SAND2020-7925C

Z Fundamental Science Program Workshop: Welcome & Introduction

Daniel Sinars, Director, Pulsed Power Sciences Center

Z Fundamental Science Workshop 8/3/2020

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia LLC, a wholly owned subsidiary of Honeywell International Inc. for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

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I'd like to extend a warm virtual welcome to all of you!

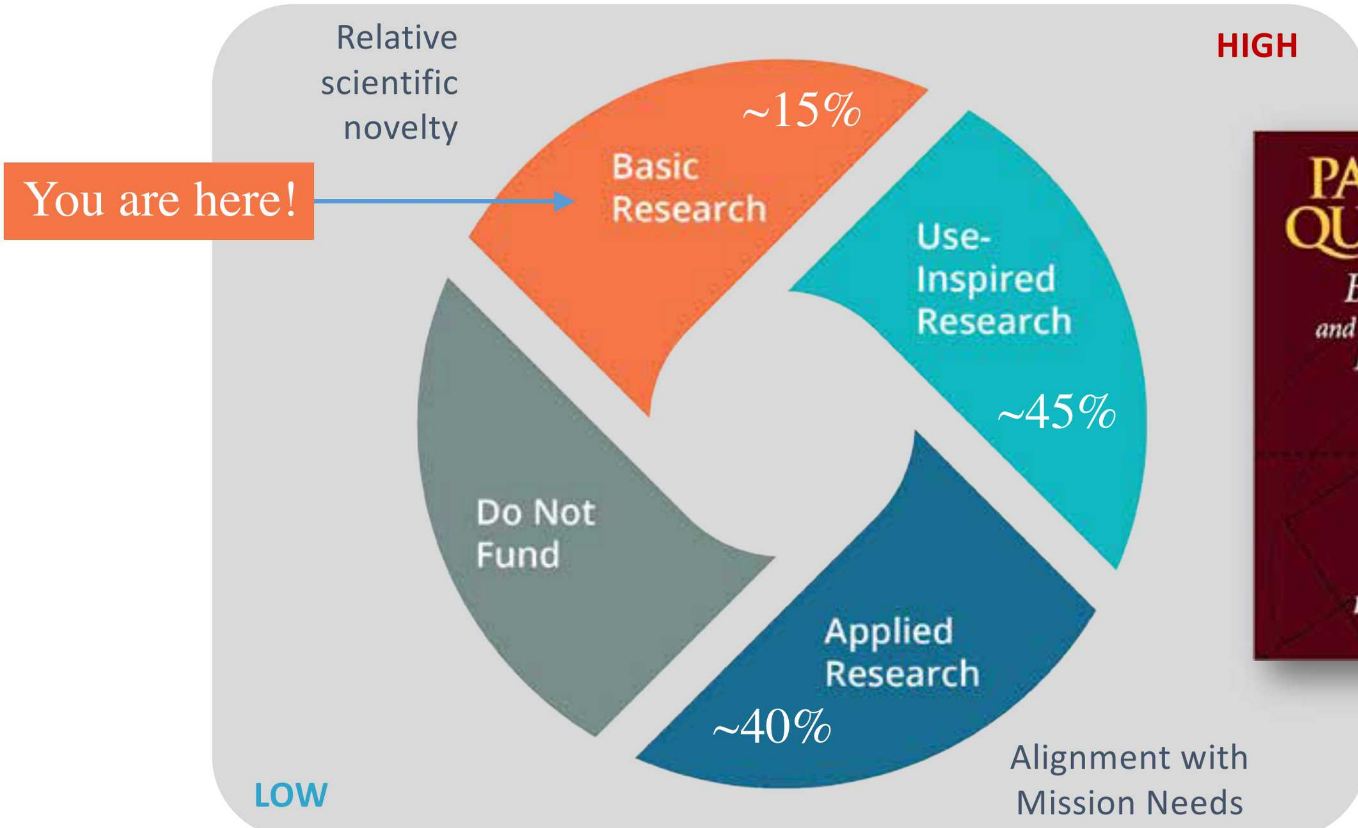
- This year we were faced with choosing the lesser of two evils…
  - Not having a workshop at all, or…
  - Having a virtual workshop without the pleasure of face to face interactions, meeting new people, and forging new scientific partnerships.

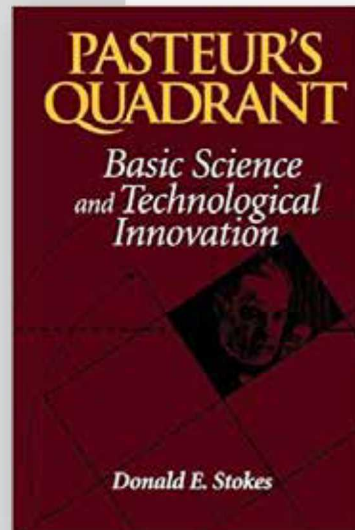
Despite the limitations of this format, we are very much looking forward to sharing our technical progress and the exchange of ideas

The Z Fundamental Science Program is a high priority for our work on the Z facility

Majority of Z research is “use-inspired”

Conducting open, novel science in the pursuit of applications benefiting the mission of the NNSA



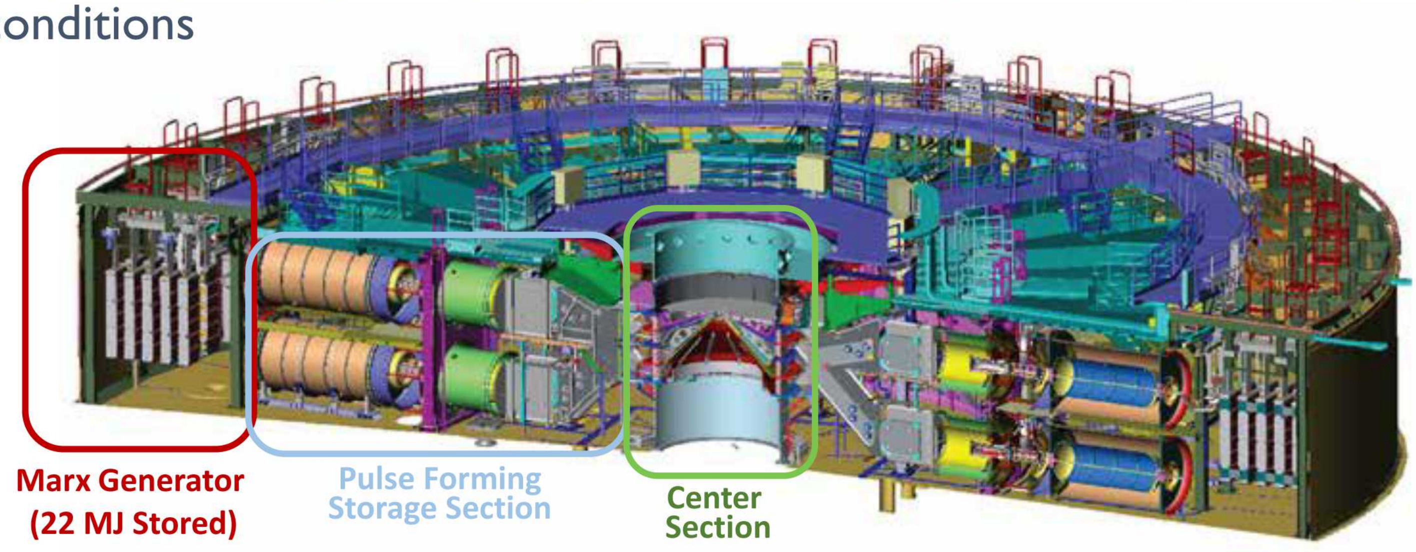


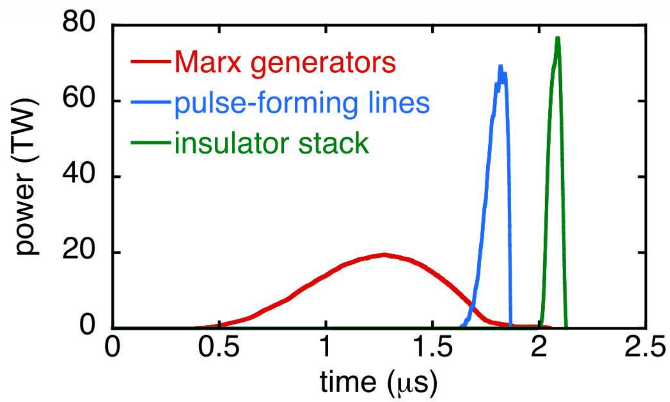
Basic

Use-Inspired

Applied

Z works by compressing energy in space and time to generate high energy density (HED) conditions





Z today couples several MJ out of 22 MJ stored to the load hardware region at the machine center.

