Hybrid Fuel Coupling in a Pulsed Z-Pinch Rocket Engine

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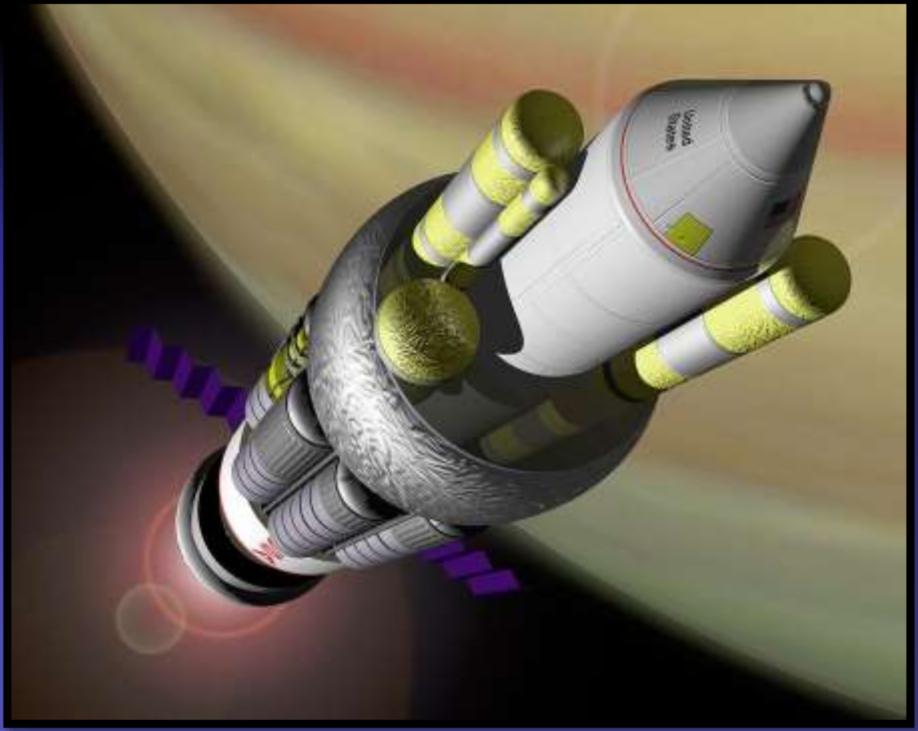
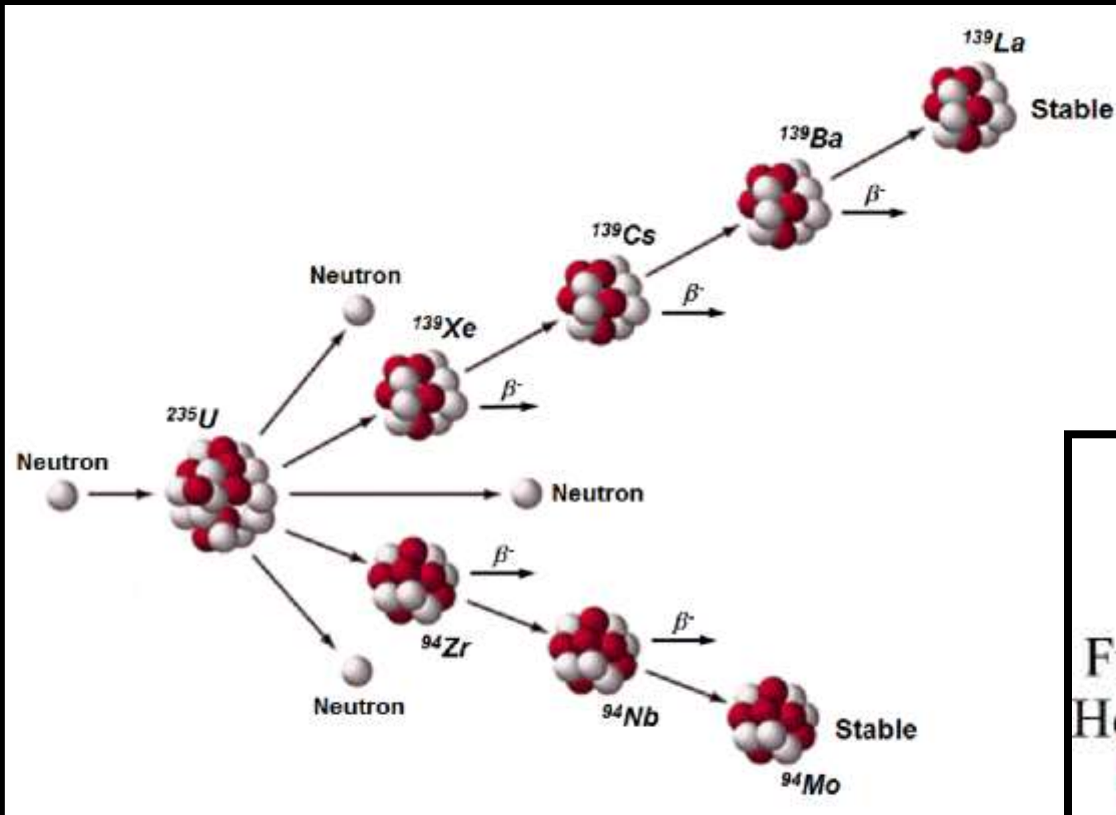
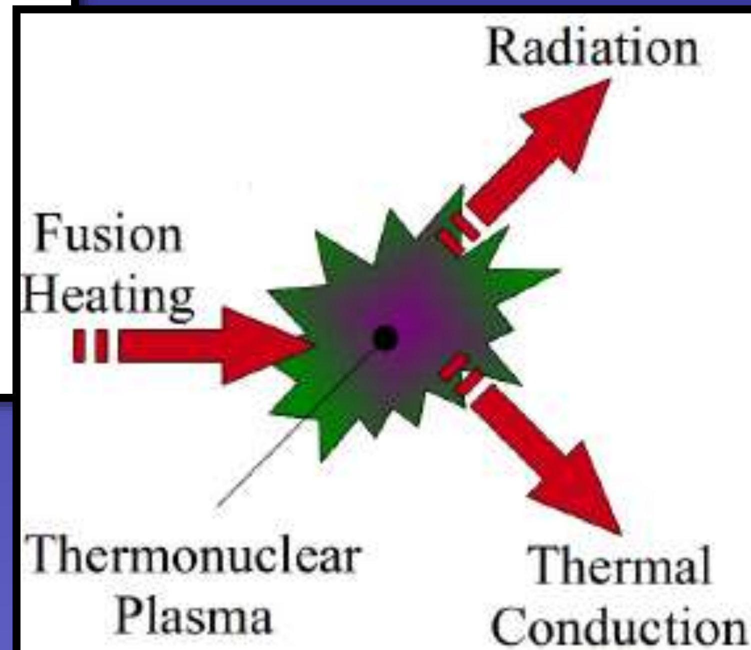
Introduction



