SAND2014-1963C

Shock-Ramp Experiments on Z

JOWOG 32mat
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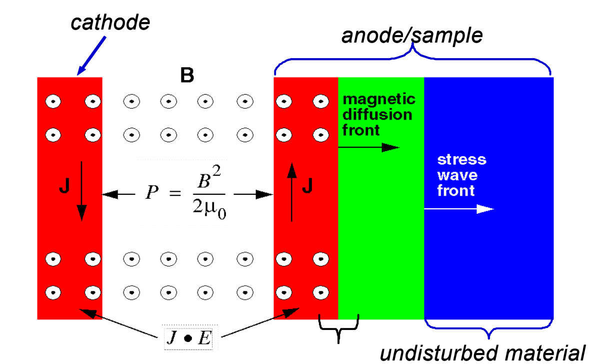

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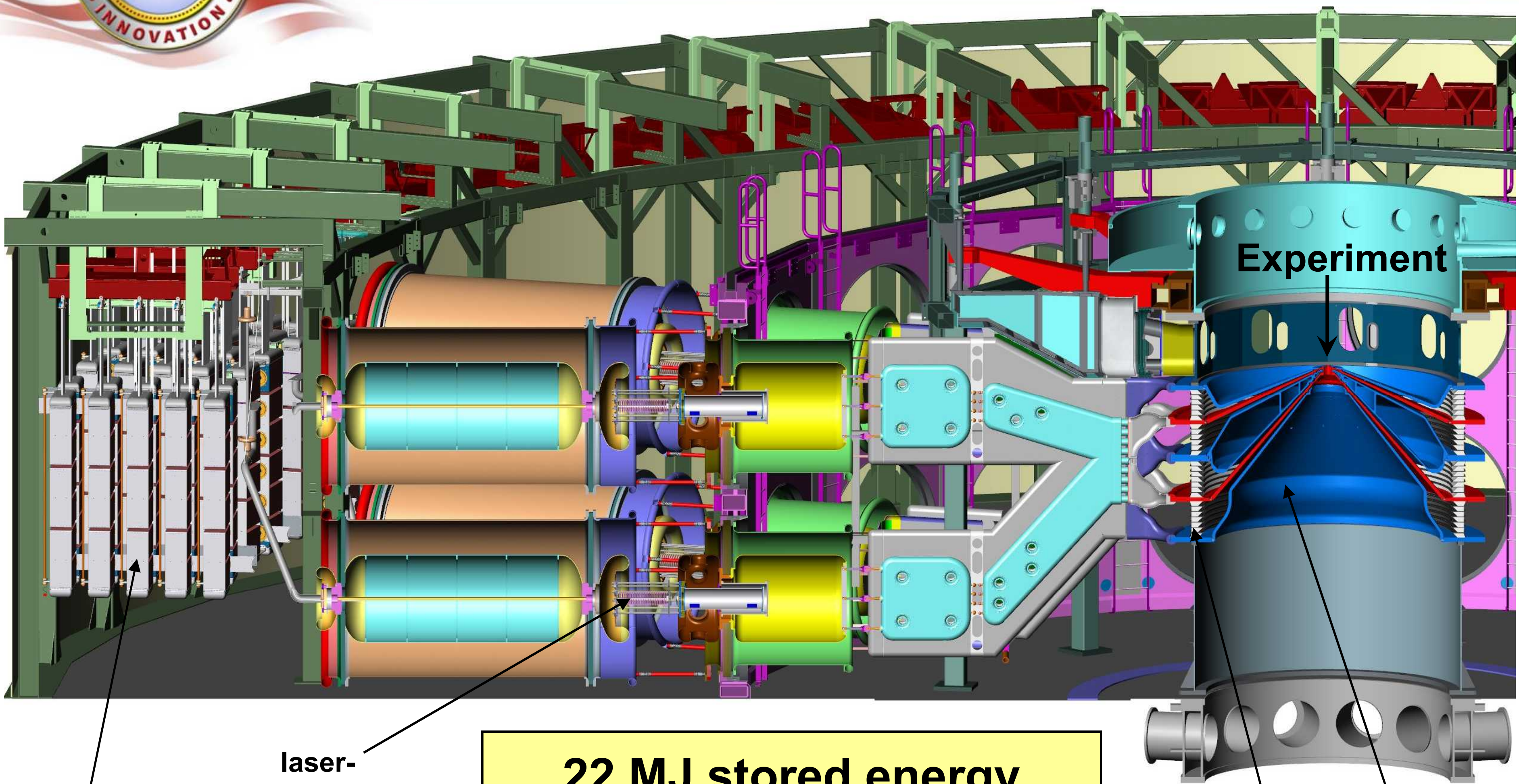
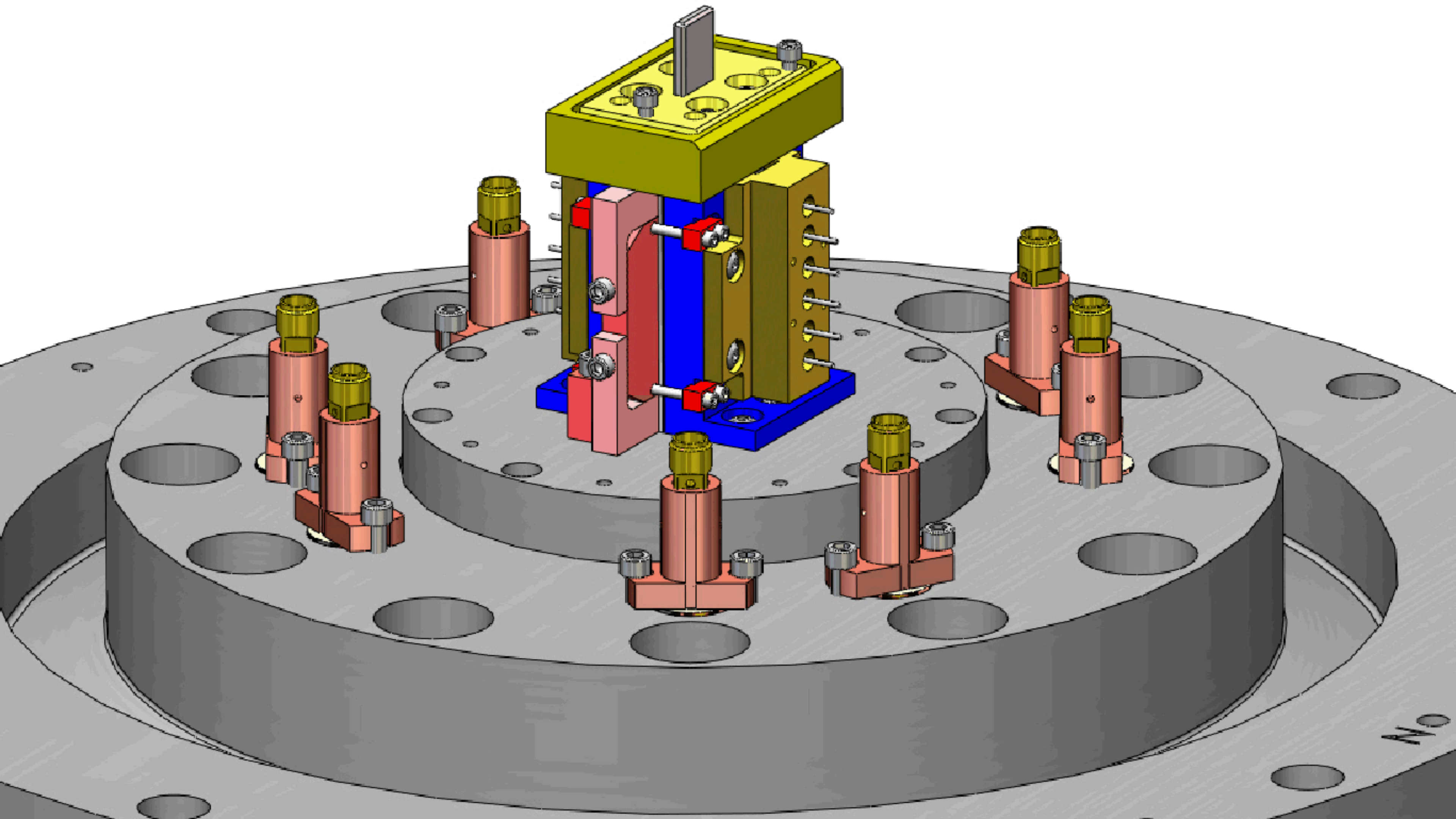
The Sandia Z Machine

