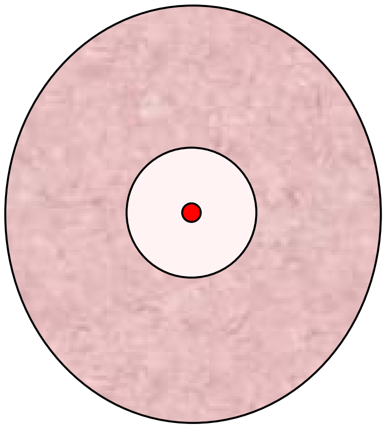
Relevant one dimensional simulations of prompt physics in thick liquid design



- C/C HIB target
- 50, 90cm radius voids (1Torr FLiBe vapor)
- void fraction (0%, 50%)
- Initial Temperature: 600C

Presented by
D. A. Haynes, Jr.

for the staff of the
Fusion Technology Institute
University of Wisconsin

- *BUCKY treats superheated liquid in a manner which conserves energy at the cost of redistributing it.*
- *Importance of plasma shielding demonstrated by varying void radius: there is more vaporized material for a 90cm void radius than for a 50cm void radius, though the ratio is less than that of the surface areas.*
- *Amount of vaporized material does not depend strongly on void fraction in jet in one dimensional simulation.*

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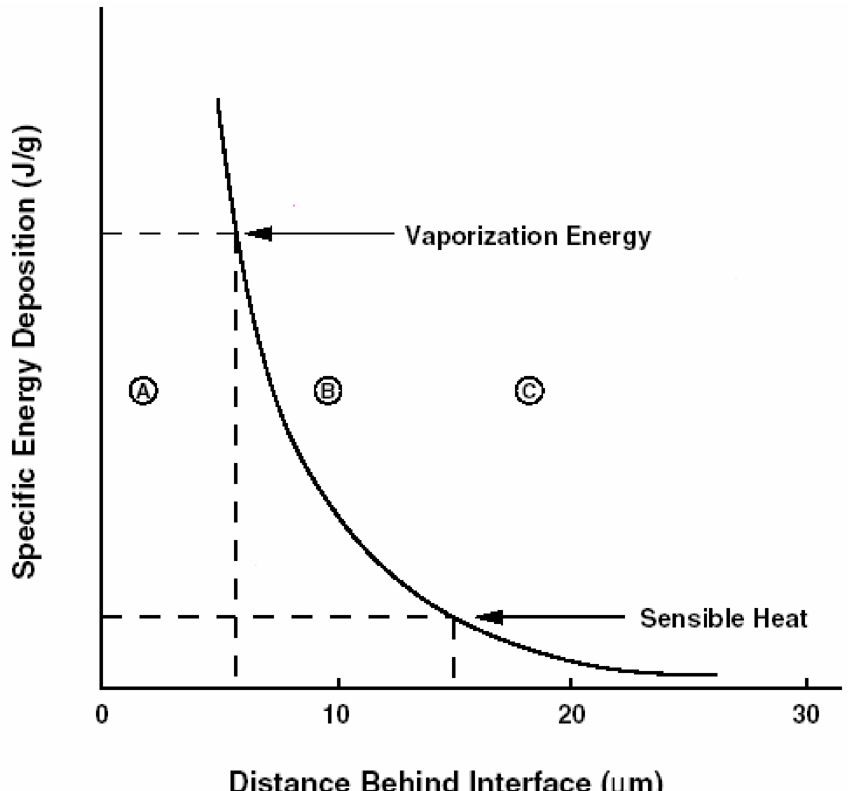
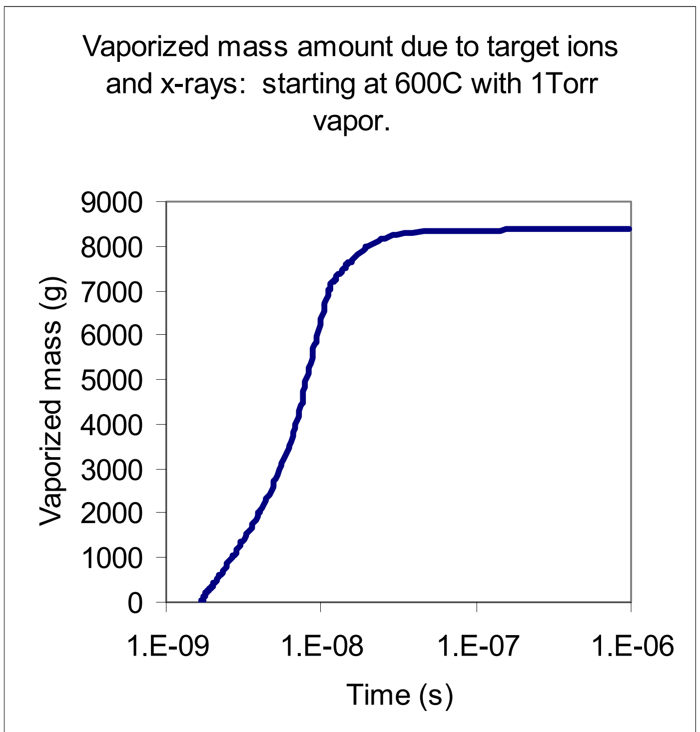
BUCKY does treat explosive boiling, in a non-explosive sense.

- Region A
  - Specific Energy > Specific Vaporization Energy
  - Zones join hydrodynamic mesh as plasma with T>=T_vap
- Region B
  - Vaporization Energy > Specific Energy > Sensible Heat
  - Energy is redistributed such that plasma facing zones are brought up to vaporization energy and vaporized, while others remain at T_vap at sensible heat.
- Region C
  - Sensible heat > specific energy
  - Hotter liquid.

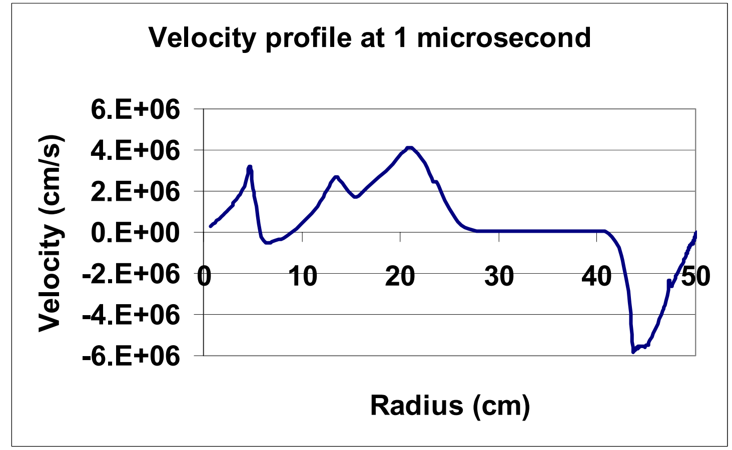


Thus energy is conserved, and after each time step, there is no super-heated liquid. What is missing, however, is the effect of exploding bubbles spewing liquid drops into the chamber.

