Dynamics of Liquid Wall Chambers

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Why Are Liquid Walls Considered When Gas-Protected Dry-Walls Can Work for Direct-Drive Laser Fusion and Are Simpler?

	Gas-Protected Dry-Wall	**Liquid-Wall**
Driver Beam Transport	**Laser or HIB with Channel Transport**	**Laser, HIB or Pulsed-Power with Vacuum Transport**
Target Type	**Direct-Drive Laser (many symmetric beams)**	**Indirect Drive Laser or HIB**
Total Target Yield per Wall Area per Shot	**< 75 J/cm^2**	**Much Higher**
Limit on Rep-Rate	**Gas Cooling**	**Condensation of Vapor and Migration of Aerosols**
First Wall Environment	**Neutron and Ion Damage, High Thermal Gradients**	**Benign**
Number of Ports	**> 60**	**1 or 2**

Liquid Walls Are Intended To Vaporize While Dry Walls Must Not

•Liquid walls may be rapidly replaceable, either as a surface film or as free-standing jets.

•Liquid walls are not subject to neutron damage, sputtering, and blistering, which are all important issues for dry walls.

•Thermal damage and erosion are serious issues for dry-walls (< 1 mono-layer of erosion allowed per shot) but are not an issue for liquid walls.

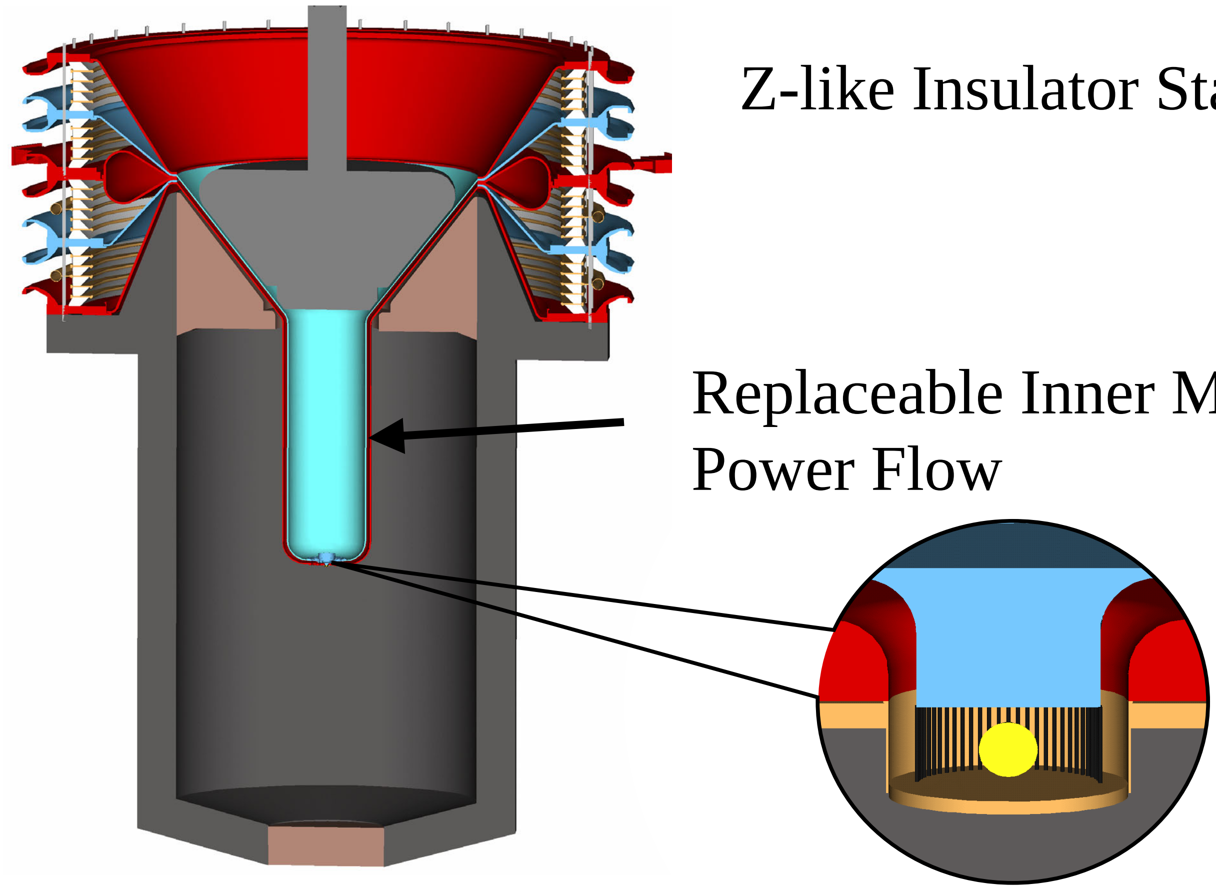
•Target remnants can be captured by liquid.

