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Title: Overview of recent experimental work studying phase transformations in metals dynamically

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Form 836 (7/06)

Overview of recent experimental work studying phase transformations in metals dynamically

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The shock and detontation physics group provides both diagnostic and research platforms which are able to probe the dynamic response of materials. Here we will present an overview of the capabilities that the group has. We have several gas gun facilities, a couple of laser facilities, and several firing sites that allow us to probe the dynamic response of materials. The range of diagnostic tools which cover everything from proton radiography, VISAR, photon doppler velocimetry, ellipsometry, and xrays. Here we present recent research of various group members that have used these facilities to better understand the dynamic behavior of materials. We will discuss briefly the work that has been done on: U-6Nb, Fe, Ce, Zr, depleted U, and metal oxide powders. The techniques and data obtained have been used to develop a better understanding of the underlying physical mechanisms surrounding processes such as, phase transitions, strength of materials, and porous material compaction.

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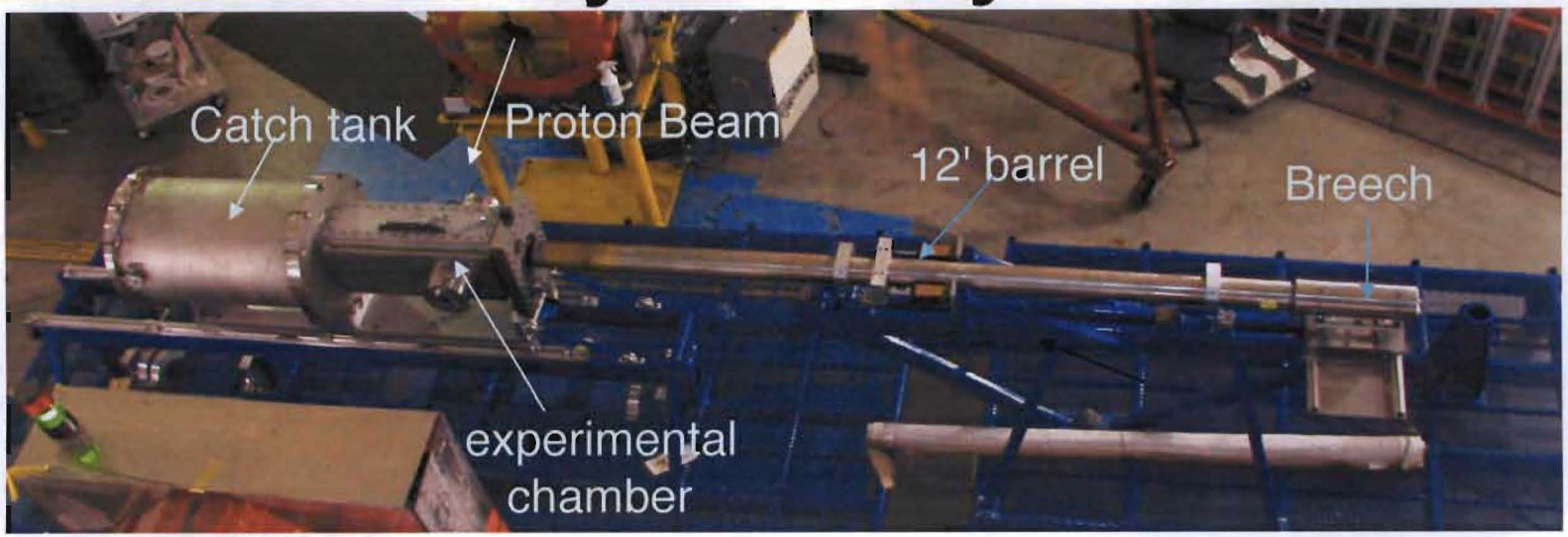
Overview of recent experimental work studying phase transformations in metals dynamically



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Los Alamos National Laboratory

Talk Overview

- General relevancy of shock physics and realistic simulation science
- Experimental facilities and diagnostics available
- Atomic processes leading to ramp waves
- Dynamic phase transformations leading to improved models
- Conclusions

Experimental activities in Shock and Detonation Physics at Los Alamos enable realistic simulations of our stockpile.

Fundamental Experiments

Development of Physics-based models

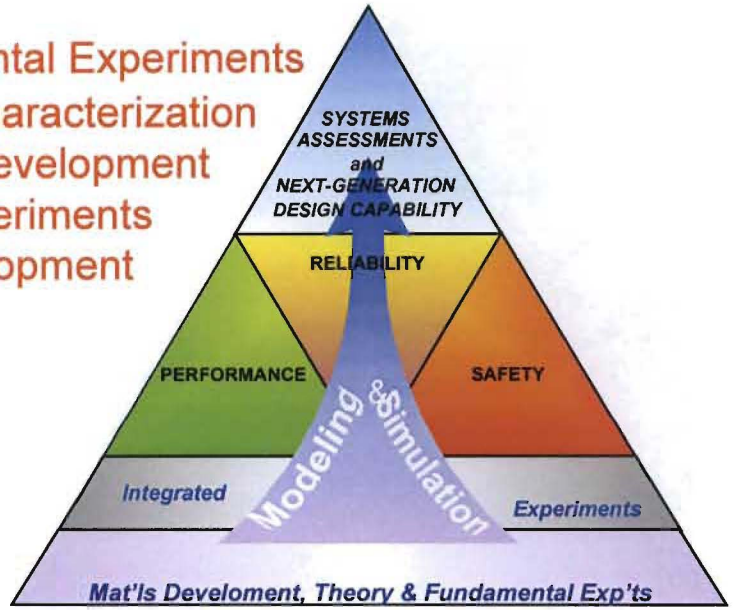
Integrated Exp'ts

Validation of models & Hydrocode calculations

Simulations of Integrated systems

The Shock and Detonation Physics Group is involved in:

