Liquid Wall Chamber Dynamics

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Outline

• Phenomenology
• Analysis Methods
• Examples
The Vapor Produced from Liquid Protection by Target X-rays can Protect material from Subsequent Ions

$t \sim 1-10 \text{ ns}$

Vapor rapidly moves off of surface

Target x-rays are rapidly deposited in the protecting liquid.

Impulse launches shocks that might damage substrate and/or splash liquid.

$t \sim 1-10 \mu s$

Debris Ions are stopped in vapor and the energy is re-radiated, some of it going to the liquid causing more vaporization.
Re-establishment of Chamber Vapor and Liquid Protection Conditions Set Rep-Rate

\[ t \sim 1-100 \text{ ms} \]

Vapor atoms migrate towards Knudsen layer at thermal velocity

Condensation occurs as vapor atoms transit the Knudsen layer, which becomes filled with non-condensable gas.

\[ t \sim 100-500 \text{ ms} \]

Protecting liquid is re-established.

Vapor density and temperature are suitable for beam transport and target injection.
Wetted-Wall Chamber Physics Critical Issues Involve Target Output, and First Wall Response

Target Output
Simulations (BUCKY, etc)
Target Disassembly
Energy Partition

X-rays, Ion Debris, Neutrons

Liquid Dynamics
Simulations (BUCKY)
X-ray Deposition
Vaporization
Self-Shielding
Shocks in Liquid

Wall Design
Liquid Properties

Chamber Recovery
Simulations (1-D: BUCKY, 2, 3-D TSUNAMI, ?)
Re-condensation, Substrate Survival

Beam Transport Criteria
Vapor Opacity

Vapor Mass Impulse

Target Design
Low T, Hi ρ Opacity

Rep-Rate
BUCKY, a Flexible 1-D Lagrangian Radiation-Hydrodynamics Code; Useful in Predicting Target Output and Target Chamber Dynamics

• 1-D Lagrangian MHD (spherical, cylindrical or slab).

• Thermal conduction with diffusion.
• Applied electrical current with magnetic field and pressure calculation.
• Equilibrium electrical conductivities

• Radiation transport with multi-group flux-limited diffusion, method of short characteristics, and variable Eddington.
• Non-LTE CRE line transport.
• Opacities and equations of state from EOSOPA or SESAME.
BUCKY, a Flexible 1-D Lagrangian Radiation-Hydrodynamics Code; Useful in Predicting Target Output and Target Chamber Dynamics

- Thermonuclear burn (DT, DD, DHe³) with in-flight reactions.
- Fusion product transport; time-dependent charged particle tracking, neutron energy deposition.
- Applied energy sources: time and energy dependent ions, electrons, x-rays and lasers (normal incidence only).
- Moderate energy density physics: melting, vaporization, and thermal conduction in solids and liquids.

- Benchmarking: x-ray burn-through and shock experiments on Nova and Omega, x-ray vaporization, RHEPP melting and vaporization, PBFA-II Kα emission, …
- Platforms: UNIX, PC, MAC
Radiation Transport and Hydrodynamics are Crucial to IFE Fill-Gas Calculations: Validated for BUCKY and EOSOPC

- EOSOPC represents an improvement over IONMIX for LTE plasmas:
  - Atomic Physics: multi-electron wavefunctions (UTA)
  - Degeneracy lowering: Hummer-Mihalas formalism is implemented
  - Additional effects in EOS: (partial degeneracy, modified Debye-Hückel interaction)
- Results from EOSOPC have been benchmarked against burnthrough experiments, and compared with other major opacity codes, such as STA.

**BUCKY Simulation of Shock in Aluminum**

Radiation Driven; 2ns, 225 eV, 270 kJ/cm², SESAME 3717

**X-Ray Burnthrough of Au**

Nova Experiments vs. BUCKY simulations assuming 150 TW/cm² Laser
Direct and Indirect-Drive Differ in Spectra and Energy Partition

Spectra and Energy Partition will effect Vaporization of liquid walls.

LLNL Predictions of X-ray spectra

![Graph showing X-ray output vs. Photon energy (keV)]
Chamber Clearing Dominates Rep-Rate Considerations in Low Chamber Gas Density Wetted-Wall Chamber Concepts

- In Low Chamber Gas Density Wetted-Wall and Thick-Liquid Concepts, the Re-Condensation of Chamber Vapor Can Limit the Rep-Rate.

- BUCKY Models the Vaporization and Subsequent Re-Condensation of Vapor.

- Calculation is 1-D and Only Considers Condensation on Walls (No Nucleate Condensation).

- In HIBALL, Ballistic Focusing of Ion Beam Required a Very Low Gas Density and a Low Rep-Rate.

- This is Not Nearly as Important for Concepts Such as SOMBRERO, Where Vaporization of the Wall is Avoided and the Ambient Gas Density is Much Higher.
Recoil from Rapid Vaporization Applies a Large Impulse to Surviving Liquid and Substrate

**Typical Liquid Wall Parameters**

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<table>
<thead>
<tr>
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<tbody>
<tr>
<td>X-ray Fluence</td>
<td>10-100 J/cm²</td>
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<tr>
<td>X-Ray Deposition</td>
<td>1-10 ns</td>
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<tr>
<td>Pulse Width</td>
<td></td>
</tr>
<tr>
<td>Pulse Width of Recoil</td>
<td>~ 100 ns</td>
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<tr>
<td>Pressure</td>
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</tr>
<tr>
<td>Peak Pressure</td>
<td>~ 1 GPa</td>
</tr>
<tr>
<td>Impulse</td>
<td>100 Pa-s</td>
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