•Condensation of vapor and removable of aerosols and splashed chunks limits rep-rate.

Liquid Wall Phenomenology Drives IFE Chamber Design

- Chamber gas/vapor density at beam transport (HIB: channel, self-pinched or ballistic; Laser) has limits.
- Gas in chamber at time of target explosion can partially protect liquid from vaporization (LIBRA).
- Vaporization induces strong shocks in the liquid that impart large impulses and high pressures to structures
- Blow-off vapor exhibits complex behavior, including nucleate condensation into aerosols, absorption of late x-rays and ions from the target, and re-radiation of energy to the liquid surface.
- Condensation of vapor limits rep-rate and is enhanced by large surface area (HYLIFE, HIBALL, …) and large thermal velocity of vapor atoms (Li versus Pb).
- Aerosol dynamics will also limit rep-rate.

ZP3 Concept Extends the Recent Exciting Results of Pulsed-Power Driven ICF Physics to a Power Plant

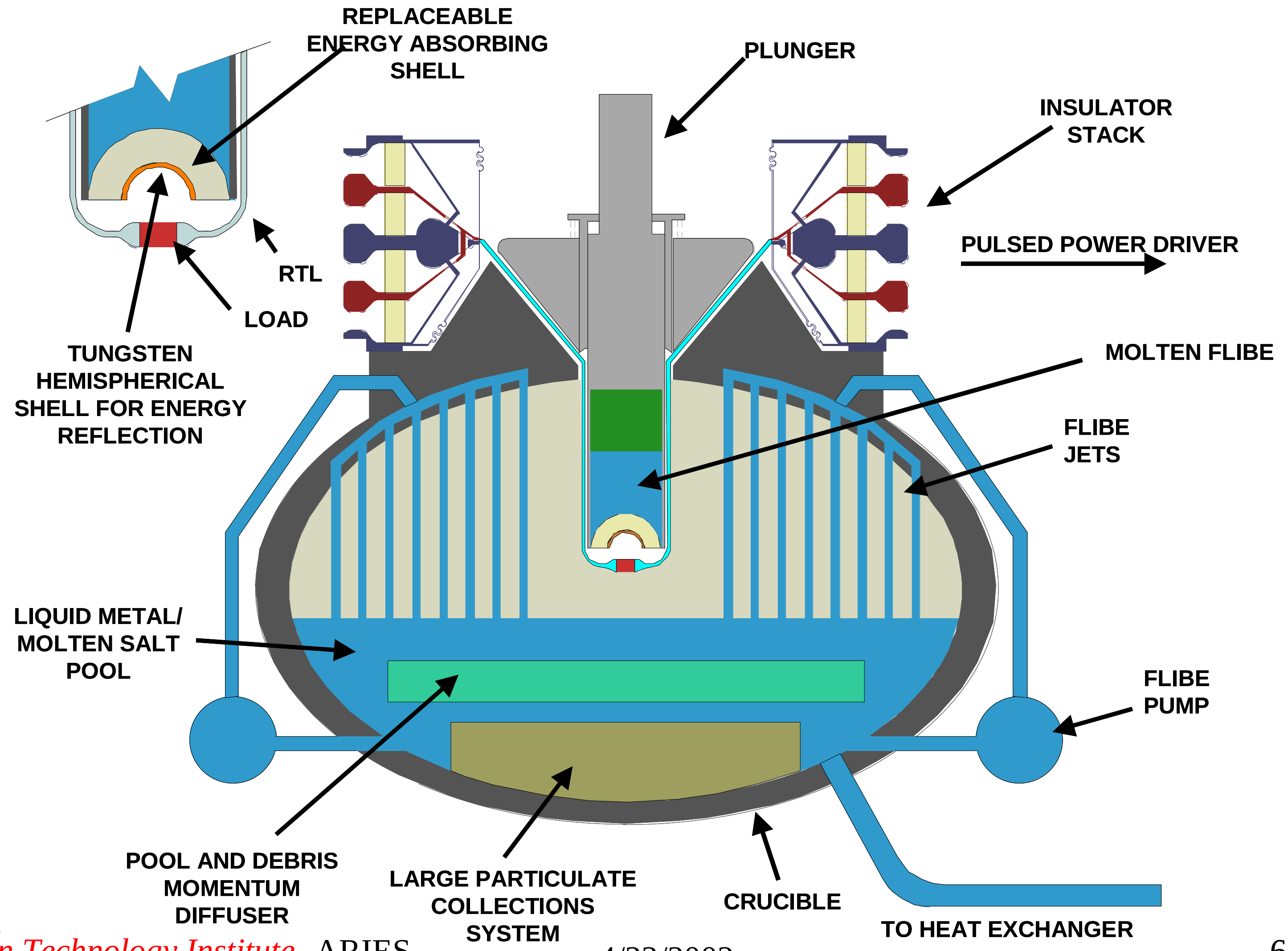


Z-like Insulator Stack and MILT

Replaceable Inner MILT and Power Flow

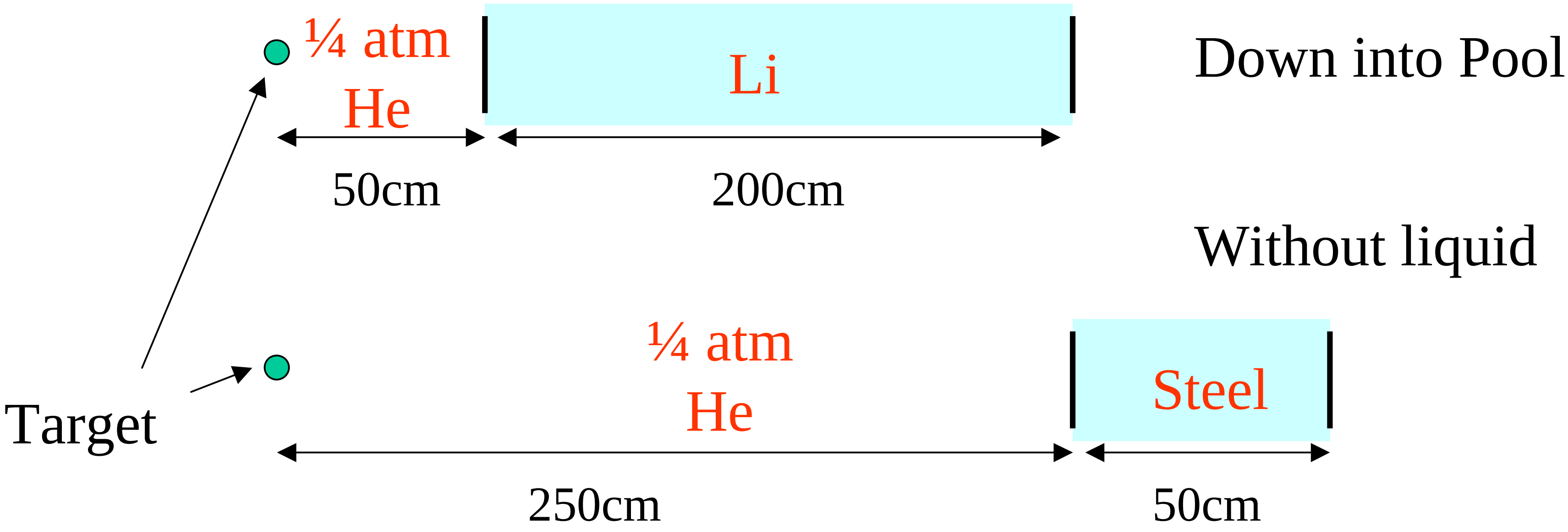
Wire-Array Hohlraum and IFE Capsule

ZP3, a Z-Pinch Power Plant is a New Example of Thick Liquid Wall Protection



1-D BUCKY Calculations for ZP3 Are Performed For Two Cases: With and Without Liquid Protection

- 1-D spherical geometry
- Preliminary: Li instead of Flibe (we now have Flibe opacity)
- ~900 MJ in x-rays
- ~100 MJ in Pb ions
- Chamber interior temperature – 600^{o}C



