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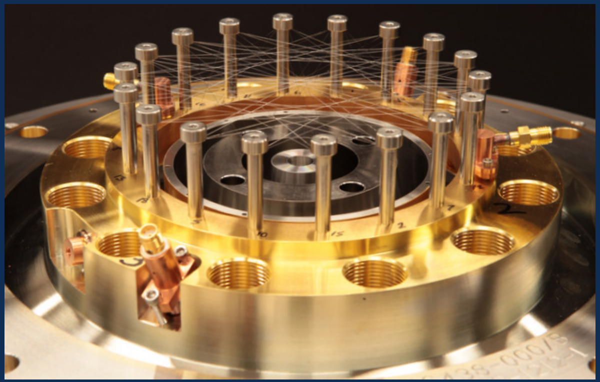

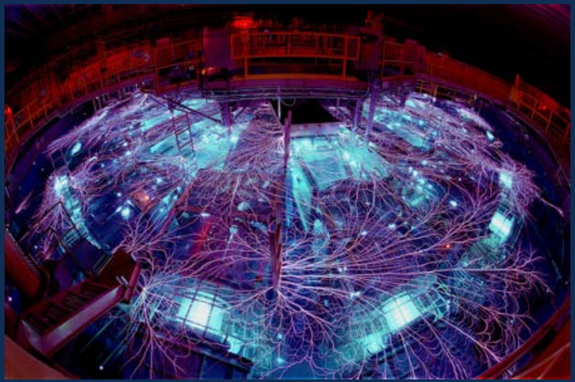

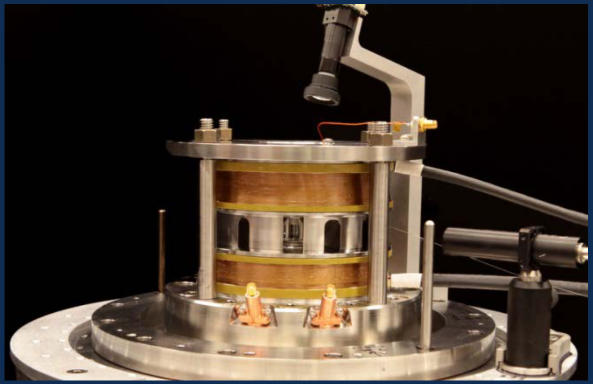

Capability Advances at the Sandia Z Machine

Joel Lash

Senior Manager, Z Facility R&D

U.S. DEPARTMENT OF ENERGY NNSA National Nuclear Security Administration

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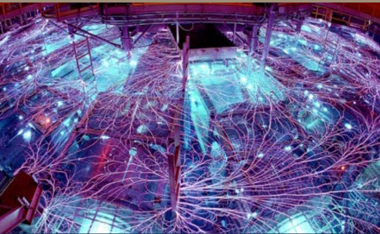


Outline

Pulsed Power / Facility

- 22 MJ stored energy
- 3 MJ delivered to the load
- 26 MA peak current
- 1 - 100 Megabar
- 100 - 1000 ns pulse length

Subsystems

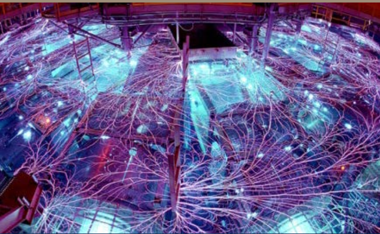
- Backlighter
- Cryogenics
- External Magnetic Fields
- Gas Fill
- Explosive Containment for High Z Materials

Experimental Loads

- Wire Arrays – Radiation Sciences
- Liners – Inertial Confinement, Material Sciences
- Gas Puff – Radiation Sciences
- Flyer Plates – Material Sciences
- Short Circuit – Material Sciences

Diagnostics

- X-Ray
- Neutron
- Optical
- ZBL Backlighter



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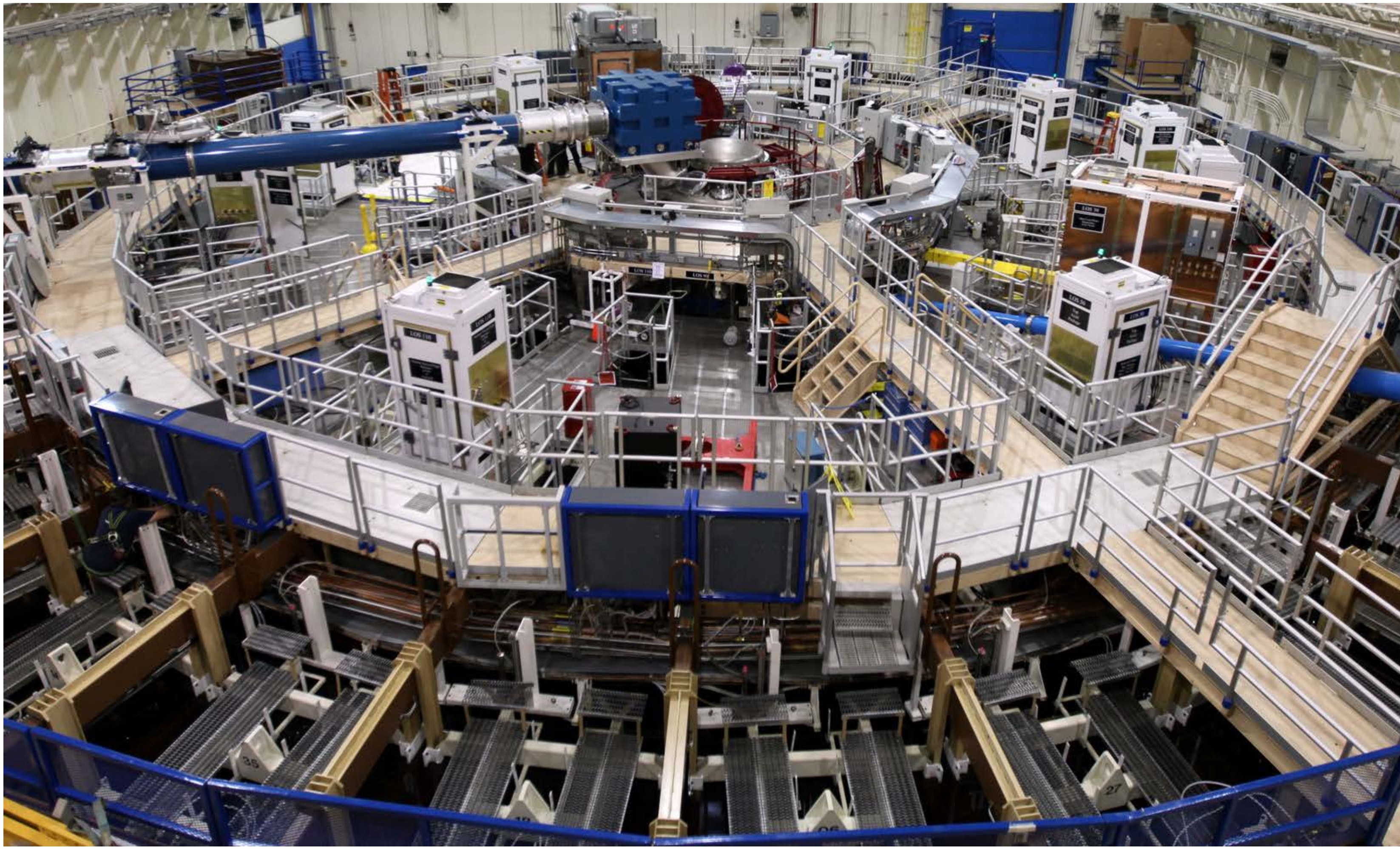
Z is a unique world class pulsed power facility at Sandia National Laboratories



