Exceptional service in the national interest

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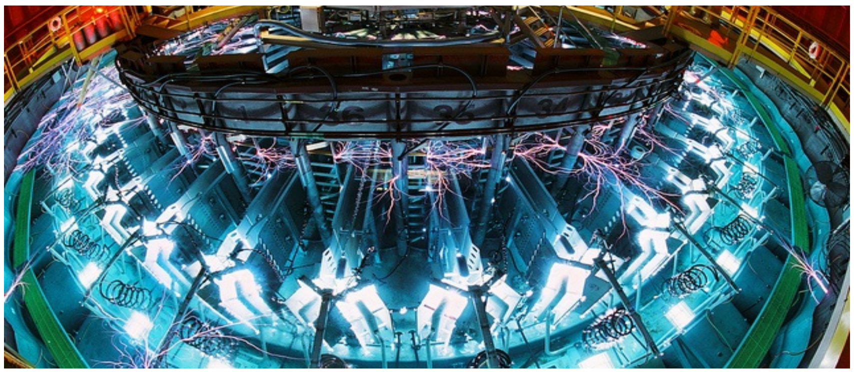
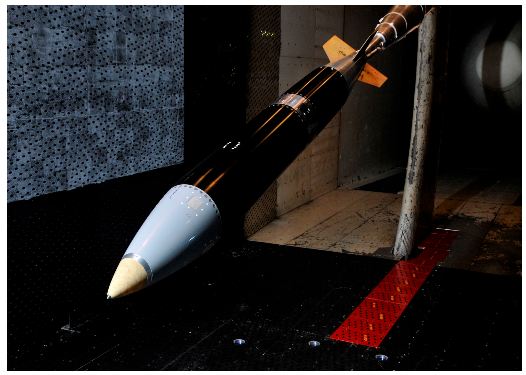


Perspectives on Pathways and Progress (Inertial and Magneto-Inertial Fusion)

Fusion Power Associates Meeting

Dec. 6-7, 2017 Washington, D.C.

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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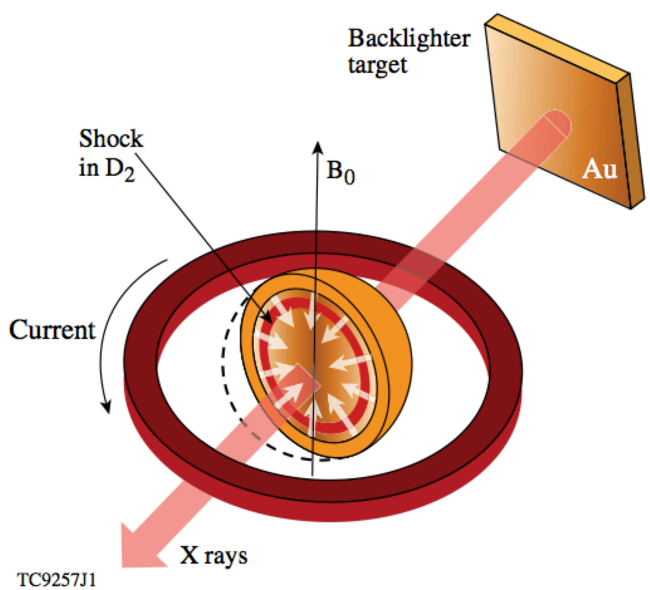
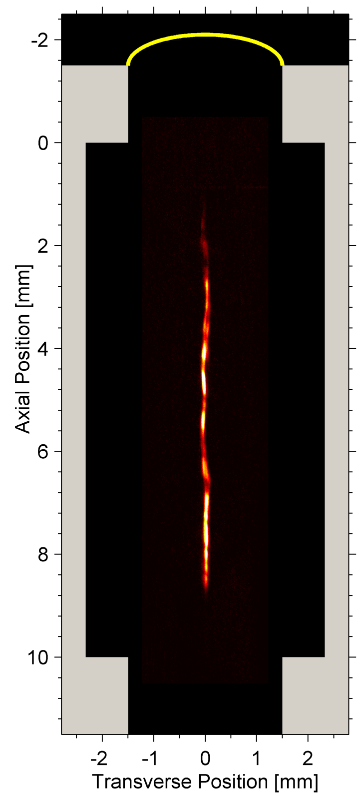
Magneto-Inertial Fusion targets on both Omega and Z have demonstrated interesting progress toward fusion

- Magnetized spherical capsule implosions on Omega clearly demonstrated significant increase in stagnation ion temperature and neutron yield with non-ideal magnetization. [P.-Y. Chang (2011)]



- Magnetized liner inertial fusion (MagLIF) targets on Z demonstrated fusion temperatures in a target that does not produce significant yield in the absence of both fuel heating and magnetization. [M.R. Gomez (2014)]

