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Sandia National Laboratories

Evolution of the Richtmyer-Meshkov process driven by a cylindrically convergent shock

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Background

The Richtmyer-Meshkov instability (RMI) occurs when a shock wave passes through an interface separating two fluids, imparting a non-uniform velocity and amplifying perturbations on the boundary.

RMI and the closely related Rayleigh-Taylor instability (RTI) play important roles in the development of stellar explosions and inertial confinement fusion (ICF) implosions.

In ICF, RMI can provide a seed to the more deleterious RTI, both of which lead to shape deformation, residual kinetic energy at stagnation, and pusher-fuel mix, ultimately limiting the attainable fuel pressure and burn duration at stagnation.

According to linear theory[2], small amplitude perturbations will grow as

$$\eta/\eta_0 = 1 + A_t k \Delta v t + \Delta v t / R_0$$

$$\eta/\eta_0 = 1 + A_t k \Delta R + \Delta R / R_0$$

A_t = Atwood number, k = instability wavenumber,
Δv = change in interface velocity, ΔR = radial displacement of rod

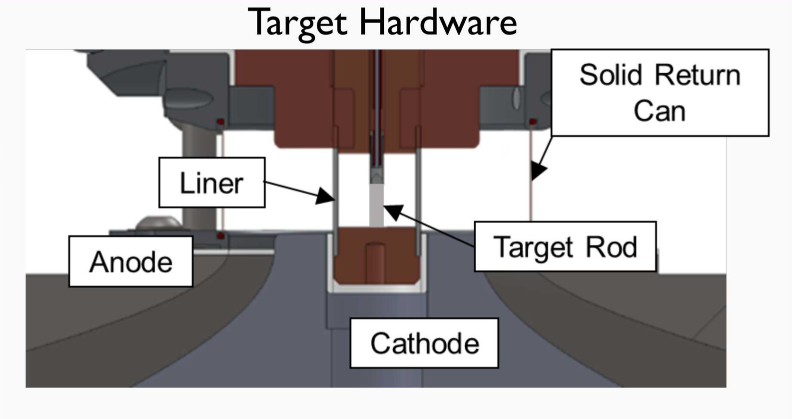
Experimental Description

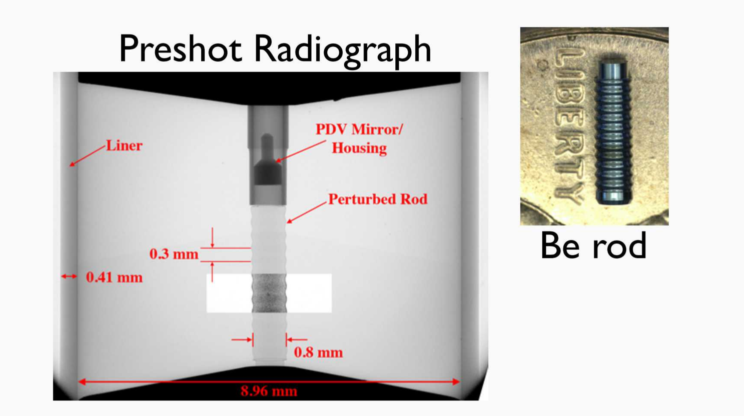
The Z Machine at Sandia National Laboratories implodes a liquid-deuterium-filled liner, driving a converging shock that strikes an on-axis beryllium rod. Calculations show the magnetic field is excluded from the interior of the liner during this process.

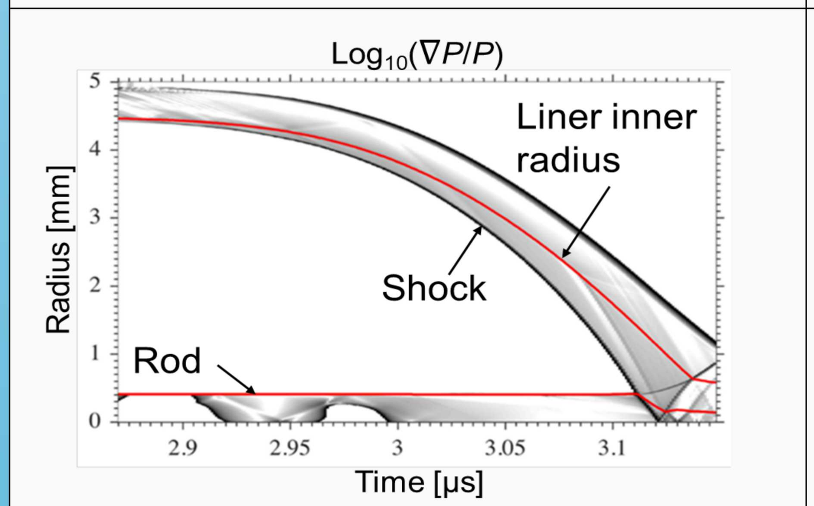
Single or multi-mode perturbations machined in the rod grow in amplitude due to the Richtmyer-Meshkov instability.