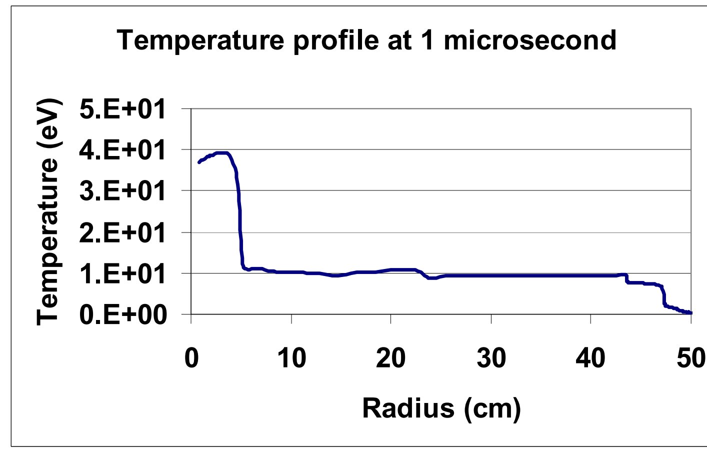
50cm void radius results (from last time) Soon after 1 microsecond, the shock from the blowoff will interact with the shock from center of the chamber, and we should hand off to a higher dimensional code which encompasses aerosolization and dynamic jet location.



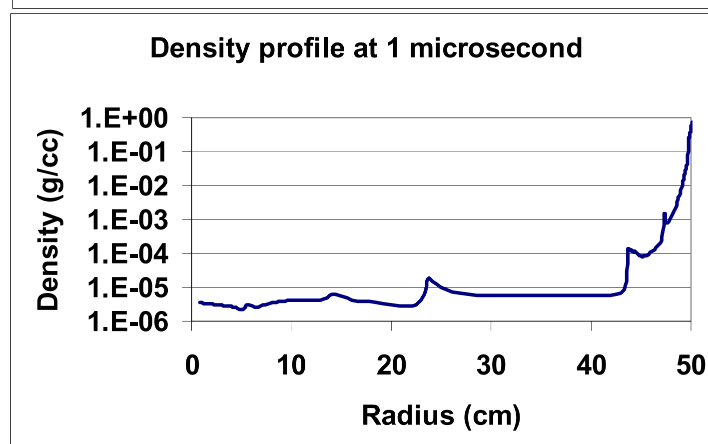
Vaporized mass amount due to target ions and x-rays: starting at 600C with 1Torr vapor.



