Z-Pinch $(LiF)_2$-BeF_2 (flibe) Preliminary Vaporization Estimation Using the BUCKY 1-D Radiation Hydrodynamics Code

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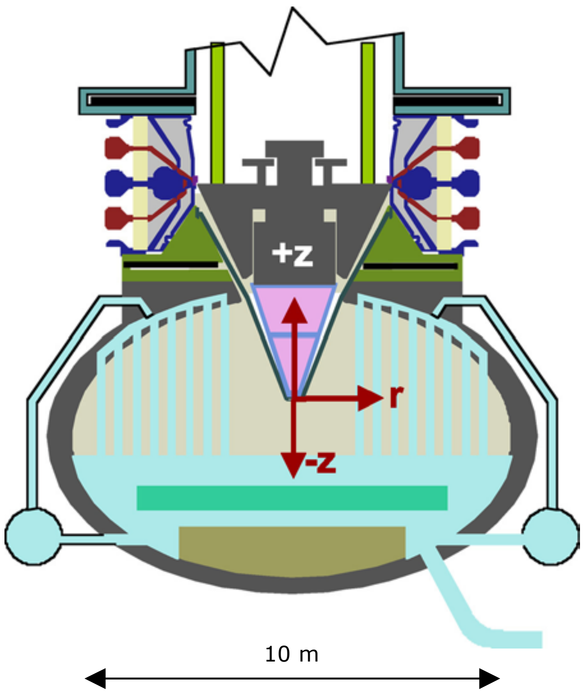
Research Overview

- The chamber thermodynamic response was modeled using 3 independent 1-D simulations
- The simulation directions were chosen along the cylindrical coordinate axes: +z, −z and r
- The simulation results were compared to a simple analytical model in order to check the validity of the BUCKY vaporization estimate
- Previous BUCKY simulations either treated the entire chamber as a plasma and solid first wall or two separate simulated systems with a common interface
- A new model was recently added to BUCKY to account for the presence of solid and liquid phase materials in a fusion reactor chamber simulation
- The implementation of the new model allows BUCKY to perform integrated target-chamber simulations for the first time



Z-Pinch Reactor Chamber Diagram

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Analytical Vaporization Model

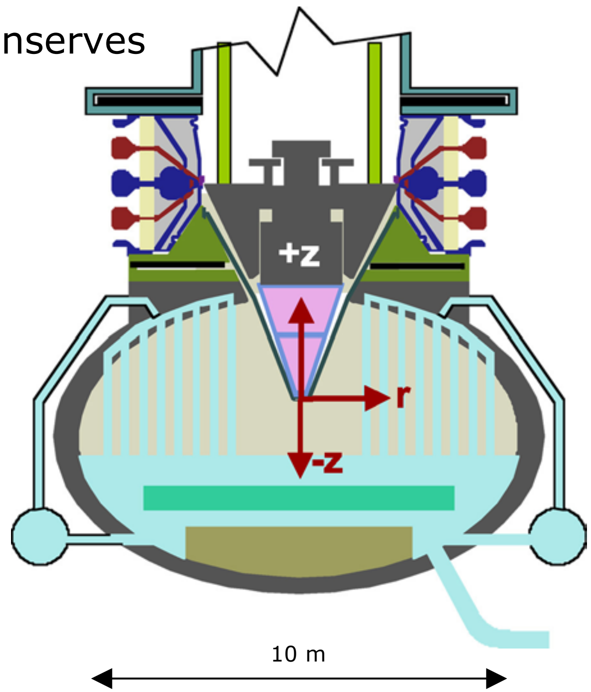
The analytical vaporization model assumes that the flibe simply conserves energy, yielding the maximum amount of vaporization possible

$$m_{vap} = \frac{3.0275\ GJ}{l_v + \int_{T_0}^{T_{boil}} C_{p,l}(T')dT'}$$

$$m_{vap} = \frac{3.0275\ GJ}{l_f + l_v + \int_{T_{melt}}^{T_{boil}} C_{p,l}(T')dT' + \int_{T_0}^{T_{melt}} C_{p,s}(T')dT'}$$

$$V_{vap} = \frac{m_{vap}}{\varepsilon\left(2.28 - T_0 \cdot 4.884 \times 10^{-4} \frac{1}{°C}\right)\frac{g}{cm^3}}$$

$$\Delta r_{vap} = \left(\frac{3}{4\pi}V_{vap} + r_0^3\right)^{1/3} - r_0$$



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Model Parameter	Value		
	+z	**−z**	**r**
T_0 (eV)	0.05	0.09417	0.09417
T_0 (°C)	307	820	820
r_0 (cm)	1.02	101.01	71.01
ε	0.08	1.00	0.50