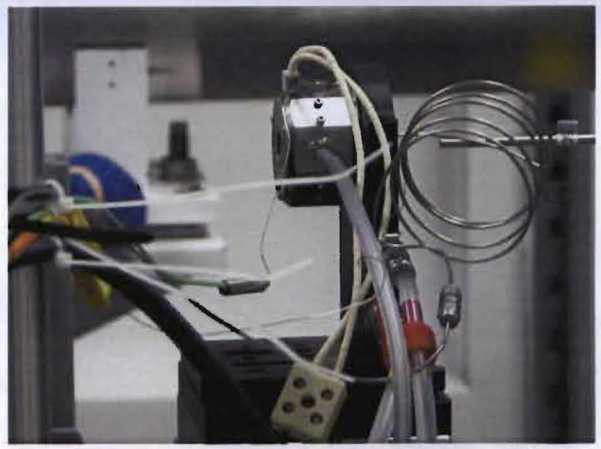
Fundamental Experiments
Material Characterization
Diagnostic Development
Integrated Experiments
New model development



Underlying Research theme is
"Materials Properties under Extreme Conditions"
Pressure, Temperature, Strain Rate, Chemistry

Understanding the behavior of materials under both static and dynamic loading conditions yield improved equations of state

- Using synchrotron and in-house x-ray sources, we study the compression behavior of materials at high-pressures and temperatures in diamond anvil cells.
- Using light gas and powder guns, explosive charges, and magnetic drives, the dynamic behavior of materials is probed to aid in the development of material models.
- Incorporating both the static and the dynamic measurements aids in the development of more accurate material models.



The shock physics research team has many experimental platforms and diagnostics available

- Experimental Platforms:
  - 40 mm powder gun (Ancho Canyon)
  - 40 mm powder gun (P-Rad)
  - 2 stage high performance gun (2-8 km/s)
  - 89 mm powder gun (up to 2.5 km/s)
  - TA-55 40 mm gun for radioactive and hazardous materials (gas and powder breeches) (up to 1.5 km/s)
  - 50 mm gas gun (up to 0.75 km/s)
  - High explosives firing sites
  - Access to ZR facility at Sandia National Laboratories

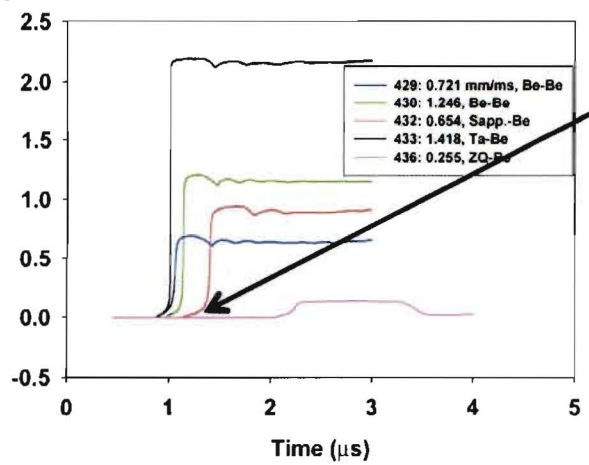
- Diagnostic Capabilities:
  - VISAR
  - PDV
  - Pyrometry/radiometry
  - X-ray shadowgraphy
  - X-ray diffraction
  - Proton radiography

LANL 7-Point Air Delay VISAR Designed/Built by NSTech

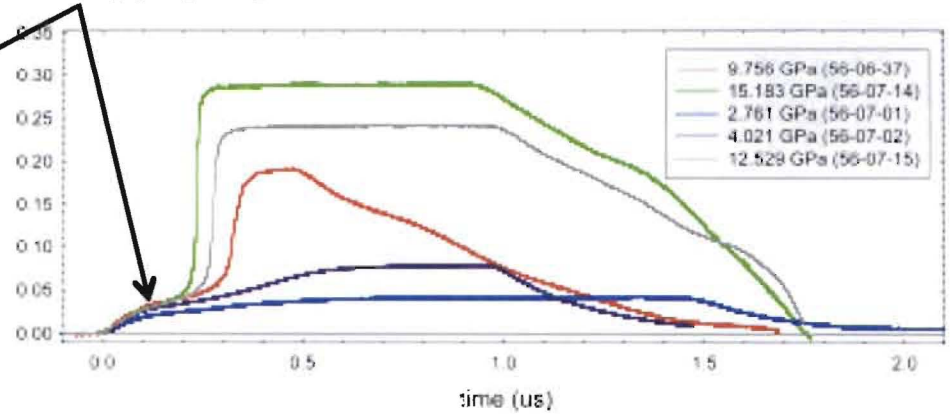
"Rampy" onset to plastic state could be an indication of twinning in depleted Uranium and Beryllium

- Time resolved VISAR measurements in both Be and depleted U show a "rampy" pre-plastic wave.
- Deformation twinning has been proposed as a possible mechanism for this behavior.
- Close examination of the foot of the wave does show a low stress elastic precursor.