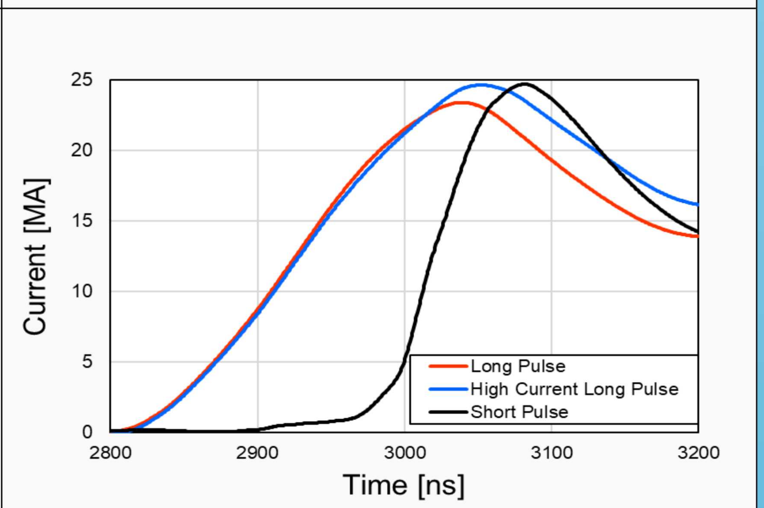
The shock reflects off axis and re-shocks the rod, initiating a complex reverberation phase.

7.2 keV penetrating radiography yields 2 frames per shot.