¼ atm He

Li

Down into Pool

50cm

200cm

Without liquid

¼ atm He

Steel

Target

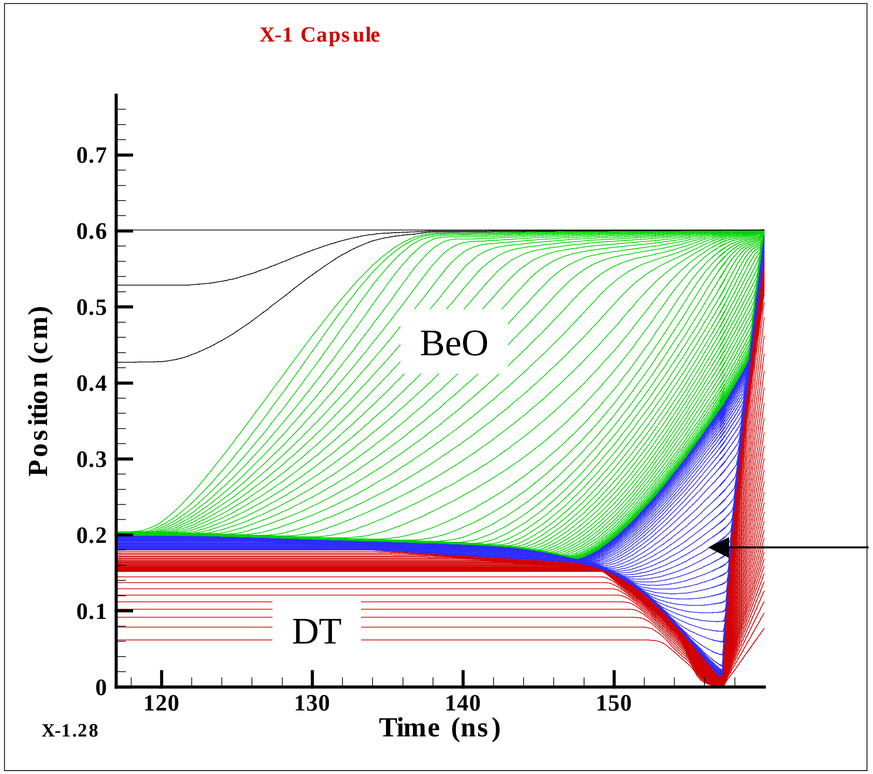
250cm

50cm

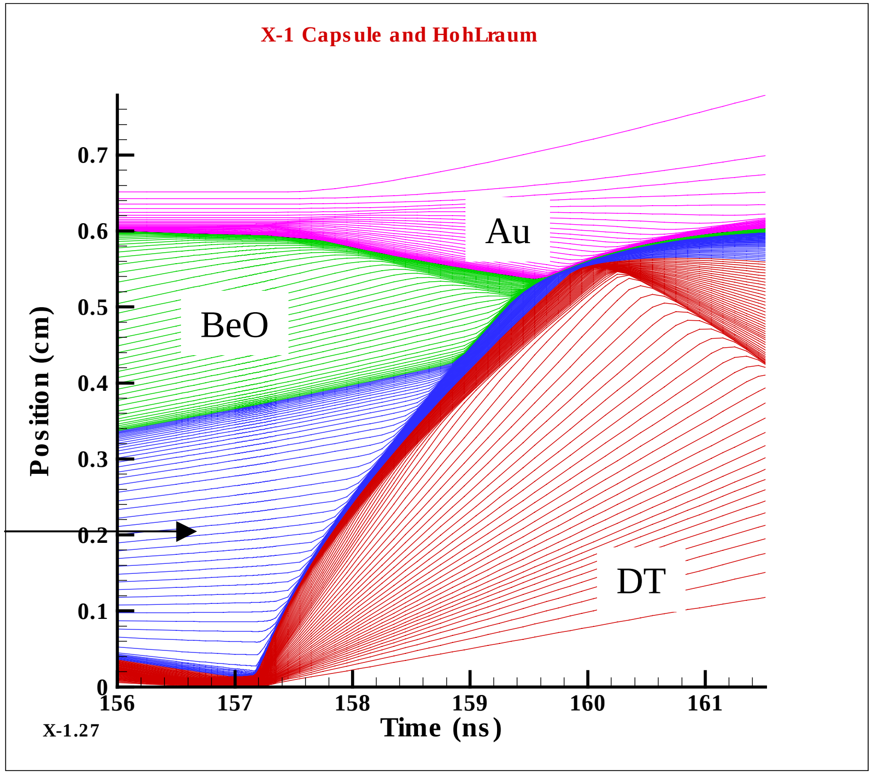
BUCKY Target Simulations of X-1 Output Were Scaled From 400 MJ to 4 GJ

