 Ion Driven Fireballs: Calculations and Experiments

R.R. Peterson, G.A. Moses, and J.F. Santarius

University of Wisconsin

High Average Power Laser Workshop
General Atomics
La Jolla, CA
April 4 and 5, 2002
This is the First of Six University of Wisconsin Presentations

2. D. Haynes, “Chamber Gas Density Requirements for Ion Stopping”.
NRL Laser-Blow-Off-Ion-Driven Fireball Experiments in the 1980’s Provide a Way to Validate Chamber Dynamics Simulations for Gas-Filled IFE Chambers

1. The importance of ion instabilities to gas-filled chamber dynamics can be tested with NRL fireball experiments.
2. A burst of ions is generated with an intense laser.
3. The ions generate a fireball in a gas, which is observed with shadowgraphy.
4. The observed fireball is compared with BUCKY simulations.
5. This is a test of ion deposition in chamber gases and fireball dynamics.

Some relevant publications:
NRL Laser-Blow-Off-Ion-Driven Fireball Experiments

Experimental Set Up

Aluminum Ions Produced by Laser

Pharos-II Laser (100 J)

<table>
<thead>
<tr>
<th></th>
<th>Pharos-II</th>
<th>IFE Chamber</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas Species</td>
<td>N₂</td>
<td>Xe</td>
</tr>
<tr>
<td>Ion Species</td>
<td>Al</td>
<td>Target Debris</td>
</tr>
<tr>
<td>Gas Density (cm⁻³)</td>
<td>1.e15 – 1.e17</td>
<td>1.e15 – 1.e16</td>
</tr>
<tr>
<td>Gas Radius (cm)</td>
<td>5</td>
<td>650</td>
</tr>
<tr>
<td>X-ray Pre-heat</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>
Shadowgram Images Give Position of Shock at Various Times and Shows “Aneurism” in Laser Track

X-rays from laser-generated Al plasma pre-heats gas to ~100 eV, much like in gas-filled IFE chambers.

5.0 Torr of 90%N₂ + 10%H₂
B=0
Ion Stopping Model in BUCKY is in Good Agreement With Experimental Data for Protons in Cold N\textsubscript{2}

Ion stopping becomes much more complicated at higher temperatures and for more complicated projectile ions.

- Ionization state
- Range shortening
- Plasma instability
BUCKY Calculations for NRL Laser-Blow-Off-Ion-Driven Nitrogen Gas Fireball Experiments

Temperature

Mass Density

Pressure

Electron Density
BUCKY Simulations with Radiation Transport Are in Good Agreement With NRL Experiments

150 J of ions (over $4\pi$ steradians)

20 to 40 J of ions are in fact emitted in a cone with a solid angle of $\sim \pi/2$ steradians

- At 5 Torr, ions are stopped in 0.5 cm
- At 0.1 Torr, ion deposition is spread over whole gas with some ions not being stopped at all.

The radiation diffusion in lowest density cases over-predicted radiative cooling.
Experimental Shock Front Trajectories Are Matched by BUCKY When Ion Effective Charge State Is Properly Chosen. At Low Gas Density the Result Is a Sensitive Function of Charge State.

BUCKY now allows on-line charge exchange calculation to get time-dependent projectile ion charge state.
NRL Fireball Experiments Do Not Show Evidence of Anomalous Ion Stopping for N₂ Between 25 and 5000 mTorr: Idealized 2-Stream Assumptions Are Not Valid

• Instability would primarily affect electrons.
  – Short Debye length (~10⁻⁷ m) in the “beam” should shield ions from fluctuations induced by the instability.
  – Ion-electron collision frequency in the “beam” is ~2x10⁸ s⁻¹, so electrons do not have time to transmit the instability.

• Dissipative effects should reduce the growth rate.
  – Landau damping.
  – Non-chromatic ion velocities in “beam”.

• Definitive calculations would be very complicated!

• See Poster by J.F. Santarius for discussion.
Summary: BUCKY Simulations Agree Fairly Well with NRL Experiments: No Evidence of Instability Enhanced Ion Deposition

• Ion-generated fireballs can be simulated with BUCKY using “classical” ion deposition physics.
• Projectile ion charge states and radiation transport were seen as issues to study.
• In the last 13 years BUCKY has evolved significantly (CRE radiation, better opacities, more energy groups, in-line projectile ion charge state) and this validation should be tried again.
• 2-stream instabilities may be mitigated by plasma non-ideal conditions.
• Experiments show aneurisms and instabilities that BUCKY, being 1-D, cannot address.
Magnetic Fields Make “Aneurisms” Much More Turbulent

BACK-UP #1

“Aneurism”

Magnetic Turbulence

5.0 Torr of 90%N₂ + 10%H₂
B=0

1.5 Torr of 90%N₂ + 10%H₂
B=600 G
Without radiation transport, predicted shock speeds for high gas densities were too high.