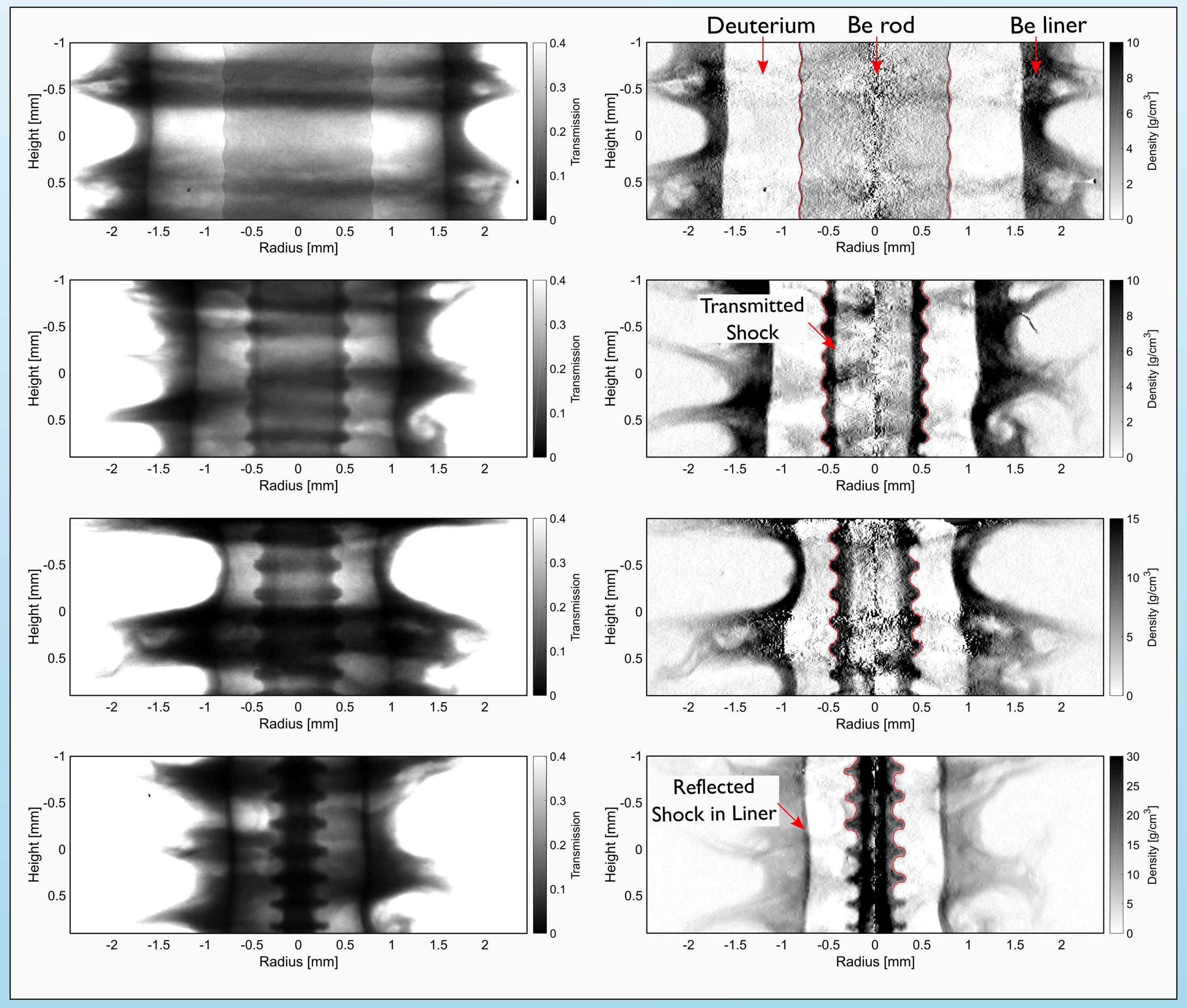






Single Shock Data

The first passage of the shock initiates RMI at the rod-deuterium interface, causing perturbations to grow linearly in time at the seeded wavelength (0.3 mm).



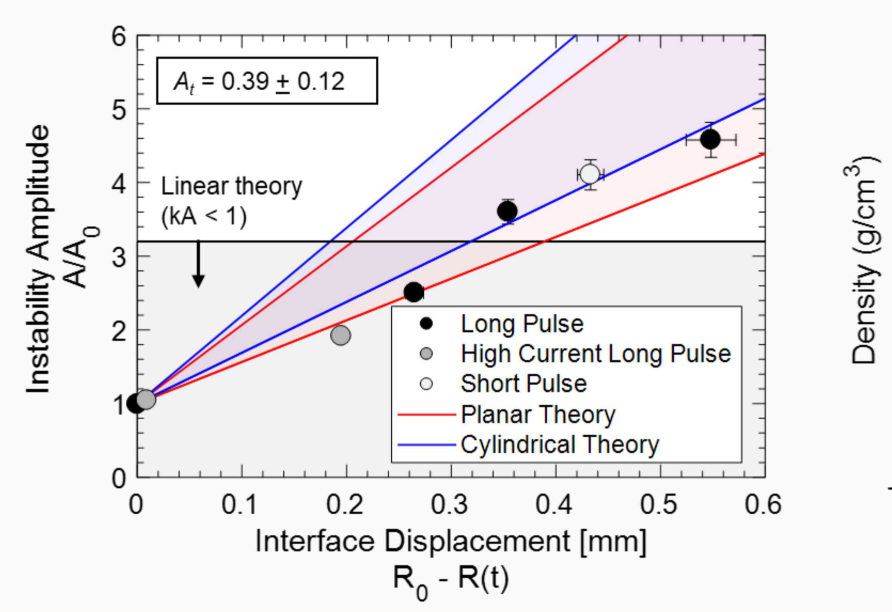
Abel inverting optical density images allows contour tracking through the dense magneto-Rayleigh-Taylor (MRT) spikes in the liner.

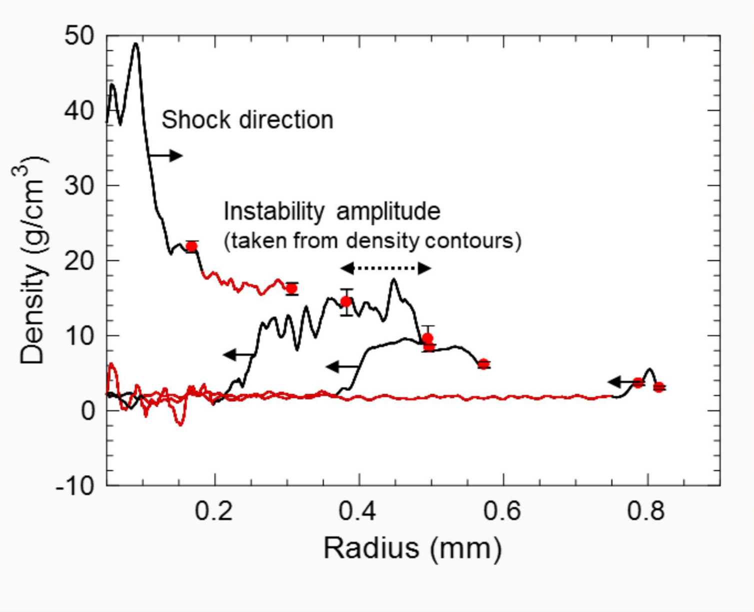
The shock converges in the rod and reflects off axis. The final frame shows instability development just before the interface is shocked for a second time.