Implosion without hohlraum; radiation drive

Final implosion and burn with hohlraum; no drive

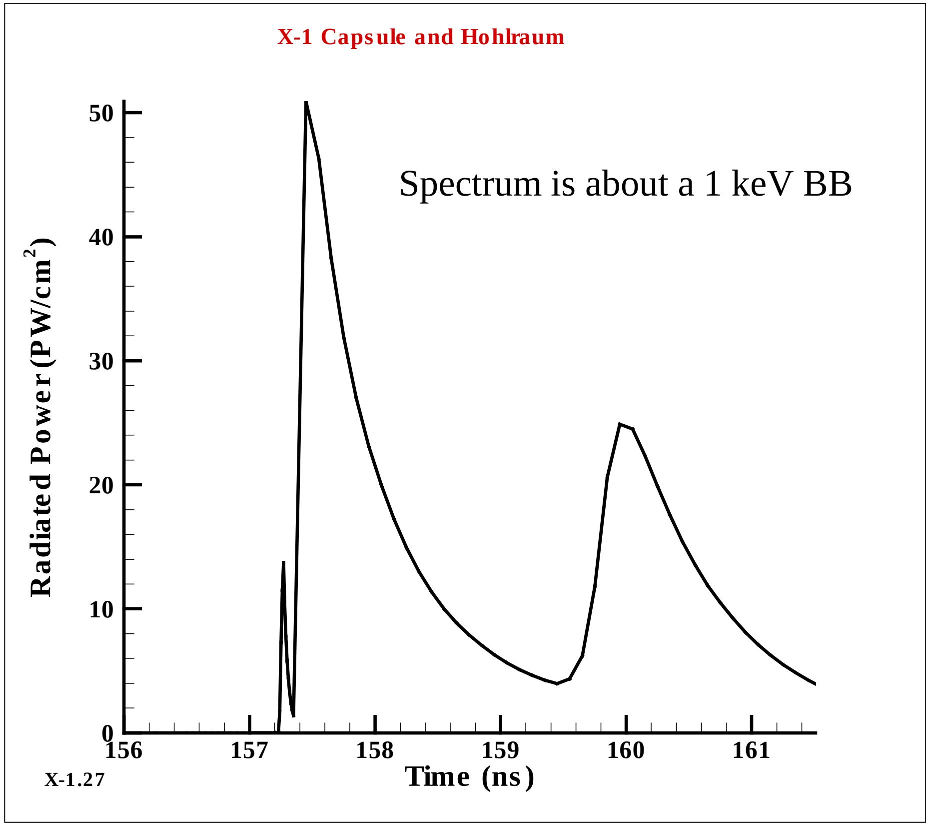


Be$_{98}$O$_2$



BUCKY Target Simulation of X-1 (400 MJ) Output Shows Two Major Pulses: Direct Emission from Capsule and From Capsule Kinetic Energy Converted to Radiation by Hohlraum

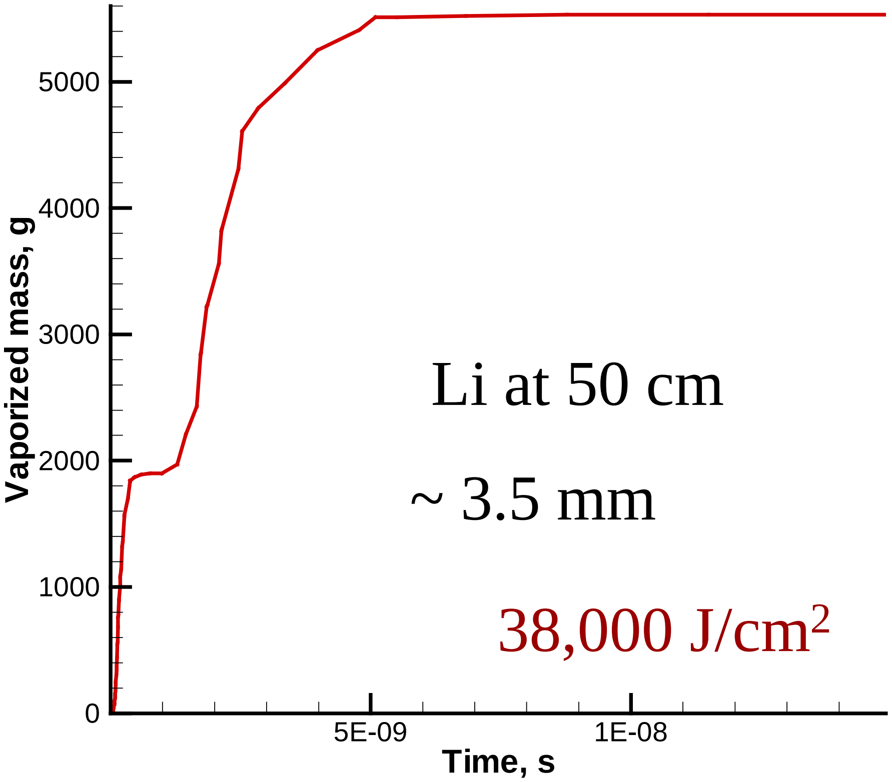
- If the Hohlraum is cylindrical, the 2nd pulse will be more spread out.
- Emissions may be anisotropic (NIF target is).


