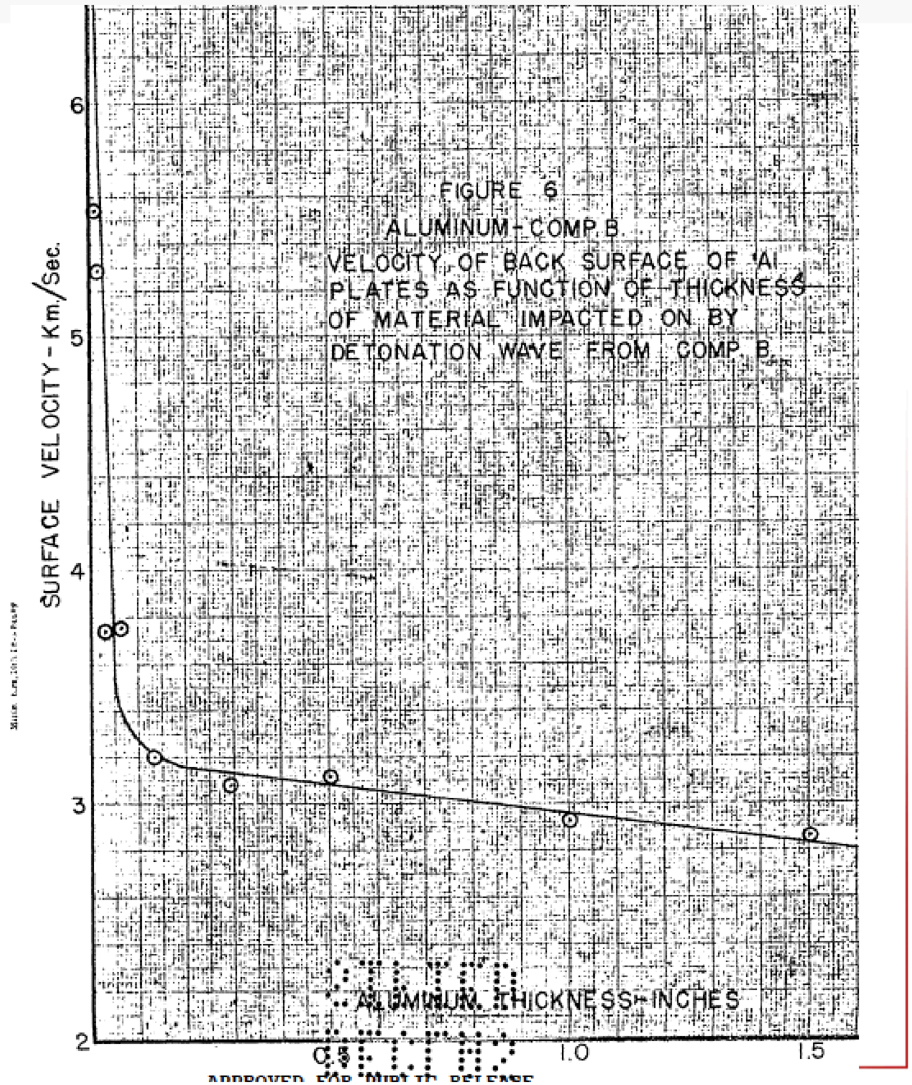
Goranson Test





- **Goranson Test is 1-D**
- **Measures free surface velocity of metal inerts of different thicknesses**
- **Experiments used to determine reaction zone thickness and detonation product EOS**