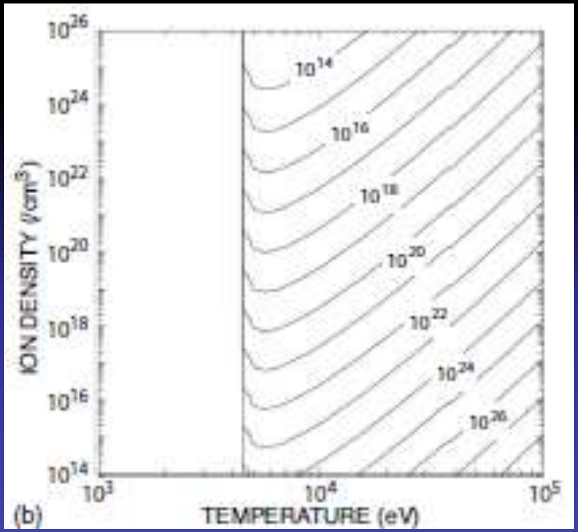
Introduction – Hybrid Nuclear Systems





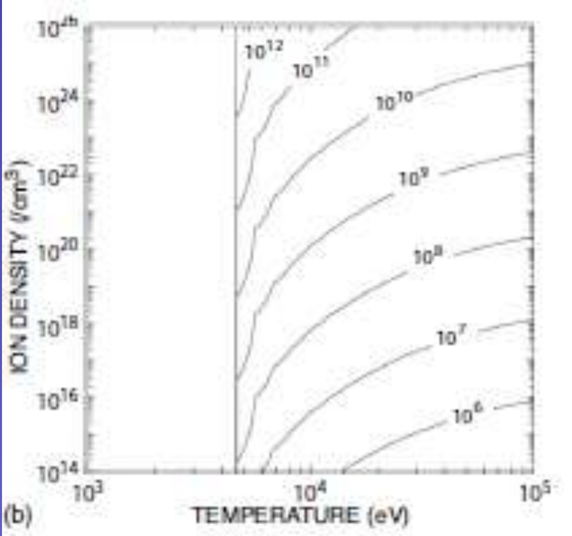
Magneto Inertial Fusion

	ITER	MTF example	NIF
Geometry	Toroidal	Cylindrical	Spherical
Cost ($M)	10,000	51	3000
n_i (/cm^3)	10^{14}	10^{20}	1.4×10^{25}
ρ (g/cm^3)	4.2×10^{-10}	4.2×10^{-4}	57
T (keV)	8	8	8
p (atm)	2.6	2.6×10^{6}	3.6×10^{11}
B (kG)	50	1000	0
τ_L (s)	0.9	9×10^{-7}	6.6×10^{-12}
M (mg)	350	1.7	0.01
a (cm)	240	0.6	3.5×10^{-3}
V (m^3)	8.3×10^{2}	4.0×10^{-6}	1.8×10^{-13}
E_{plas} (J)	3.2×10^{8}	1.6×10^{6}	9.3×10^{3}
P_{heat} (W)	1.3×10^{8}	9.0×10^{10}	1.1×10^{14}
I_{heat} (W/cm^2)	18	1.0×10^{10}	7.5×10^{17}



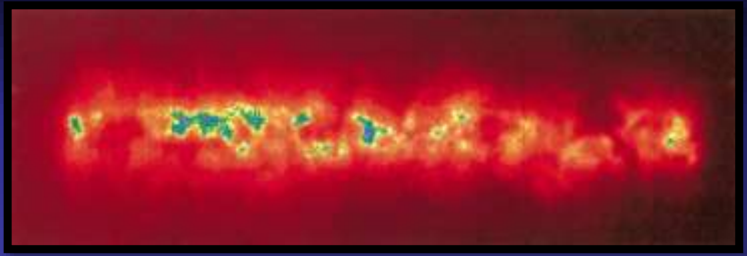
- Minimum Power Requirements
  - Unmagnetized
  - Magnetized
- Fundamental Physical Parameters

Lindemuth and Siemon, *“The fundamental parameter space of controlled thermonuclear fusion“, Am. J. Phys. 77, 2009*