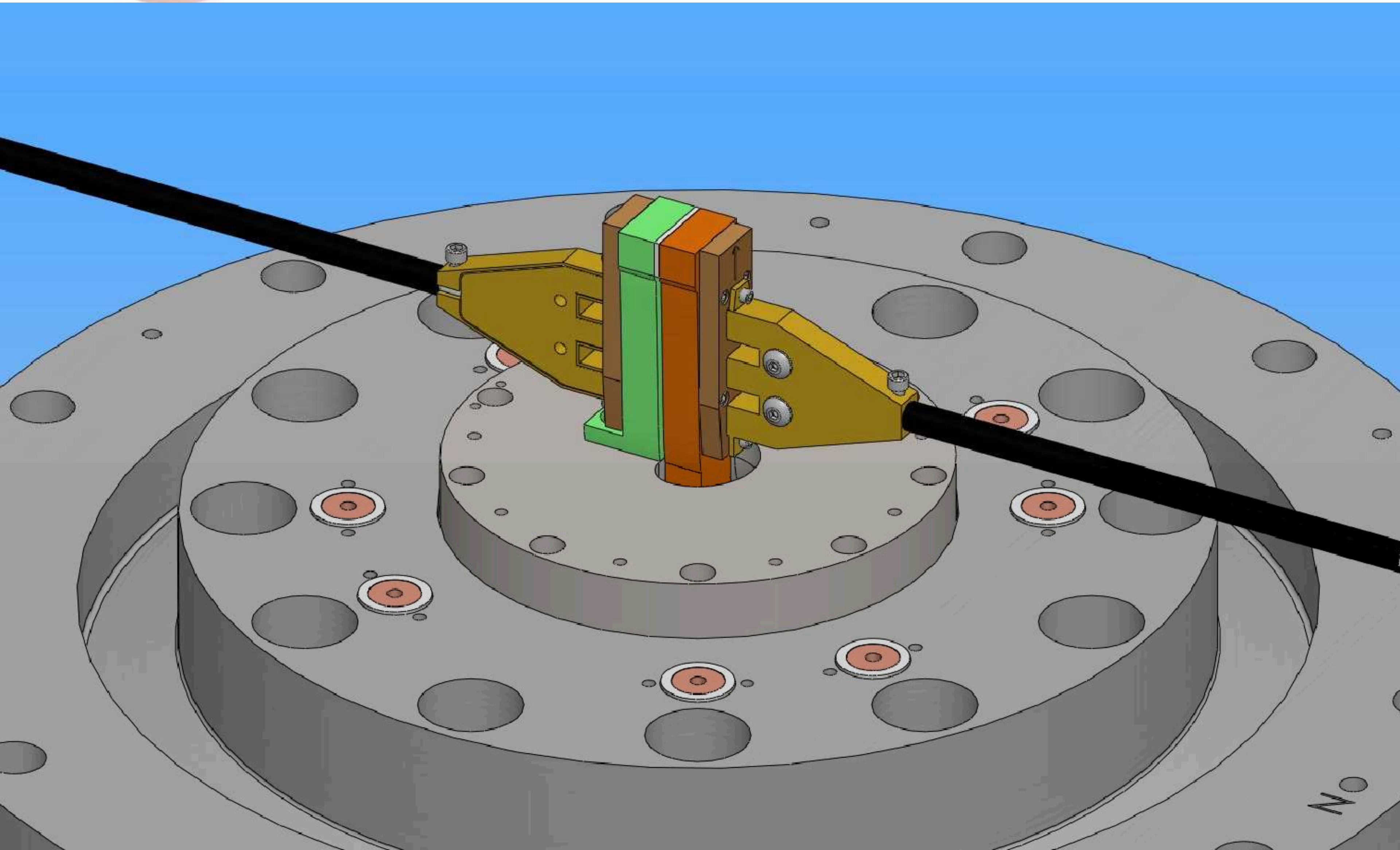


22 MJ stored energy
~25 MA peak current
~200-1200 ns rise time