X-1 Capsule and Hohlraum

Spectrum is about a 1 keV BB

X-rays vaporize material from the surface

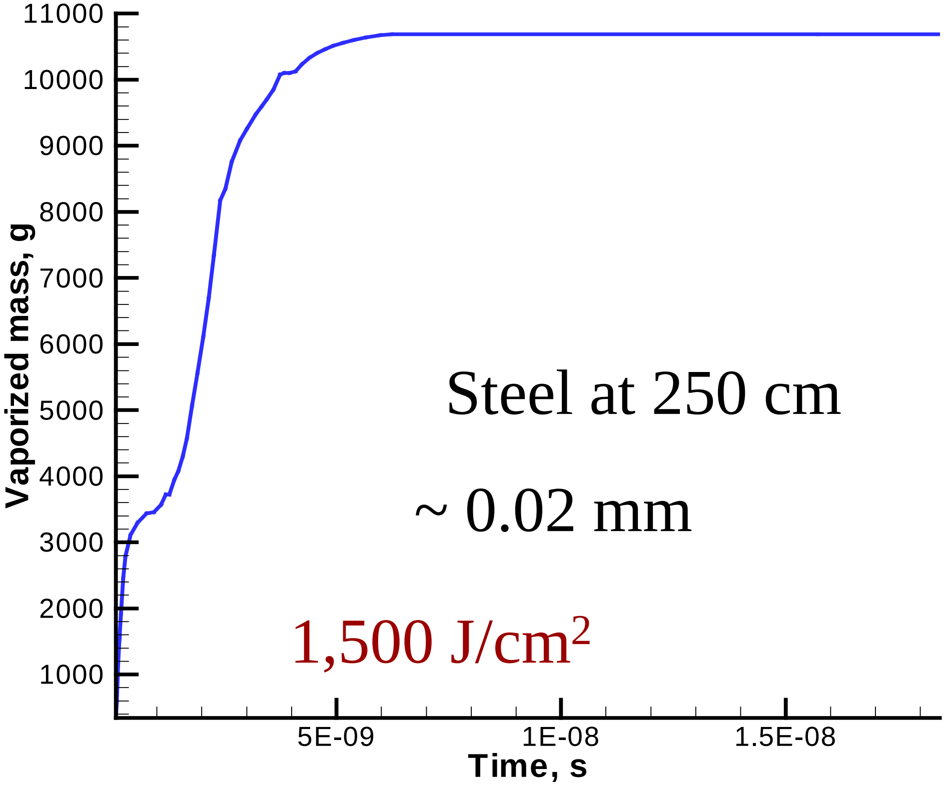
Even though Steel experiences much less vaporization depth, the total mass vaporized is greater.