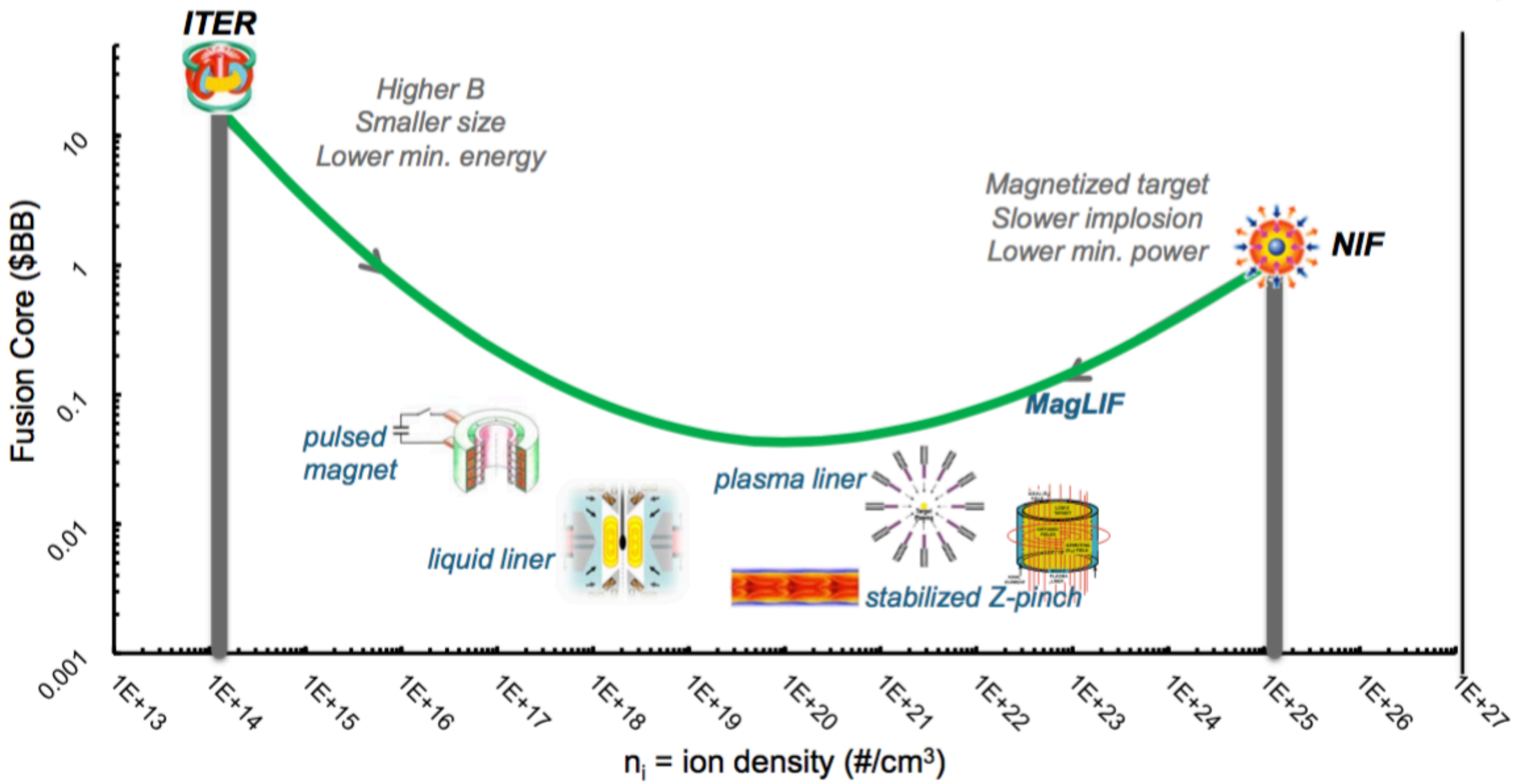


	No B-field	B-field
No Pre-heat	0.3×10^{10}	1×10^{10}
Pre-heat	4×10^{10}	300×10^{10}

DD neutron yield

This has led to a resurgence of interest in magneto-inertial fusion concepts at plasma densities intermediate to ITER & NIF

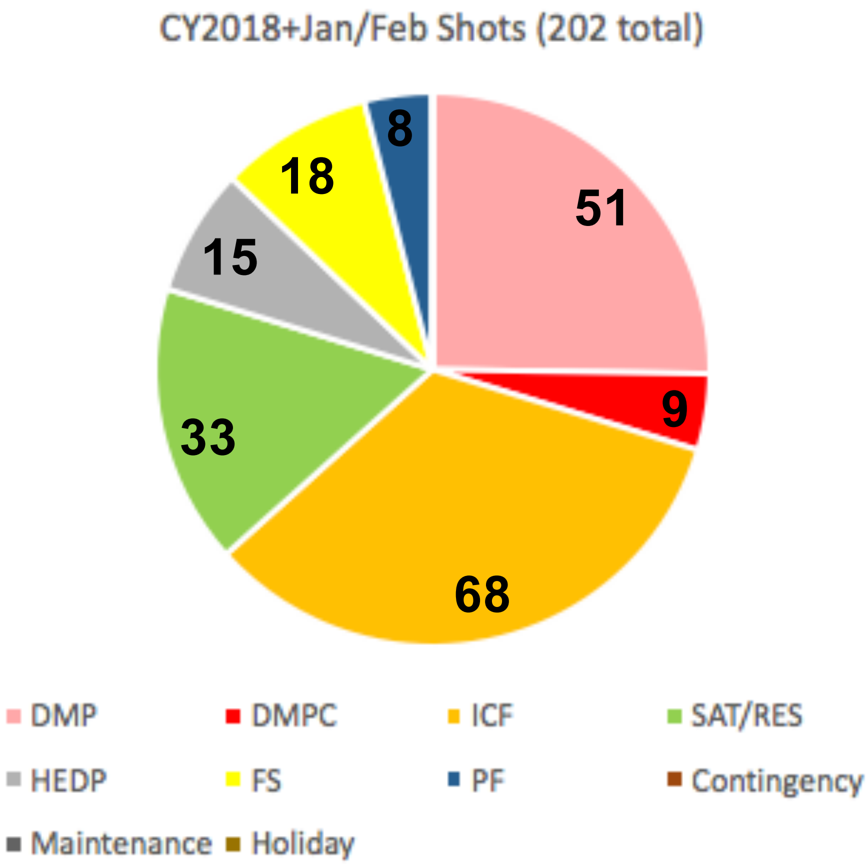
More Fusion Approaches!