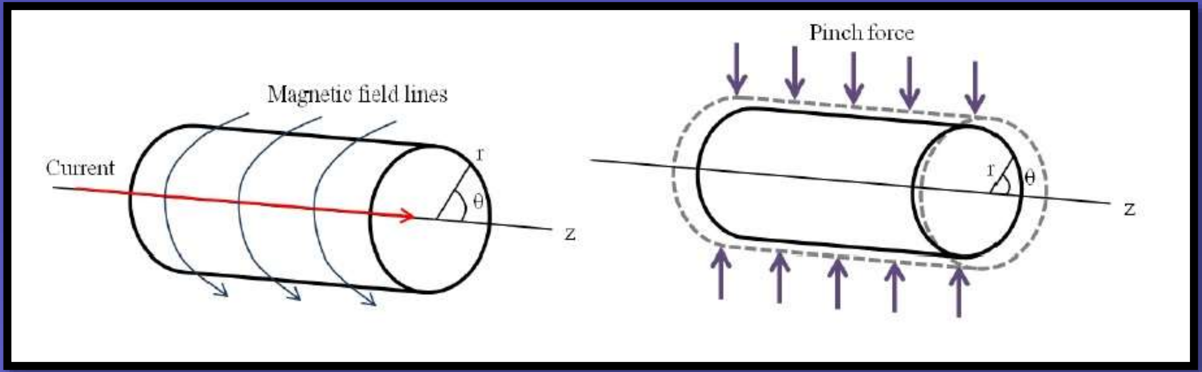


Introduction – What is a Z-Pinch?

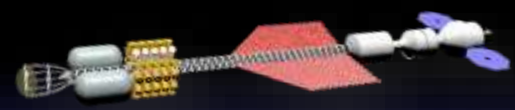
- Current pulse (time varying current) travels along z axis inducing an azimuthal B-field and the Lorentz force toward the axis
- Heat material to a hot dense plasma
- Compresses and contains the dense plasma
- Fundamentally unstable process

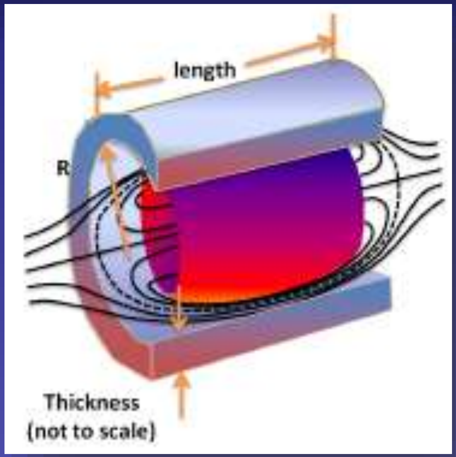


Pinch radiation from experiment on Z machine
D. D. Ryutov, et al, *“**The physics of fast** Z **pinches**“*



Pulsed Fission Fusion Engine (PuFF)