Li at 50 cm

~ 3.5 mm

38,000 J/cm^2



Steel at 250 cm

~ 0.02 mm

1,500 J/cm^2

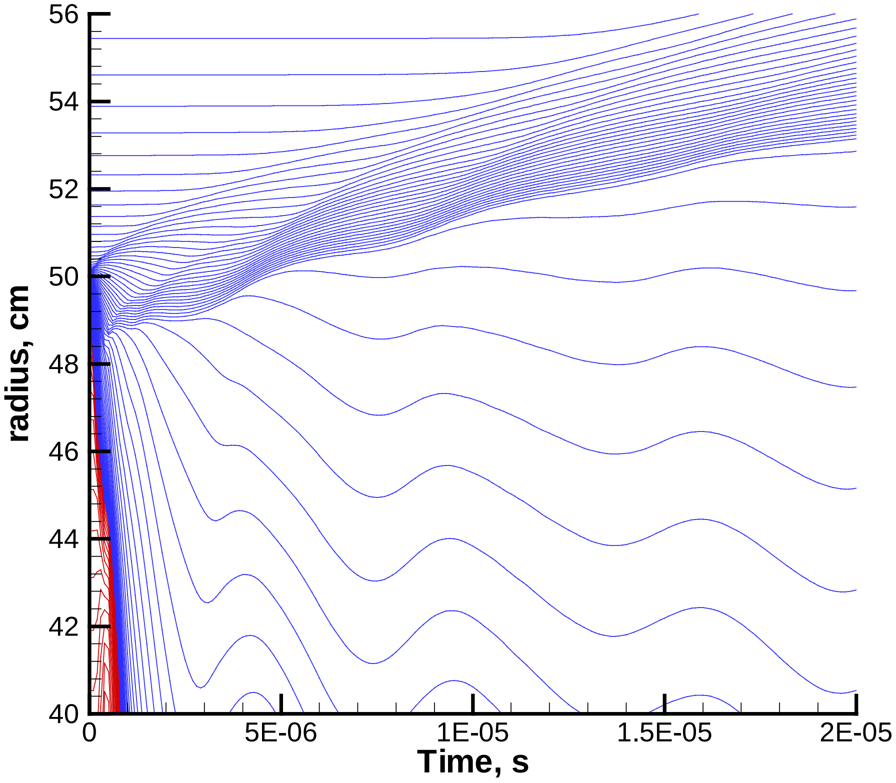
Thickness of vaporized material

Non-neutronic fluence

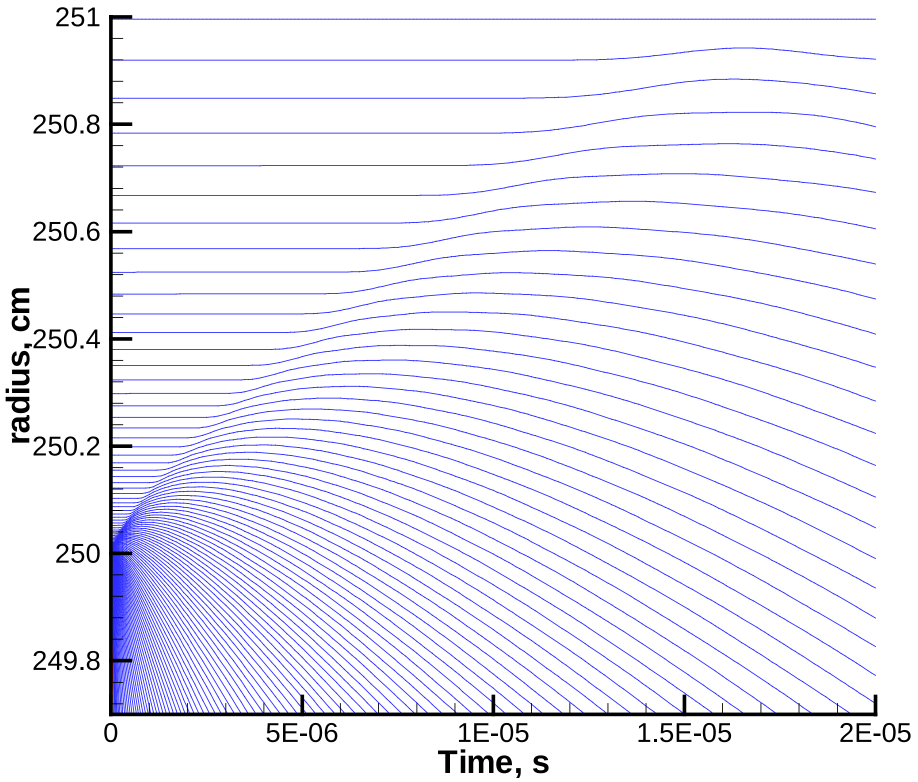
Recoil Pressure From Intense Vaporization Drives Shock Wave Propagation in the Materials

Vaporization driven shock structure in Lithium is initially complex but it smoothes as it moves into the fluid.