Velocity profile at 1 microsecond

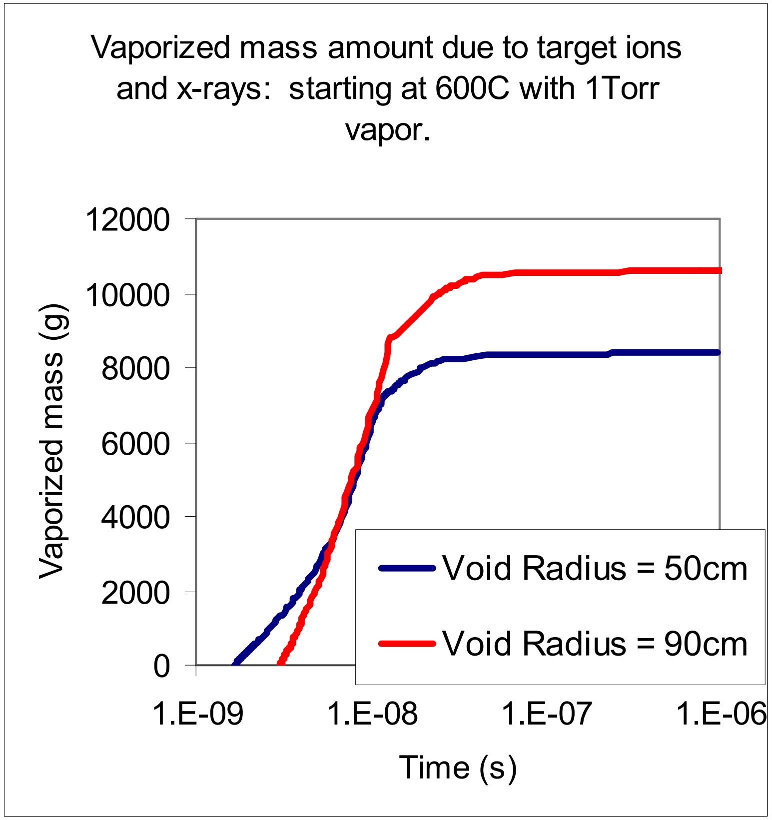


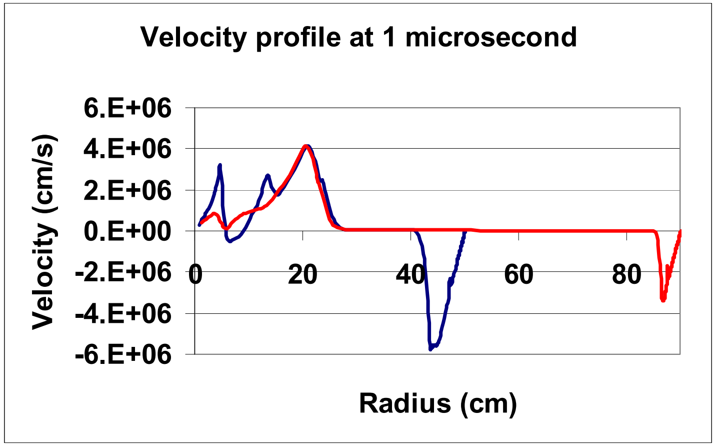
Temperature profile at 1 microsecond

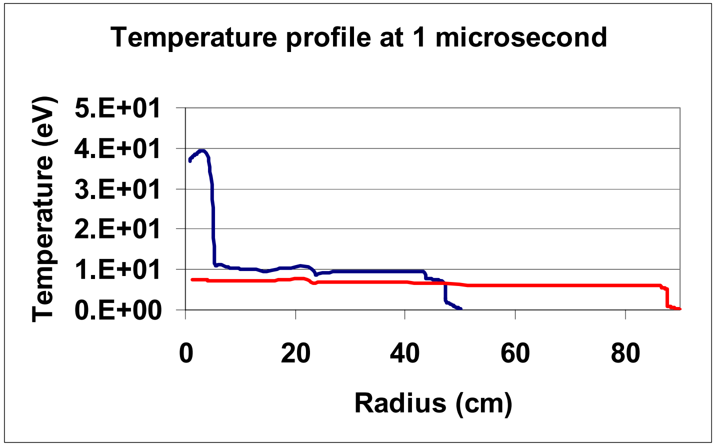


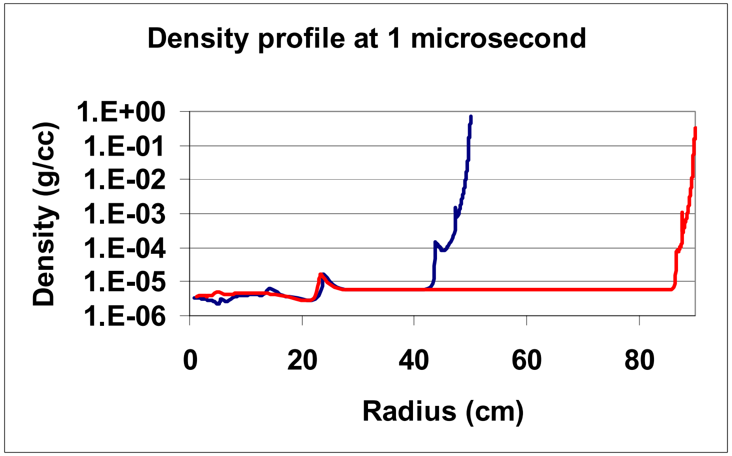
Density profile at 1 microsecond

Increasing the initial void radius to 90cm from 50cm results in more vaporization and lower plasma temperatures.









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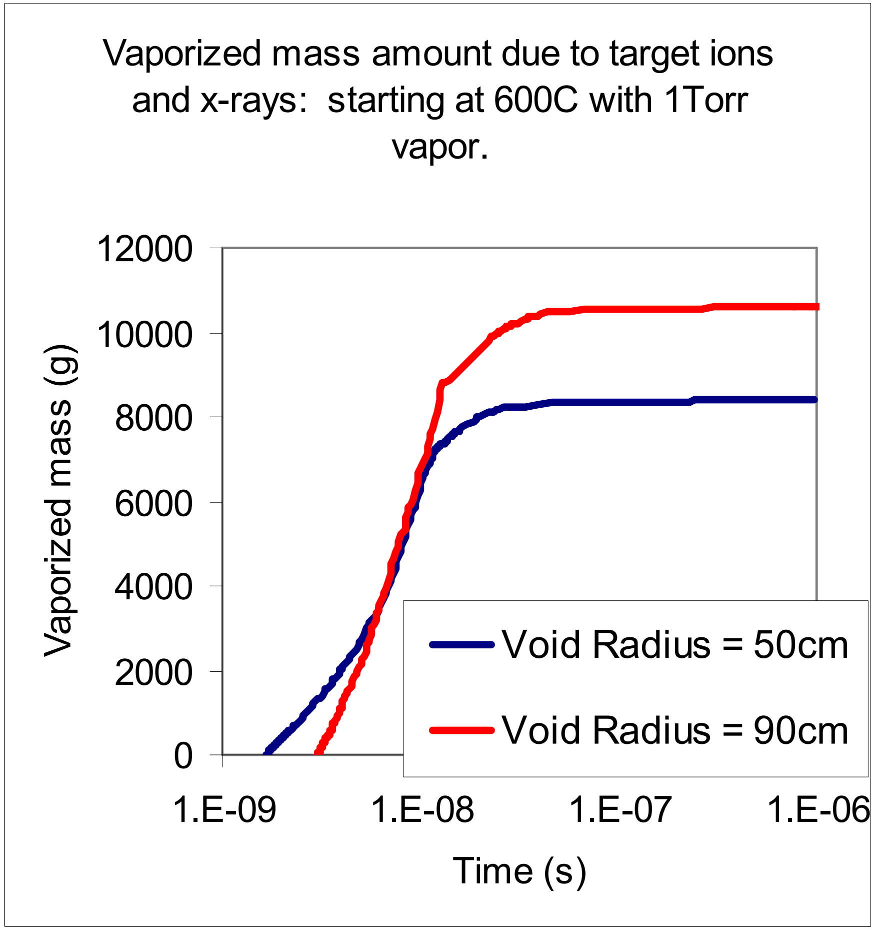
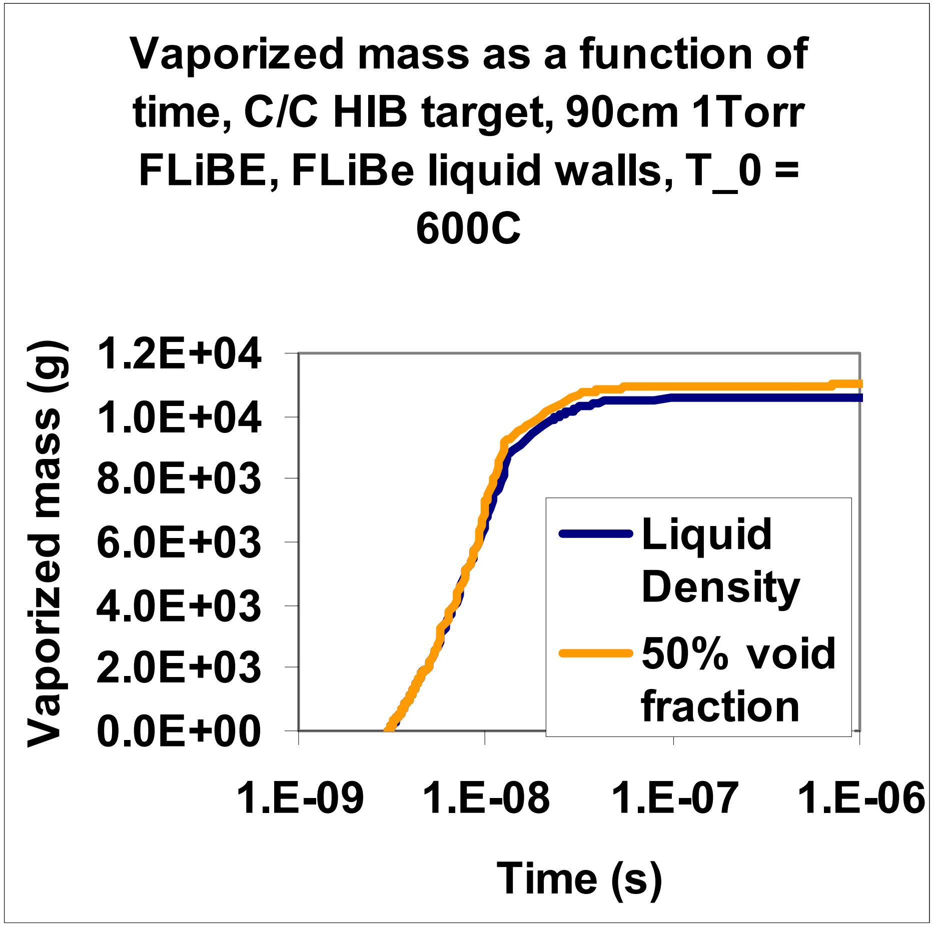
Increasing the void radius from 50cm to 90cm increases the amount of vaporized mass, but by significantly less than 81/25



- This behavior is consistent with that found for thin liquid walls.
- Practically all of the absorption of x-rays is done by vaporized wall rather than the initial contents of the "void" (18g in the 90cm case).