Direction	Δr_{vap} (cm)
+z	78.0
−z	1.8
r	6.6

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BUCKY Simulation Setup

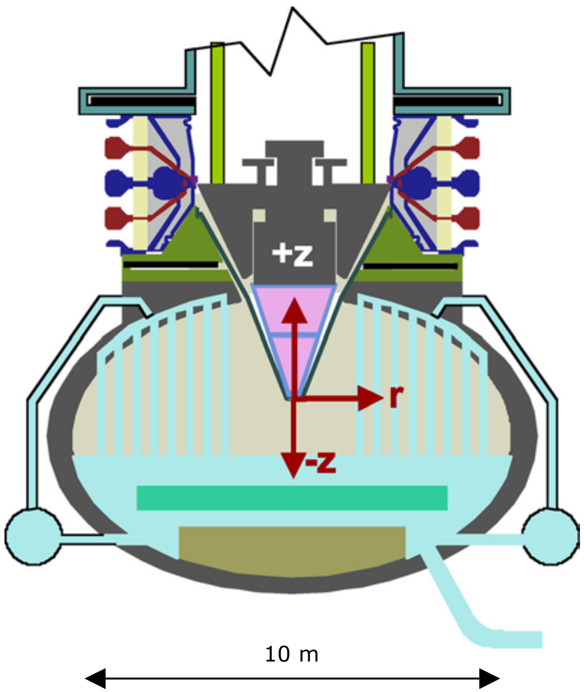
- The original target as provided by LANL had a yield of 5 GJ, which was lowered to the 3 GJ specification by preventing DT burn in the outer fuel zones

- The resulting yield was 3.0275 GJ, which is what was used in the analytical equations to determine the maximum amount of flibe vaporization

- +z simulation adds a 100 µm Steel (Fe) layer to represent the RTL material and a flibe foam at 8% solid density

- −z simulation adds a 100 cm layer of argon gas at 10 torr and a liquid flibe layer at 100% density to represent the pool at the bottom of the reactor chamber

- r simulation adds a 70 cm layer of argon gas at 10 torr and a liquid flibe layer at 50% density to represent the liquid jets in the reactor chamber