"Rampy" pre-plastic wave

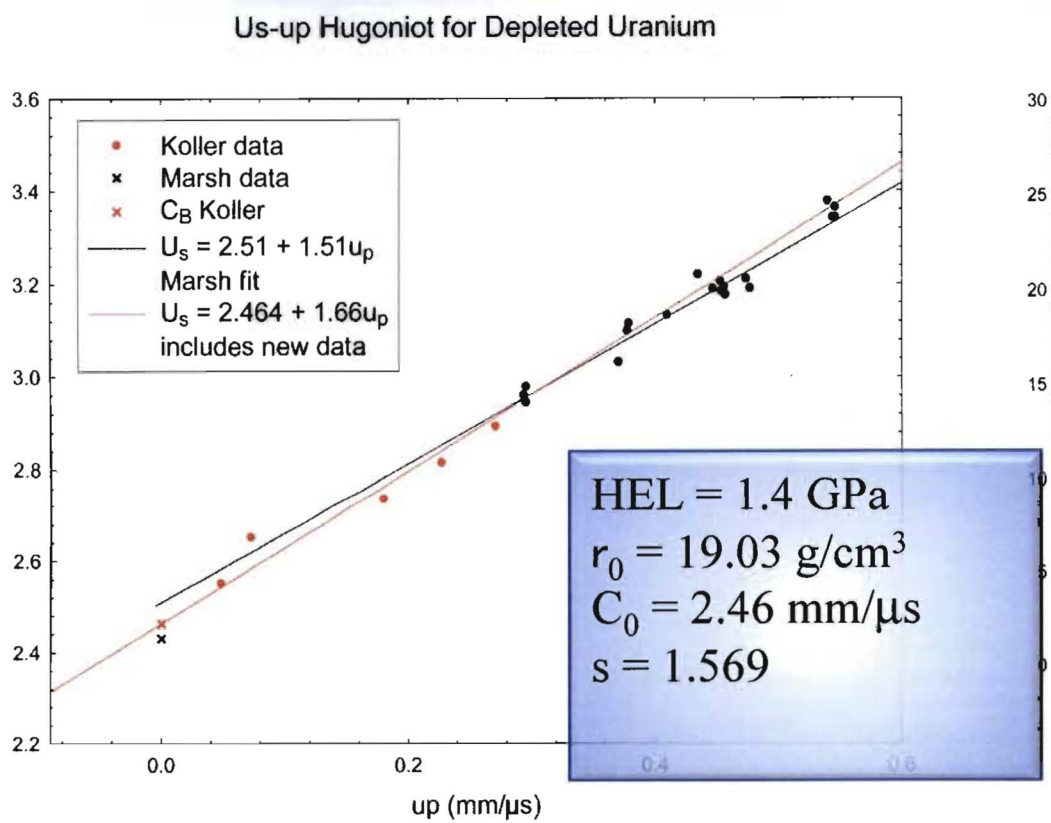


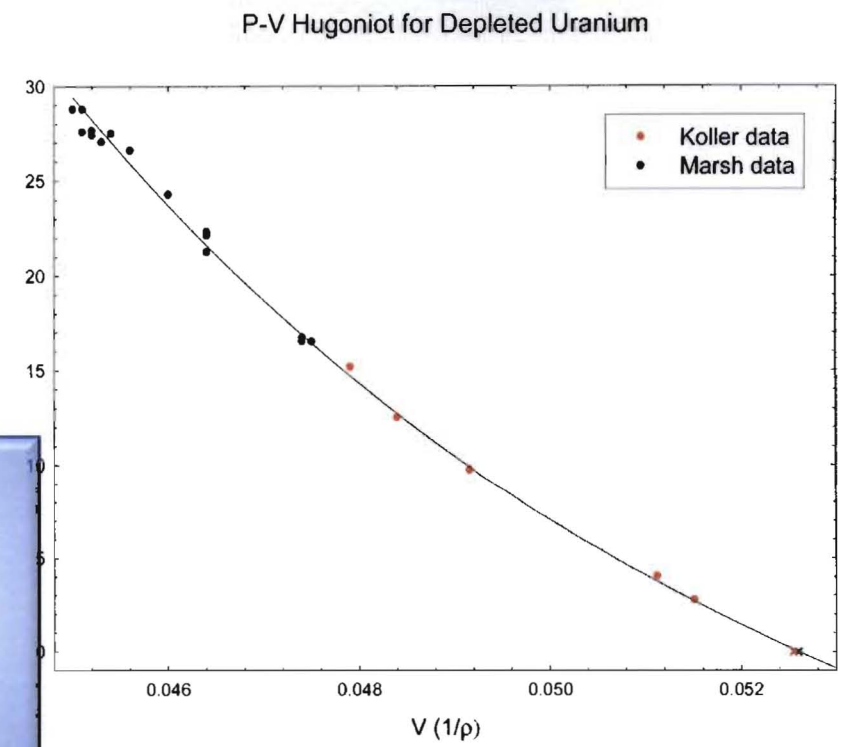
Be



Depleted-U

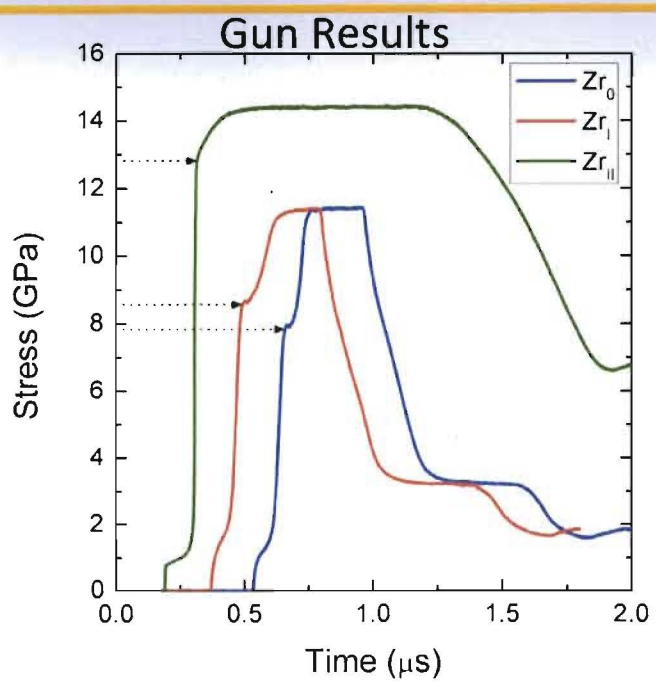
Low pressure Hugoniot for Depleted Uranium provides a refinement to the Marsh compendium data