In BUCKY's one dimensional approximation, varying the void fraction leads to little change in amount of material vaporized or in the conditions of the resulting plasma



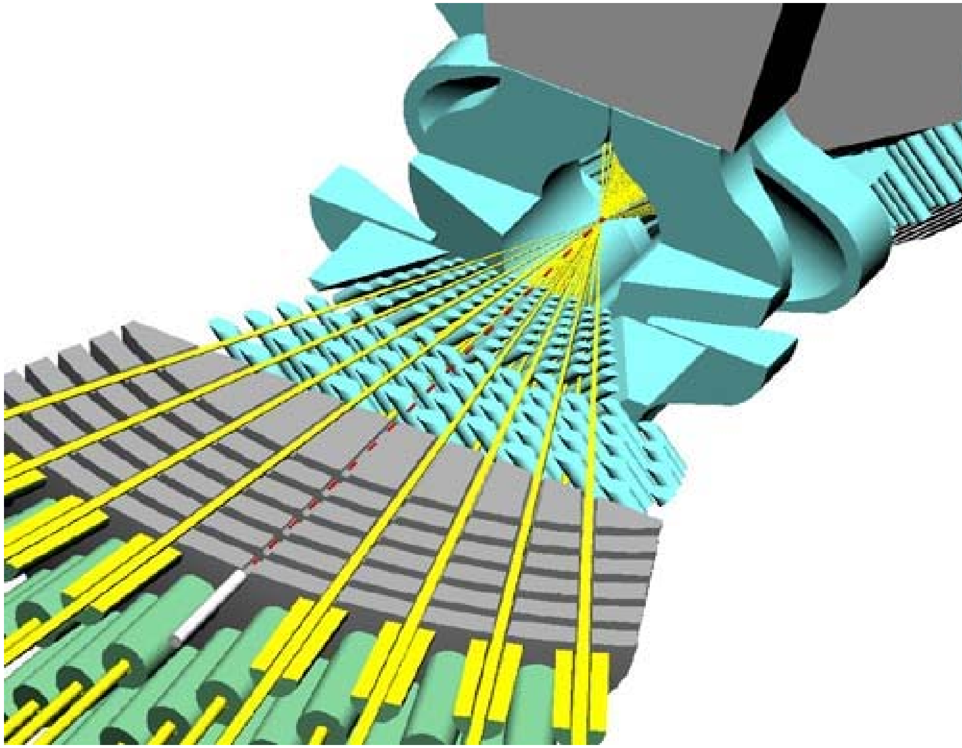
- For this case, a 90cm "void" (1Torr FLiBe vapor) radius, the C/C HIB target output, the vaporization depth differs for void fractions from 50% to 0%, but the total vaporized mass is relatively invariant.
- However, increased surface area of jets may lead to increased vaporization for 3-d geometry.

Are these one dimensional simulations even relevant?

•Does the enormous surface area of the flapping and crossing jets assure that any aerosol, plasma, or shock-induced droplets will be swept up by the next shot?

•If not, what fraction of aerosol and plasma from the void gets out and stays in the critical driver target injection paths?

•Let’s take a moment now to discuss this.



Outstanding issue, conclusions

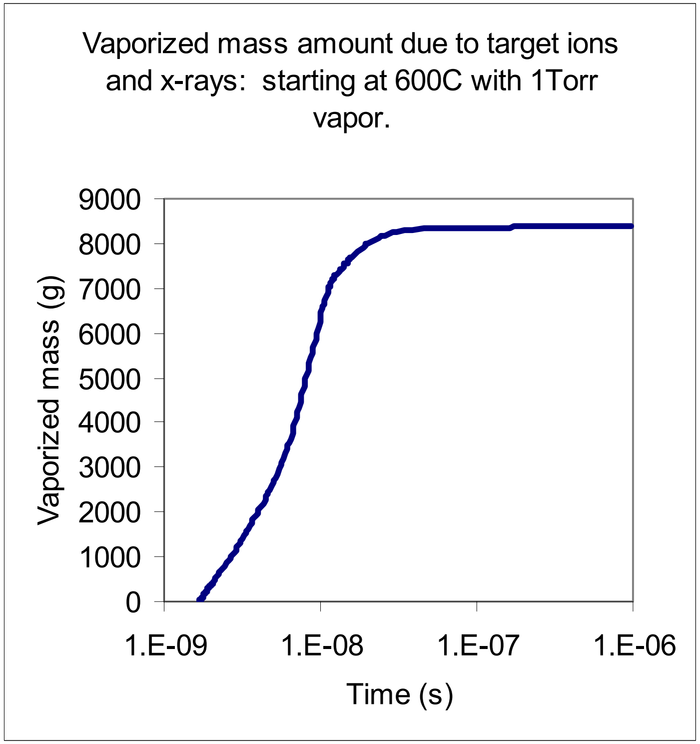
- Do vaporization amount, plasma charge state, aerosol amount, aerosol size matter?
- If so, increasing the void size will effect:
  - amount of plasma/aerosol (increase, though less than surface area),
  - conditions (cooler, less dense),
  - importance of edge effects (increase surface to edge).