*Slide shown by Dr. Patrick McGrath at August 2017 ARPA-E ALPHA meeting

Despite this promise and renewed interest, practical progress is highly limited by learning opportunities

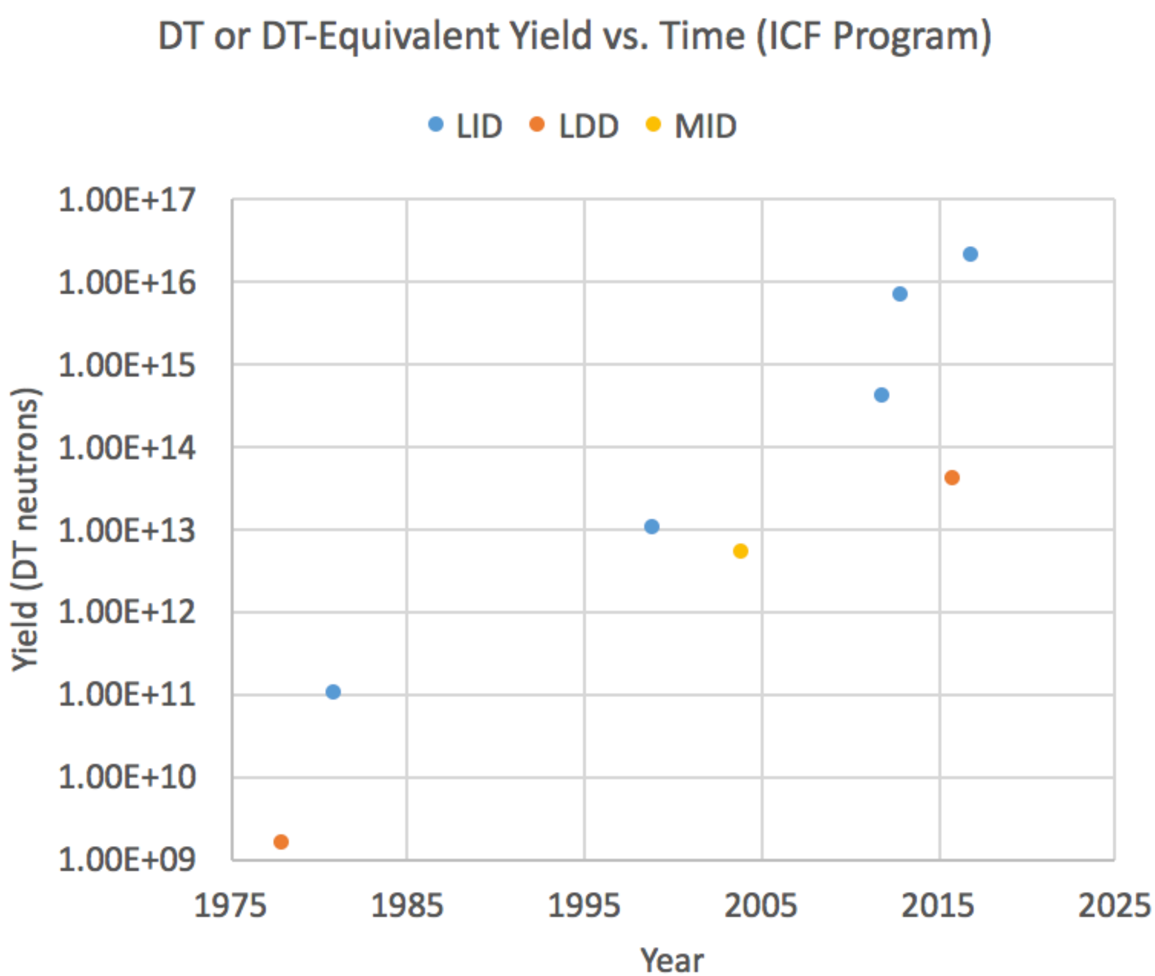
Z shot schedule distribution
(next 14 months)



- Z facility is in high demand across multiple NNSA missions
- Omega/Omega-EP facilities are likewise in high demand—about 3 shot days/year for MagLIF research
- Most of ARPA-E portfolio is only just now beginning active experiments after 1.5-2 years of 3-year, ~$30M investment
- Private companies with a head start over ARPA-E have also struggled with rate of learning constraints

Traditional ICF has similar challenges for the rate of learning, though we note steady progress in increasing yield over several decades

- “Moore’s Law in fusion”
- Yield doesn’t tell the whole story—significant progress has been made in understanding and general plasma conditions as well!
- Like Z, shot time on NIF is constrained by the multiple mission areas of the NNSA.
- Real progress in improved performance and understanding is overshadowed by our expectations, despite the fact that we are making extrapolations over orders of magnitude in these jumps.



Fusion energy research in inertial and magneto-inertial fusion is focused almost entirely on target physics

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- Critics of magneto-inertial fusion concepts tend to focus on two general categories of risk*
  - High-Z material may mix rapidly with low-density fusion fuel, leading to unacceptably large radiation losses/cooling.
  - Pulsed systems are unlikely to meet practical requirements for pulsed repetition rate and cost per target, if it involves replacing liner hardware on every pulse.