Axially averaged density lineouts show shock propagation and enable estimation of the Atwood number:

$$A_t = \frac{\rho_{Be} - \rho_D}{\rho_{Be} + \rho_D}, \quad \rho_D \approx \rho_{D,0} \left(\frac{R^2_{\mathrm{Liner},0} - R^2_{\mathrm{rod},0}}{R^2_{\mathrm{Liner}} - R^2_{\mathrm{rod}}} \right)$$

Instability data show a linear increase in amplitude, showing general agreement with linear theory[2] using the estimated experimental Atwood number.

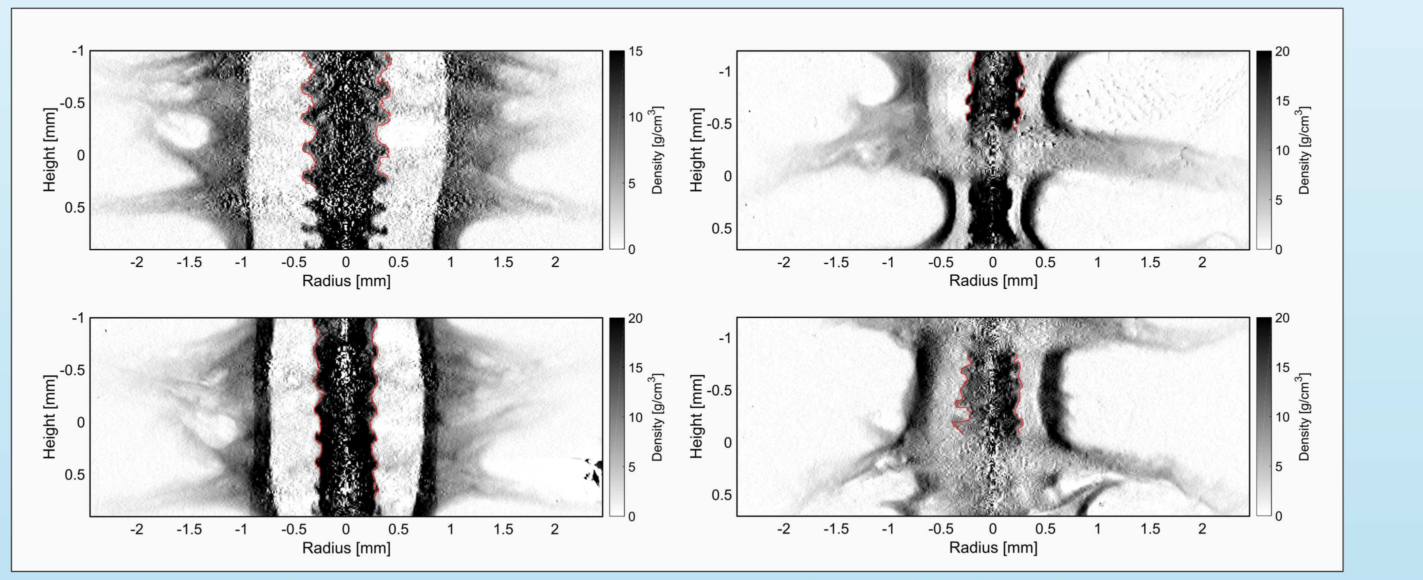




Reverberation Phase

The shock reflects off axis and re-strikes the rod-deuterium interface. A secondary shock is reflected from the interface back towards the rod axis, initiating a complex reverberation phase.

The instability amplitude is initially reduced in what appears to be a phase inversion.