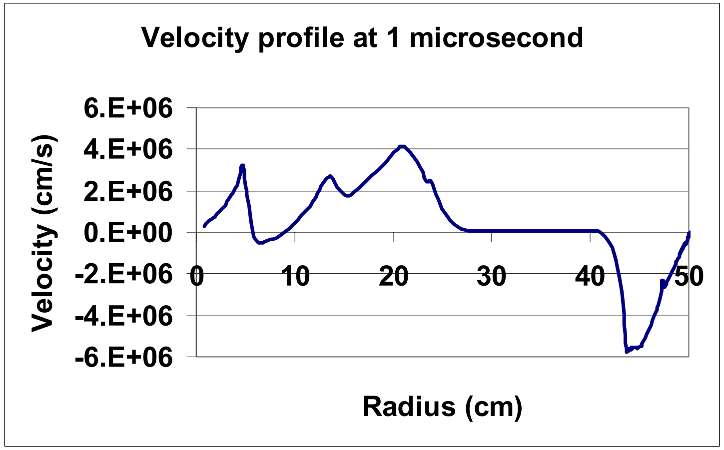
OLD SLIDES FOR BACKUP

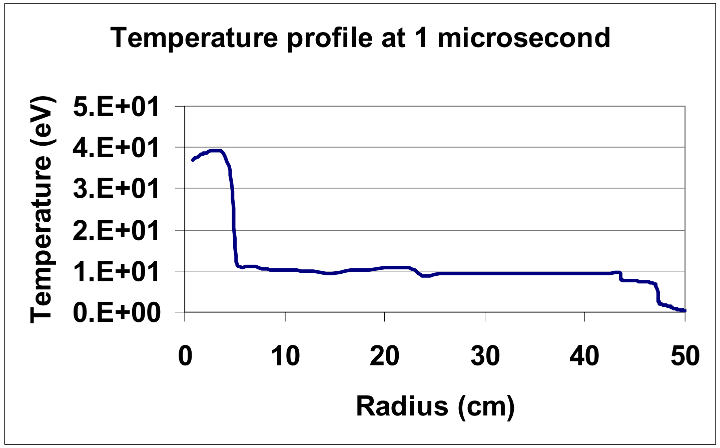
BUCKY can treat “walls” in two modes, each of which has advantages and disadvantages

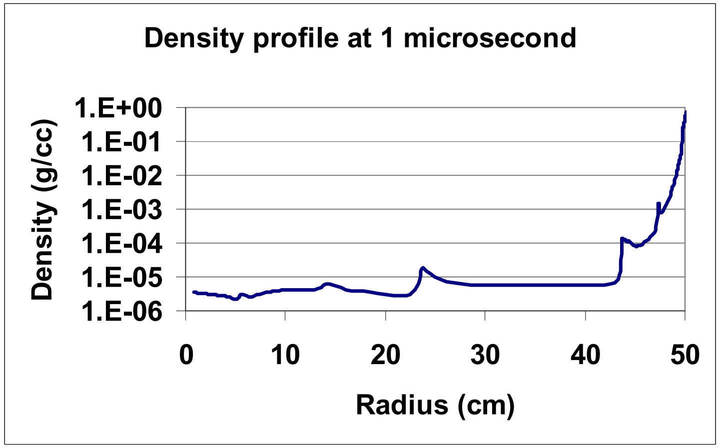
- “Heat capacity” EOS
  - Advantages:
    - Latent heats easily incorporated
    - Bookkeeping
  - Disadvantages:
    - Inconsistent EOS/Opacity as zone moves from wall to vapor.
    - No shock tracking within wall.
    - Only current surface zone can vaporize
- “Plasma” EOS
  - Advantages:
    - Consistent EOS/Opacity
    - Shock tracking within the wall
    - “Buried” “evaporation”
  - Disadvantages
    - Currently: no latent heats in FLiBe tables
    - Bookkeeping (plasma/wall distinguished only by density)

Soon after 1 microsecond, the shock from the blowoff will interact with the shock from center of the chamber, and we should hand off to a higher dimensional code which encompasses aerosolization and dynamic jet location.