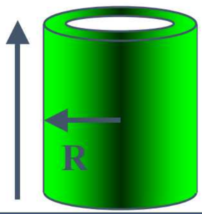
Z is an "Engine of Discovery" for stewardship and fundamental HED science

Pulsed power can generate ~100 Mbar drive pressures, which can be used to obtain even higher pressures such as those in inertial fusion

Magnetically Driven Implosion

$$P = \frac{B^2}{8\pi} = 105\left(\frac{I_{MA}/26}{R_{mm}}\right)^2 \text{ MBar}$$

drive current I



100 MBar at 26 MA and 1 mm

100 GPa = 1 Mbar ≈ 10^6 atmospheres

Pressure equivalent to Energy Density (J/m^3)

1 Mbar = 10^{11} J/m^3

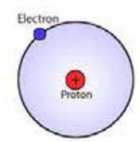
Z Storage capacitor

2e-6 Mbar

TNT

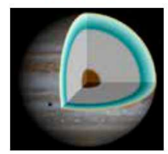
0.07 Mbar

Internal Energy of H atom



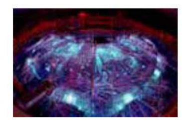
1 Mbar

Metallic H in Jupiter's core



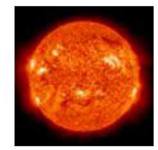
30 Mbar

Z Magnetic Drive Pressure



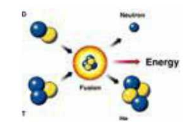
~100 Mbar

Center of Sun



250,000 Mbar

Burning ICF plasma

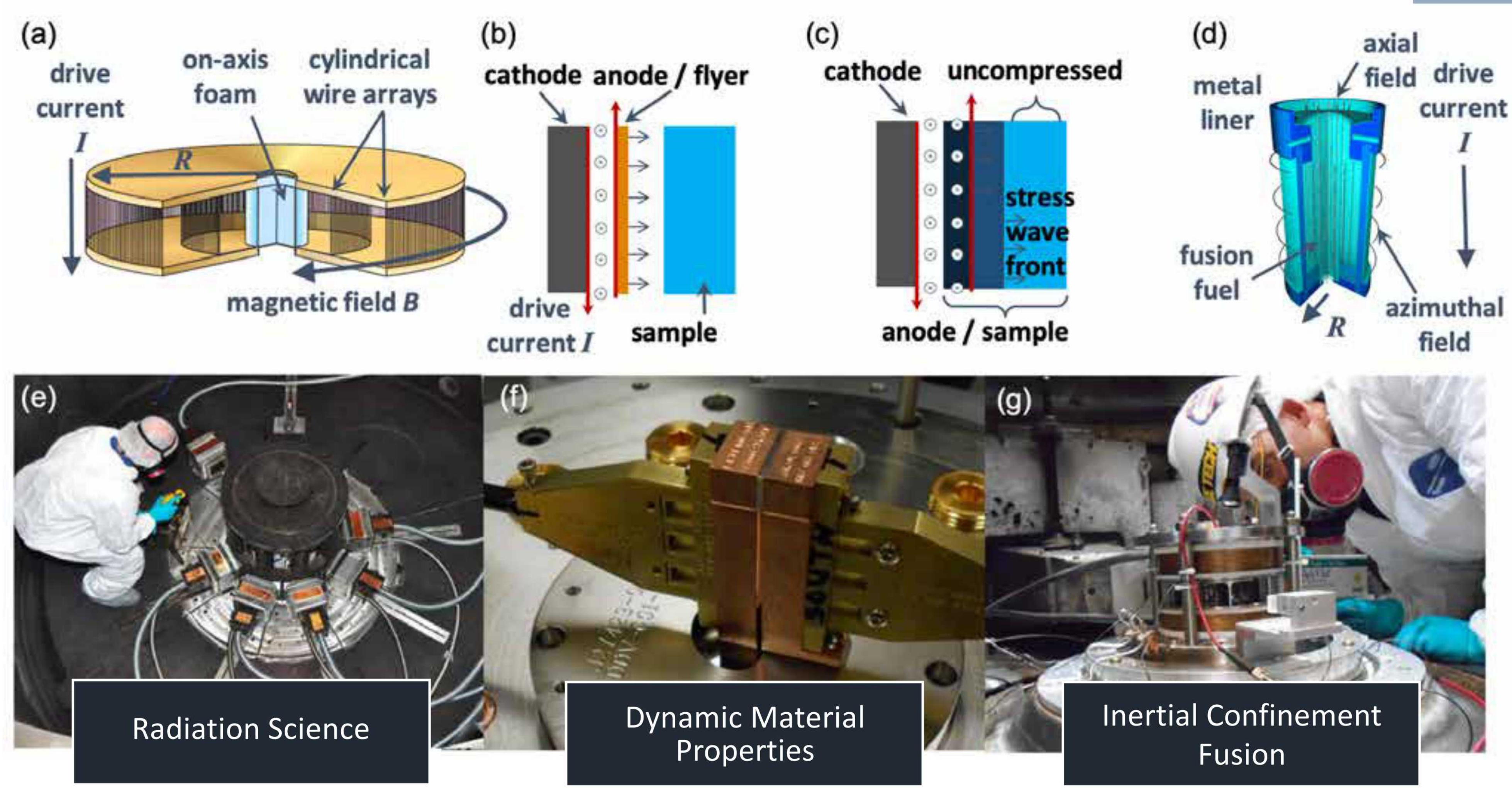


800,000 Mbar

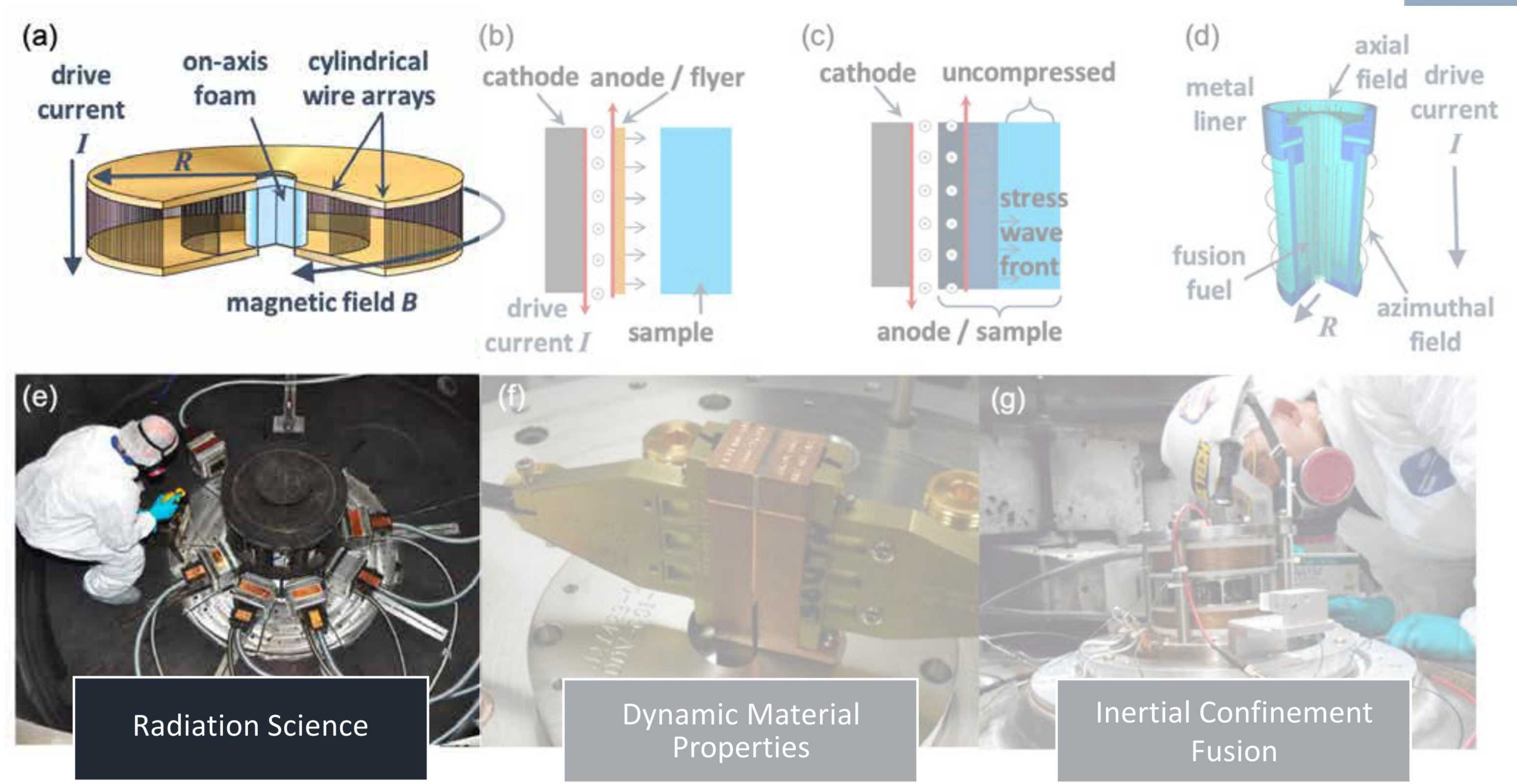
Push on samples

Compress fuel at high velocity

Z is a precision tool for high energy density science in three broad areas

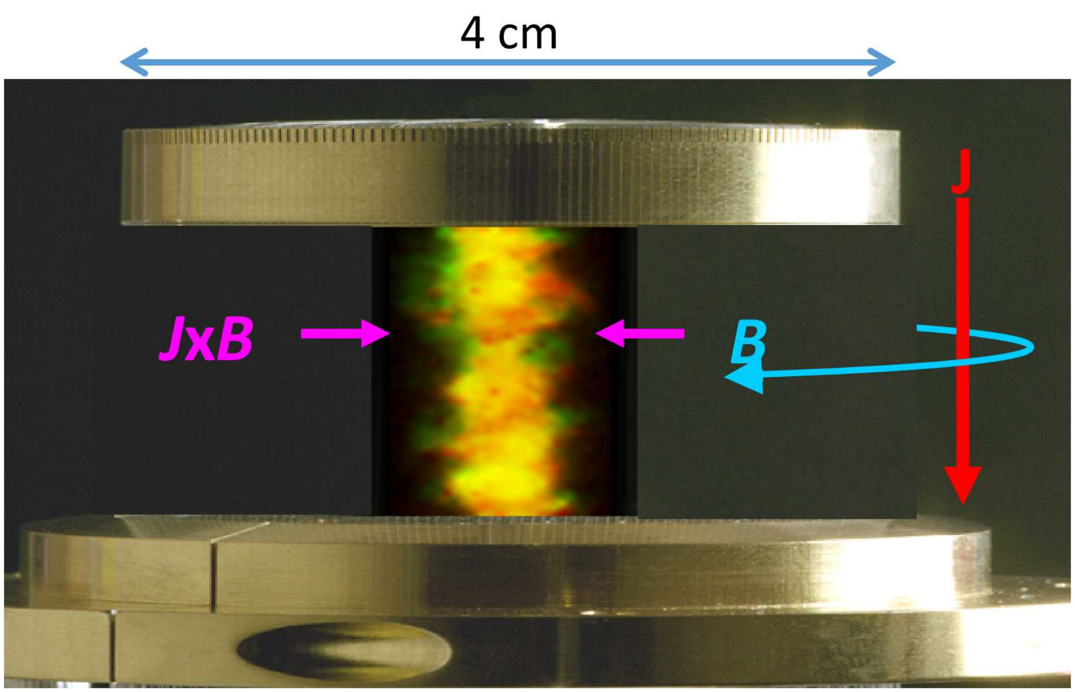