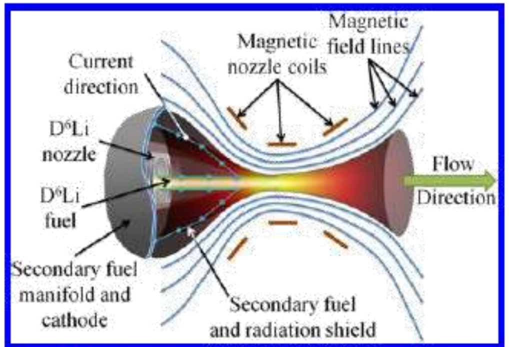
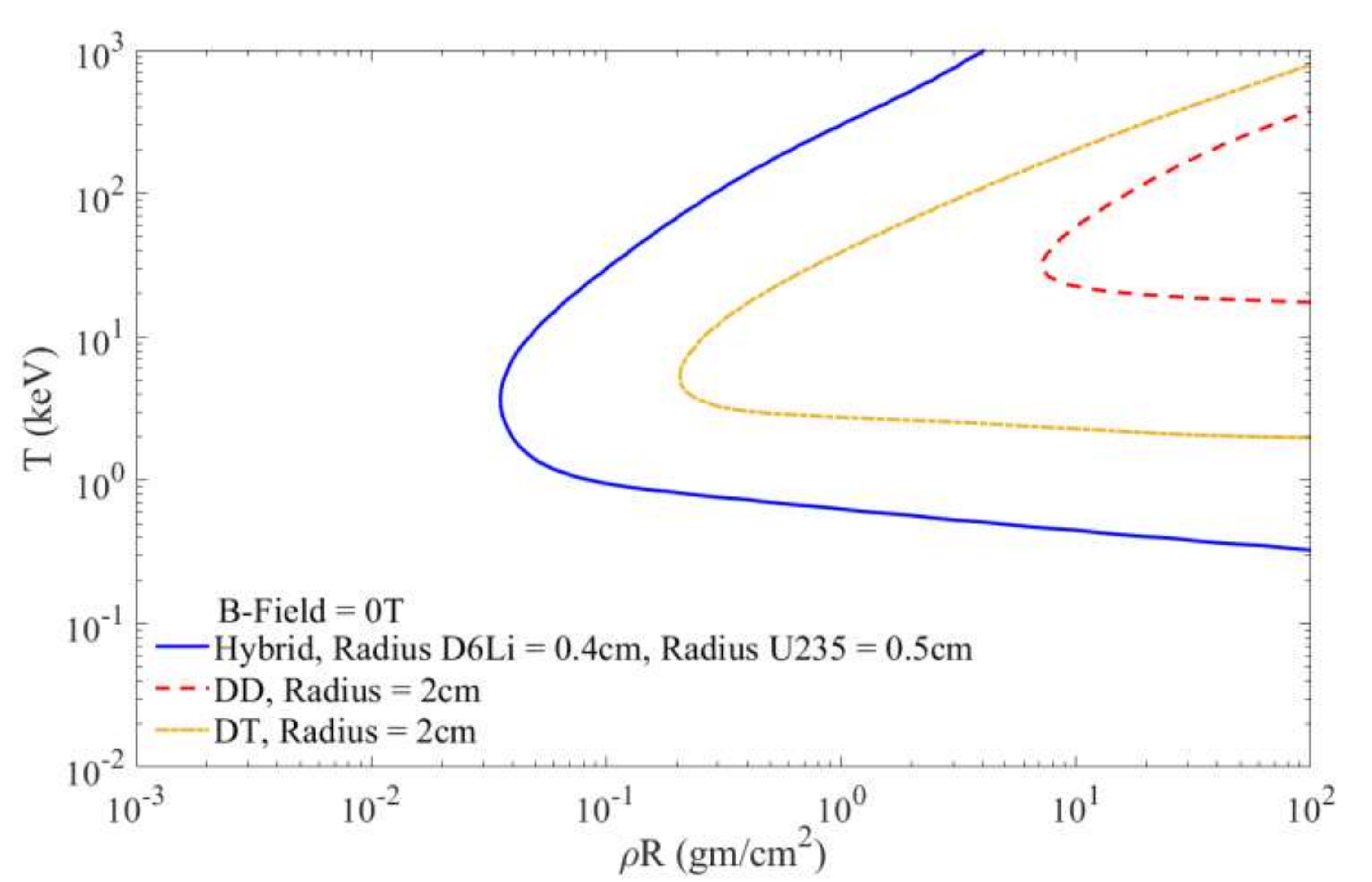


Fig. 11 ^{6}Li-D^{6}Li fusion propulsion concept. Magnetic nozzle topology is qualitatively similar to that of [102].