36 Marx generators
2160 capacitors

~ 1M gallons of transformer oil
~ 0.5M gallons of deionized water

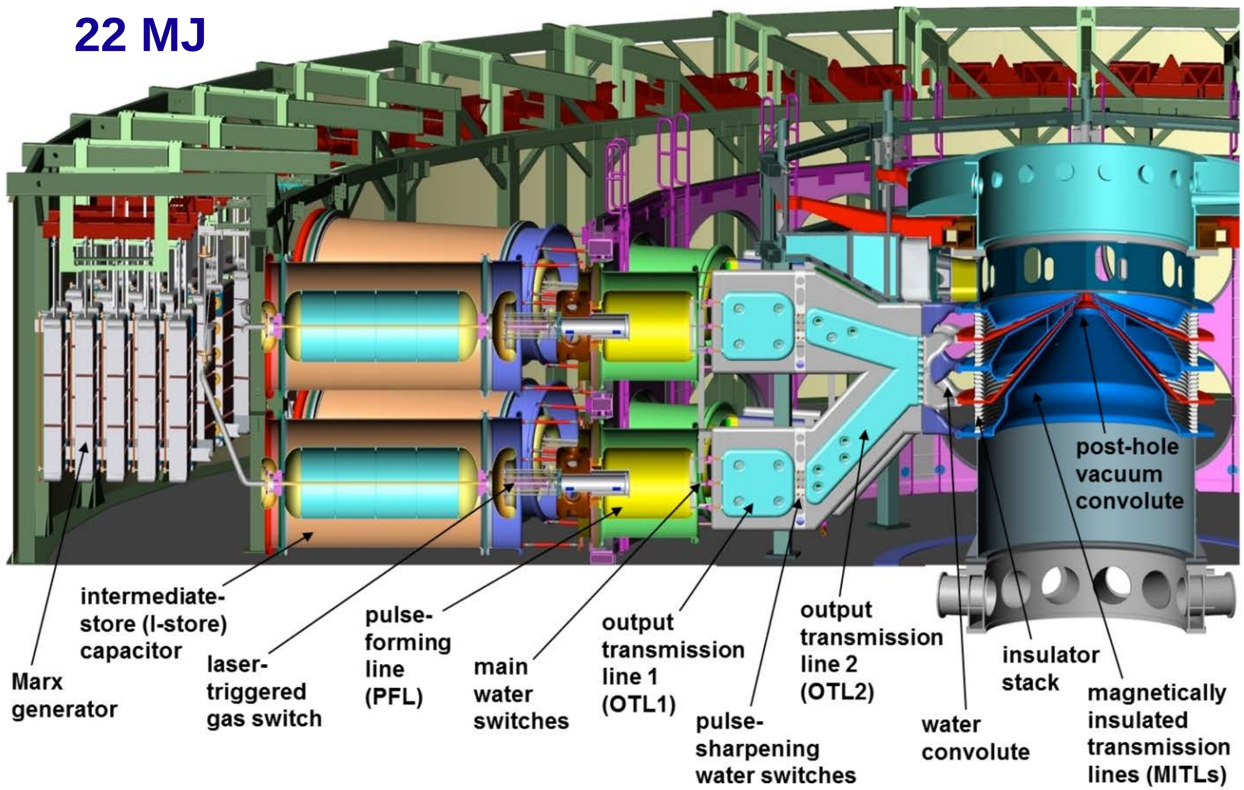
100,000 liter
vacuum vessel

Z is a unique world class pulsed power facility at Sandia National Laboratories

20 TW
22 MJ

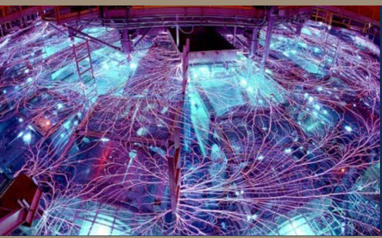
80 TW
8 MJ

Charge for 3 minutes to reach 85 kV



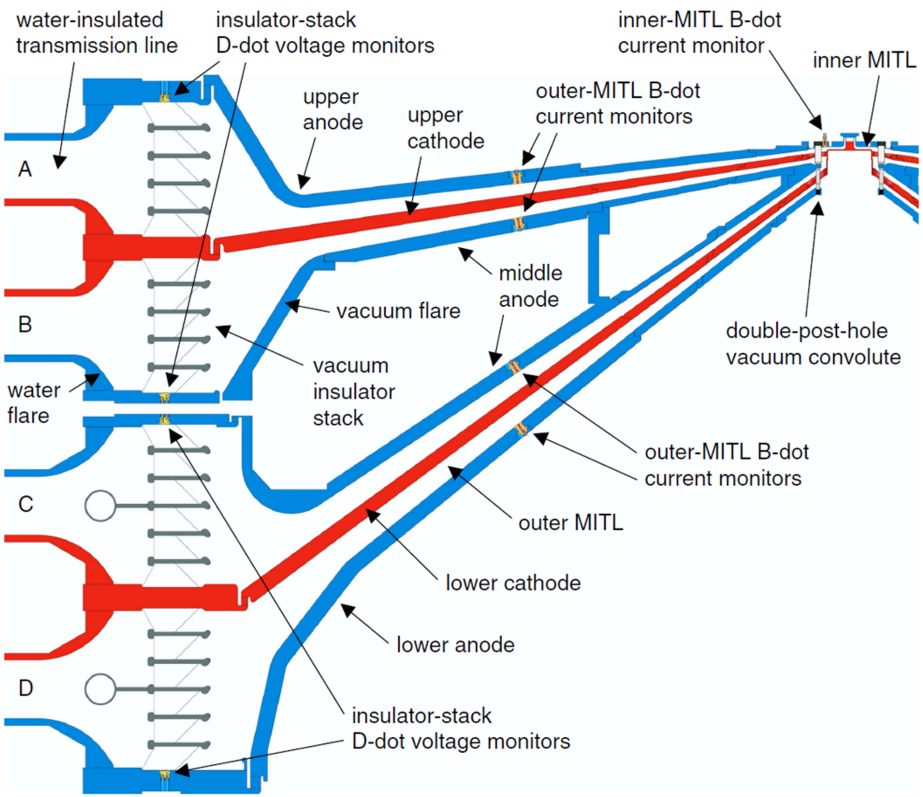
330 TWs & 2.5 MJ of X-ray output

The Z machine compresses energy in both space and time

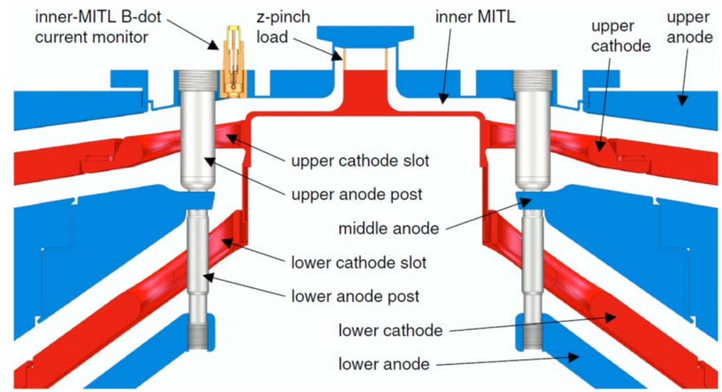


Z is a unique world class pulsed power facility at Sandia National Laboratories

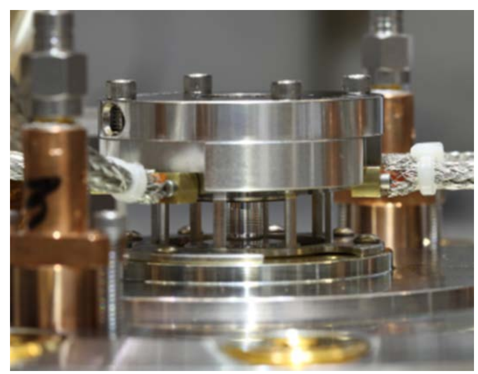
Z vacuum insulator stack and MITLs



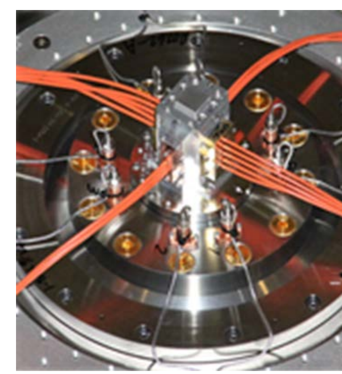
Post hole convolute system and load



ICF liner load

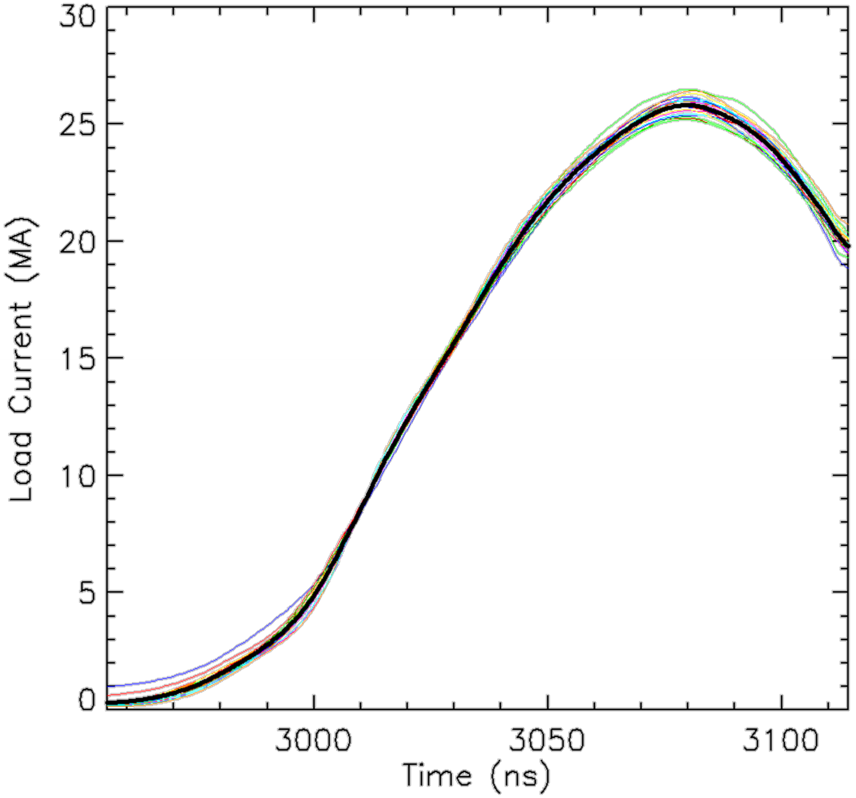


DMP load

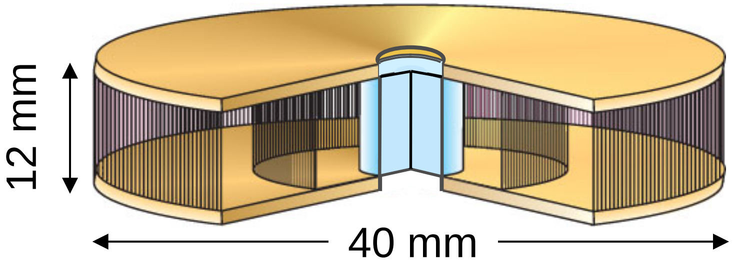


Pulse Shape Flexibility and Reproducibility

Load Currents (20 shot average)