- Addressing these risks in a clear fashion is challenging
  - Only a small number of schemes have actually assembled fusing MIF systems where a study of mix challenges can occur at limited shot rates
  - Outside of minimal Laboratory Directed Research and Development investments at the National Laboratories, minimal work on economical schemes for pulsed fusion drivers is occurring. NNSA has little appetite for fusion energy, given its stewardship mission.

* G.A. Wurden *et al.*, J. Fusion Energy (2015).

Sandia has used LDRD in the past to look at options for pulsed fusion energy systems with recyclable transmission lines—but little real investment in testing the ideas to date

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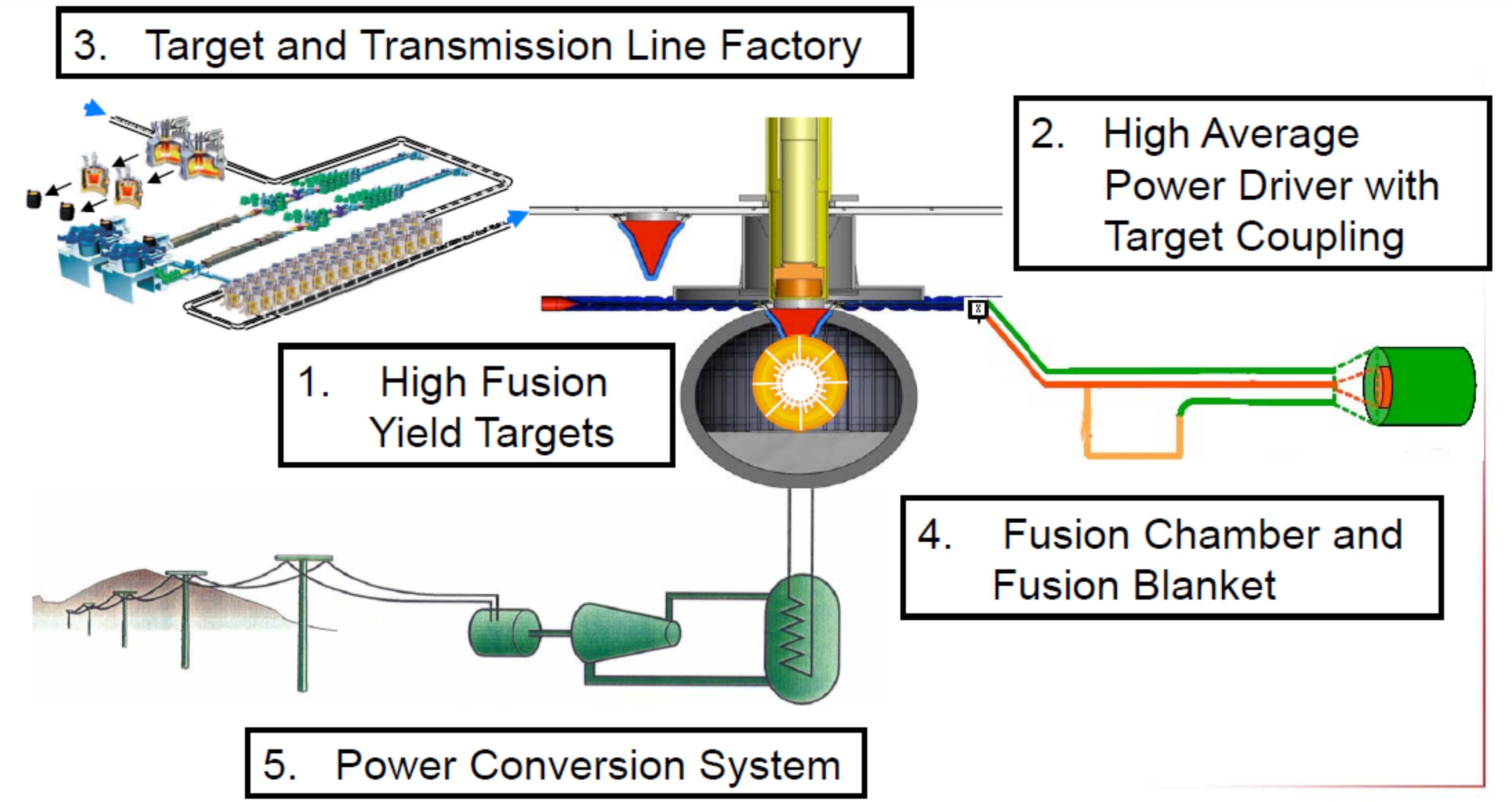
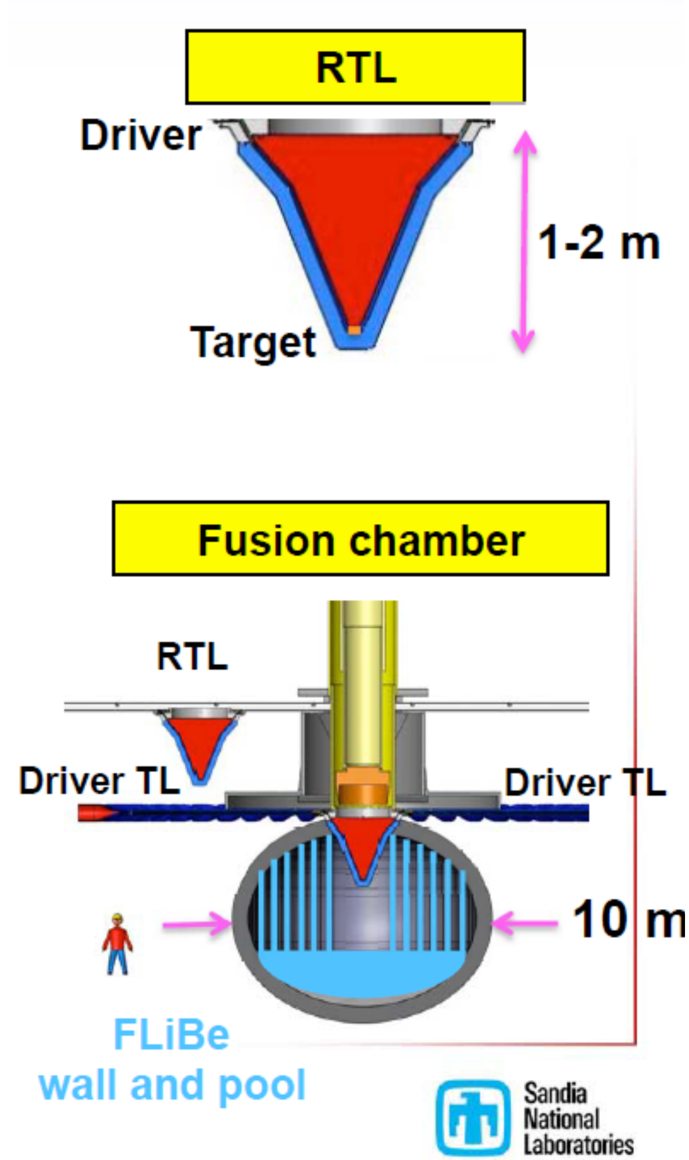