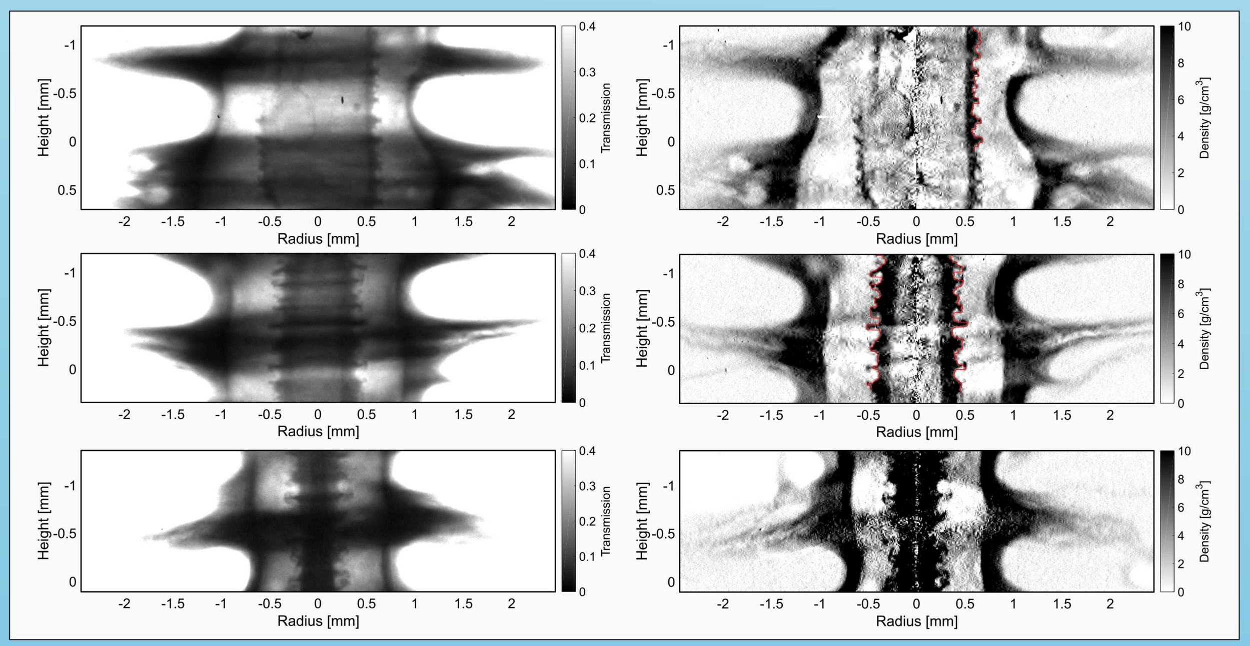
New Platform (short pulse) | Original Platform (long pulse)

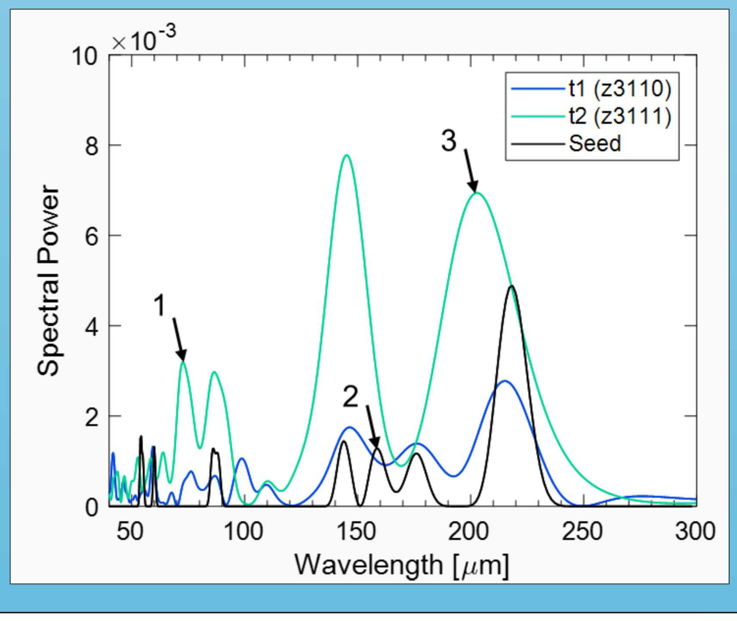
A new platform was successfully developed to investigate this stage by reducing MRT instability growth in the liner and increasing the standoff between the liner and rod.

Multi-mode perturbations (single shock)

The beryllium rod was seeded with multiple modes generated using random wavelengths (50 μm to 300 μm), phases, and amplitudes.

The instability development is highly non-linear, exhibiting mushroom-shaped spikes that appear to fold over and begin to merge.





Fourier spectra show development at (almost) all seeded modes.

1. New modes appear! The 72 μm mode is the second harmonic of the seeded 144 μm mode.

2. The seeded 159 μm mode appears to initially disappear.

3. The 203 μm mode appears to be a combination of the seeded 176, 218, and 219 μm modes.

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[1]Los Alamos National Laboratory

[2]M. Lombardini and D. I. Pullin, "Small-amplitude pertubations in the three-dimensional cylindrical Richtmyer-Meshkov instability," Phys. Fluids 21, 114103 (2009).