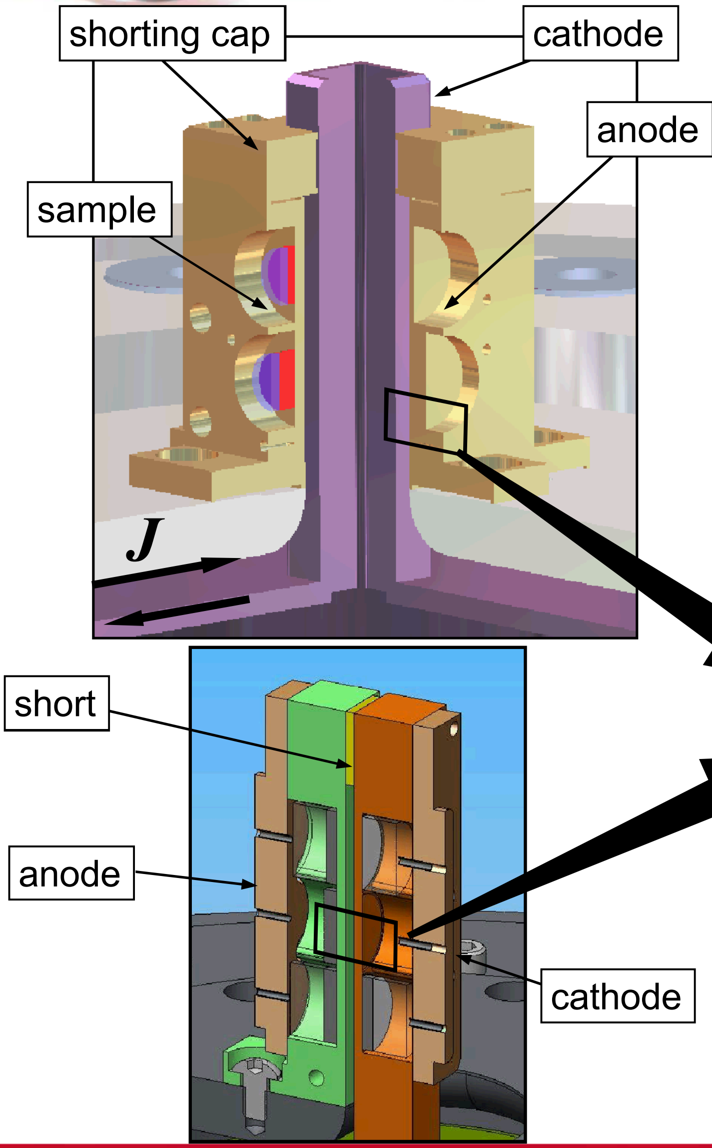
Typical coaxial load for multi-Mbar shock compression experiments on Z