R. W. Goranson, LA-487, (1946)

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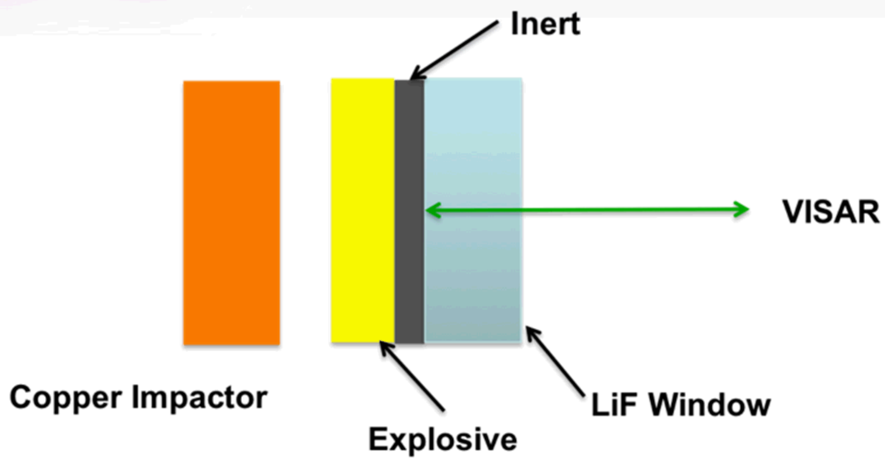
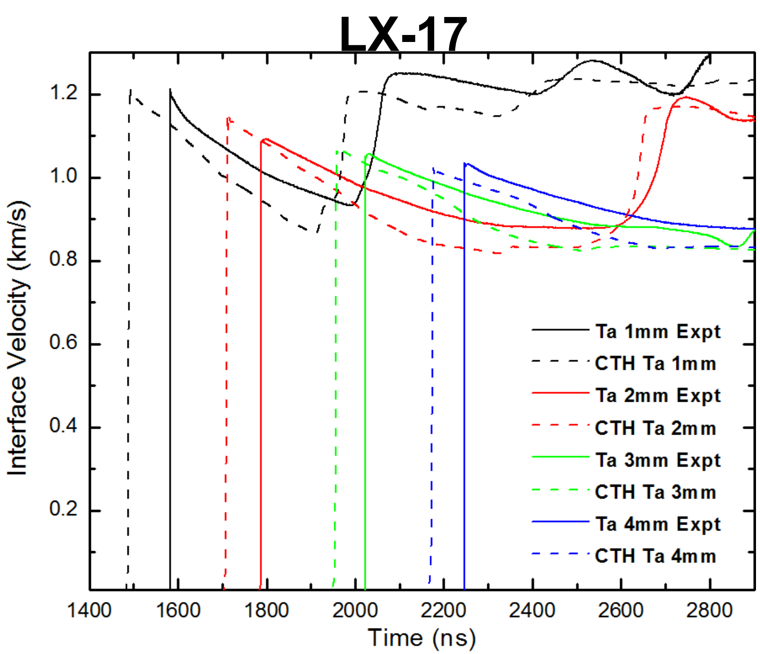
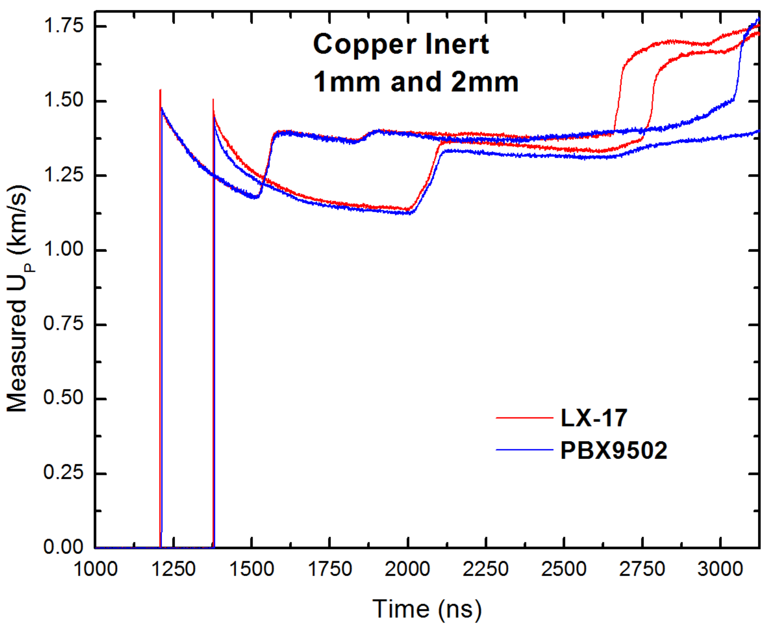
Modified Goranson Test



- Detonation wave propagates into a metal inert (Al, Cu, and Ta)
- Experiment is 1D
- Various thicknesses of inert
- LiF VISAR window used to eliminate possible spall effects
- Used to examine PBX9502 and LX-17





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