

Z-Pinch (LiF)₂-BeF₂ (flibe) Preliminary Vaporization Estimation
Using the BUCKY 1-D Radiation Hydrodynamics Code



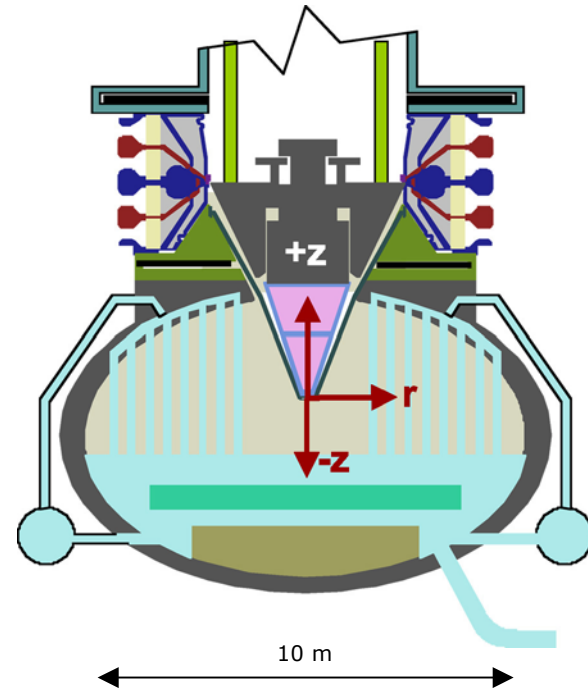
T.A. Heltemes^a, E.P. Marriott^a, G.A. Moses^a, R.R. Peterson^b

^a*Fusion Technology Institute, University of Wisconsin, Madison, WI, United States of America*

^b*Los Alamos National Laboratory, Los Alamos, NM, United States of America*

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



Analytical Vaporization Model

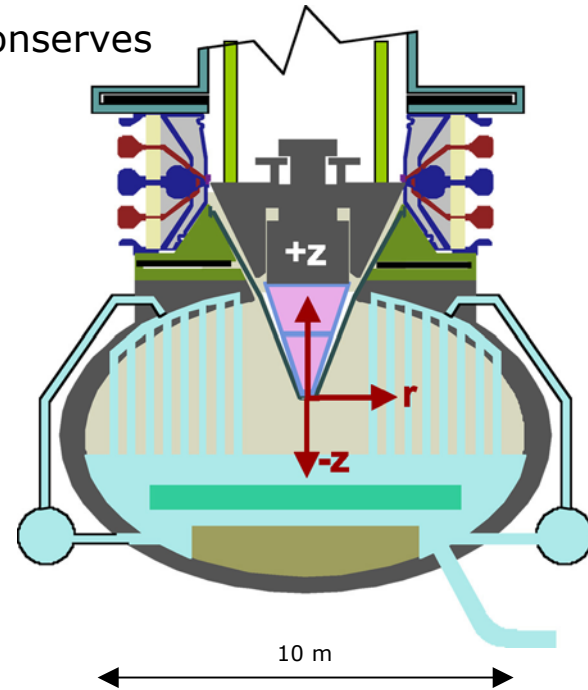
The analytical vaporization model assumes that the flibe simply conserves energy, yielding the maximum amount of vaporization possible

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

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

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

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



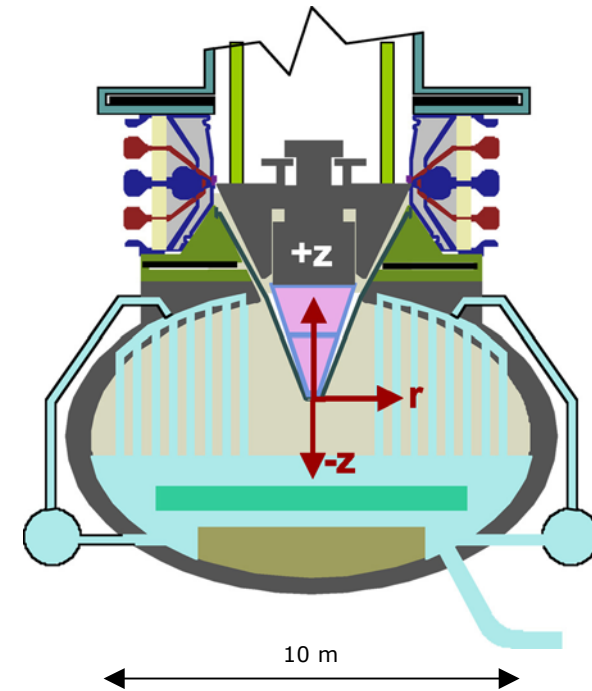
Z-Pinch Reactor Chamber Diagram

Model Parameter	Value		
	+z	-z	r
T_0 (eV)	0.05	0.09417	0.09417
T_0 ($^\circ\text{C}$)	307	820	820
r_0 (cm)	1.02	101.01	71.01
ε	0.08	1.00	0.50