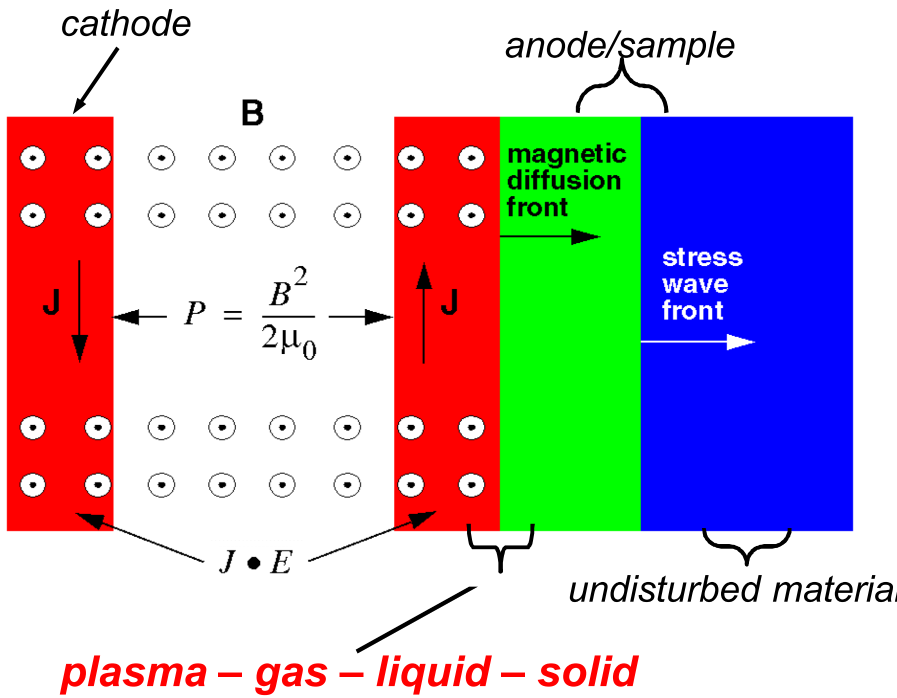
Typical stripline load for multi-Mbar ramp compression experiments on Z



Magnetic compression on Z produces smooth ramp loading to ultra-high pressures



- pulse of electric current through experimental load (shorted at one end) induces magnetic field
- *J´B* magnetic force transferred to electrode material



Shock-Ramp probes between the principal Hugoniot and isentrope

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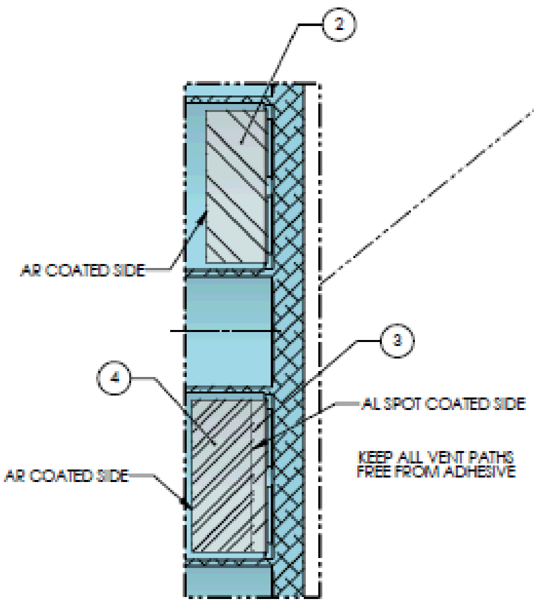
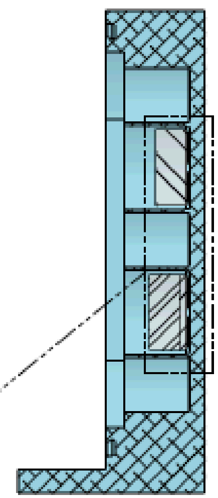
Ramp compression from a Hugoniot state results in intermediate temperatures at high compression.

SESAME 3700: Kerley, 1987

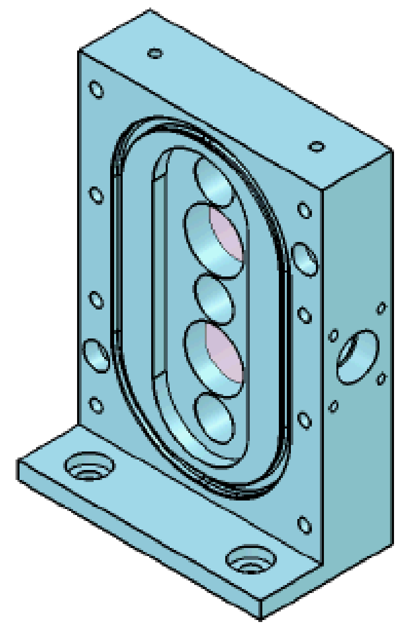
Shock-ramp experiments use coaxial or stripline with flight gap