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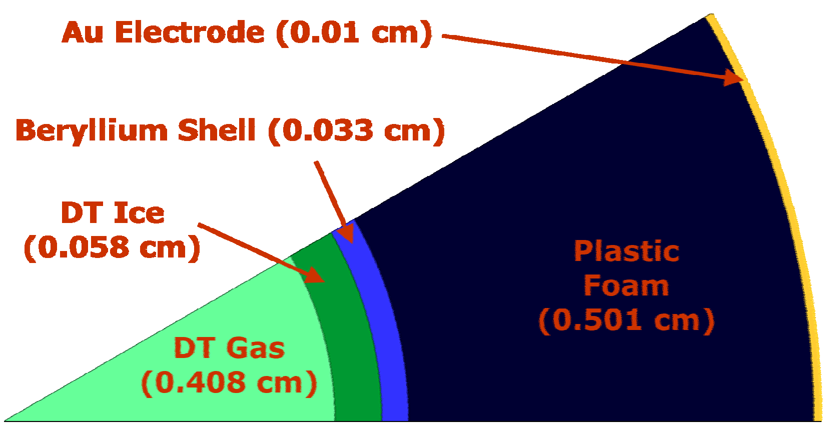
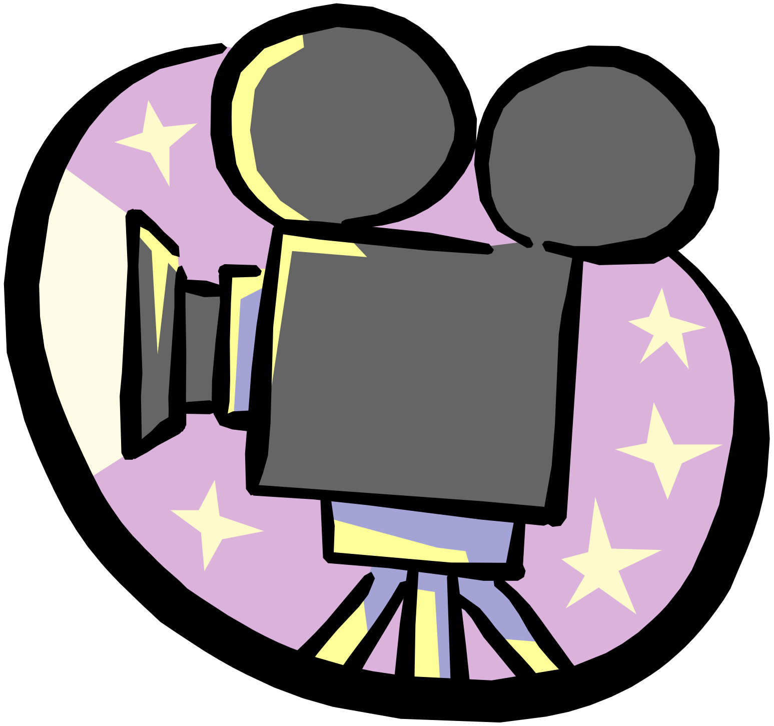
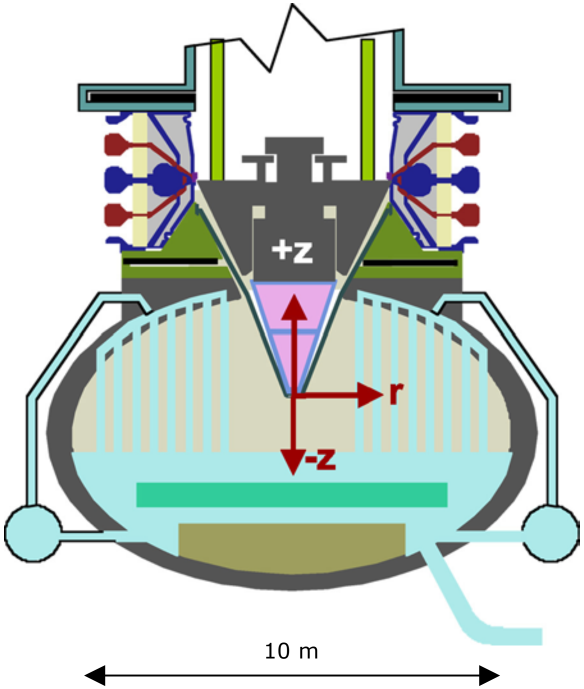


Simulation +z Animation





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Simulation Results

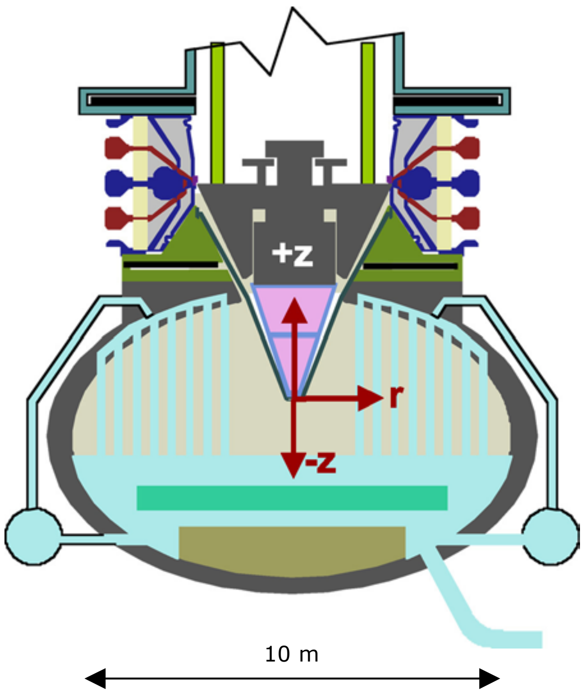
At 80 μs, the simulations were analyzed to provide a revised estimate of material vaporization.

$$\bar{T}_{gas}(eV) = \frac{1}{m_{gas}} \sum_{i=1}^{N} T_i(eV) \cdot \Delta m_i$$

$$m_{vap} = \left(\frac{\bar{T}_{gas}(eV) - 0.147eV}{0.147eV - T_0(eV)} - 1 \right) m_{gas}$$

$$V_{vap} = \frac{m_{vap}}{\varepsilon \left(2.28 - T_0 \cdot 5.6679 \frac{1}{eV} \right) \frac{g}{cm^3}}$$

$$\Delta r_{vap} = \left(\frac{3}{4\pi} V_{vap} + r_0^3 \right)^{1/3} - r_0$$



Z-Pinch Reactor Chamber Diagram

Parameter	Value			Unit
	+z	−z	r	
T_0	0.05	0.09417	0.09417	eV
$<T_{gas}>$	55.49	10.62	10.66	eV
r_{gas}	6.3149	101.0123	71.01238	cm
m_{gas}	181.74	1,044.56	823.74	g
ε	0.08	1.00	0.50	