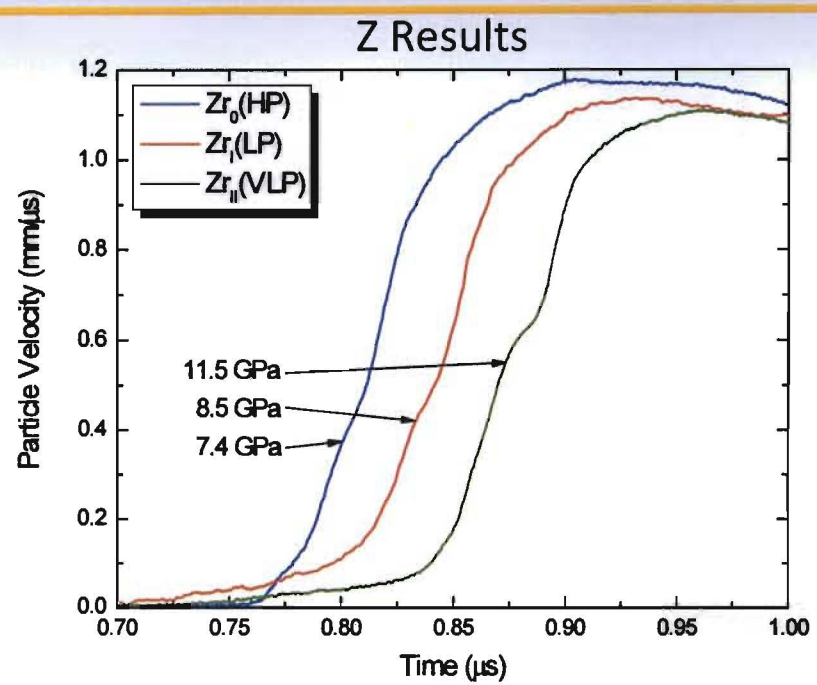




HEL = 1.4 GPa
r_0 = 19.03 g/cm^3
C_0 = 2.46 mm/μs
s = 1.569

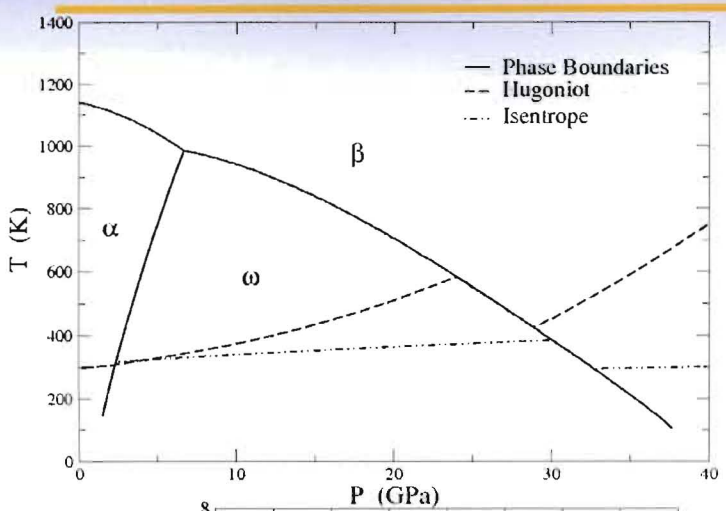
The presence of oxygen in Zr dramatically increases the stress at which the α – ω phase transition occurs