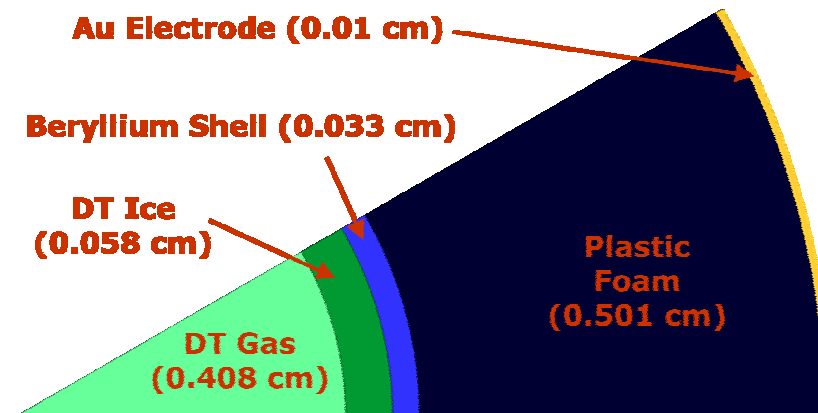
Direction	Δr_{vap} (cm)
+z	78.0
-z	1.8
r	6.6

BUCKY Simulation Setup

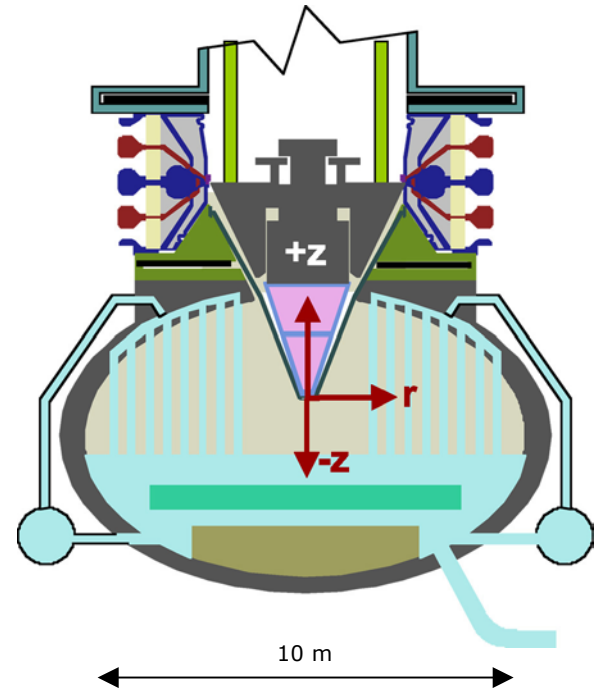
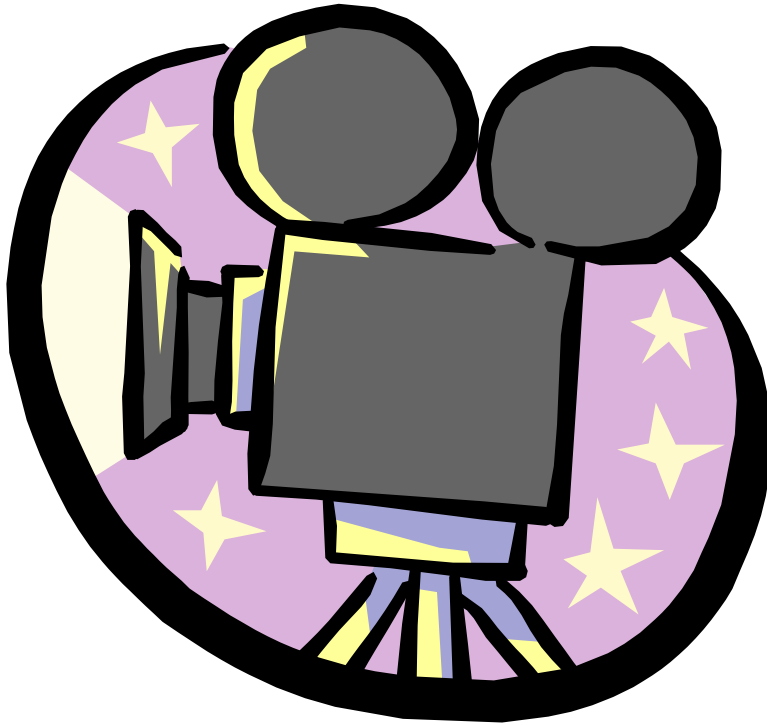
- The original target as provided by LANL had a yield of 5 GJ, which was lowered to the 3 GJ specification by preventing DT burn in the outer fuel zones
- The resulting yield was 3.0275 GJ, which is what was used in the analytical equations to determine the maximum amount of flibe vaporization
- +z simulation 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