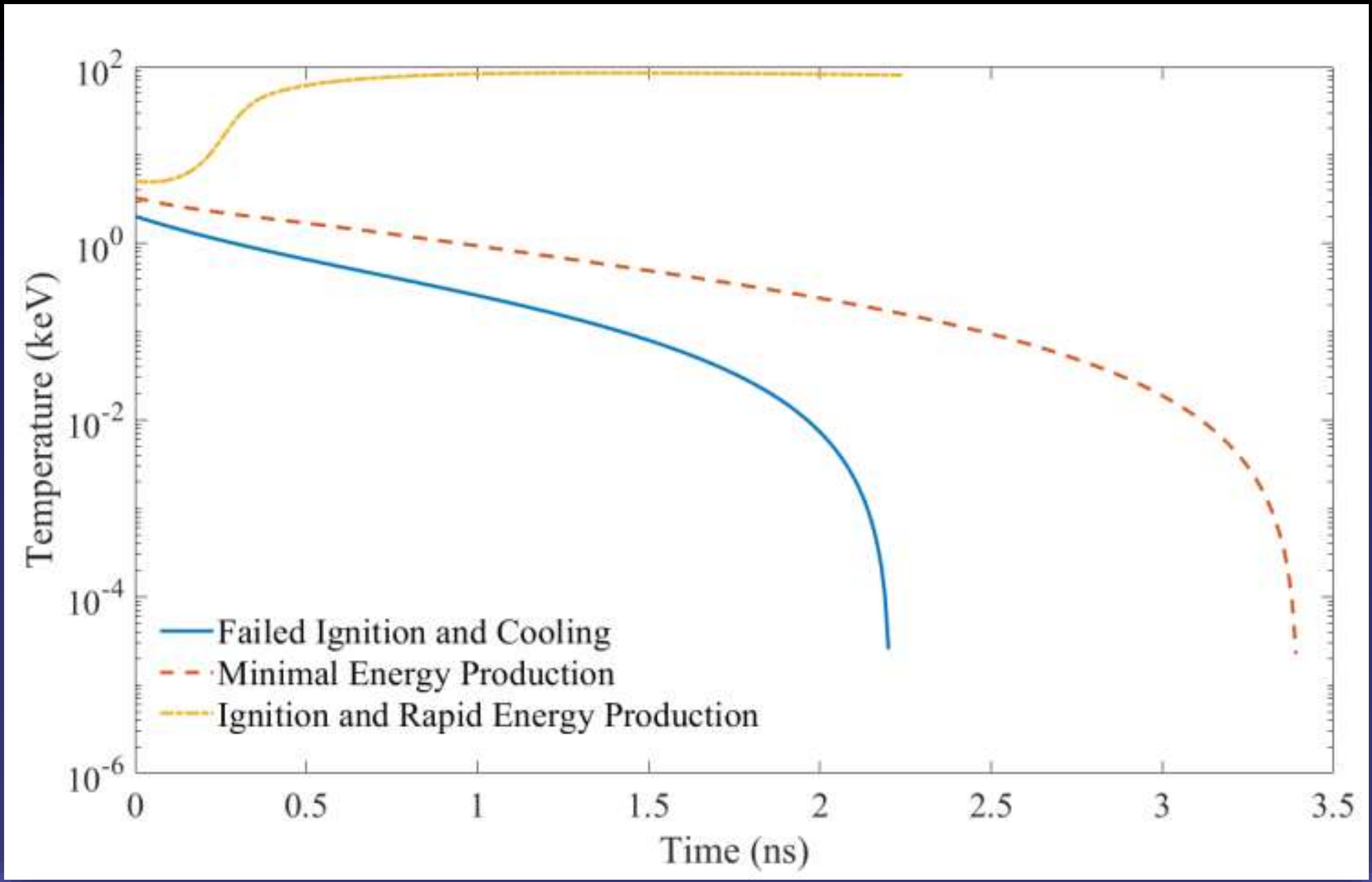
0D and 1D burn wave parameter space study

- **Energy balance**
  - Yield from nuclear reactions
  - Losses from conduction and radiation
- **0D parameter space**
  - calculated over a range of temperature, T, and areal density, ρR
- **1D burn wave**
  - defines density profile similar to post shock compression
  - Energy balance for each time step
  - Captures burn wave expansion and coupling between the fission and fusion reactions