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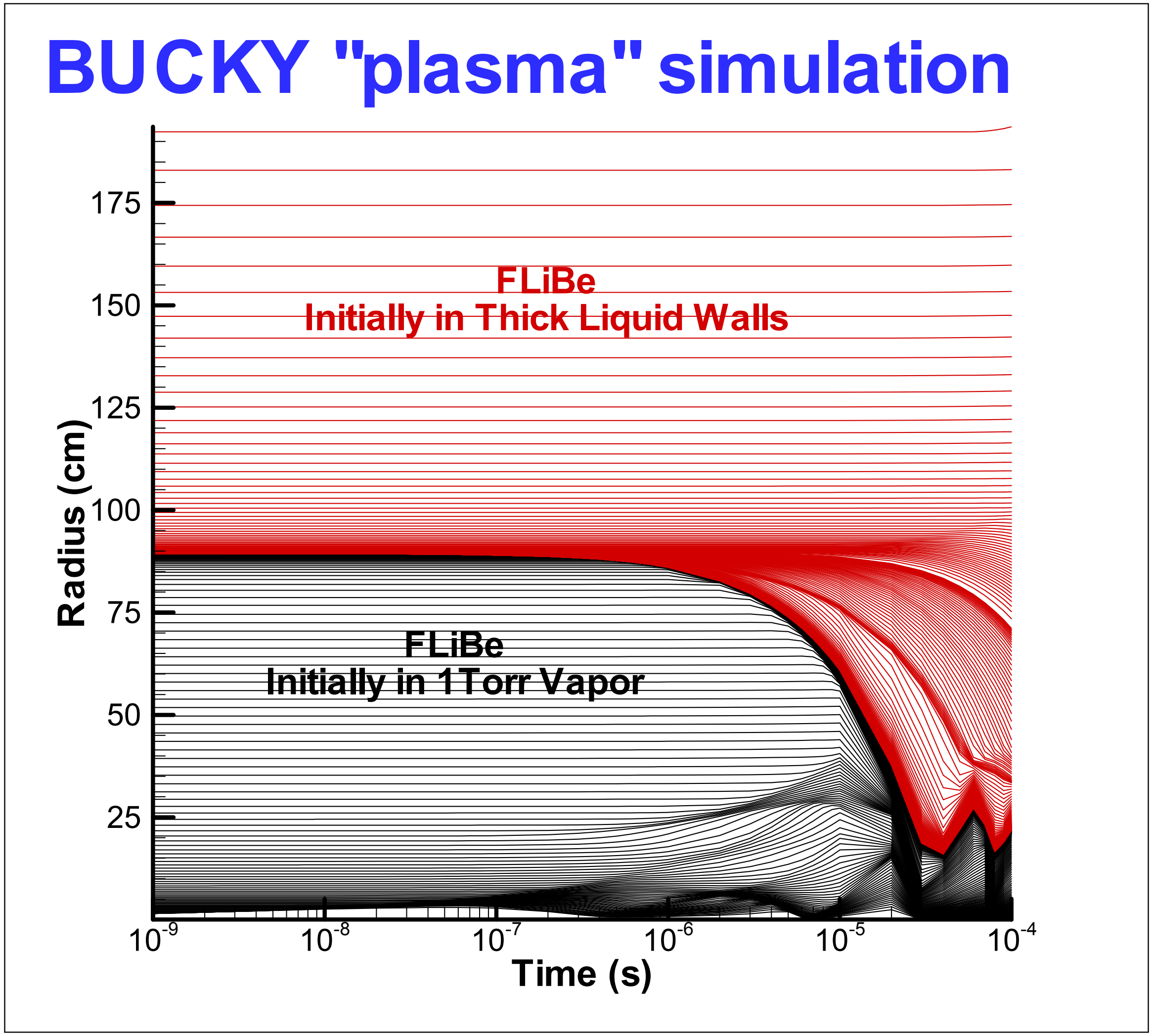
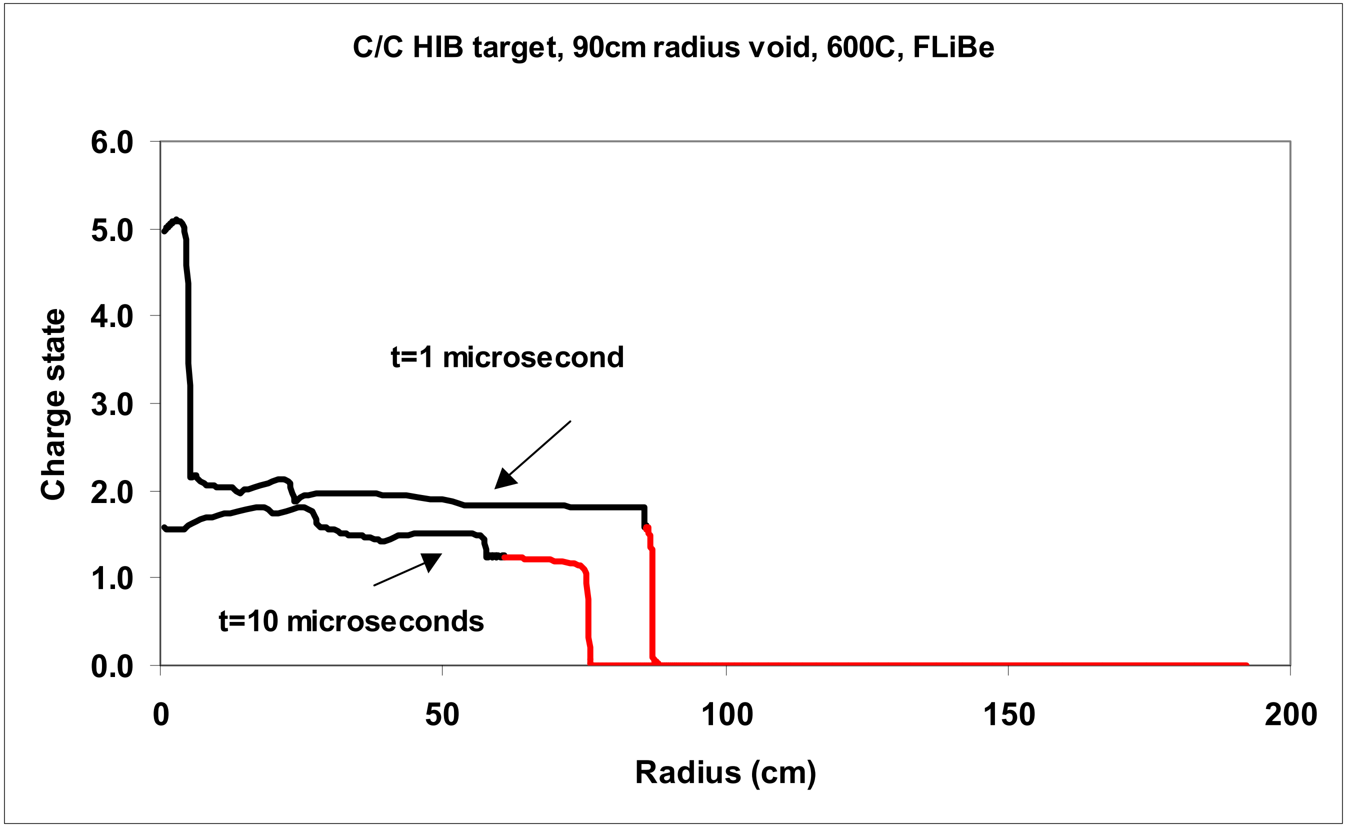
The shocks rattling around the central void render 1 dimensional simulations suspect after 20 microseconds.

- For an initial void radius of 90cm, the outward moving shock interacts with the wall blowoff around 10 microseconds.
- Note the outer wall movement at late times.



As the wall blowoff moves in the chamber, it cools but remains significantly ionized as aerosolization initiates.

Initially in vapor　　　　Initially in "wall"