Z-pinch Dynamic Hohlraum



Standard ZPDH Characteristics

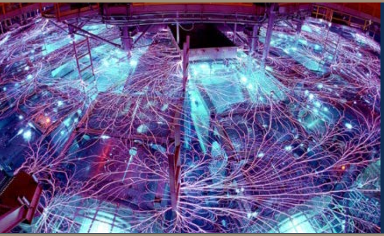
360 W wires – 11.4 μm diameter

m = 8.5 mg W total

V_{marx} = 85 kV (20.3 MJ)

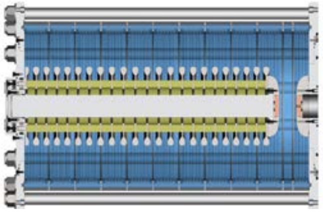
I_p = 25.8 ± 0.4 MA [20 shots]

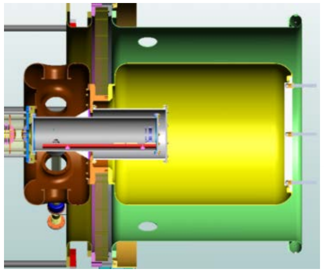
The z-pinch produces record currents of 25.8 MA with 1.5% reproducibility

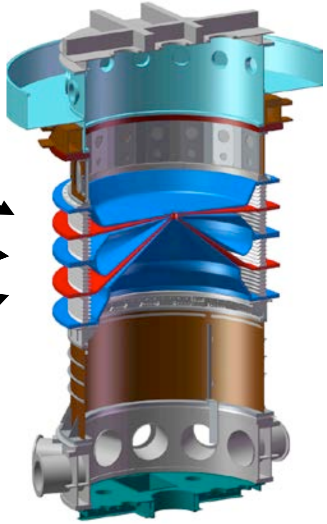


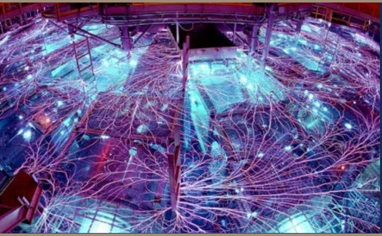
We are increasing the peak current available on Z from 26 to 32 MA

- **6.7 MV laser-triggered gas switches – done!**
  - The new switches allow increasing the Marx voltage from 85 to 95 kV, double the precision of the pulse shape, and increase the shot rate by reducing maintenance.
- **6.7 MV pulse-forming lines – done!**
  - The new PFLs will allow us to increase the Marx voltage from 85 to 95 kV, and improve worker safety.
- **Next generation vacuum insulator stack – in progress**
  - The new stack will allow operation at 95 kV, and eliminate flashovers that can affect the pulse shape.
- **Lower-inductance MITL-convolute system**
  - A new system would increase the peak current 5%, lower convolute costs by $1M each year, and increase the shot rate by 5%.
- **Horizontal water triplates that connect the PFLs to the stack**
  - The new triplates will eliminate the 3D water convolute, which will increase the current by 7%.

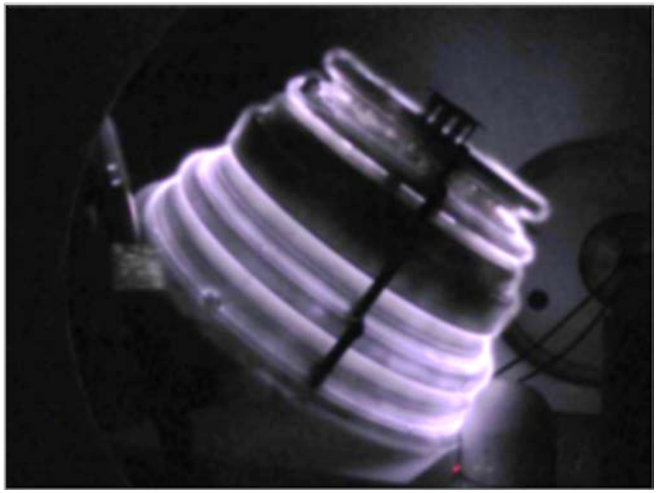




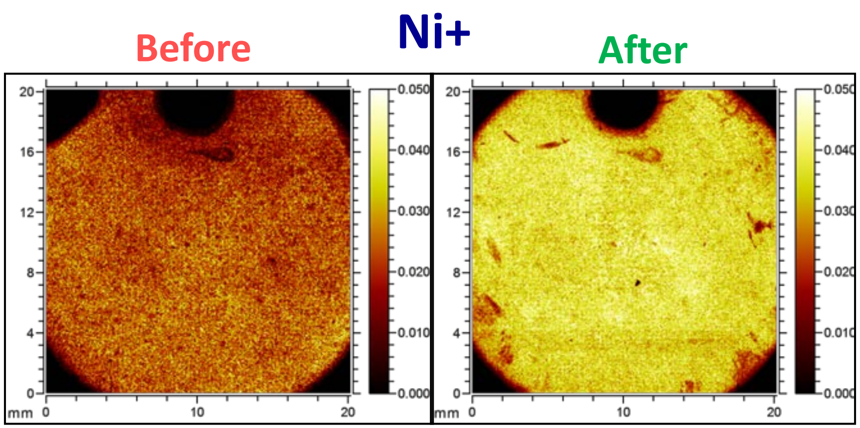




We are working to improve current delivery to the experimental load



Plasma cleaning development on Z Convolute hardware



*Coupon with environmental exposure survey, shown **Before** and **After** plasma cleaning. Increase in detected bulk nickel indicates reduced surface contaminants on SS304 sample.*

- **Increased load current will benefit nearly all Z experiments**
  - Achievable pressure in dynamic materials experiments
  - Radiated power in wire array experiments
  - Fuel compression in MagLIF experiments
- **An *in-situ* plasma cleaning system will remove surface contaminants from highest power density surfaces**
  - Delay or mitigate creation, evolution of cathode and anode plasmas
  - Hydrocarbons and desorbed water likely culprits
  - Quantitative testing underway to evaluate removal rates for surface contamination materials

Safety and Facility Upgrades

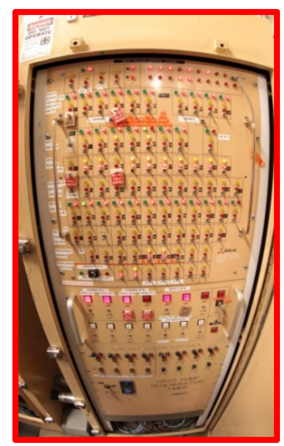
Vacuum Chamber Air Exchange

Replacing the Be Refurbishment Tent

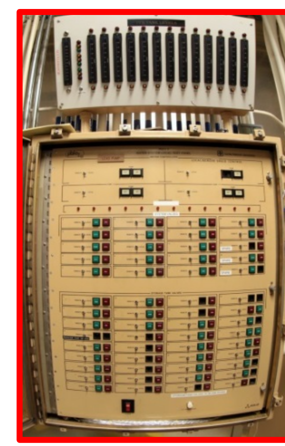
Replacing Aging/Legacy Equipment

- Over the past few years, many legacy control and monitoring systems used have been replaced and/or upgraded. (ZBL, Mykonos, …)
- We are developing new systems to improve the capability, safety and reliability of control systems for Z and other machines.

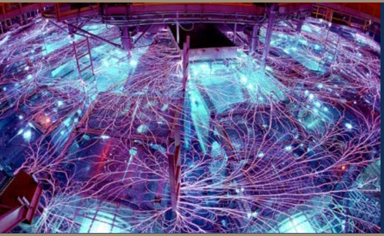
Z's control system computer. In place since 1993. Replaced May 2015



Z's vacuum control system In place since 1985.

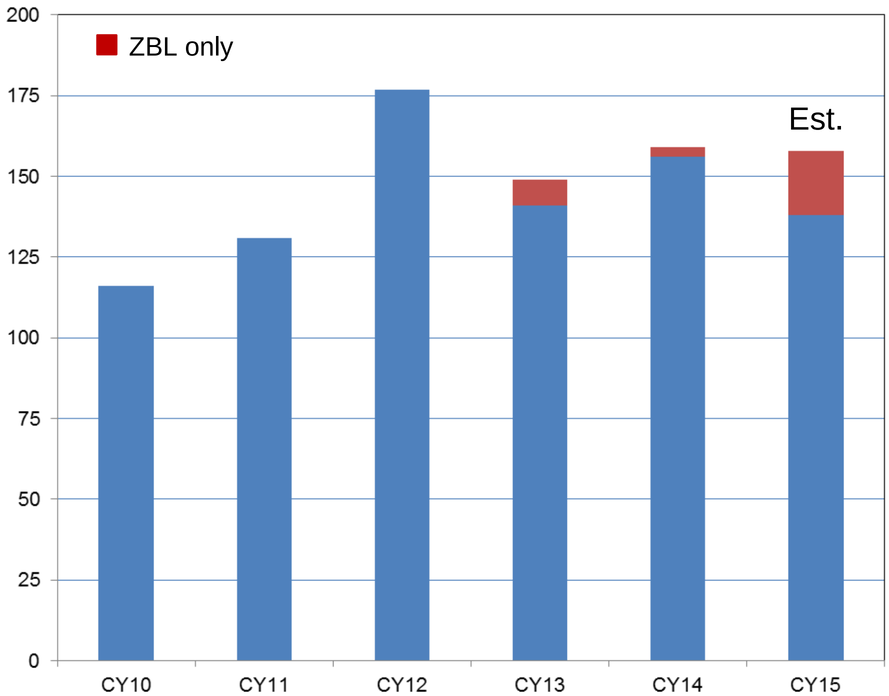


Z's water drain/fill control system In place since 1985.