Z is a precision tool for high energy density science in three broad areas



The Z machine uses 26 mega-amperes of current to create >1 mega-joule of x rays

Basic

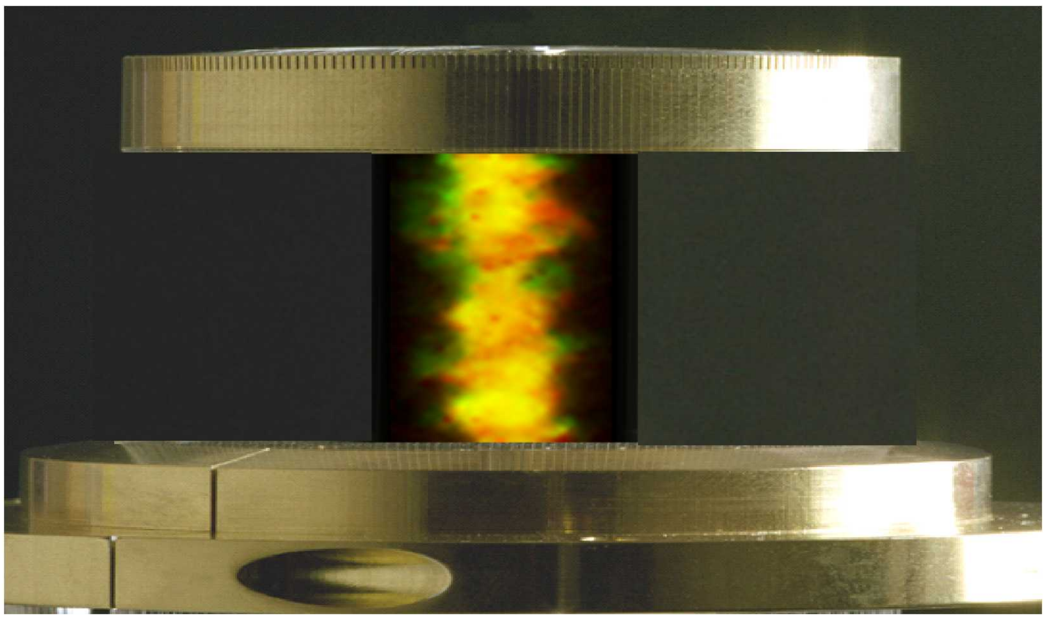


	ZR > 2011
Marx Energy	20.3 MJ
Ipeak	25.8 MA (1.5%)
Peak Power	220 TW (10%)
Radiated Energy	1.6 MJ (7%)

Sanford *et al.*, *PoP* (2002); Bailey *et al.*, *PoP* (2006); Slutz *et al.*, *PoP* (2006); Rochau *et al.*, *PPCF* (2007); Rochau *et al.*, PoP (2014).

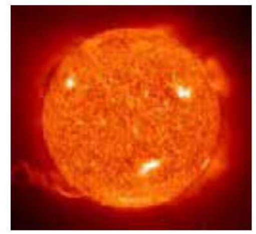
We collaborate with several institutions to do multiple radiation-driven basic science experiments on a single Z shot

Basic



Partners: LLNL, LANL, University of Texas, Ohio State, West Virginia U., U. Nevada-Reno, CEA

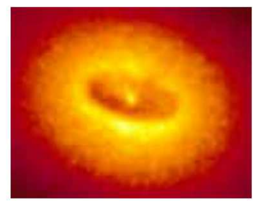
Stellar opacity



Question:
Why can't we predict the location of the convection zone boundary in the Sun?

Achieved Conditions:
T_e ~ 200 eV, n_e ~ 10^{23} cm^{-3}

Accretion disk



Question:
How does ionization and line formation occur in accreting objects?

Achieved Conditions:
T_e ~ 20 eV, n_e ~ 10^{18} cm^{-3}

White dwarf

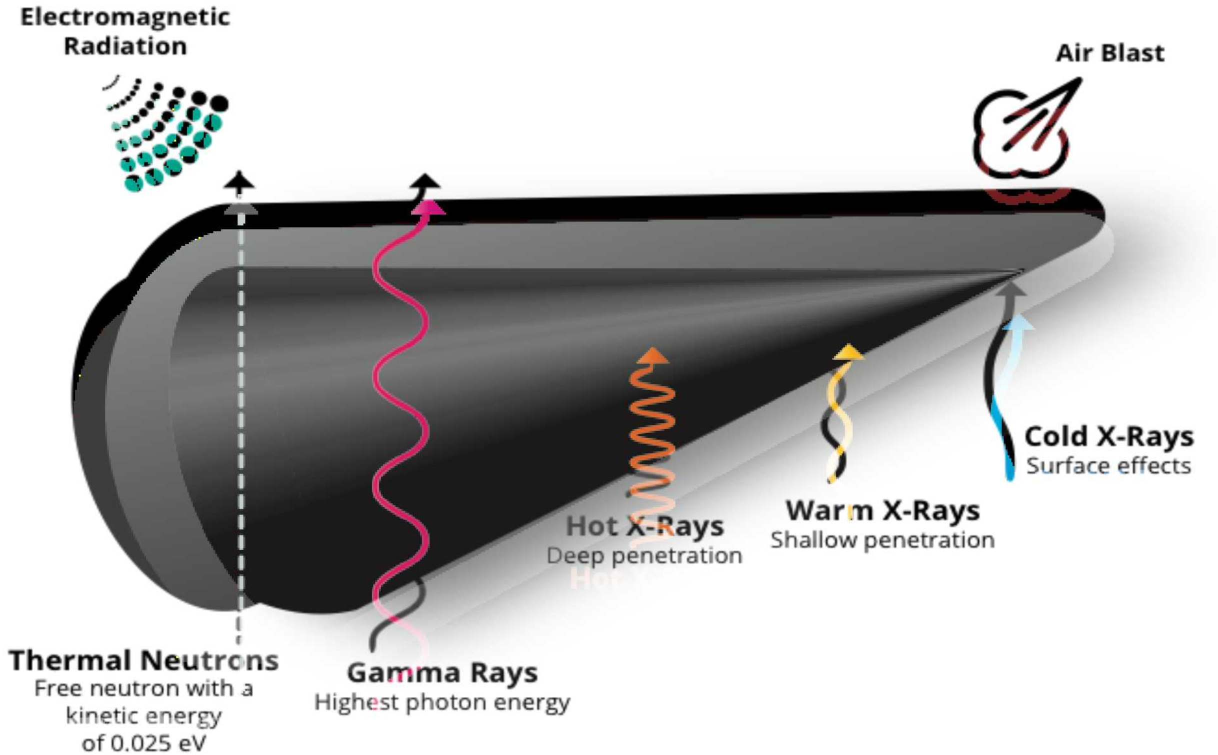
Question:
Why doesn't spectral fitting provide the correct properties for White Dwarfs?