Z-Pinch Reactor Chamber Diagram



Simulation +z Animation



Z-Pinch Reactor Chamber Diagram



THE UNIVERSITY
of
WISCONSIN
MADISON

Simulation Results

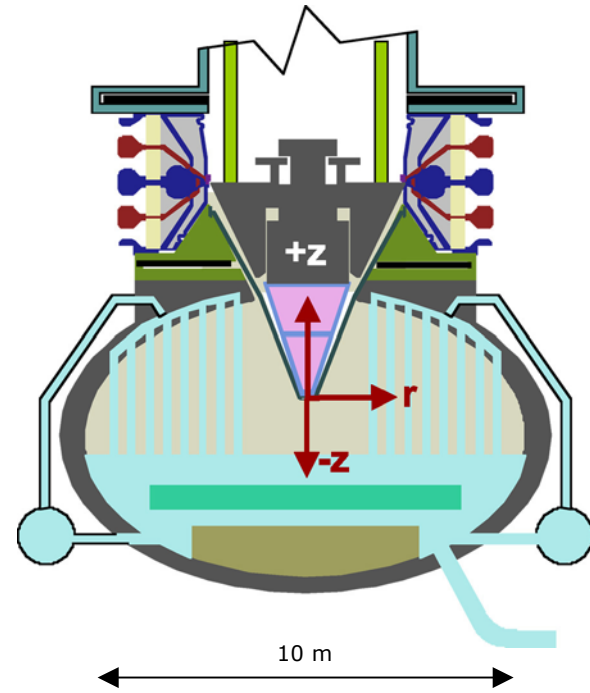
At 80 μs , the simulations were analyzed to provide a revised estimate of material vaporization.

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

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

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

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



Z-Pinch Reactor Chamber Diagram

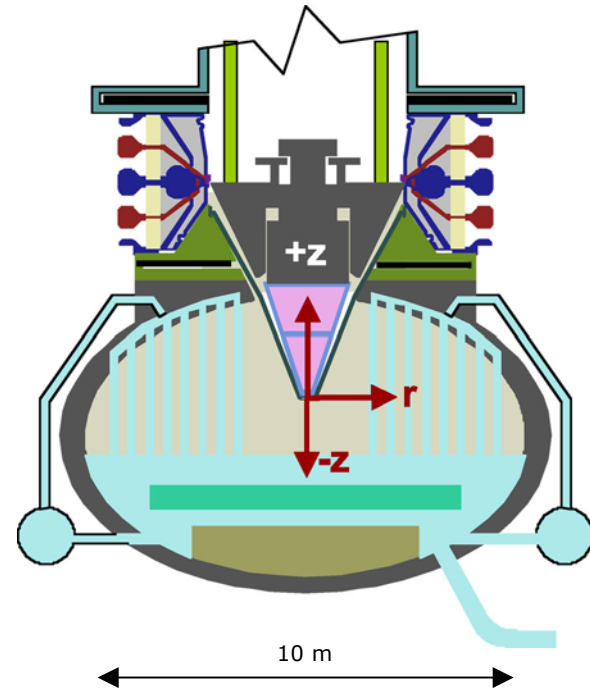
Parameter	Value			Unit
	+z	-z	r	
T_0	0.05	0.09417	0.09417	eV
$\langle T_{gas} \rangle$	55.49	10.62	10.66	eV
r_{gas}	6.3149	101.0123	71.01238	cm
m_{gas}	181.74	1,044.56	823.74	g
ε	0.08	1.00	0.50	

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



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

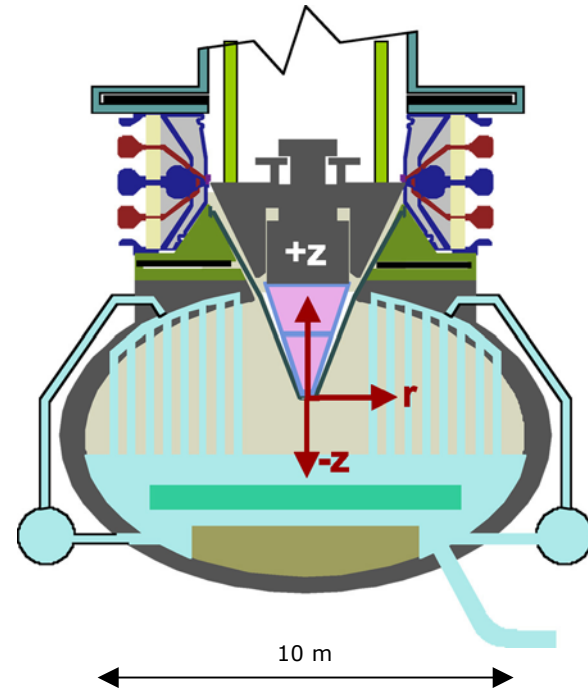
Direction	$\Delta r_{vap}(cm)$
+z	78.0
-z	1.8
r	6.6

BUCKY Result

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

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



Z-Pinch Reactor Chamber Diagram