Z Shot Rate and Shot Planning

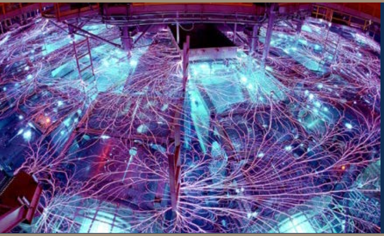
Z Shots by Calendar Year



~550 Shot Days were requested by LANL, LLNL, and SNL in CY15 – 3X more shot requests than available!

Z Shot Planning

- Typically plan for 140 – 160 shots a year based on budget
- Single shift operation:
  - 6 am shift start
  - 5 pm shot window closes
- Nominally 1 shot per shot day
  - 3 – 6 days for containment shots
- Most maintenance performed in parallel with daily shot preparations
- External PIs work with internal PIs for planning and execution



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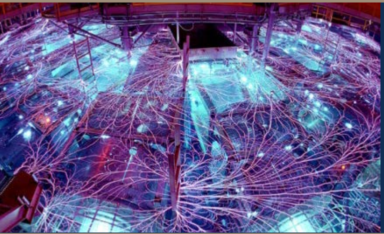
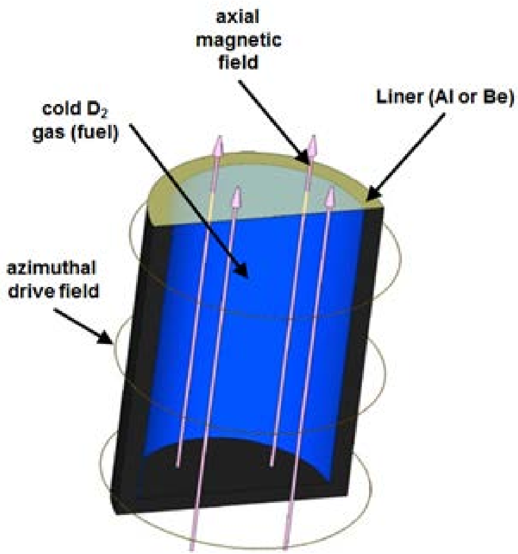


Flexibility in Experimental Platforms: ICF

ICF experiments are exploring novel methods to produce thermonuclear neutrons

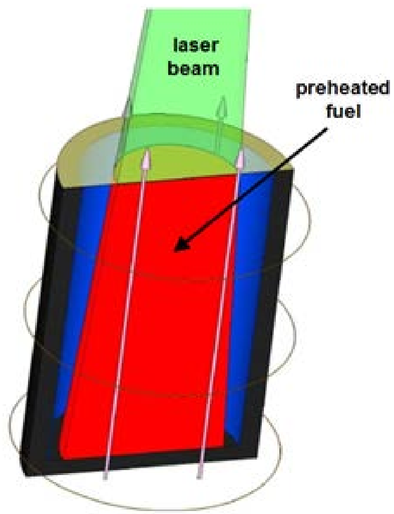
Magnetization



An initial ~10T axial magnetic field is applied

- Inhibits thermal conduction losses
- Enhances alpha particle energy deposition
- May help stabilize implosion at late times

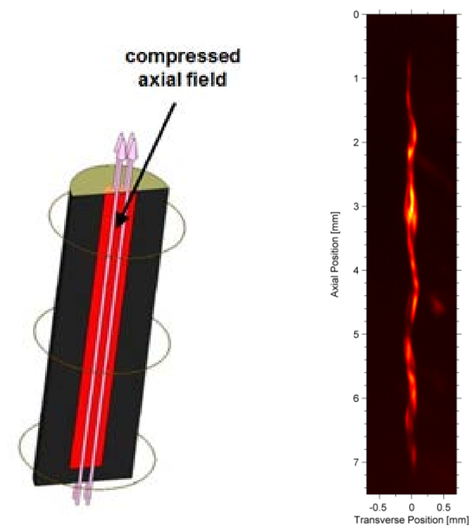
Laser Heating



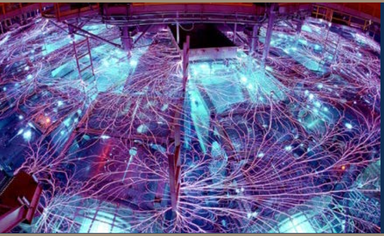
During implosion, deuterium fuel is heated using the Z-Beamlet laser

- Preheating reduces the compression needed to obtain ignition temperatures to 20 - 30
- Preheating reduces the implosion velocity needed to “only” 100 km/s (slow for ICF)
- Stagnation pressure required is a few Gbar, not a few hundred Gbar

Compression



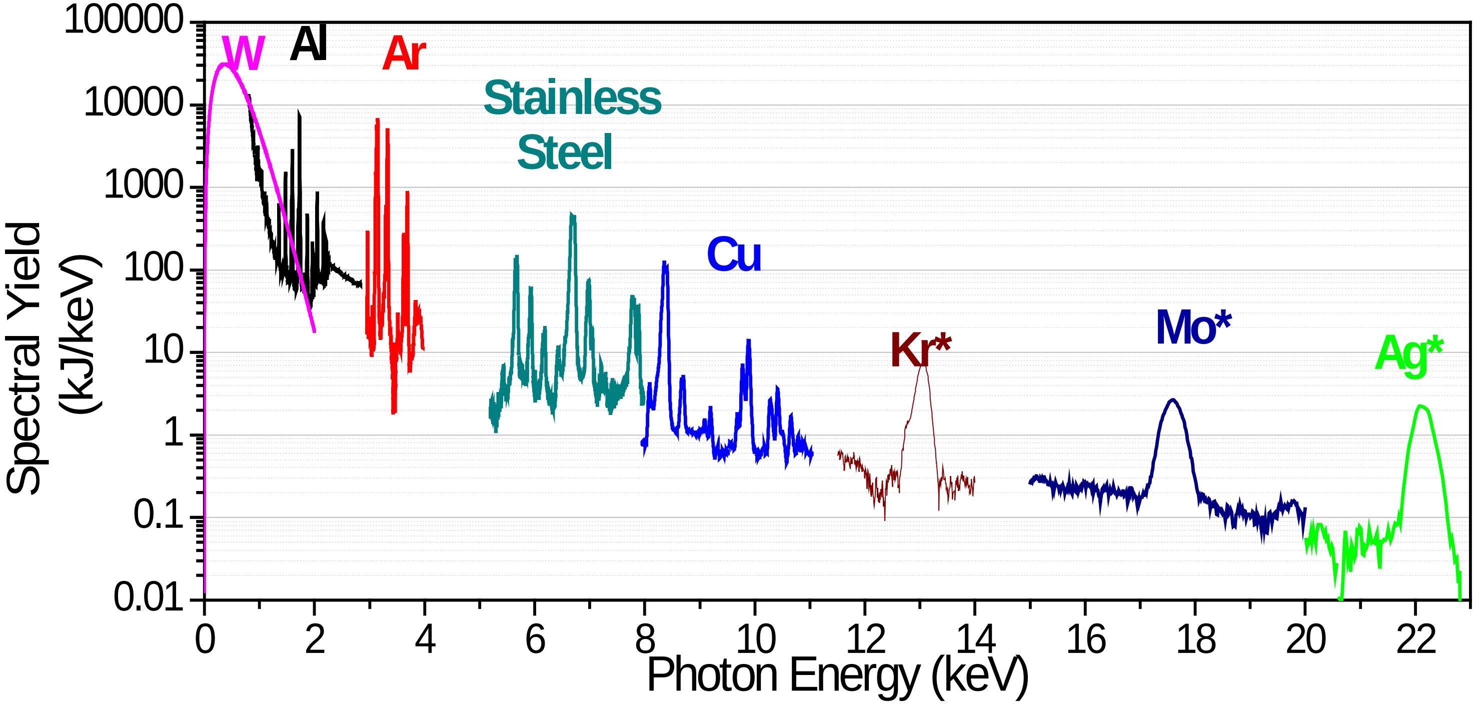
The Z machine efficiently drives a z-pinch implosion which produces high fuel compression producing approximately 10^{12} fusion neutrons



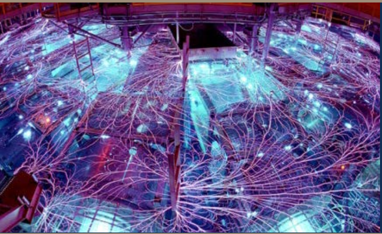
Flexibility in Experimental Platforms: Radiation Sciences

Radiation Effects Sources

Z provides intense x-ray sources at different energies for radiation effects studies



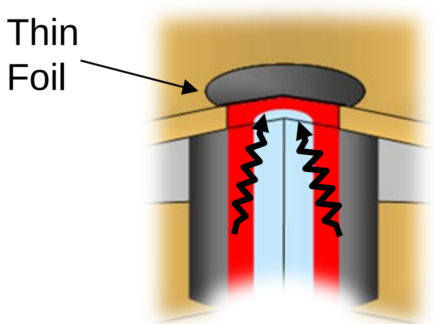
Z is capable of producing x-rays with an energy greater than 20 keV