Achieved Conditions:
T_e ~ 1 eV, n_e ~ 10^{17} cm^{-3}

Sanford *et al.*, *PoP* (2002); Bailey *et al.*, *PoP* (2006); Slutz *et al.*, *PoP* (2006); Rochau *et al.*, *PPCF* (2007); Rochau *et al.*, PoP (2014).

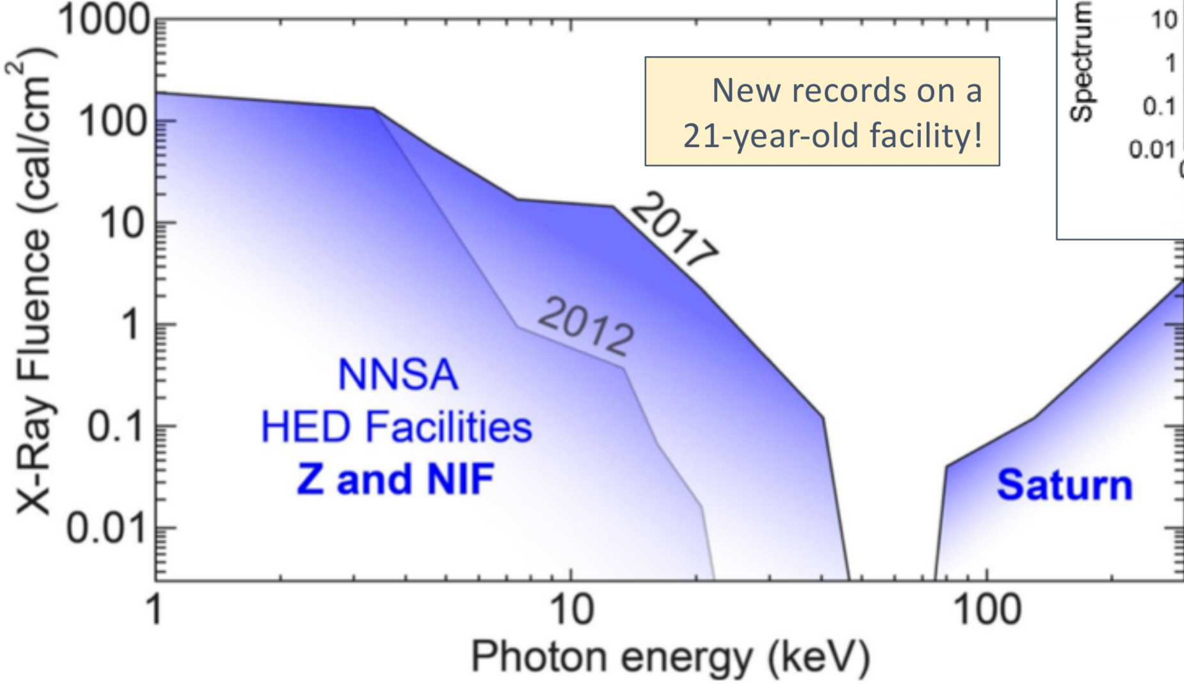
A major mission focus for Sandia is assessing the effects of hostile environments on nuclear weapons systems

Applied

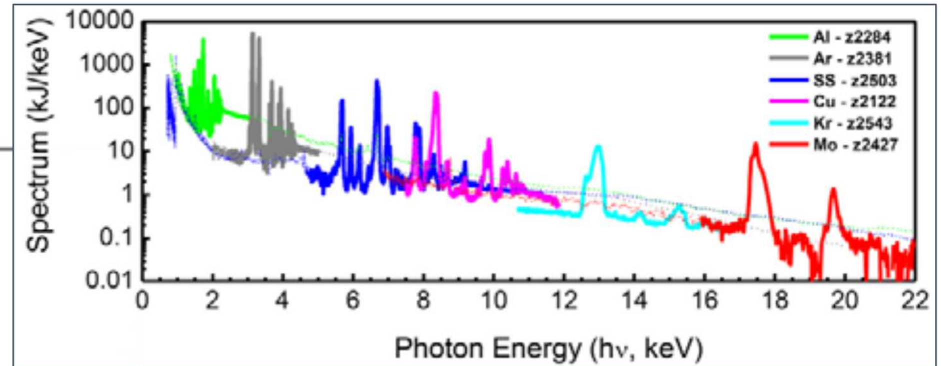


Sandia and Lawrence Livermore National Laboratories are collaborating to produce record levels of >10 keV X-rays using a variety of Z-pinch sources*

Applied



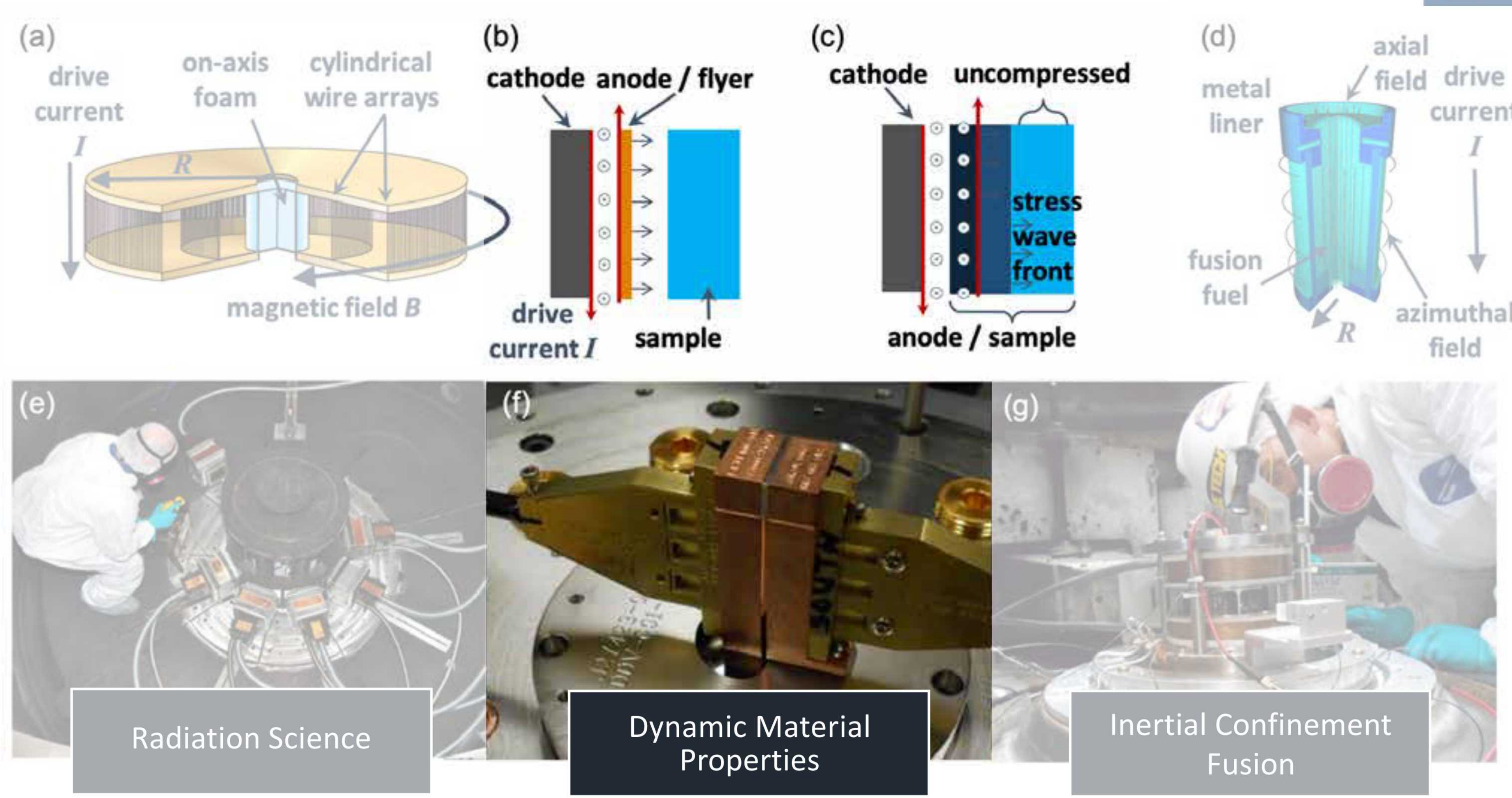
New records on a 21-year-old facility!