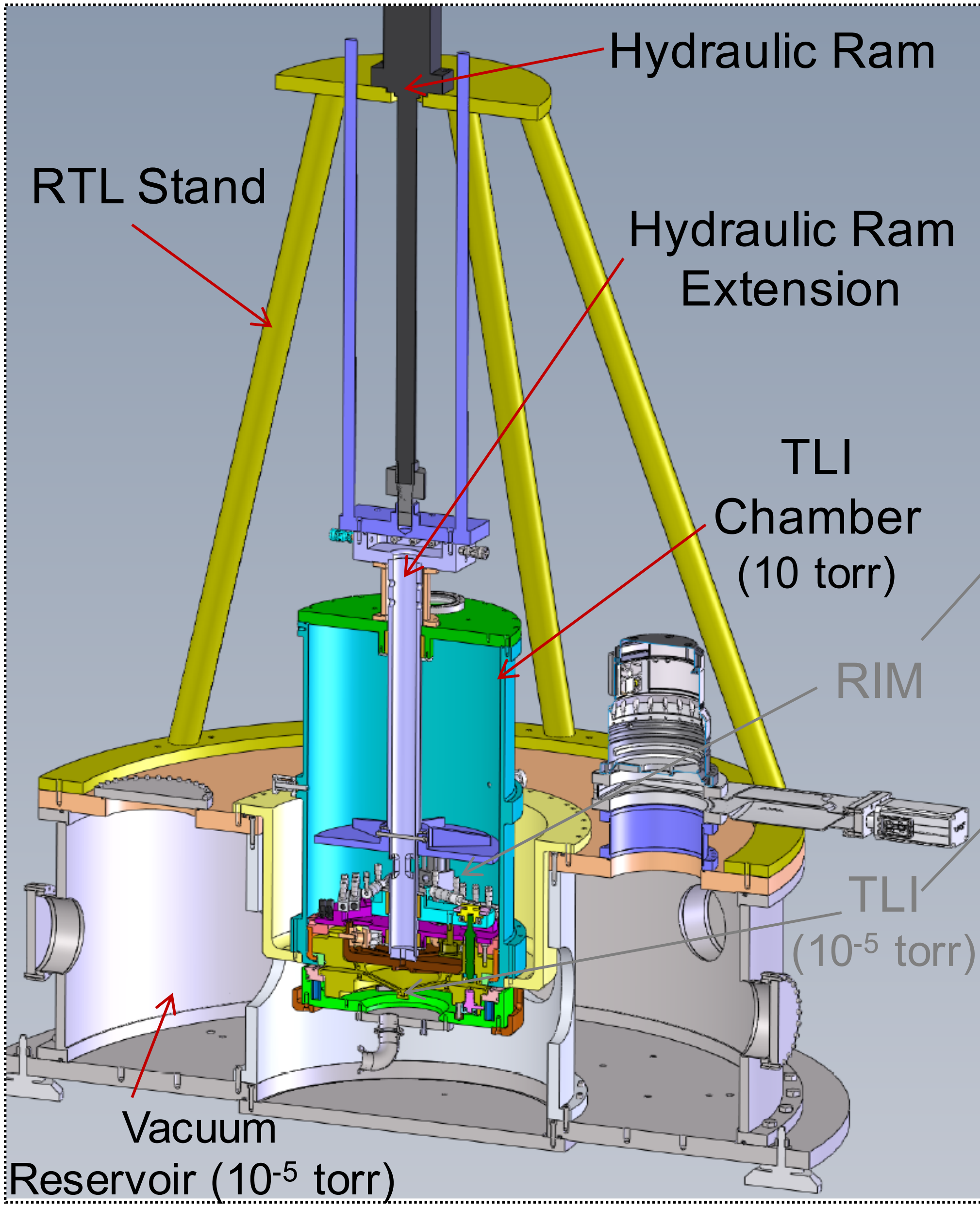
e.g., "Z-pinch IFE" Sandia reports from Craig Olson (2004-2006).