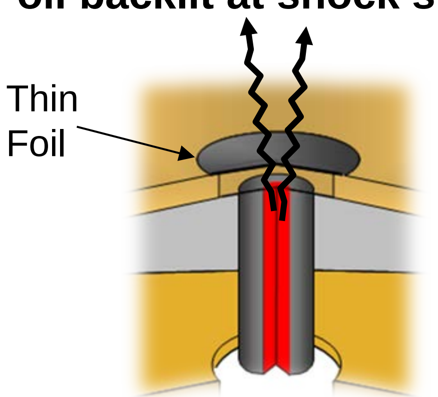
Flexibility in Experimental Platforms: Radiation Sciences

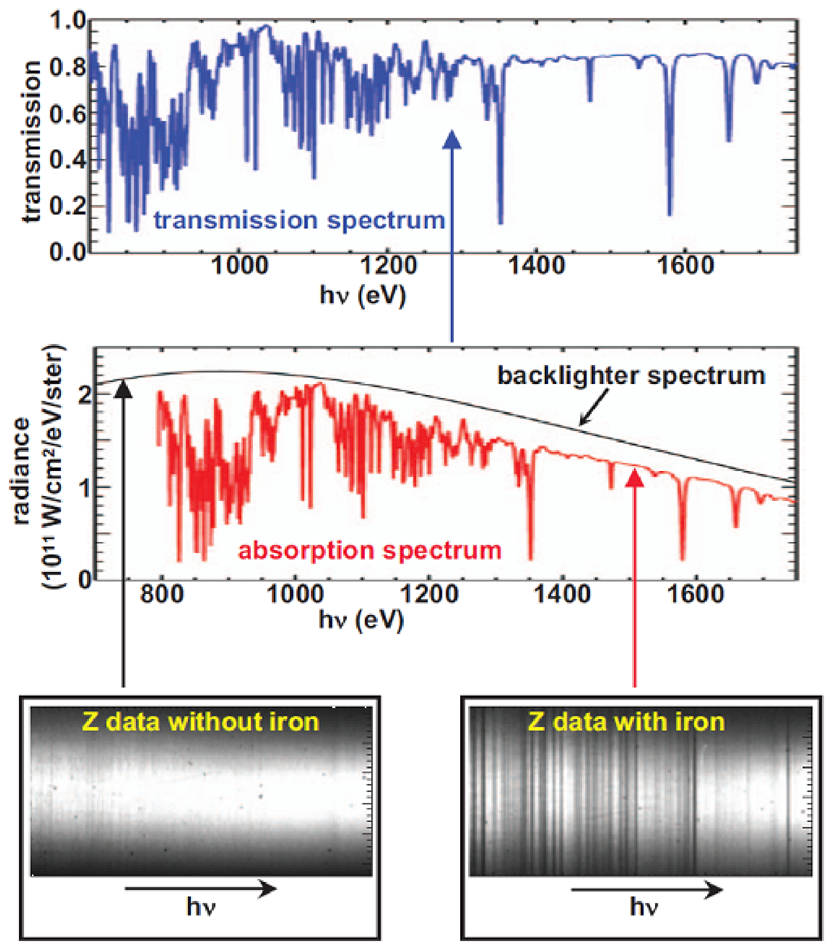
Opacity Measurements with a Z Pinch Driven Dynamic Hohlraum

Foil heated during Dynamic Hohlraum implosion



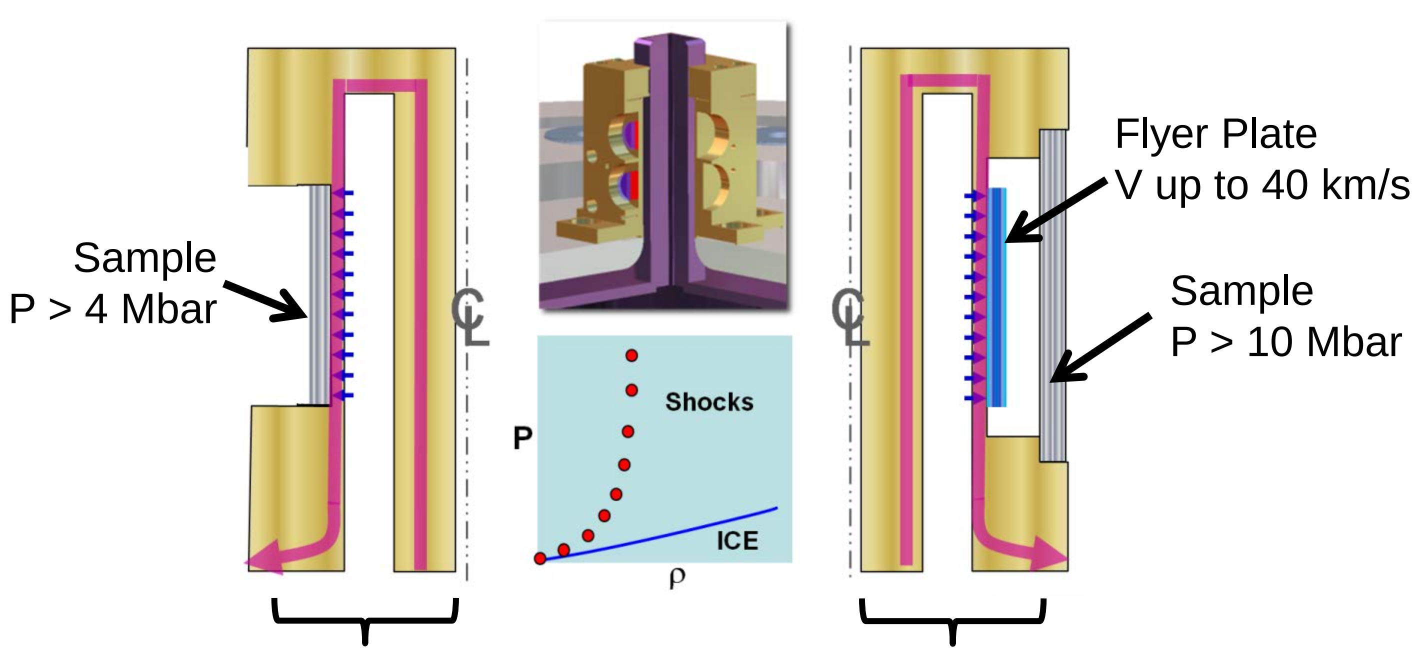
Foil backlit at shock stagnation





Flexibility in Experimental Platforms: Dynamic Materials

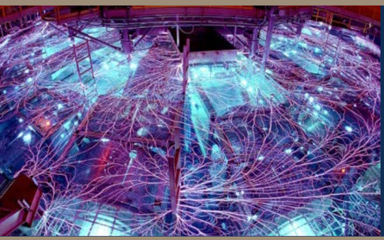
Z isentropic compression and shock wave experiments enable access to key equation of state regions for many materials, including Uranium and Plutonium



Isentropic compression: gradual pressure rise in the sample

Shock Compression: shock wave launched in sample at impact

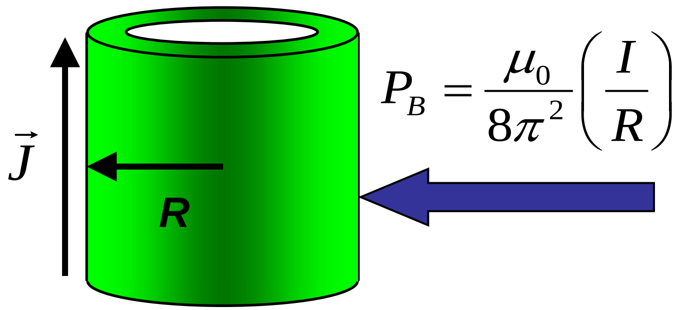
Z acquires data never seen before and is resolving fundamental EOS differences



Flexibility in Experimental Platforms: Dynamic Materials

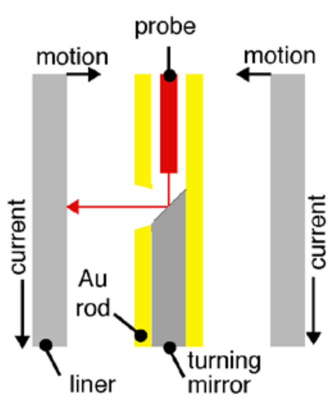
Quasi-isentropic Compression to Stresses ≈20 Mbar in Cylindrical Implosions

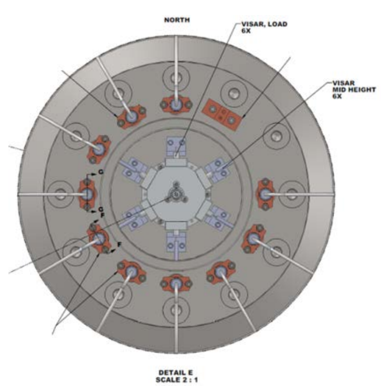
Liner Z-Pinch Implosion



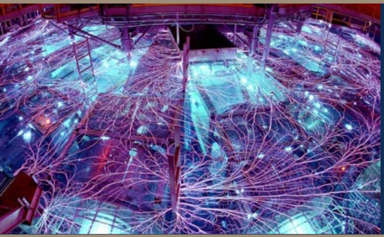
$$P_B = \frac{\mu_0}{8\pi^2}\left(\frac{I}{R}\right)^2$$

I = 20 MA; R = 0.1 cm; $P_B \approx$ 64 Mbar





- 3 - 4 times higher pressure than can be achieved in planar geometry
- Material stress increases monotonically
- Shockless compression by shaping the current profile
- A key challenge is diagnosing the compressed state
- *Successfully fielded internal radial photonic Doppler velocimetry (PDV) to measure the implosion velocity to very high precision*
- *A remaining challenge remains in obtaining accurate drive conditions to infer the pressure in an unfold*