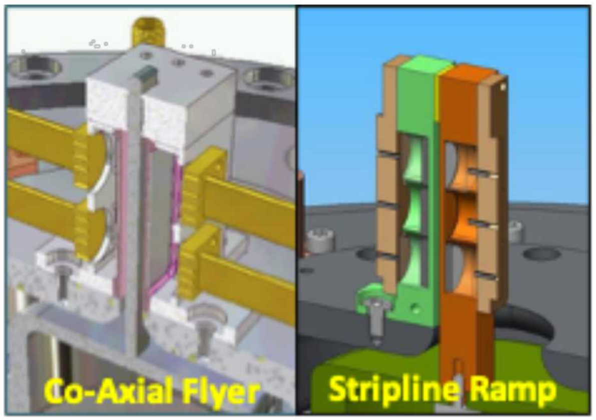
Z and NIF are developing advanced x-ray sources that provide unprecedented >10 keV yields

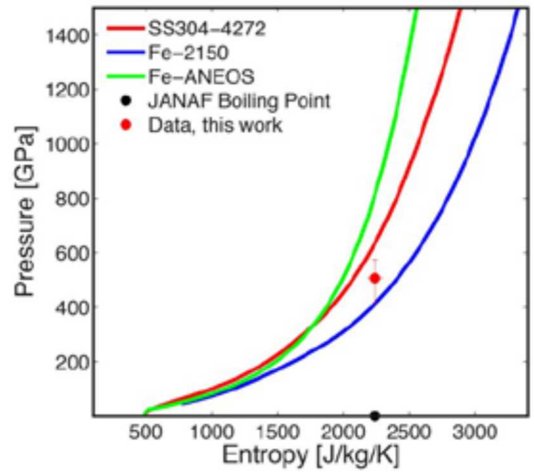
* D.J. Ampleford *et al.*, Phys. Plasmas 21, 056708 (2014).

Z is a precision tool for high energy density science in three broad areas



We collaborate with several institutions to do a large number of basic and use-inspired dynamic materials experiments every year





Basic

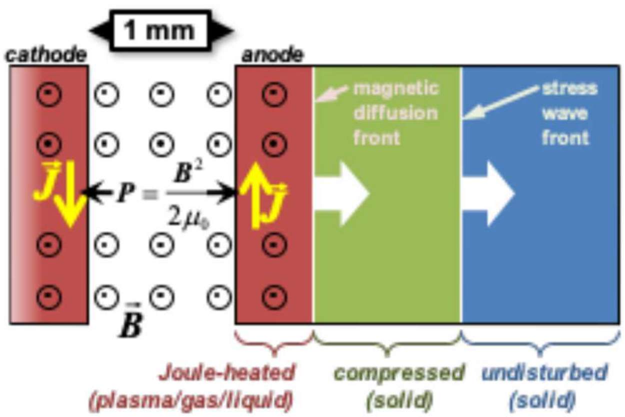
Question:

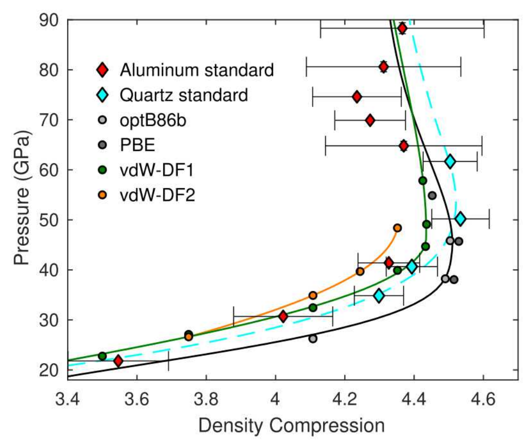
Would an iron meteor plow into a planet as a bullet, splatter as a drop of rain, or vaporize into a cloud and make iron rain?

Achieved Conditions:

One of the first determinations of the thermal state of an opaque material on the Hugoniot

Partners: Harvard, UC Davis, LLNL





Use-Inspired

Question:

How compressible is deuterium under high-pressure conditions? (Affects how easy it is to achieve ignition in the laboratory and planetary physics).

Achieved Conditions:

Unprecedented precision enabled discrimination between subtle differences in theoretical predictions

Sandia applies techniques and diagnostics matured on our use-inspired platforms to directly address mission needs in more challenging experiments

Applied

Z is a unique platform for dynamic materials research

- Large samples, high pressures, and relevant loading paths
- Containment capability allows us to field a wide range of hazardous materials without relying on surrogacy

Compared response of 5- and 52-year-old Pu samples to improve pit aging analysis for certification models

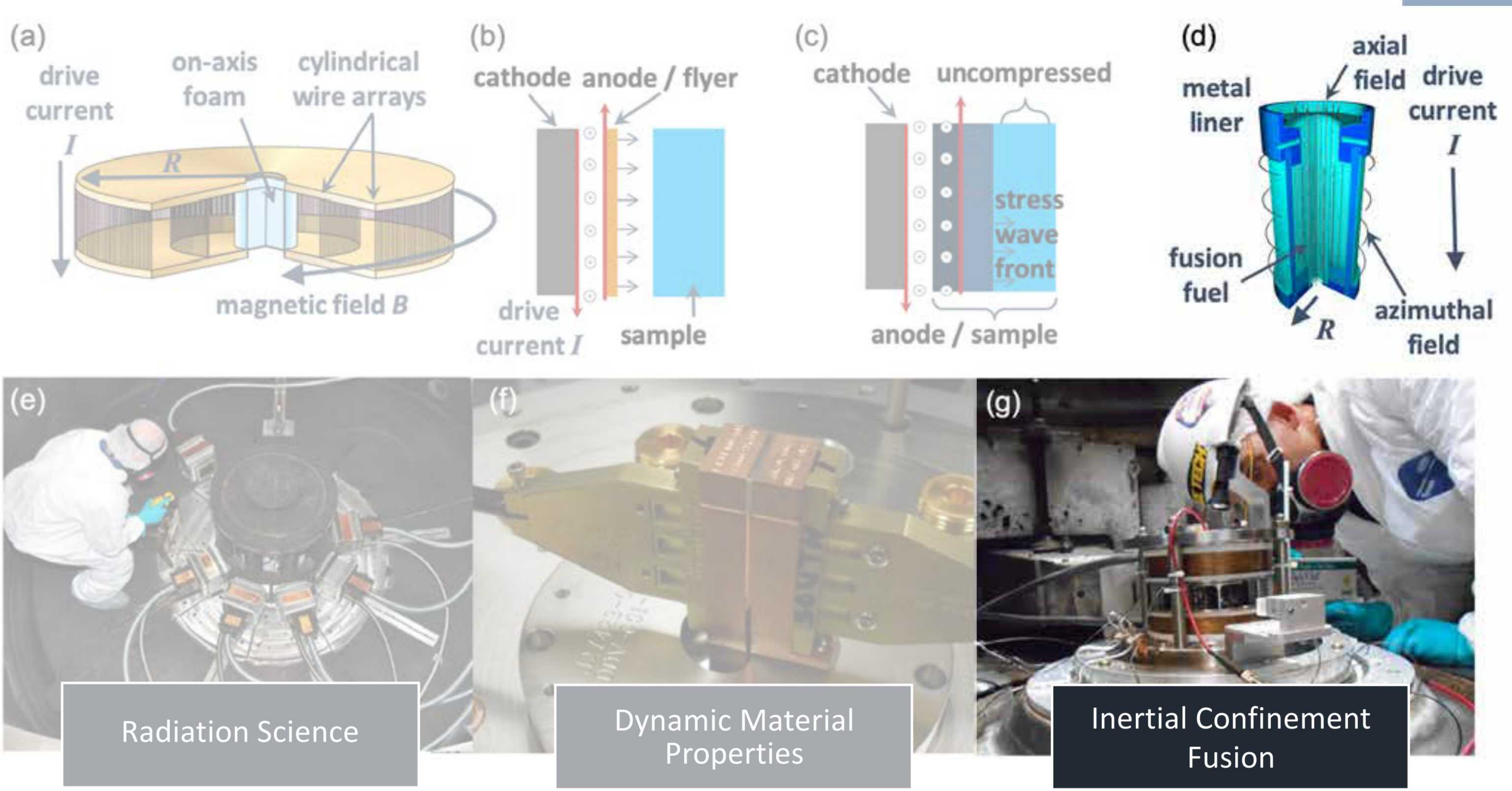
Conducted high-pressure uranium experiments on Z to benchmark LANL and LLNL EOS models

New capabilities are being developed over the next several years to extend our impact for mission work