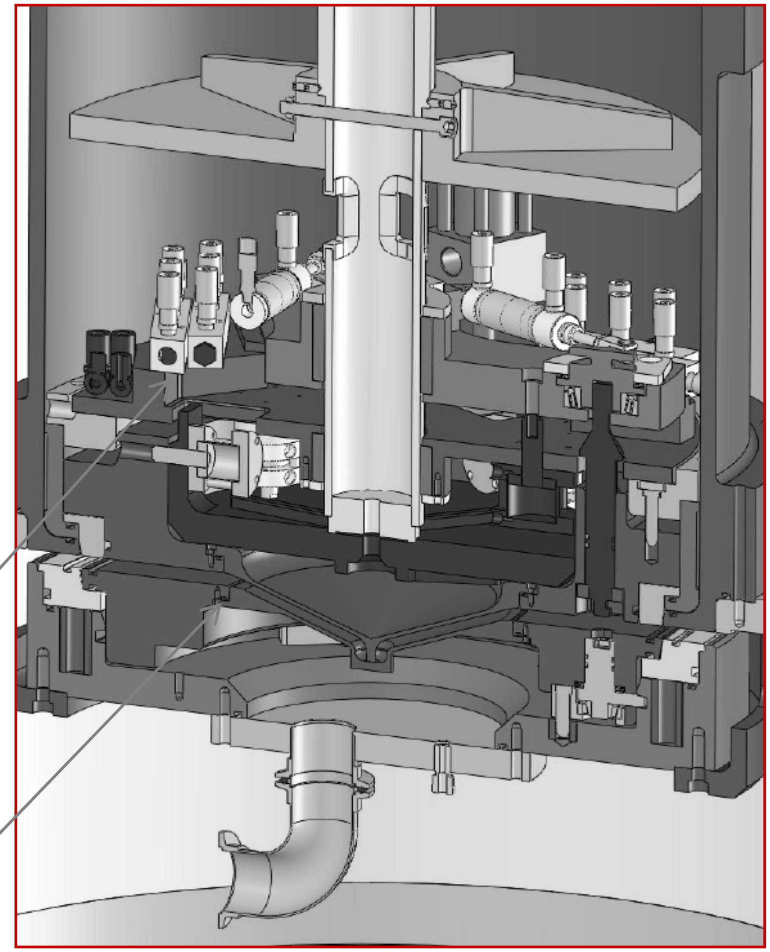
A LDRD ending in 2013 developed the design for a test bed that would demonstrate key recyclable transmission line ideas, but it has never been built

- Central concepts of RTL
  - Low-mass, pre-pumped magnetically insulated transmission line
  - Central portion is recyclable; surrounding hardware survives
  - Compatible with thick liquid first wall, chamber clearing is not required
  - Assumes high yield (GJ-class) and low repetition rate (~0.1 Hz) to be economic



Prototype RTL test stand





RIM = Rapid Insertion Mechanism
TLI = Transmission Line Insert

The ICF community is undergoing annual self-reflection on the scaling to multi-MJ fusion yields with Red Team reviews

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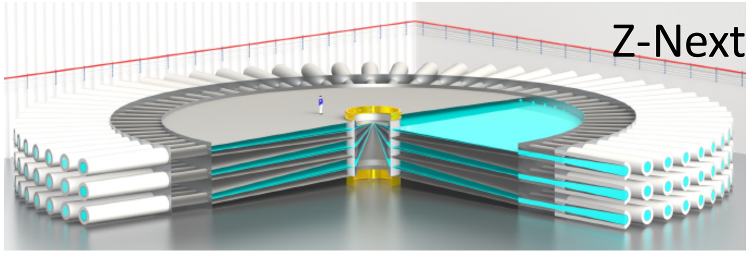
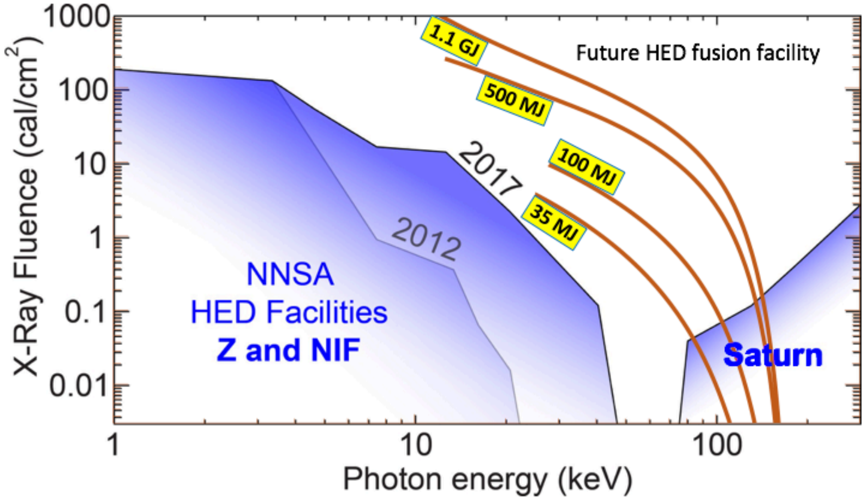
- Program goal for 2020 of understanding the scaling to multi-MJ fusion yields for all three approaches
  - Laser Indirect Drive
  - Laser Direct Drive
  - Magnetic Direct Drive
- First internal review of our progress toward developing a scaling argument occurred at Sandia in May 2017. Next review is scheduled for April 2018 at LLNL.
- This process is helping us confront the key risks and challenges for these extrapolations. Stayed tuned for progress over the next few years!