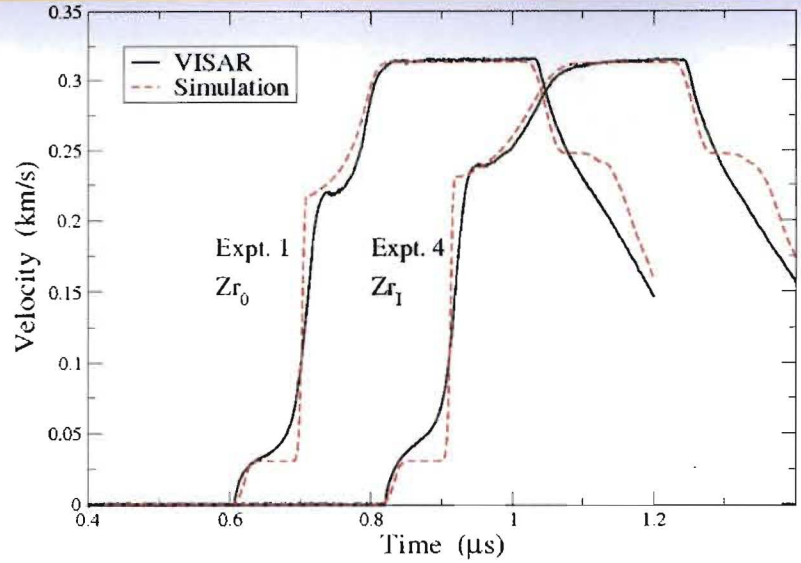


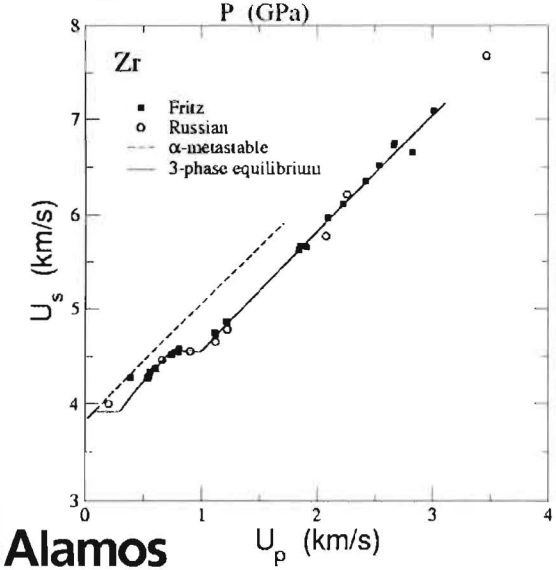


- Oxygen levels are < 50ppm for Zr_0, 390ppm for Zr_I, and 1200ppm for Zr_{II}.
- The phase transition signature is very subtle in the shocked impure sample and is overdriven just a few GPa higher.
- In contrast, the signature is more pronounced for the isentropically loaded impure sample indicating that strain rate is important.

Finally, all available data are used to develop a multi-phase equation of state to describe Zr