DETAIL B
SCALE 4 : 1



SECTION A-A



PICTORIAL VIEW
FOR REFERENCE ONLY
APPROX WEIGHT 0.20 LB

Double-ramp pulseshape accelerates flyer to ballistic impact, then pushes harder

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Flight gaps and pulseshape co-designed to enable impact at nearly constant velocity

This velocity plateau also generates a “hold” in the shock state

Measured velocities exhibit shock-hold-ramp profiles

65 GPa Shock Stress

22 GPa Shock Stress

- **Delay between the shock and following ramp at the front (windowed) surface is critical for analysis**

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Lagrangian Analysis of Shock-Ramp data

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Lagrangian Analysis of In-Situ data is Exact

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$$\rho = \left[\frac{1}{\rho_0}\left(1 - \int \frac{du}{C_L(u)}\right)\right]^{-1} \rightarrow \left[\frac{1}{\rho_0}\left(1 - \frac{u_p^H}{u_s}\right)\right]^{-1} + \left[\frac{1}{\rho_0}\left(1 - \int_{u_p^H}^{u} \frac{du^*}{C_L(u^*)}\right)\right]^{-1}$$

$$P = \rho_0 \int C_L(u)du \rightarrow \rho_0 u_s u_p^H + \rho_0 \int_{u_p^H}^{u} C_L(u^*)du^*$$

Characteristics leads to errors for large shocks

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- **This example results in ~2-3% errors in pressure using the correct (input) EoS. Possibly worse for an Iterative Lagrangian Analysis.**
- **Small shocks have lower discrepancy/error**
- **"Small/Large Shock" is material dependent – Large shock: resulting isentrope is experimentally distinguishable from the principal isentrope**

Case 1: In-Situ LiF Shock-Ramp

- **Pulseshape generated at the load was not the shape intended due to machine issues**

- **Data is in-situ and can still be used, albeit with large errors**

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LiF Results

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Case 2: Small Shock in Aluminum

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- **“Small” because the principal and elevated isentropes are nearly identical**

Case 2: Small Shock in Aluminum

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- **“Small” because the principal and elevated isentropes are nearly identical**

Case 3: Large Shock in Tin (into liquid)

- **Initial 65 GPa shock melts the tin**
- **Liquid isentrope significantly different (experimentally distinguishable) from the principal isentrope**

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Backward Integration/Minimization

$$\rho_0^T \frac{\partial v}{\partial t} = \frac{\partial u}{\partial x},$$

$$\rho_0^T \frac{\partial u}{\partial t} = -\frac{\partial P}{\partial x}.$$

Integrate hydrodynamic equations backward in space to the drive (*x* = 0) surface

ρ^T_0 is the zero pressure density on the elevated isentrope

Boundary conditions derived from:

- (1) measured velocity

$$u(x_w, t) = u_{measured},$$

- (2) Guess of sample response (window assumed)

$$\rho(x_w, t) = \rho_{sample}(P_{window}),$$

- (3) Hugoniot particle velocity (interior)

$$u(x_s(t)) = \begin{cases} u_p \ if \ x_s < x_w \\ u_{measured}(t_s) \ if \ x_s = x_w \end{cases},$$

- (4) Hugoniot density (interior)

$$\rho(x_s(t)) = \begin{cases} \rho_H \ if \ x_s < x_w \\ \rho_{sample}(P_{window}[t_s]) \ if \ x_s = x_w \end{cases};$$

Minimize the difference between two sample thicknesses at the drive surface

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- **Density profiles from two sample thicknesses are compared at the drive surface from the initiation of the ramp to the time when the window release from the thin sample reaches the drive surface**

$$f(k,\ k') = \int_{t_0}^{t^*} (\rho_1(0,\ t) - \rho_2(0,\ t))^2 dt$$

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Liquid tin equation of state

Results from backward minimization are applicable from release up to compression at *t (~40-110 GPa for liquid tin)**

Liquid tin is stiffer than currently available EoS models

Acknowledgements

Jean-Paul Davis

Matt Martin

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Marcus Knudson