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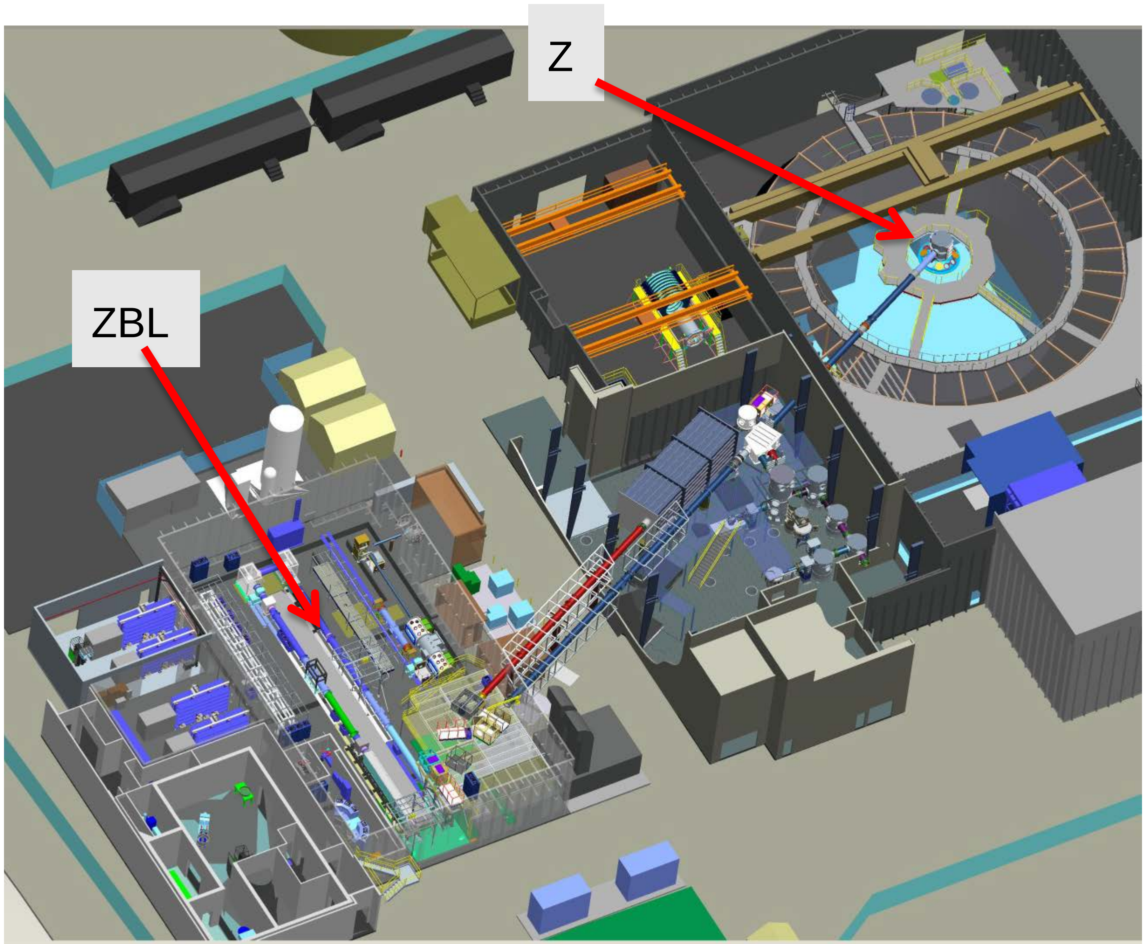
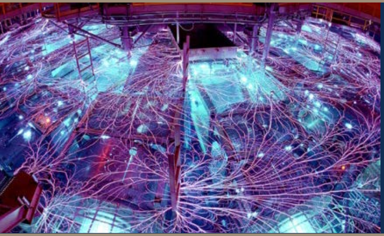
Z Core Capabilities: ZBL

Z-Beamlet Basics

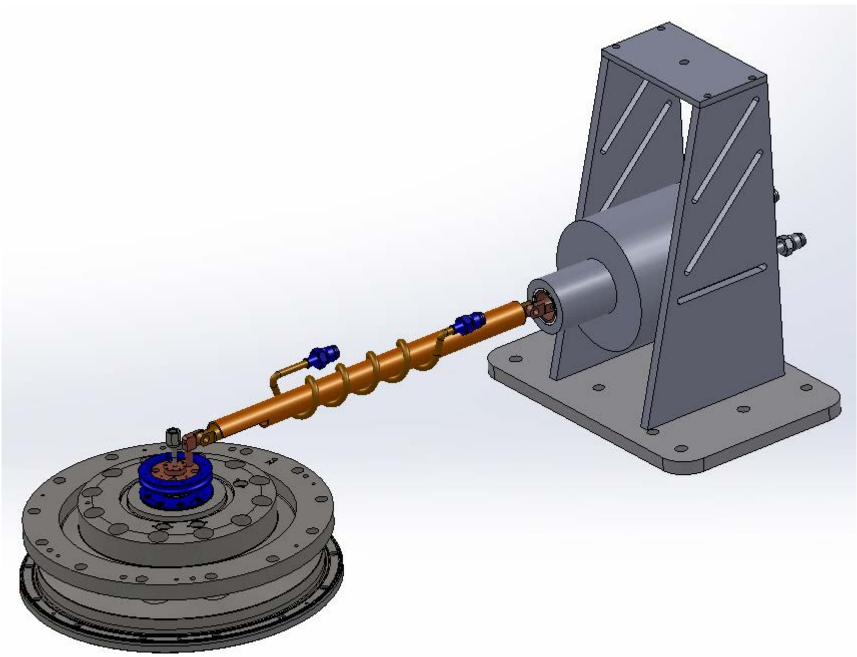


- The Z-Beamlet Laser (ZBL) was the LLNL NIF Prototype (1992-1998) and is now used on Z
  - 1st shots into Target Chamber: March 2001
  - 1st active Z radiographs: June 2001
- The two facilities are co-timed to within 200ps
- ZBL Parameters:
  - Up to 6kJ @ 1053nm
  - Up to 4kJ @ 527nm
  - Up to 4 shots per day
  - Typically 0.3 - 4ns pulse length in a 31x31 cm^2 beam
  - 1 - 9 keV radiography



Z Core Capabilities: Cryogenics

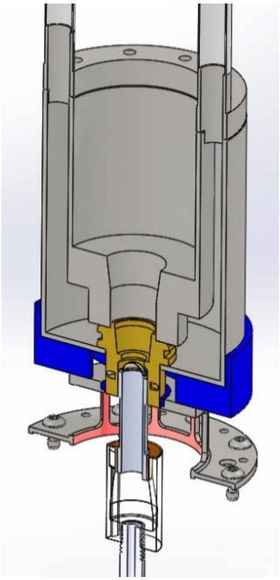
Standard Configuration (Mini Cryostat)



- Assembly outside blast shield.
- Cooled with liquid helium or nitrogen
- Achievable temperature range 200K to 18K
- Cooling time 20 - 45 min depending on configuration

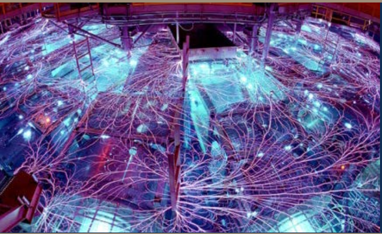
MagLIF Cryostat

- Liquid helium cooled
- Integrated into the assembly of the target
- Achievable temperature range 100K to 25K with current configuration
- Allows cooling of MagLIF target with coil assembly



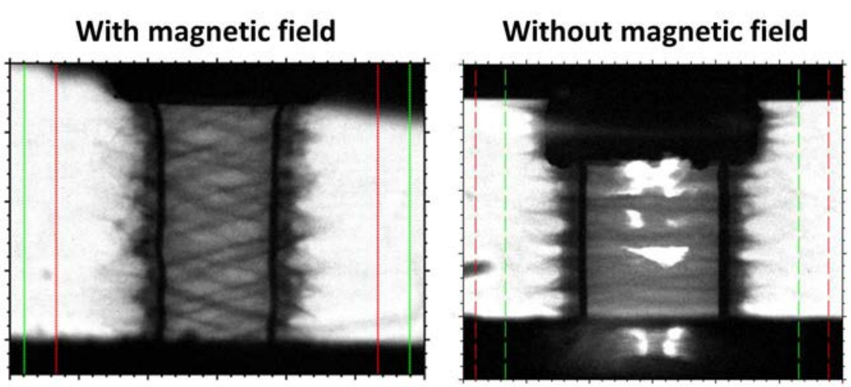
Liquid Helium Reservoir Cryostat

- Achievable temperature range 4.2K to 2.17K
- Cooling time 60 - 90min
- Cryostat must have vacuum applied at 4.2K to achieve lower temperatures