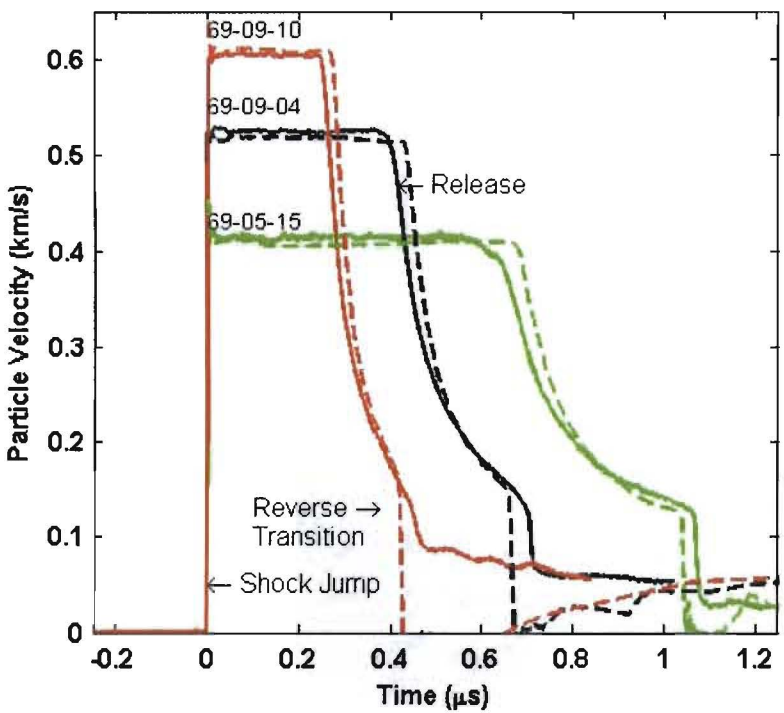


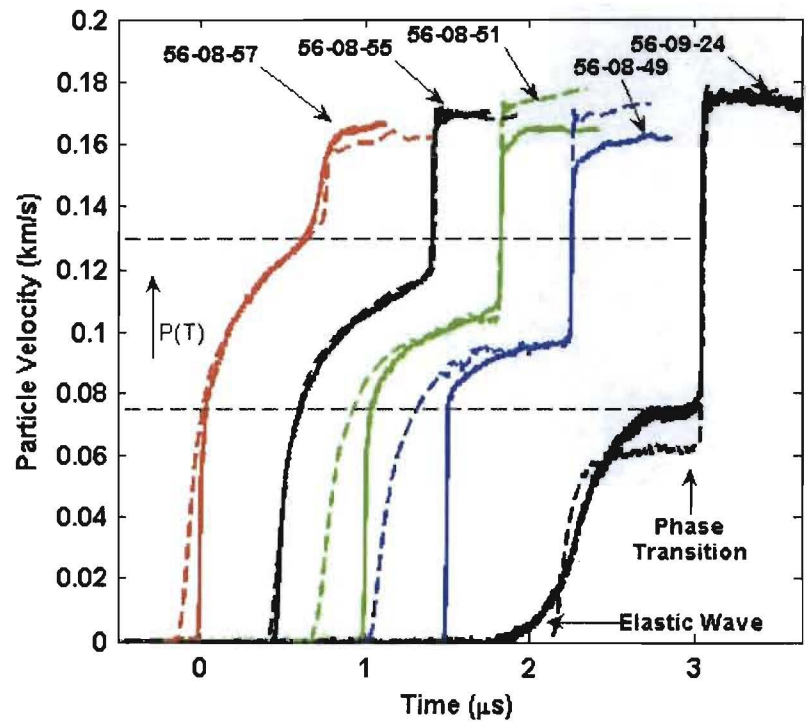


- Carl Greeff (T-1) has used all available data to develop and evaluate a multi-phase EOS for Zr.
- Reasonable agreement is obtained between experimental data and simulations for Zr_0 and Zr_I.
- More work is needed in order to describe the least pure material, Zr_{II}.
- This work is helping us understand the influence of impurities and the mechanisms responsible for phase transformations.
- This, and similar work, is helping to develop more accurate equations of state for use in today's hydrocodes.

The robustness of the multi-phase equation of state of cerium is shown through calculations

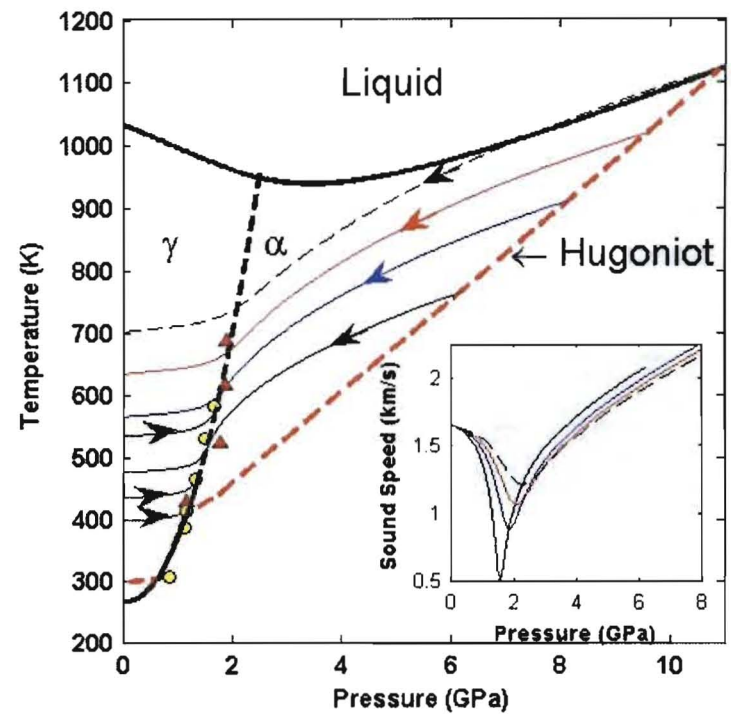
- Front surface and heated experiments show phase transition behavior in cerium.