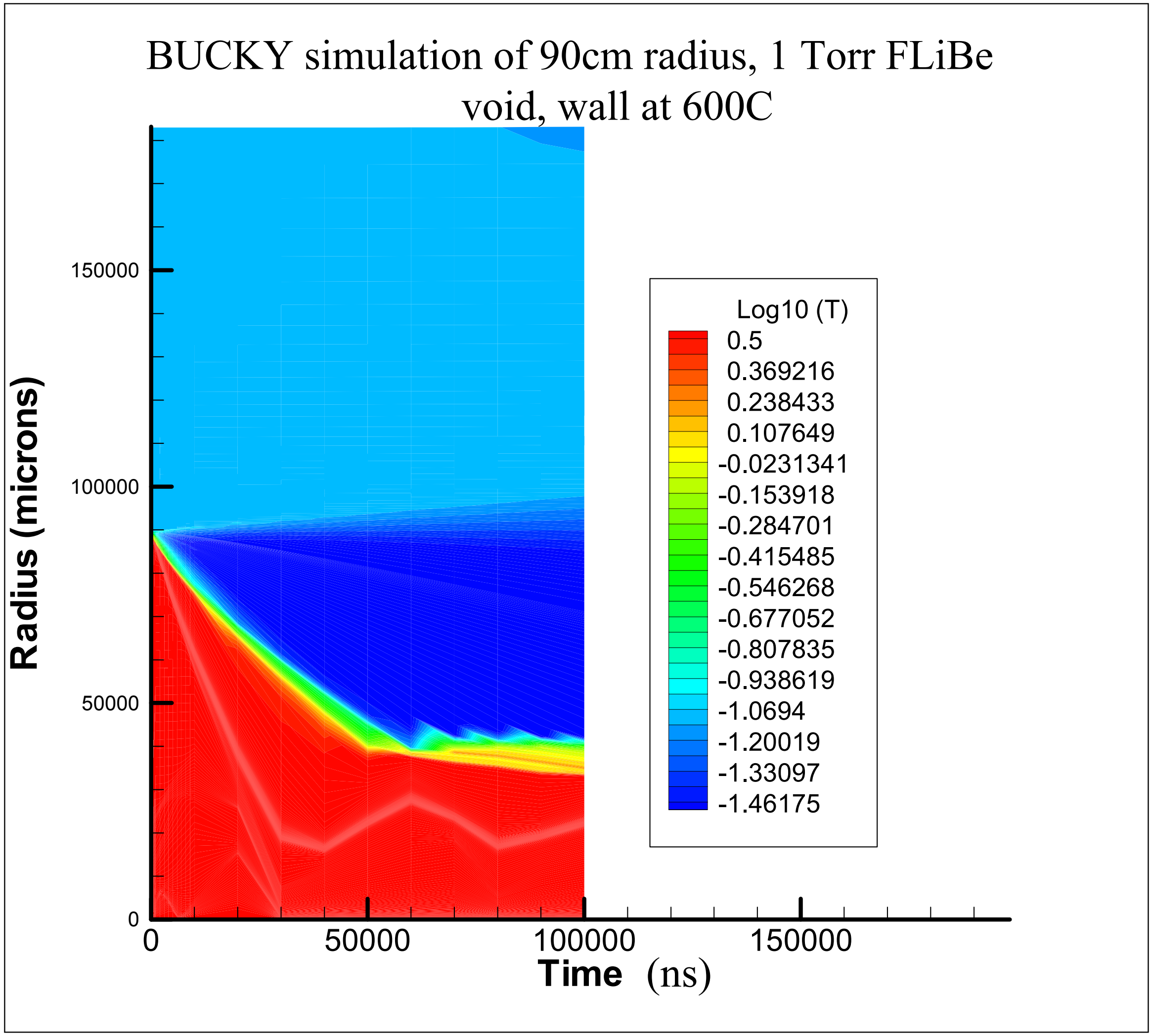


Does this ionization inhibit aerosol formation?

A narrow band of the blowoff plasma shields the rest of the liquid from the target emissions, slowly re-radiating and causing the rest of the wall to simmer.

- For FLiBe, with its simple atomic physics, EOS/Opacity tables can be created in DCA/NLTE with accurate emissivity values.

- For Pb, LiPb, LiSn, an alternative procedure can be employed.