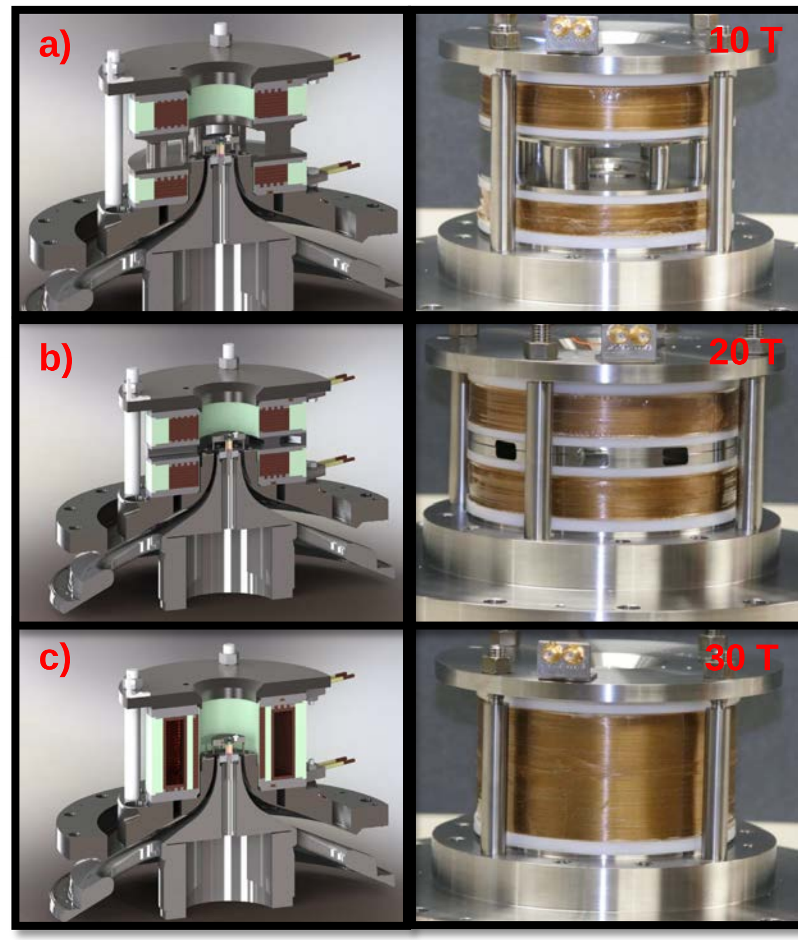


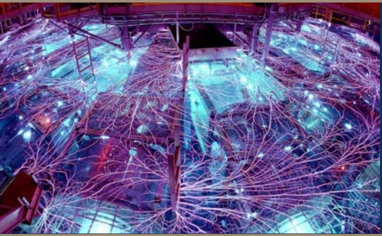
Z Core Capabilities: Applied B

- Applied B on Z (ABZ) system enables HED magnetized target experiments on Z
- Since February 2013, over 75 HED experiments have used magnetization
- External capacitor bank can store up to 900 kJ for coil load in target chamber
- Different coil geometries have been designed and implemented to trade radial diagnostic access with field strength



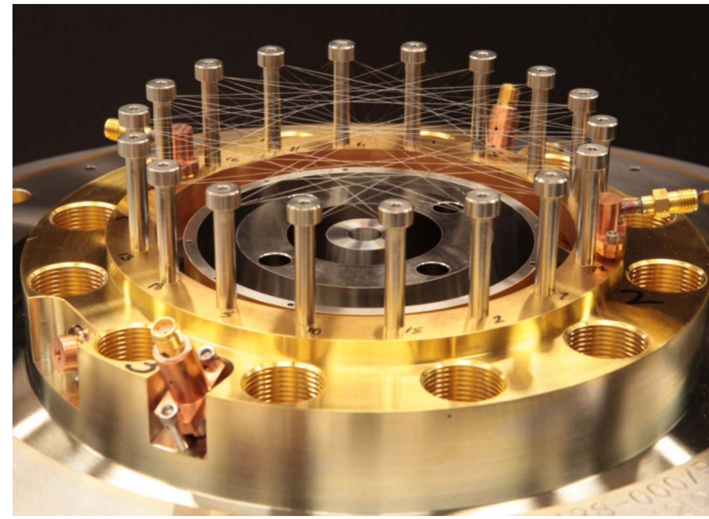
ABZ Field Coil Configurations

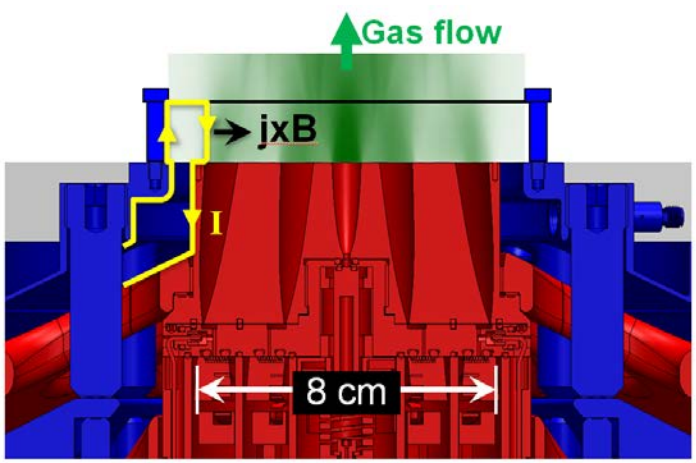


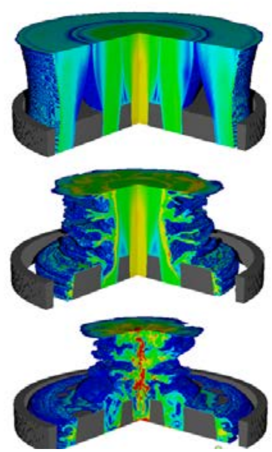


Z Core Capabilities: Gas Puffs

- Gas Puffs provide unique loads for tailoring x-ray outputs through judicious choice of gases
- Nozzle design and characterization is critical with development being done at the Sandia Systems Integration Test Facility
- Record K-shell x-ray outputs are robustly generated on Z

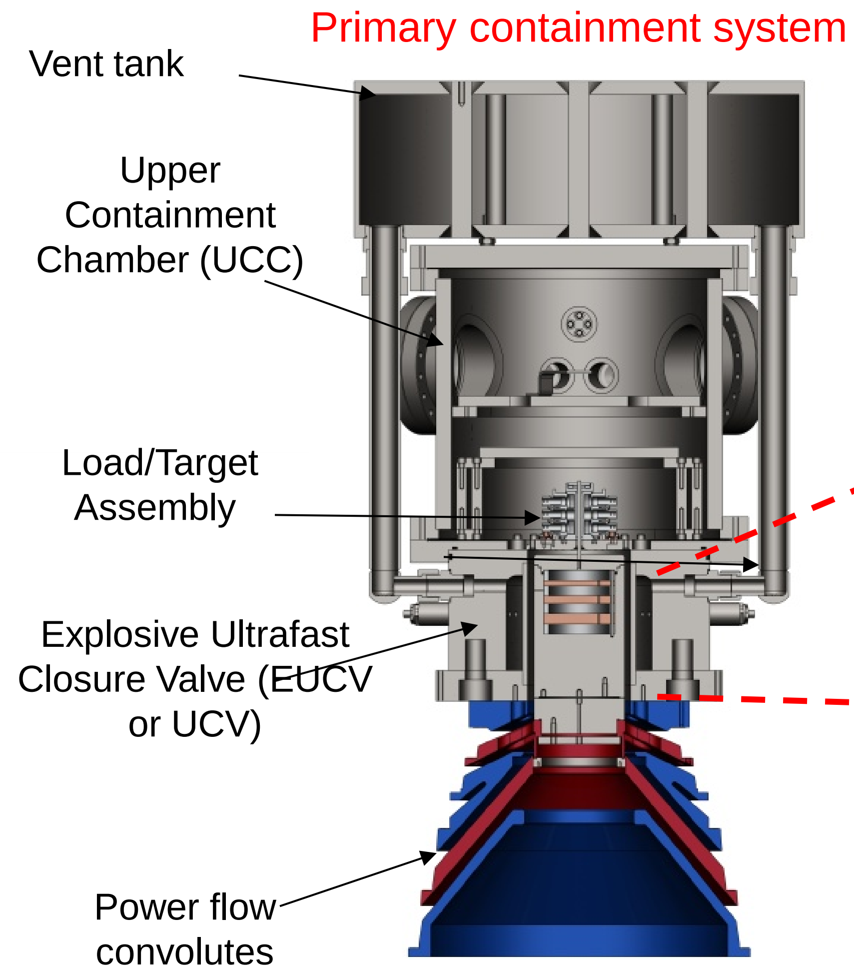






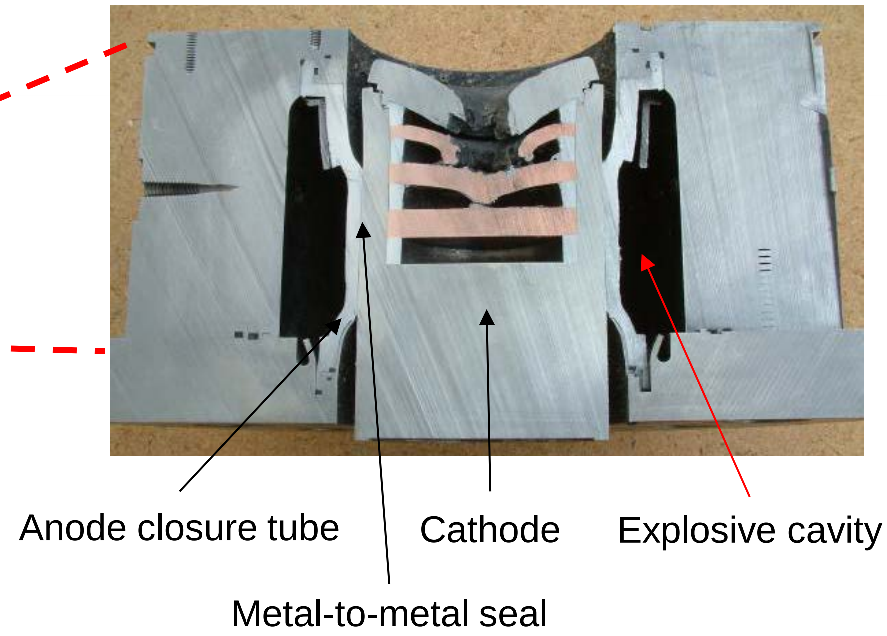
- The use of deuterium gas creates a neutron source producing ~4e13 DD neutrons
- A gas puff neutron source enables studying stagnation physics for comparison with MagLIF
- Robust yields also support diagnostic development