Partners: LANL, LLNL

Los Alamos NATIONAL LABORATORY EST 1943

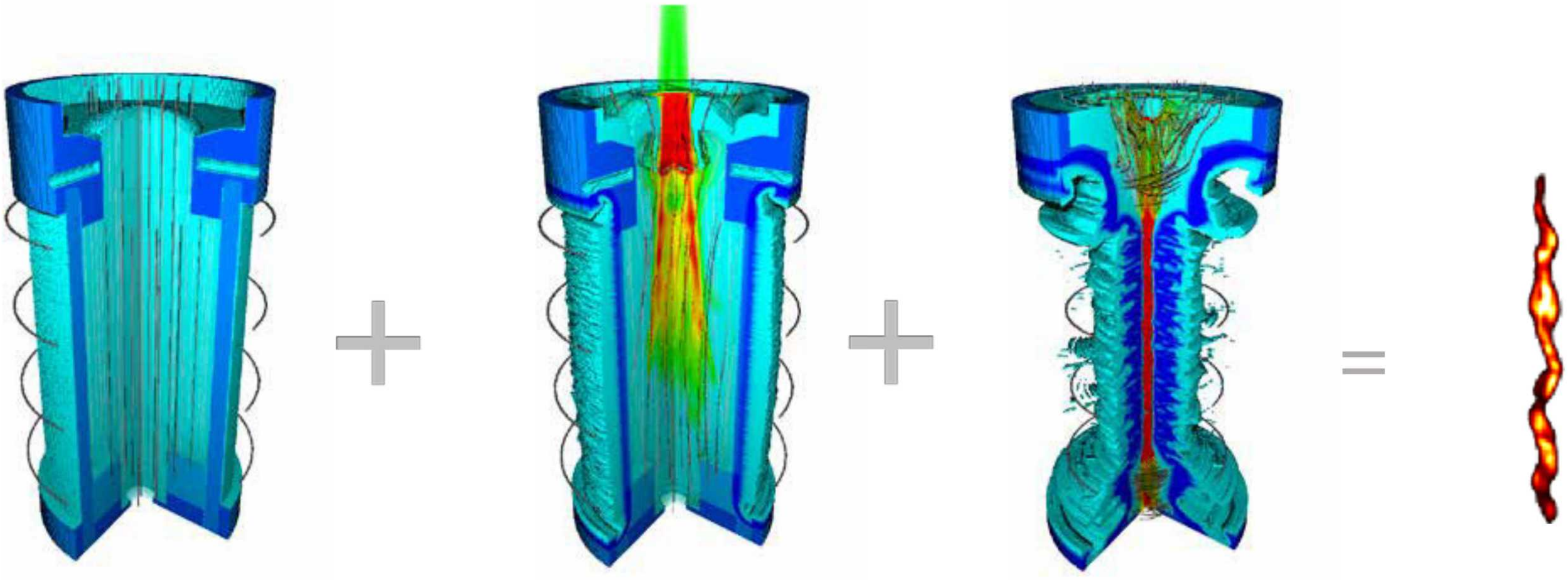
Z is a precision tool for high energy density science in three broad areas



MagLIF is a Magneto-Inertial Fusion (MIF) concept

Use-Inspired

Relies on three components to produce fusion conditions at stagnation



Magnetization
- Suppress radial thermal conduction losses
- Enable slow implosion with thick target walls

Preheat
- Ionize fuel to lock in B-field
- Increase adiabat to limit required convergence

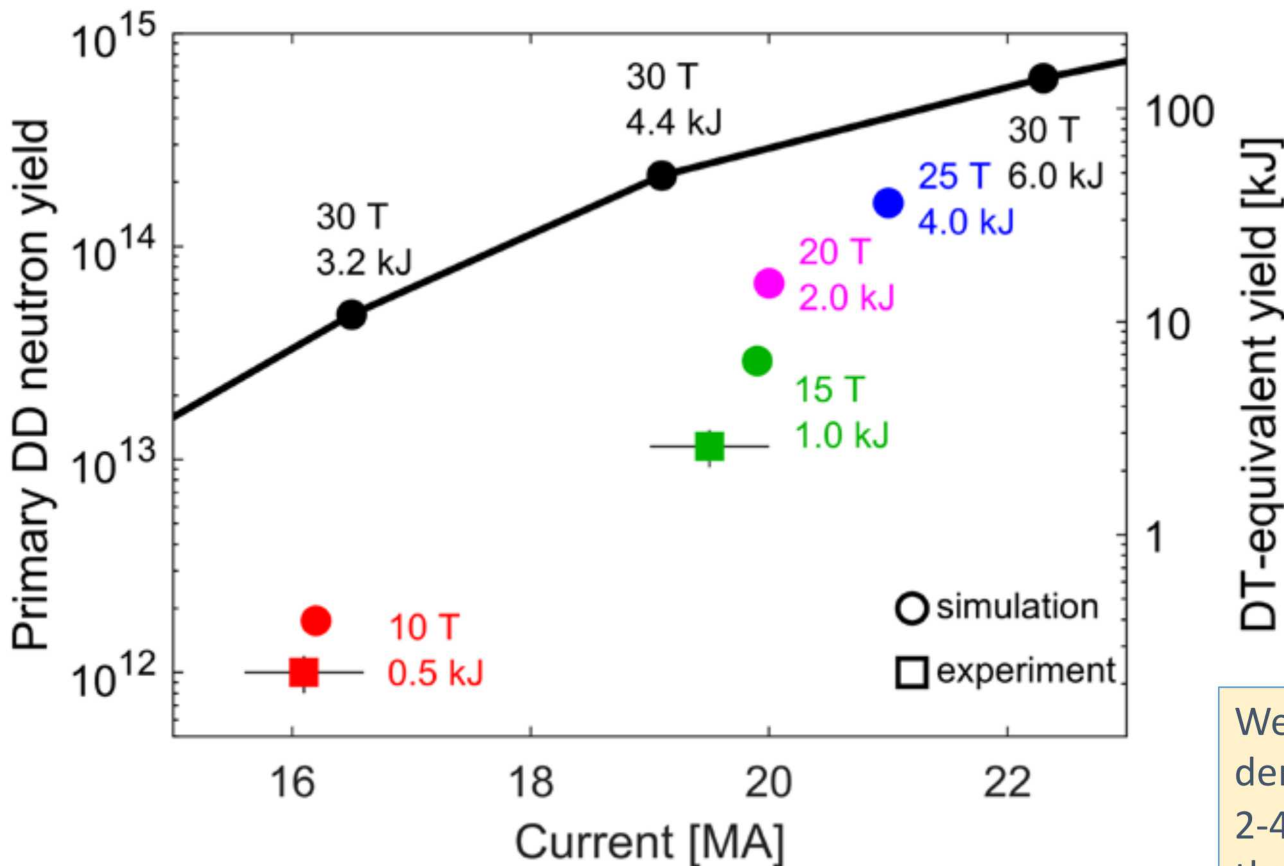
Implosion
- PdV work to heat fuel
- Flux compression to amplify B-field

Stagnation
- Several keV temperatures
- Several kT B-field to trap charged fusion products

S.A. Slutz *et al.*, Phys. Plasmas (2010); A.B. Sefkow *et al.*, Phys. Plasmas (2014); S.A. Slutz *et al.*, Phys. Plasmas (2018).

We will continue to test MagLIF scaling through further increases in magnetization, preheat, and drive current; 10s of kJ DT-equivalent yield possible in next 2 years

Use-Inspired



We are working to demonstrate 20-25 T, 2-4 kJ, 20-21 MA in the next 2 years

S. A. Slutz, et al., Phys. Plasmas (2018).

Fusion drives exciting fundamental and use-inspired science!
it is also intended as an enabling tool for stockpile stewardship applications

Applied

Yield	High Energy Density Science Applications
~0.01 MJ	• Interplay of thermonuclear fusion burn and mix • Nuclear physics data (reaction-in-flight, fission, and radiochemistry)
>0.1 MJ	• Transport of charged particles in plasmas • Threshold for fusion-fission physics
~few MJ	• Threshold for enabling complex mix physics studies. • Robust radiation and charged particle transport • Robust fusion-fission experiments
20-30 MJ	• Higher fidelity versions of the above experiments are possible • Neutron sources for outputs and environmental studies
>500 MJ	• Use of fusion targets to drive complex experiments • Use of fusion targets for material properties (EOS, opacity) research • Combined neutron and x-ray environments for outputs and effects studies