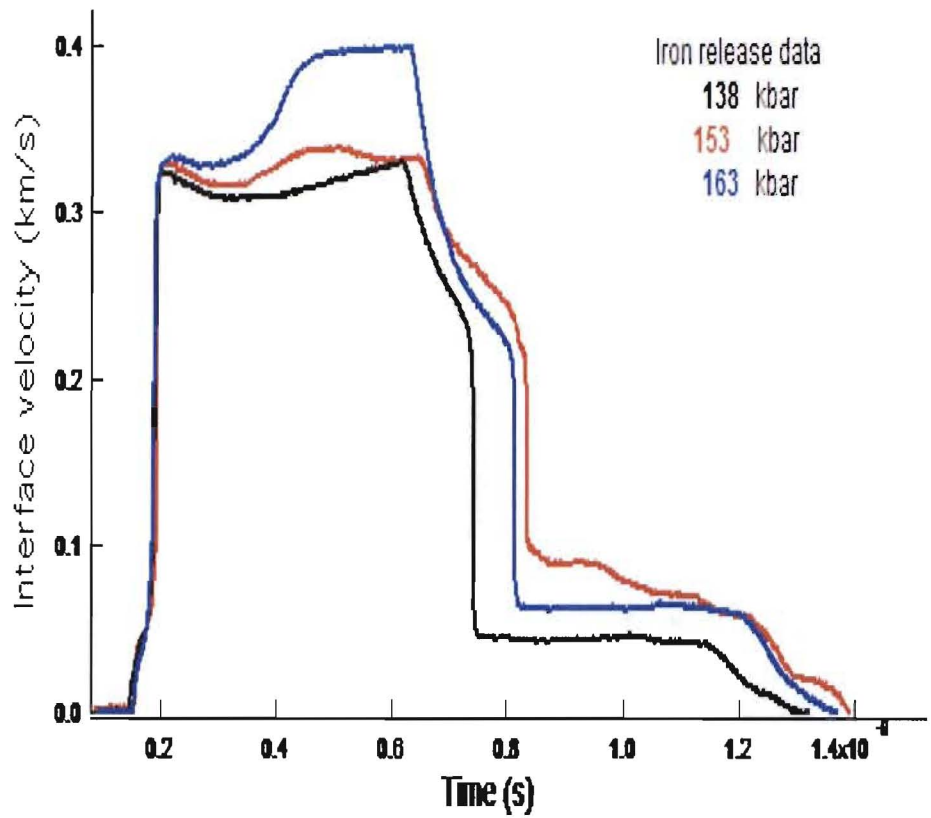
Between the experiments and the calculations the γ→α phase boundary is mapped out

- On account of the difficulties in measuring low temperatures experimentally, we use cerium's multiphase equation of state to provide a calculated temperature of transition either on release or on compression.
- Experimental stresses are plotted with the temperature to define the Υ→α phase boundary.



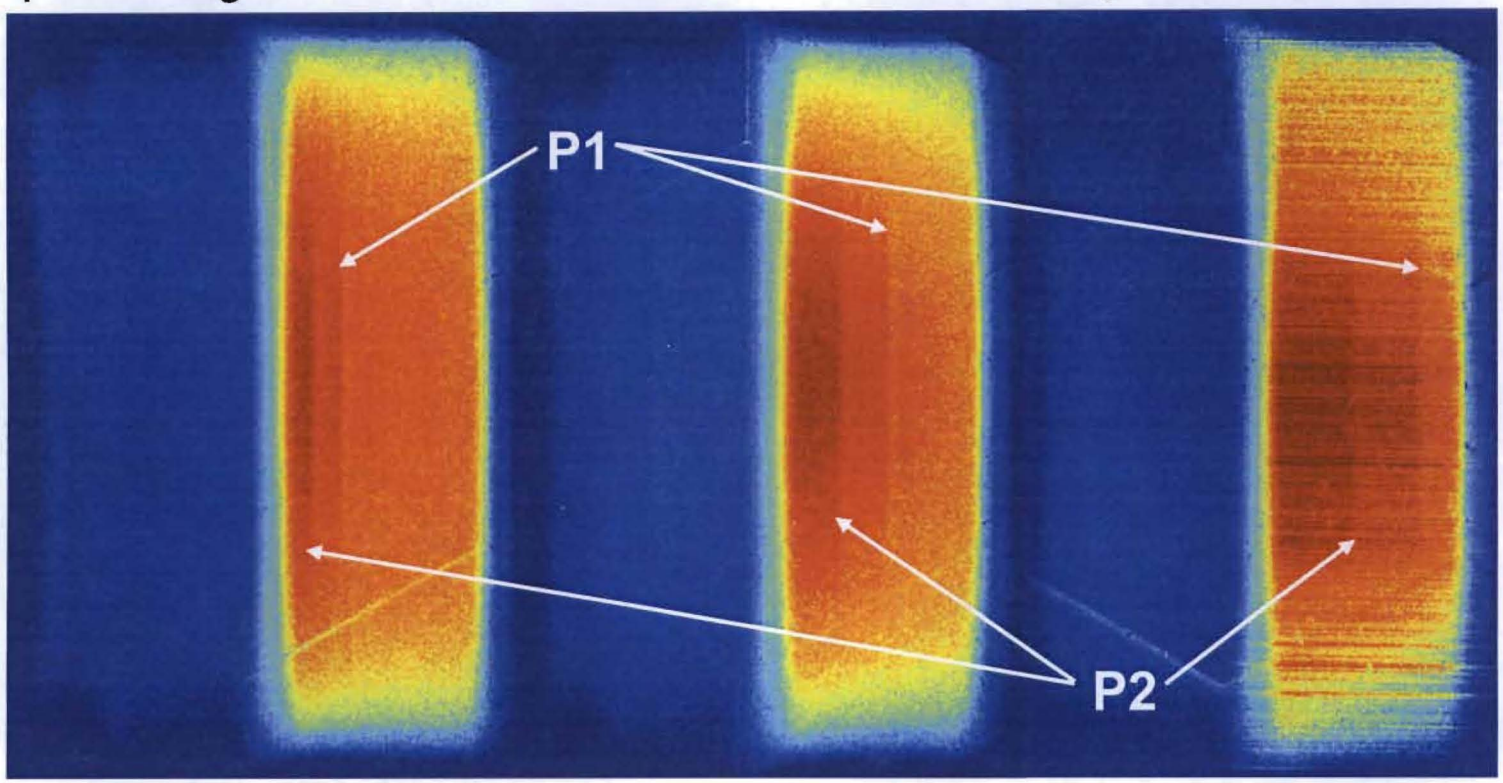
Phase Transition Studies: Iron

- α to ε transition observed in Fe at ~13 GPa
- Transition is relatively insensitive to purity
- Reverse transition clearly observed as evidence by rarefaction shock