Li Layer 50 cm



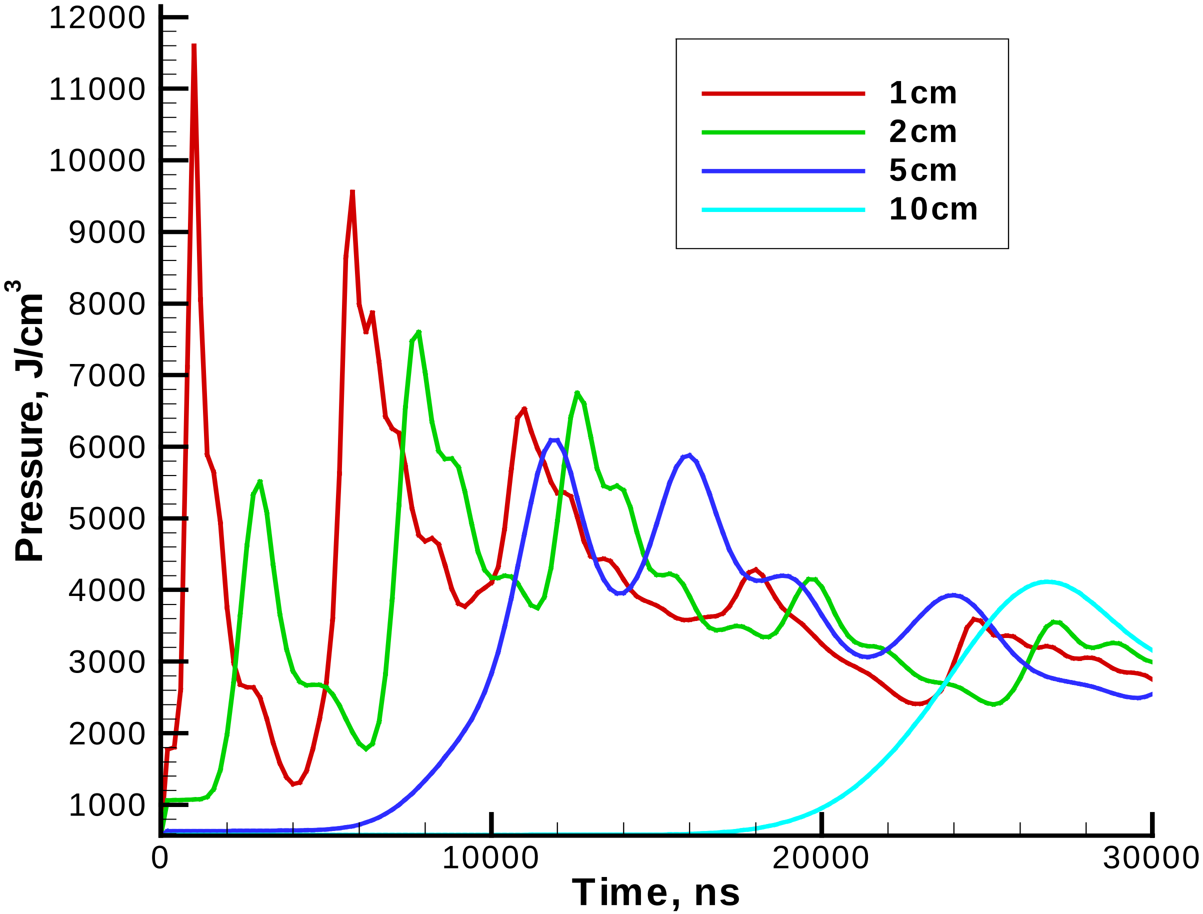
Steel at 250 cm



Pressure Within Lithium Shows Multiple Shocks Decaying at Increasing Depth

- Importance of dissipation.
- At 1 cm into Li, initial shock is 115 kbar in < 1 μs.
- 10 cm into Li, shock pressure is still 45 kbar and is spread over 7 μs.
- Eventually shocks coalesce.

Pressure temporal profiles at different depths (Li)



Impulse is Conserved As Shock Moves into Lithium

Maximum pressure and corresponding impulse at the back surface for different thickness of Li layer

Thickness (cm)	Pressure (kbar)	Impulse (Pa-s)	Time (μs)
1	384	4175	0.77
2	185	25973	5.24
5	221	43532	10.36
10	147	43448	20.00

Analysis of Liquid Wall Chamber Concepts Needs Validation

Validation of BUCKY has been in progress for about 15 years.

- Fireball experiments on Pharos-II.
- X-ray vaporization experiments on Nova, Helen, Saturn, and Z.
- Ion vaporization experiments on RHEPP.

Additional validation is needed.

- Wall condensation
- Nucleate condensation
- X-ray driven shock impulse measurements.
- Fireball radiation (what can we learn from Tokamak disruption experiments?)
- Target output spectra

Proposed new role for BUCKY

- Extend BUCKY to community code status
- Restricted access to BUCKY collaborators, who are expected to help with validation and/or new models
- Extend documentation
- Example input files and data files for many types of calculations
- Web interface to conveniently submit jobs and retrieve results
- BUCKY application server at UW

BUCKY Has Been Under Development for About 3 Decades

PHD-IV

- TN burn
- Gray Radiation Diffusion
- 1-D Lagrangian Hydro
- Te ≠ Ti

Target Implosion, Burn, Explosion

FIRE

- Start with PHD-IV
- Remove TN burn
- Multi-group Diffusion
- X-ray and ion energy sources
- Te = Ti

Gas filled target chambers

CONRAD

- Start with FIRE
- Vaporization and Condensation by Chamber Wall

- **Vaporizing IFE chamber walls**
- **Tokamak disruption divertor vaporization**

BUCKY

- Combine PHD-IV and CONRAD
- TN burn
- Multi-group Diffusion
- Laser deposition
- Te ≠ Ti
- Time-dependent CRE radiation transport

- **NIF Capsules**
- **NIF chamber wall**
- **Ω experiments**
- **NRL laser targets**
- **Z experiments**
- **ARIES target chamber**

EOS and Opacity Codes for BUCKY have Also been written over a long time

MIXERG

- Gray and Multi-group Opacities for FIRE
- Rosseland and Planck
- Semi-Classical absorption coefficients
- Tabulated ionization energies
- Saha or Coronal Ionization
- Self-consistent ionization for mixtures
- EOS: ideal gas + ionization and excitations

IONMIX

- MIXERG +
- Non-LTE Ionization
- Multi-group
- Rosseland and Planck absorption and emission

EOSOPA

- Hartree-Fock (Cowan) atomic structure
- LS coupling
- UTA or DCA/LTE or CRE for Z (≤ 18)
- UTA/LTE for Z (≥18)
- Creates data for CRE in BUCKY
- Pressure ionization
- Muffin-Tin EOS

RSSOPA

- Relativistic (Dirac eqn.)
- JJ coupling
- SOSH UTA’s

JATBASE

- JAVA interface for EOSOPA
- User friendly