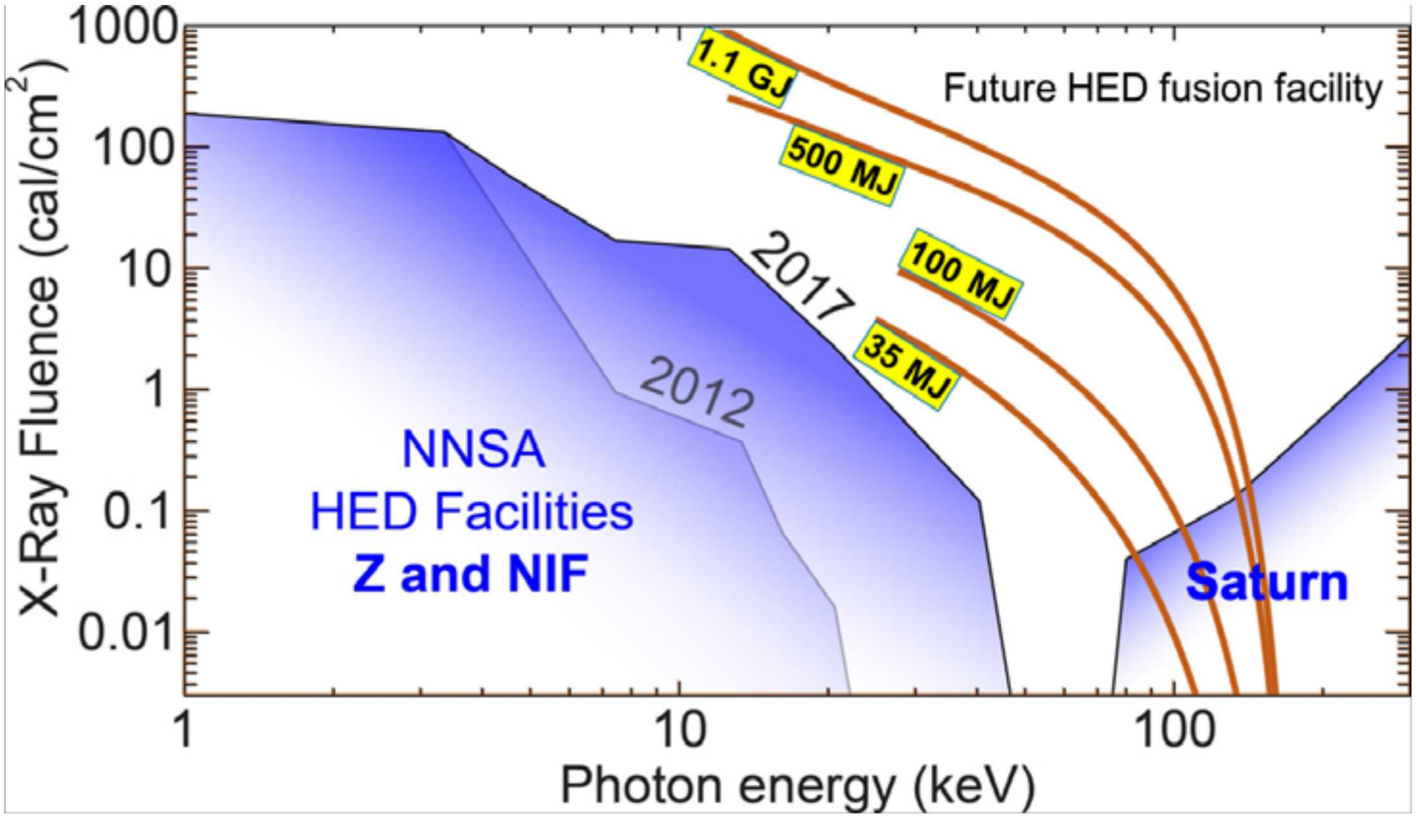
Excerpt from NNSA 2018 ICF Framework Document

Future high yield fusion facilities would create hot plasmas that would provide even more powerful sources of 10-100 keV X-rays

Basic

Use-Inspired

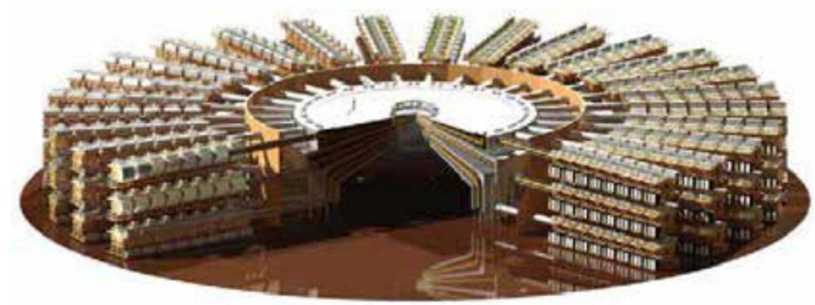
Applied



Such a Z-pinch driver would also be capable of powerful radiation-only x-ray sources, and high-pressure dynamic materials experiments.

Sandia has proposed a next generation pulsed power facility to the NNSA

- **World's most powerful warm x-ray and fast fusion neutron source**
  (hostile nuclear survivability)
- **Enabling capability for high energy density physics**
  (nuclear explosive package certification)
- **It would attract and test tomorrow's stewards of pulsed power research**
- **It would provide a venue for scientific and technical innovation for national security**



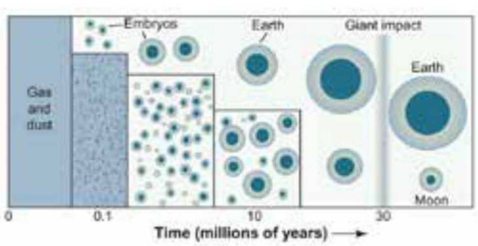
Proposed project start date ~2025
Proposed project completion date ~2032

Z will celebrate ~35 years of z-pinch physics in 2030, with some parts of infrastructure ~45 years old.

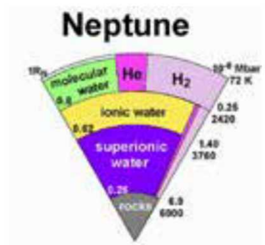
Sandia is evaluating pulsed power architectures
- ~3x diameter of Z today
- Delivers 800-1000 TW of electrical energy
- Couples ~10 MJ to fusion targets
- Requires new operations concepts to reduce manual labor and potential worker hazards

Sandia is trying to support a growing community of practice in pulsed power research on Z and smaller-scale facilities