Sandia is considering a Z-Next as a multi-mission pulsed power facility to address scientific opportunities and threats to our nuclear stockpile

- **A Z-Next facility capable of ~30 MJ yield could address key physics gaps**
  - Provide x-ray and neutron environments for radiation effects science.
  - Achieve higher-pressure capabilities for actinide dynamic material properties
  - Address critical nuclear weapon primary and secondary physics issues

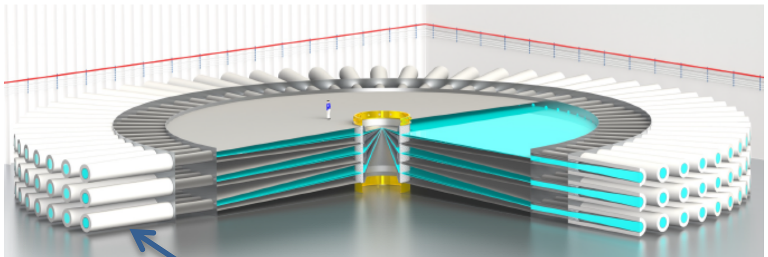
- **A Z-Next would invigorate pulsed power and inertial fusion research in the United States**
  - Both China and Russia have active proposals to build larger pulsed power (and laser) facilities than the U.S. A Z-Next would allow the U.S. to maintain preeminence in high energy density physics research.
  - Both Z and NIF have been "engines of discovery," producing frontier science in multiple fields. A Z-Next would increase those possibilities substantially.

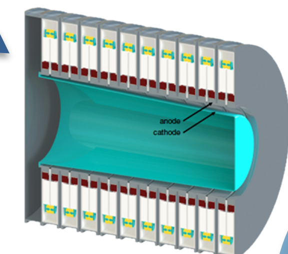




China's 10 MA Primary Test Stand

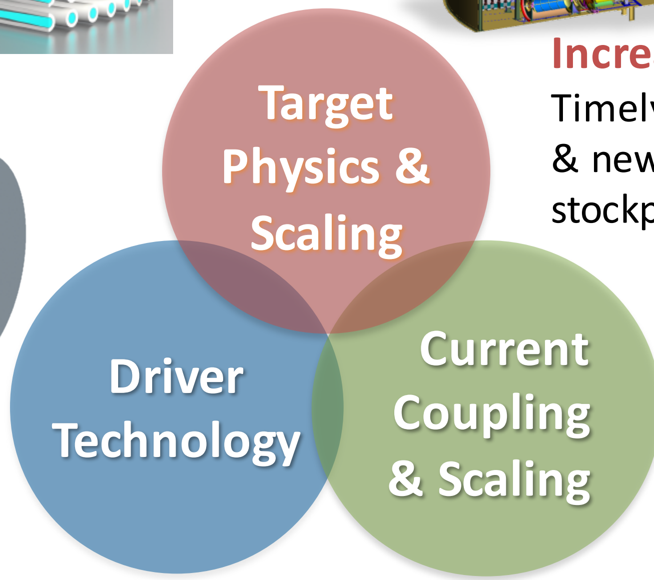
Multiple major investments are required to build up a more credible science & technology foundation for Z-Next

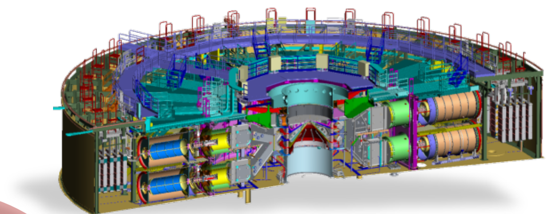




Build a Z-Next Module

Demonstrate technology & develop supply chain



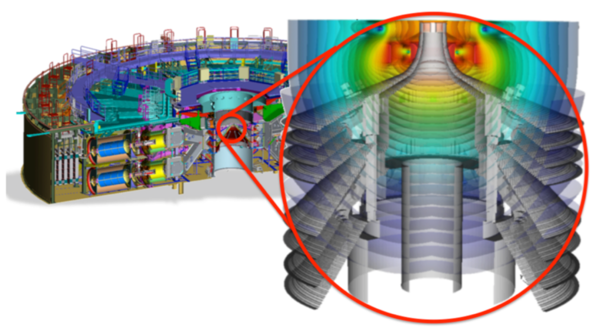


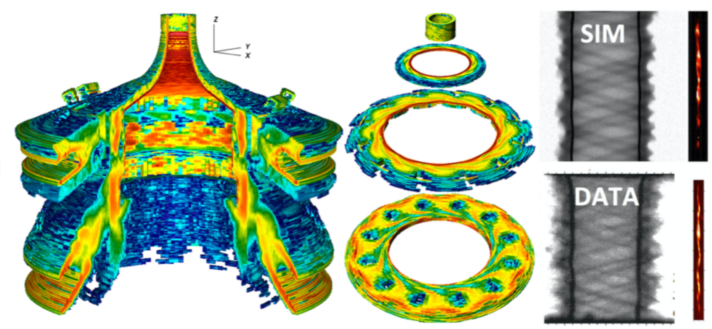
Increase the shot capacity of the Z facility

Timely evaluation of new magnetic drive targets & new capabilities while supporting today's stockpile