Hybrid reactions significantly expand parameter space in 0D power balance



Minimal gain of 1-2 MJ occurs with cooling of the hot spot in 1D model



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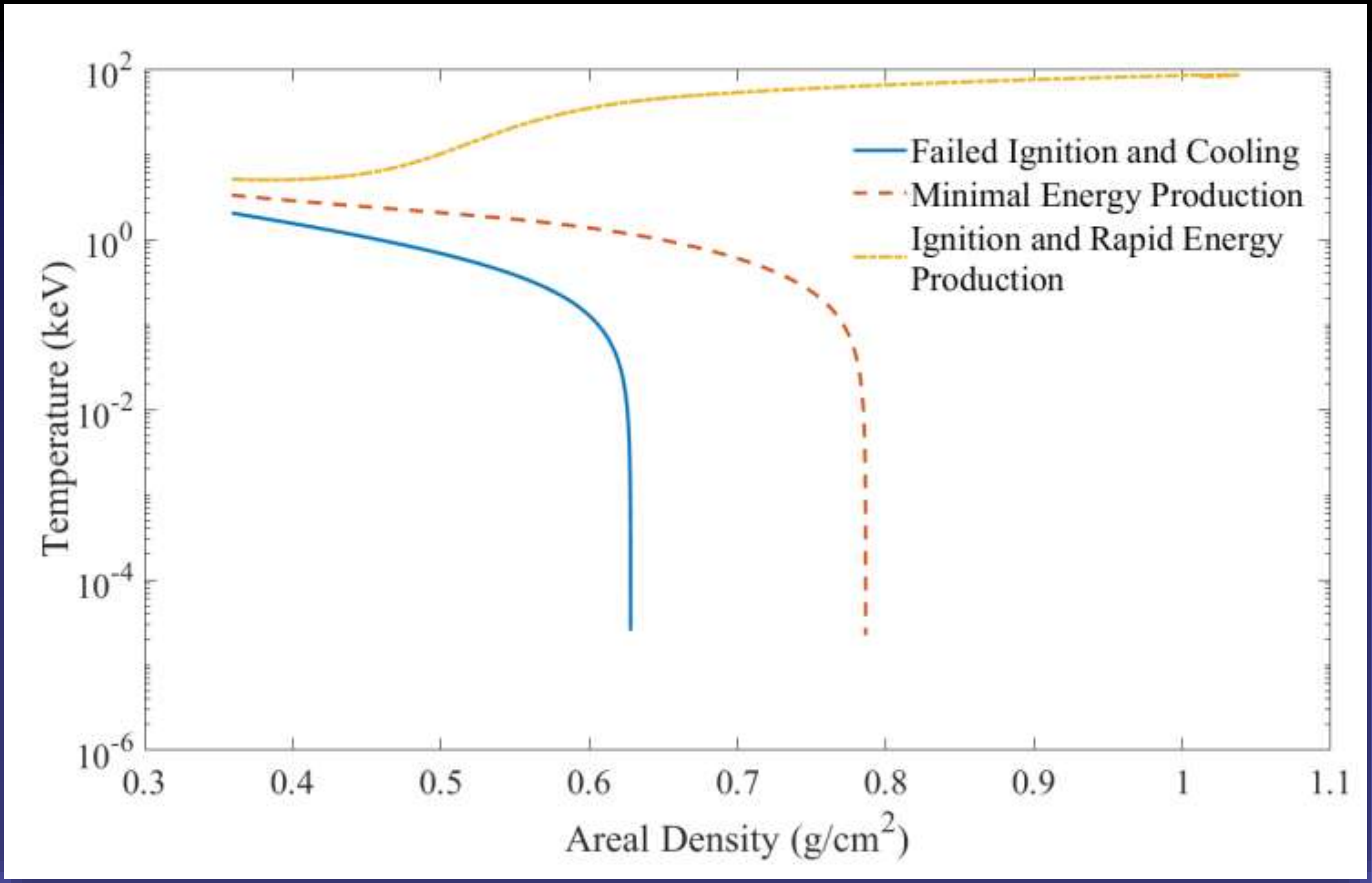