Direction	Δr_{vap}(cm)
+z	52.7
−z	0.9
r	2.9

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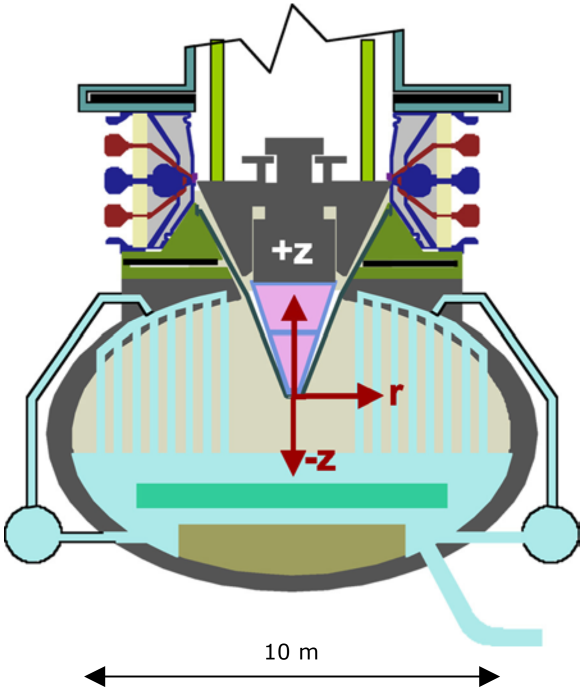
Simulation Results

- As expected, the BUCKY simulations predict less flibe vaporization than the simple analytical model
- The reduced flibe vaporization is due to the lack of neutronic effects in BUCKY, which are only utilized in the DT fuel region
- The simulation results are valid for times when the outward blast and energy transfer remain nearly spherical
- Zones of phase change were discovered in the BUCKY output, verifying that melting and boiling were occurring properly in the code



Z-Pinch Reactor Chamber Diagram

Analytical Result

Direction	$\Delta r_{vap}(cm)$
+z	78.0
−z	1.8
r	6.6

BUCKY Result

Direction	$\Delta r_{vap}(cm)$
+z	52.7
−z	0.9
r	2.9

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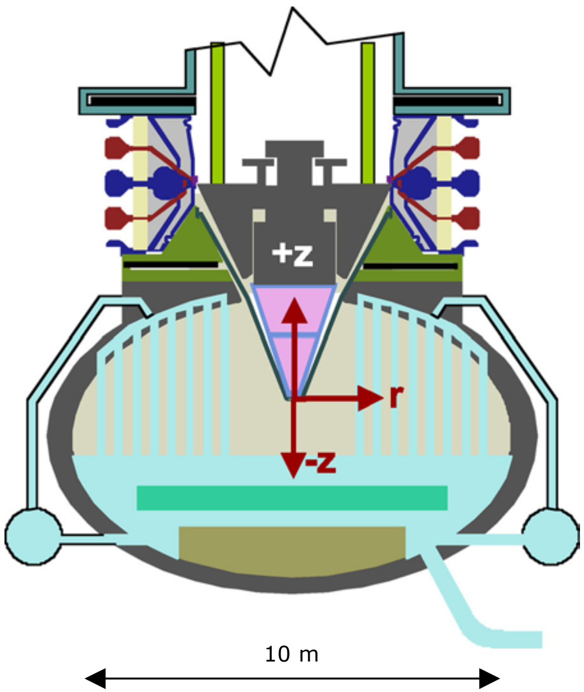
Future Work

- Extend the simulation time to the millisecond regime so we can obtain the vaporization radii directly from the BUCKY output
- Add capability to model mechanical shock in the liquid and solid zones
- Improve the Equation-of-State to more accurately model the thermal and mechanical response of an open-celled metallic foam
- Model individual liquid flibe jets instead of a homogenized flibe zone
- Implement an implicit differencing scheme and/or rezoning capability to speed up post-burn hydrodynamic simulation by relaxing the CFL condition
- Use the simulation data to create a dynamic 2-D graphical model for chamber thermal response



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