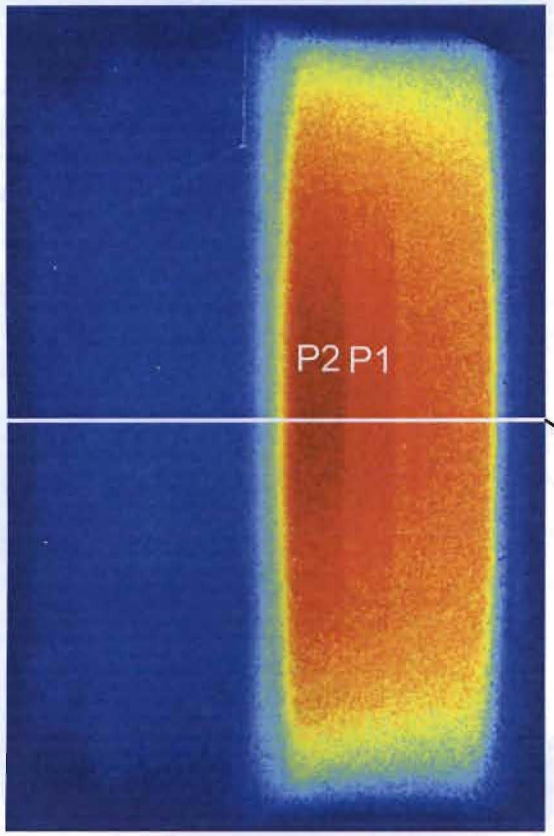


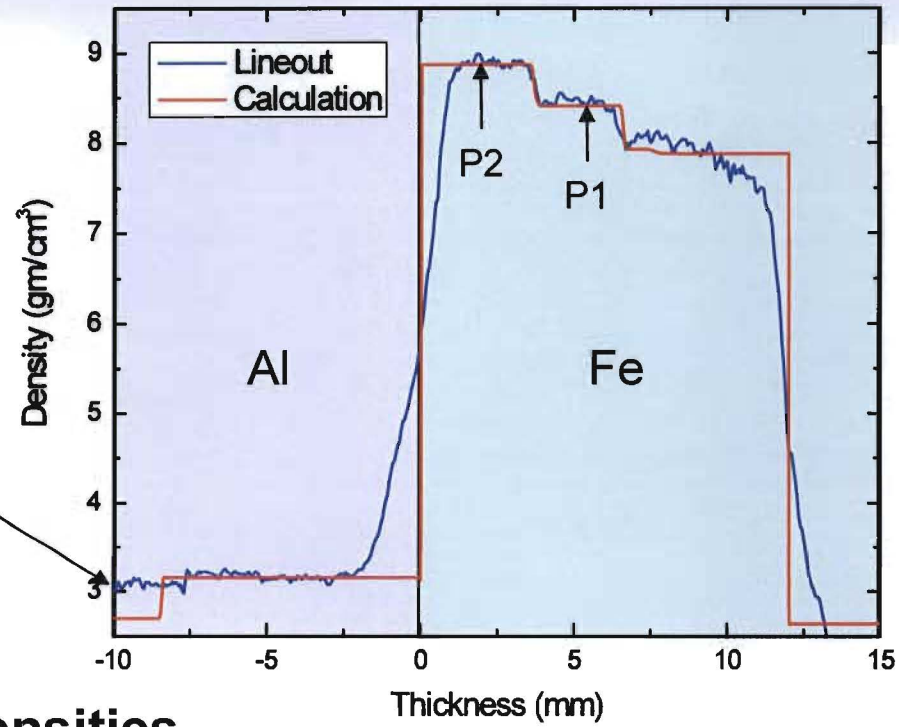
Two-wave structure observed in Iron

- Aluminum impacting Iron backed by Sapphire @ 1.45 km/s -> 175 kbar in Fe
- 3X pRad Magnifier used to enhance contrast and sharpness



Measured and Calculated Densities - Iron





Densities

State	Measured	Calculated	Agreement
P1	8.346	8.342	<0.1%
P2	8.854	8.846	0.1%

Summary and Conclusions

- Our experimental facilities provide advanced diagnostics for obtaining fundamental equation of state of materials of programmatic interest to Los Alamos National Laboratory.
- The time resolved data obtained by the shock physics team explores phase transition kinetic and dynamic atomic processes induced by shock compression.
- Both static and dynamic experiments yields an understanding for the development of enhanced physics based models.