Evolution of the Transition Patterns from Low Z to High Z

Transition: $3d^8 4s - 3d^8 4p$

- **Under jj coupling, the initial configuration is split into:**

$$3d_{3/2}^2 3d_{5/2}^6 4s_{1/2}$$

$$3d_{3/2}^3 3d_{5/2}^5 4s_{1/2}$$

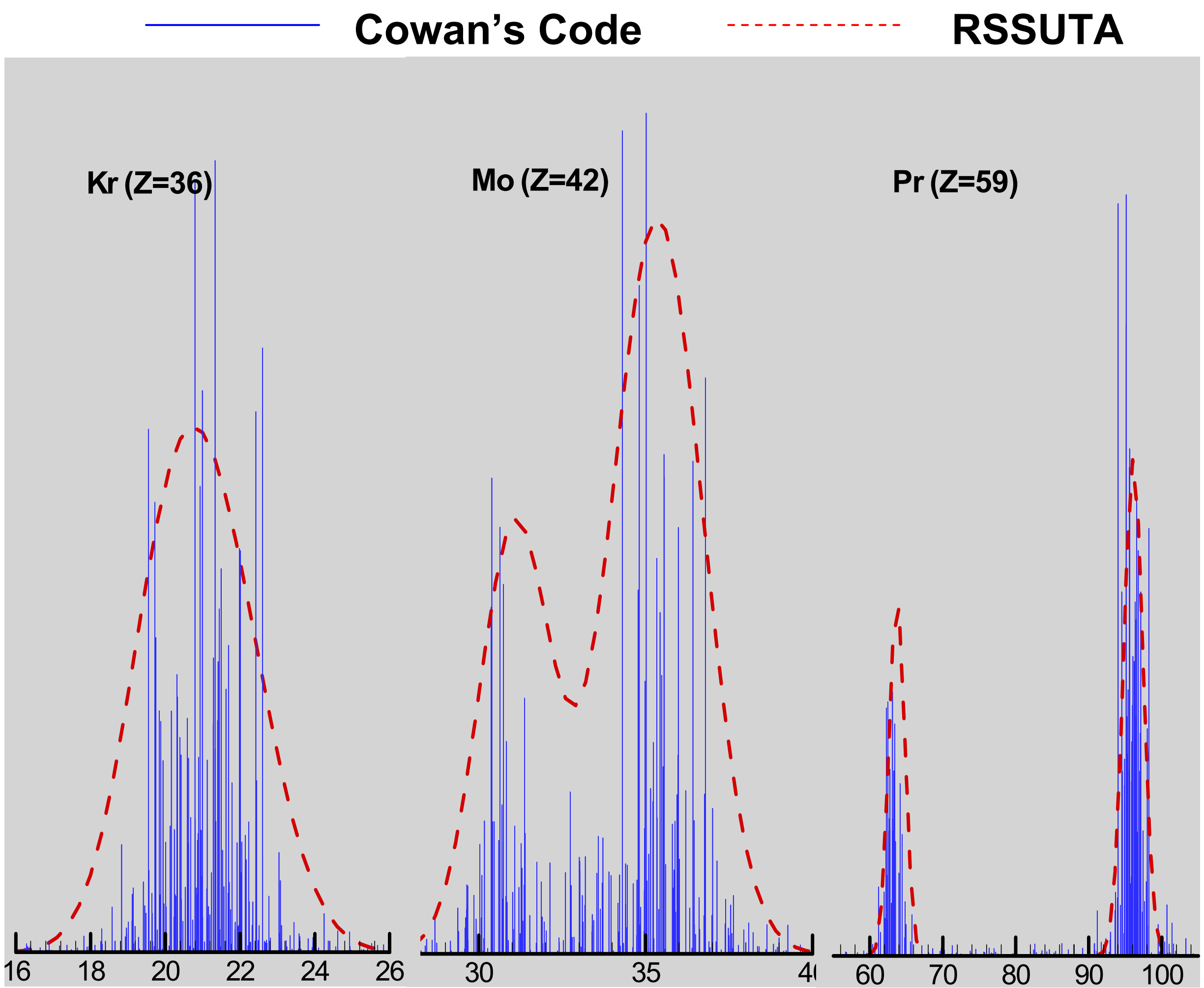
$$3d_{3/2}^4 3d_{5/2}^4 4s_{1/2}$$

- **For each subconfiguration, there are two transitions:**

$$4s_{1/2} - 4p_{1/2}$$

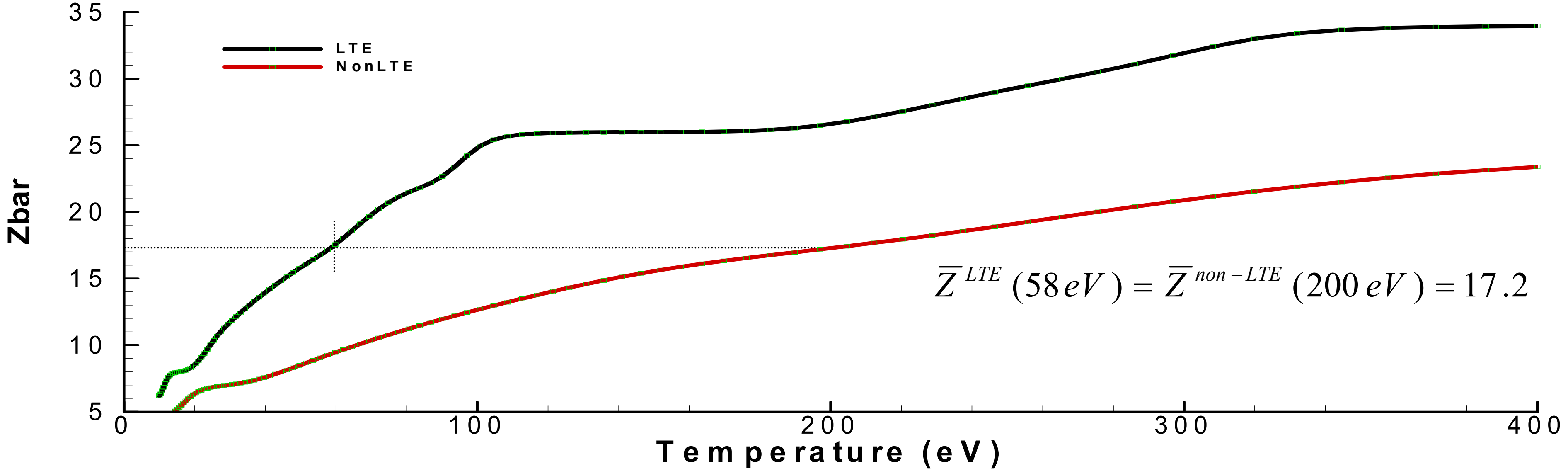
$$4s_{1/2} - 4p_{3/2}$$

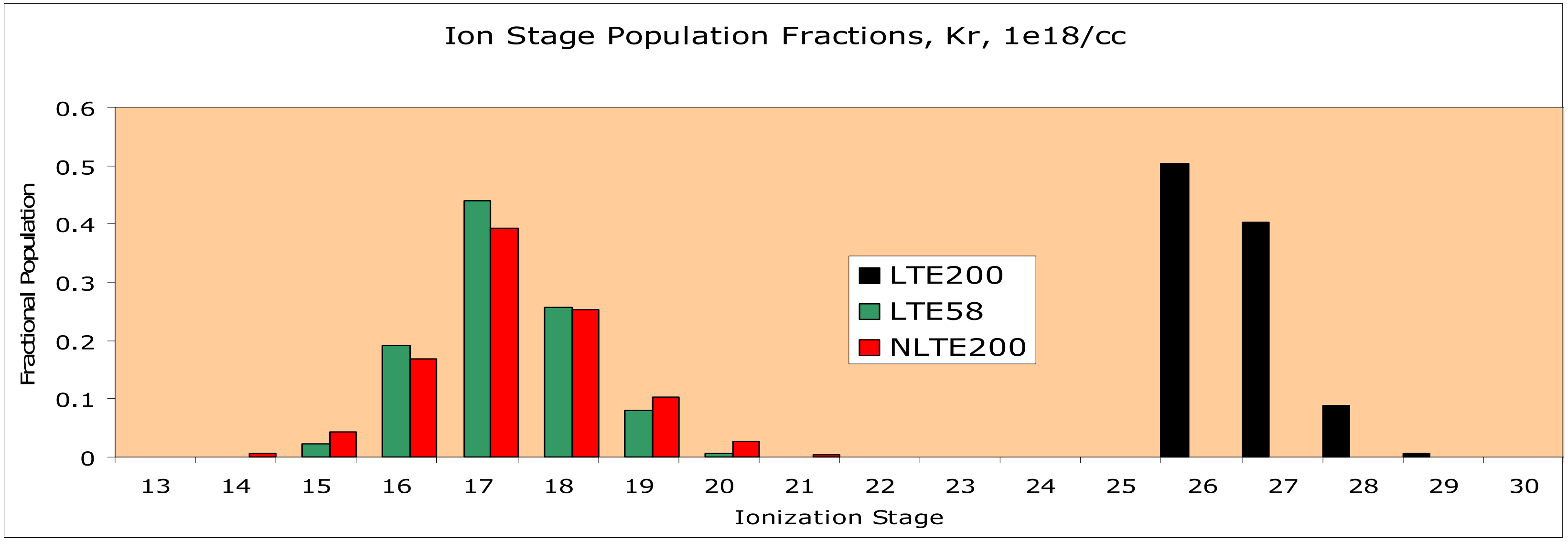
- **Spin orbital integrals** $\propto (Z^*)^4$ are greater than Slater integrals $\propto Z^*$



(Examples from C. Bauche-Arnoult, et al., *Phys. Rev. A, 31, 2248, 1985*)

Ion distributions under LTE and Non-LTE and Busquet Method





Path forward: prompt chamber response for thin and thick liquid wall protected IFE chambers

- What needs to be done?
  - Identification of variables for operating window studies
  - Combination of validated, relevant prompt physics simulation (rad. transport, ionization, evaporation) with validated, relevant aerosol model, and validated, relevant 3-d hydrodynamics code.
  - Validation of combination!
  - Addition of latent heat to plasma modeling of liquid wall phenomena (combine the best parts of BUCKY's split personality)
  - Post-vaporization/ionization chemistry before/during/after aerosolization.
  - Comparison of initial vaporization phase in spherical (chamber-centric) and cylindrical (jet-centered) geometries

Path forward: prompt chamber response for thin and thick liquid wall protected IFE chambers

- Importance of results to feasibility of HIB concept
  - Assuming the “protection part” of the schemes work, then the key from the point of prompt chamber response is providing the correct source term for aerosolization and 3d hydrodynamic simulations.
  - Target conditions pre-target and pre-beam injection are crucial in determining feasibility of HIB concept.
  - We need a soup-to-nuts exercise of the combination mentioned previously to determine importance of prompt response to pre-next-shot conditions
- Paper study vs experimental work to get results

Path forward: prompt chamber response for thin and thick liquid wall protected IFE chambers

- Paper study versus experimental work to get results:
    - Wrong way to phrase the item.
- Experimental validation of models used in predictive design codes:
    - Need experimental validation of evaporation, ionization, explosive evaporation.
    - Need aerosolization studies at extremely high temperatures with appropriate nozzles to simulate density profile (iterative).
    - Shock-tube work for jet array reaction to shock wave.

- ***RESULTS ARE VALIDATED PREDICTIVE CODES/SUITES AND THE RESULTS TEY PRODUCE.***