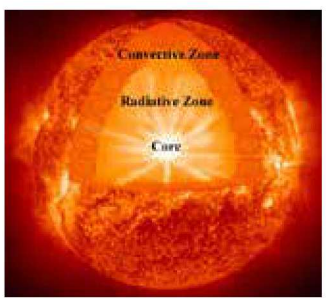
Z Fundamental Science Program



Earth and super earths
Properties of minerals and metals



Jovian Planets
Water and hydrogen



Stellar physics
Fe opacity and H spectra

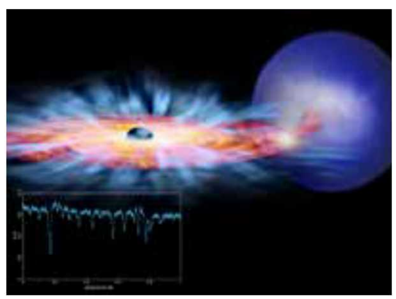


Photo-ionized plasmas
Range of ionization param. ξ

https://www.sandia.gov/Pulsed-Power/workshop/2020.html

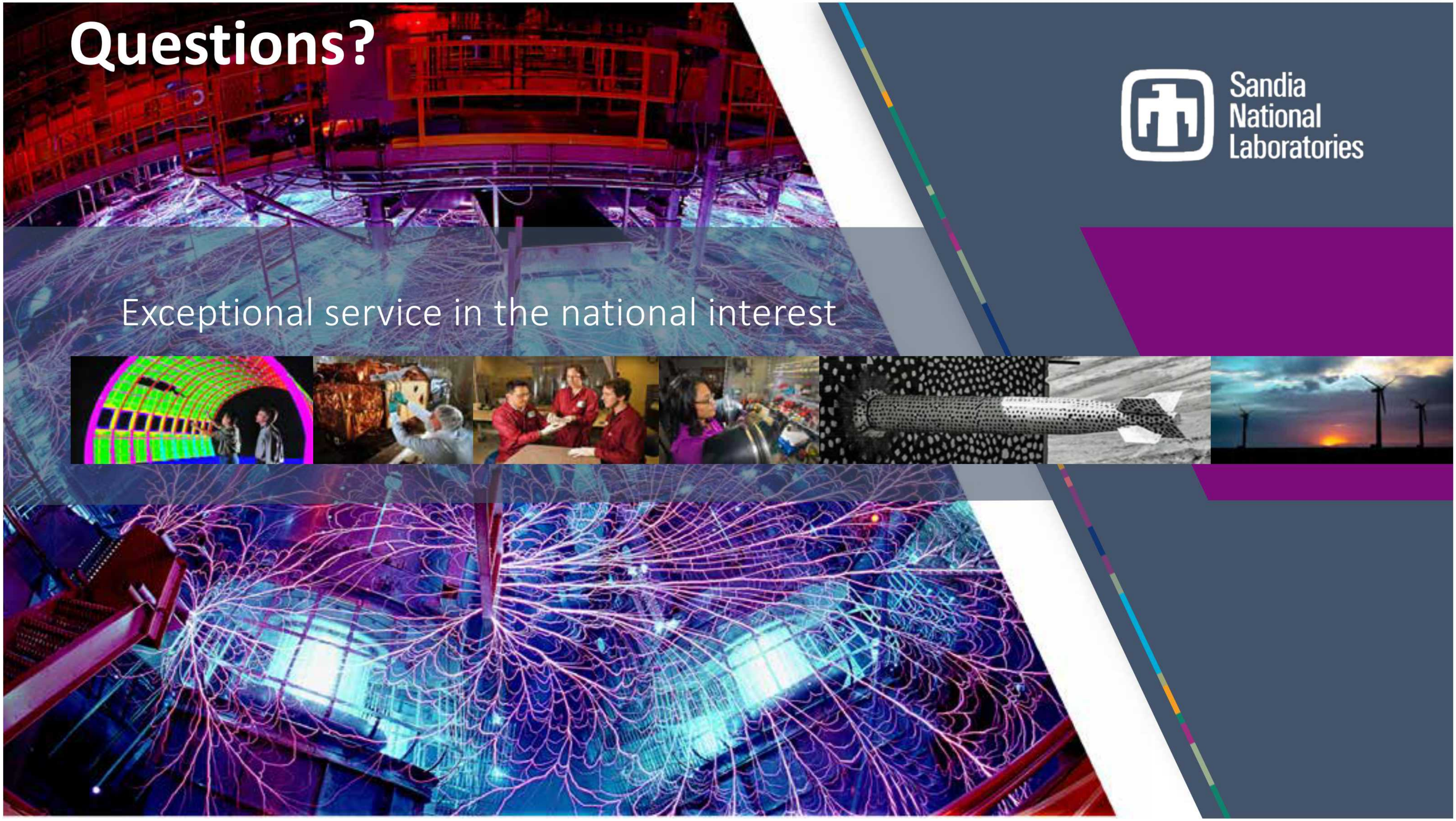
ZNetUS Community

- Intended to build upon success of the LaserNetUS consortium
- 1st workshop held January 6-8, 2020 at La Jolla Shores Hotel
- Hosted by Center for Energy Research at UCSD (Prof. Farhat Beg)
- Executive Committee and Charter formed
- Topics include
  - Pulsed power technology
  - Magneto-inertial fusion
  - Astrophysical plasmas and planetary science
  - MHD and hybrid code development
  - Magnetized HED

https://cer.ucsd.edu/_news-events-articles/2020/ZNetUS_Workshop_2020.html

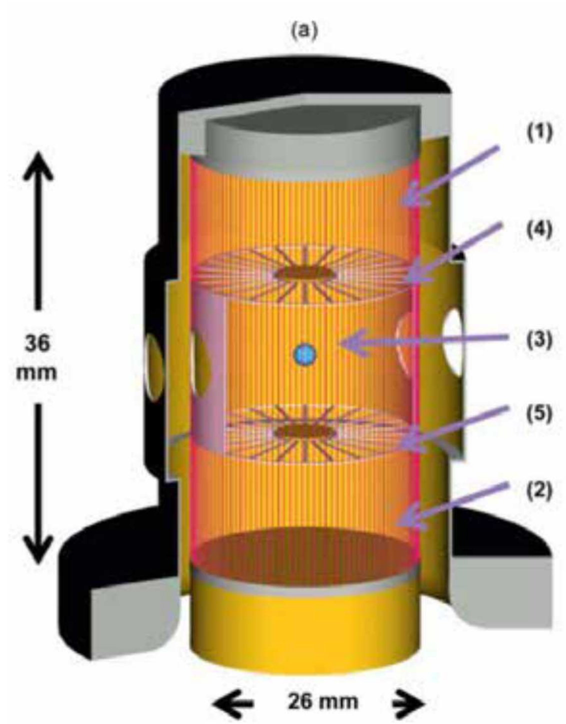
Sandia is continuing to operate Z during the pandemic

- As a national security laboratory, Sandia has maintained continuous operations this year, including Z operations.
  - >50% of our staff are teleworking, including most of the scientists
  - We have implemented a number of processes to protect our on-site workforce
- Z was shut down for 2 weeks in July due to a positive case in the operations workforce, but resumed shot operations on Friday, July 31.
- Travel to Sandia requires prior approval, particularly if we wish to avoid a two-week quarantine prior to stepping foot on site.
- Travel by Sandia staff requires prior approval to avoid two-week quarantines upon returning to New Mexico, and is discouraged.

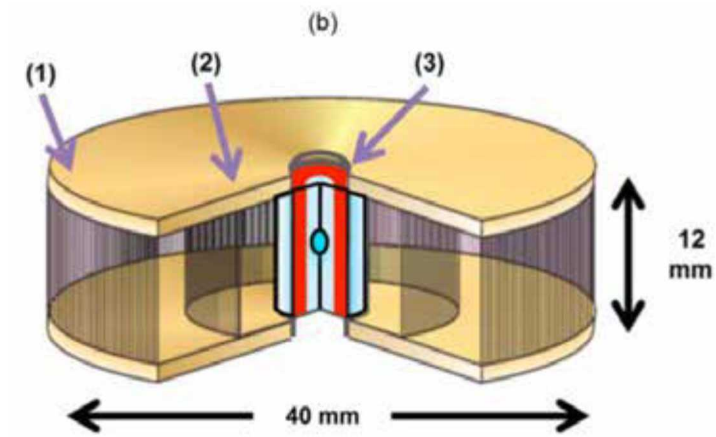

Questions?
Exceptional service in the national interest
Sandia National Laboratories

In 2007, the Sandia Inertial Confinement Fusion (ICF) program switched from indirect drive (radiation-driven) to magnetic direct drive target research*

Basic



Double-ended Hohlraum

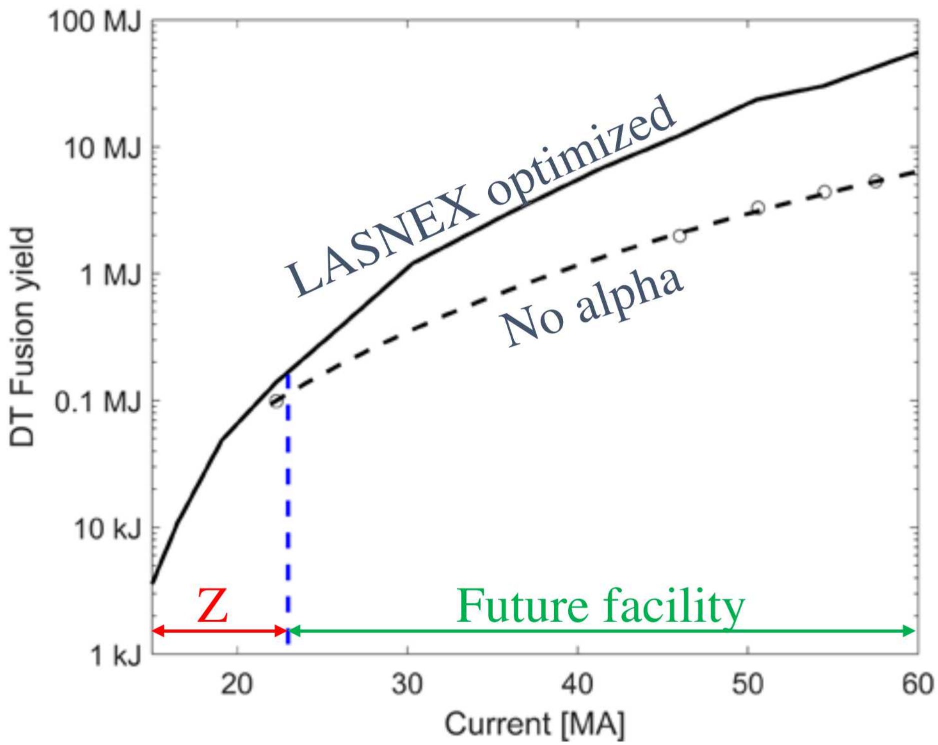


Z-pinch Dynamic Hohlraum (with capsule!)

* M.E. Cuneo *et al.*, IEEE Trans. Plasma Sci. (2012).

Achieving close to 100 kJ yield on Z with MagLIF would improve the credibility of scaling to multi-MJ fusion yields on a future facility

2D clean simulated MagLIF performance



- At >60 MA, MagLIF appears capable of >10 MJ yields
- Most credible scaling is for gas (volume) burning targets; ice-burning targets may be capable of higher gains*
- Program of work on Z, NIF, and Omega continues to address scaling physics
  - 3D Effects
  - Mix
  - Magnetization
  - Implosions

S. A. Slutz *et al.*, Phys. Plasmas (2018); * Slutz & Vesey, Phys. Rev. Lett. (2012).

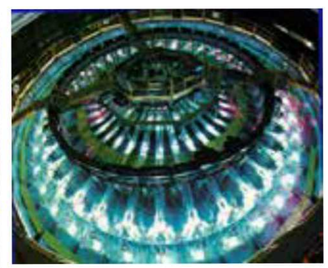
Z is one of three pulsed power facilities used at Sandia for this mission

Applied

Z Machine
Cold/warm X-rays; fast fusion neutrons

Annular Core Research Reactor Fission neutrons

HERMES III Gamma rays



Saturn Hot X-rays