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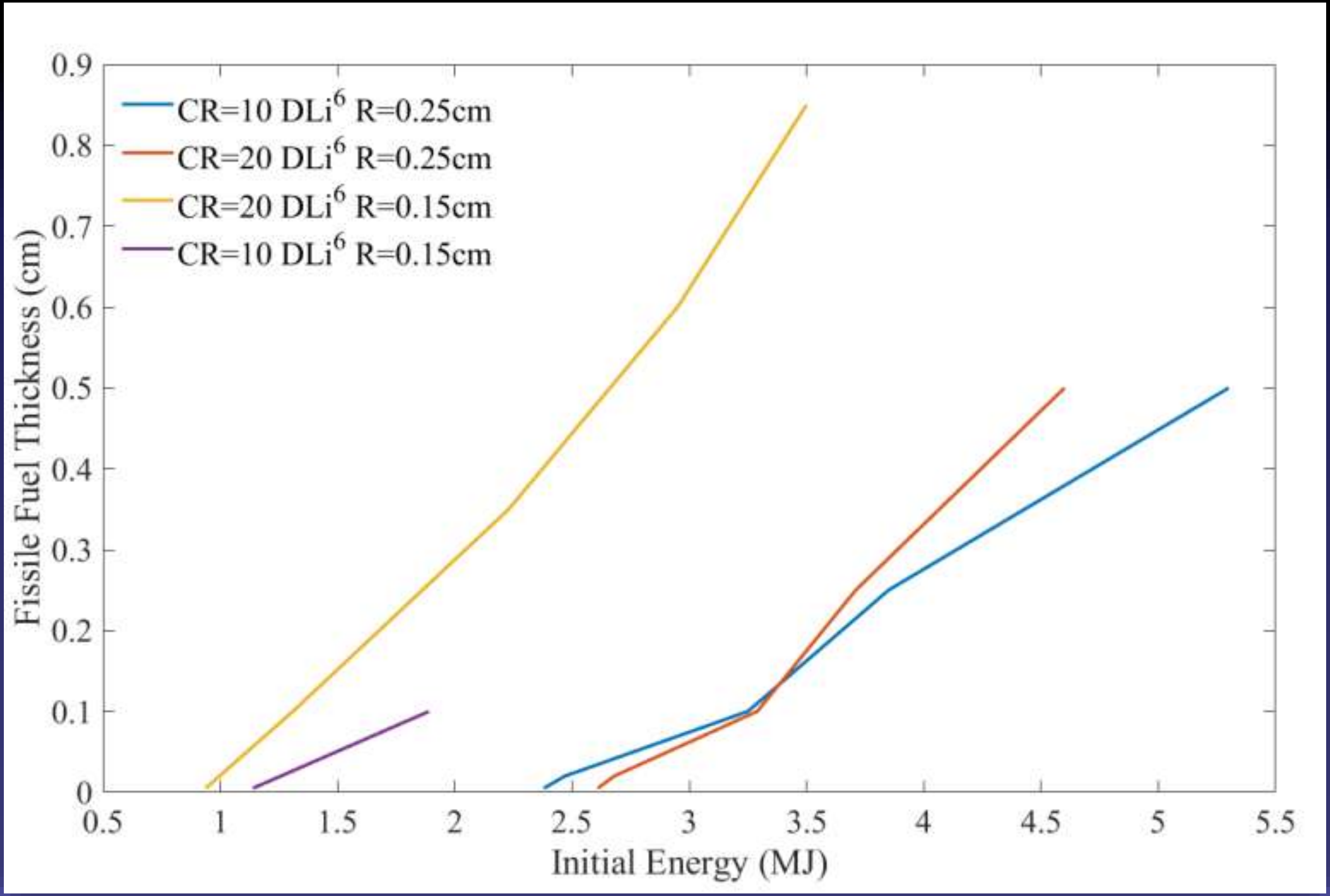
Breakeven at only a few MJ may be possible



Conclusions

- **A hybrid nuclear reaction has the potential to significantly decrease the energy and density requirements compared to a pure fusion system**
- **A vehicle propelled by a pulsed fission fusion engine could out perform current technology by orders of magnitude**
- **A hybrid z-pinch system could potential breakeven with an initial system energy of just a few MJ for optimal targets**
  - However greatly dependent upon implosion dynamics
  - May be able to further reduce ignition requirements with an external neutron source
  - More sophisticated modeling is required for a better estimate
  - Modeling must be coupled with experiments

CLOSING DISCUSSION