Develop next-generation plasma science & engineering code

Reduce risks & increase predictive capability tools for scaling to a Z-Next



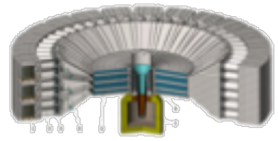


We seek to make progress on target physics, advanced driver technology, and simulation capability between now and ~2025

1st PTS Experiments (China)

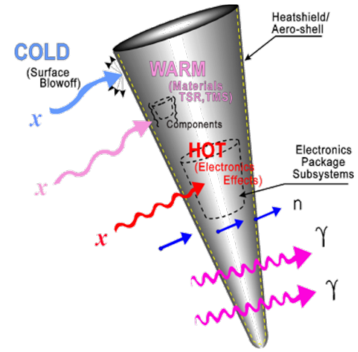
Tri-Lab Directors Letter HED Physics

Tri-Lab PPS&T Report

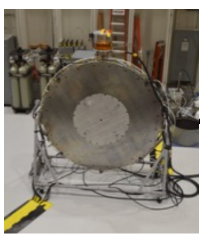


Baikal Operation Begins? (Russia)

Conduct Major Program Review to assess the facility investments needed to meet future stockpile stewardship requirements (FY18 SSMP)



2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030



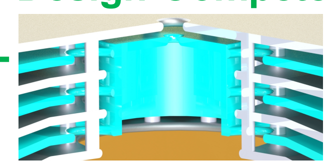
1-cavity LTD

Plasma Physics GC LDRD

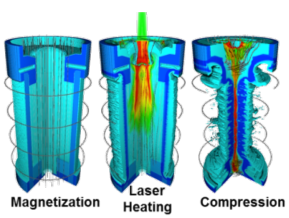
Initial Hybrid Power Flow Modeling Capability

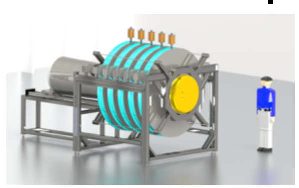
Production Codes Available

Z-Next Power Flow Design Compete

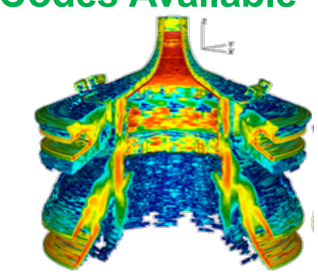


1st Integrated MagLIF Experiments

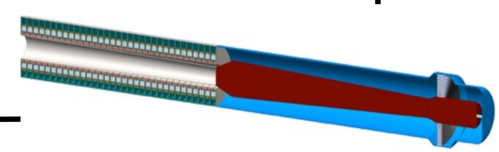




5-cavity LTD & IMG module

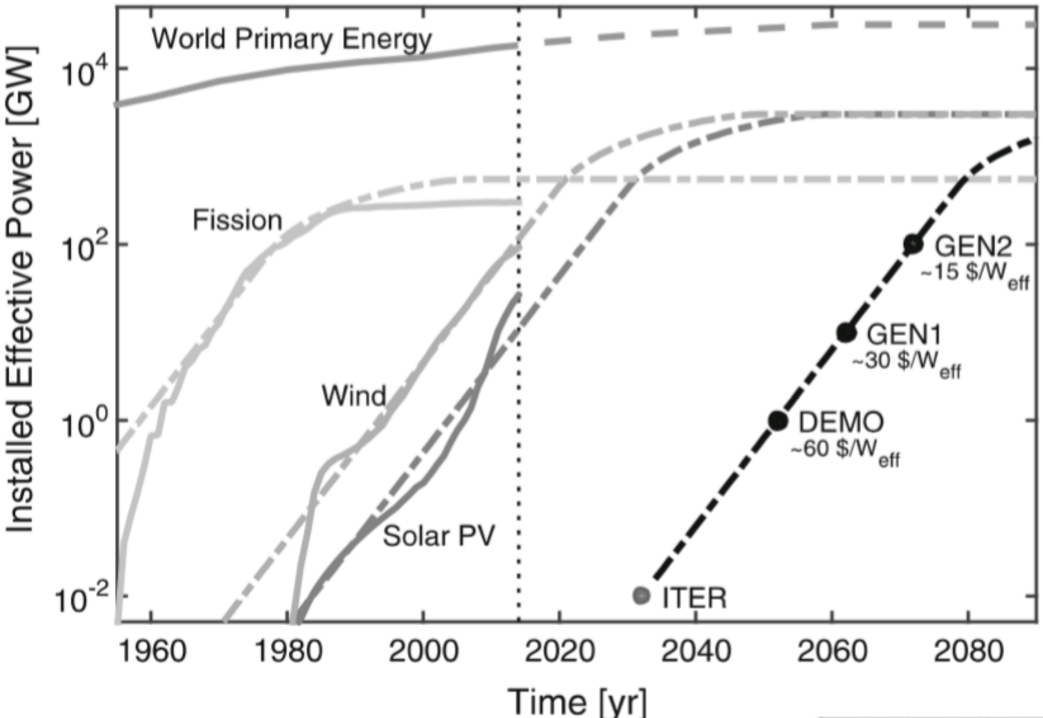


Z-Next Prototype LTD Module Complete



Backup Slides

Realistically, even if we had a working ICF reactor concept today, we are decades away from affecting the grid…



Source: Cardozo et al.,
J. Fusion Energy (2016)

Source: Sinars et al.,
J. Fusion Energy (2015)