Z Core Capabilities: High Z



Post-shot cross section of UCV showing metal to metal seal between anode closure tube and cathode

- Valve closes in ~ 40 μs
- Leak spec is < 1e-5 atm-cc/sec
- Typical leak rates are 1e-8 atm-cc/sec

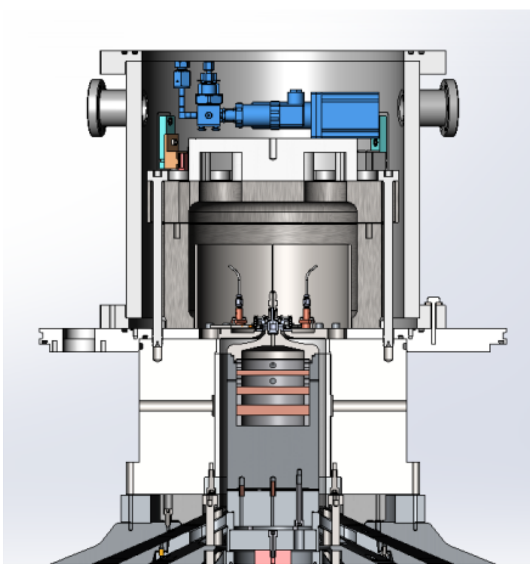


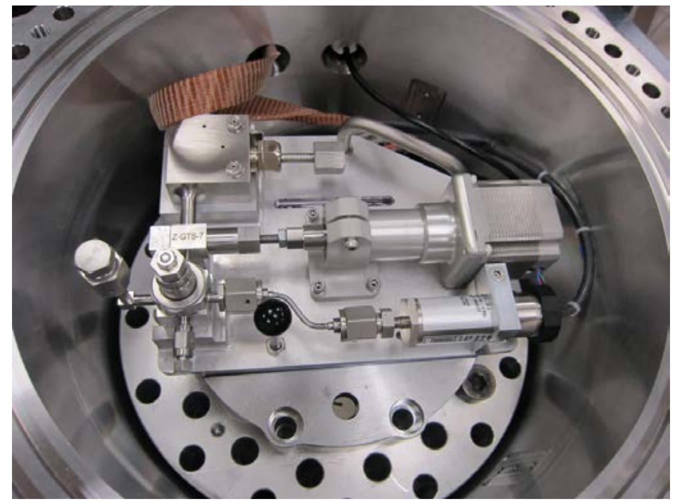
We have a proven containment system for Pu experiments used many times

Z Core Capabilities: Tritium

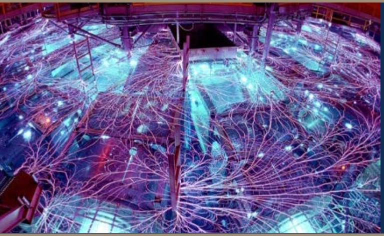
A Sandia Grand Challenge LDRD project is assessing the feasibility of using an explosive containment system

- Conducted three tritium containment development experiments using light gas surrogates
- Validated use of the existing hazardous material containment system as a viable test platform for tritium





- Developed and demonstrated the Z Gas Transfer System (ZGTS)
- Planning to conduct two trace tritium (0.1% - 1.0%) experiments in CY16 using the ZGTS in a containment system



Outline

Pulsed Power / Facility

- 22 MJ stored energy
- 3 MJ delivered to the load
- 26 MA peak current
- 1 - 100 Megabar
- 100 - 1000 ns pulse length

Subsystems

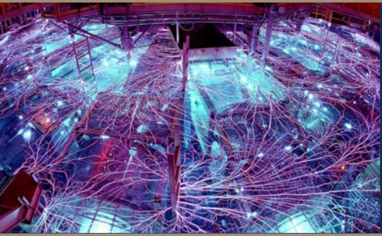
- Backlighter
- Cryogenics
- External Magnetic Fields
- Gas Fill
- Explosive Containment for High Z Materials

Experimental Loads

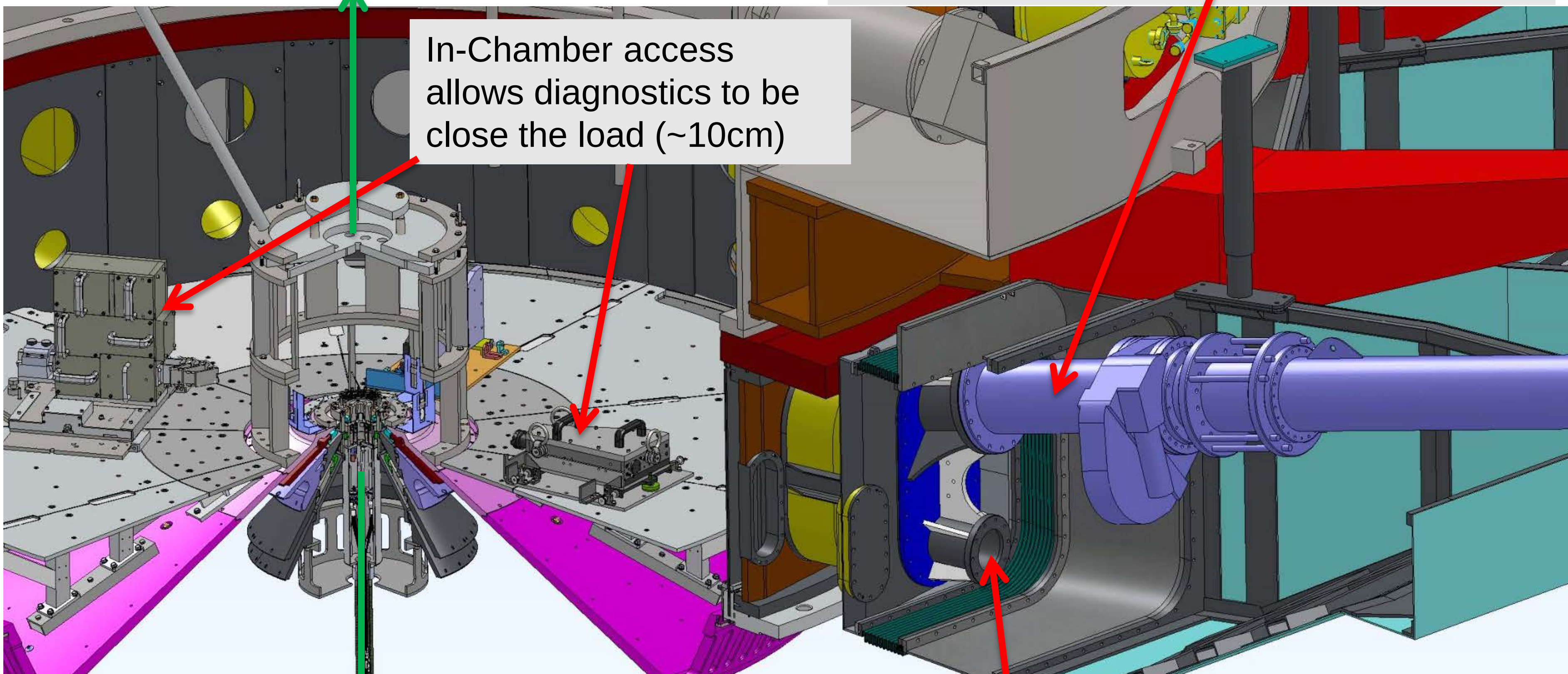
- Wire Arrays – Radiation Sciences
- Liners – Inertial Confinement, Material Sciences
- Gas Puff – Radiation Sciences
- Flyer Plates – Material Sciences
- Short Circuit – Material Sciences

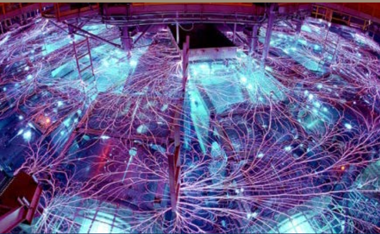
Diagnostics

- X-Ray
- Neutron
- Optical
- ZBL Backlighter



Diagnostics: Overview





Diagnostics: Overview

X-Ray Diagnostics

- Time Resolved X-ray Power and Energy
- Time Resolved Pinhole Cameras
- Time Integrated Pinhole Cameras
- Time Resolved Multi-Layer Mirror Cameras
- Time Integrated Spectrometers
- Time Resolved Spectrometers

Visible / Shock Diagnostics

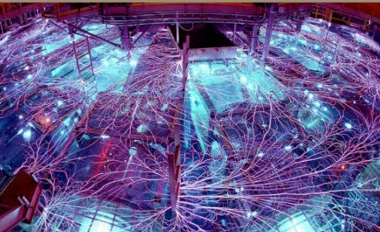
- VISAR
- Photonic Doppler Velocimetry (PDV)
- Streaked Visible Spectrometry (SVS)

Neutron Diagnostics

- Neutron Activation
- Neutron Time of Flight
- Neutron Imaging
- CR-39 in progress
- MRS under study

Z-Beamlet Laser

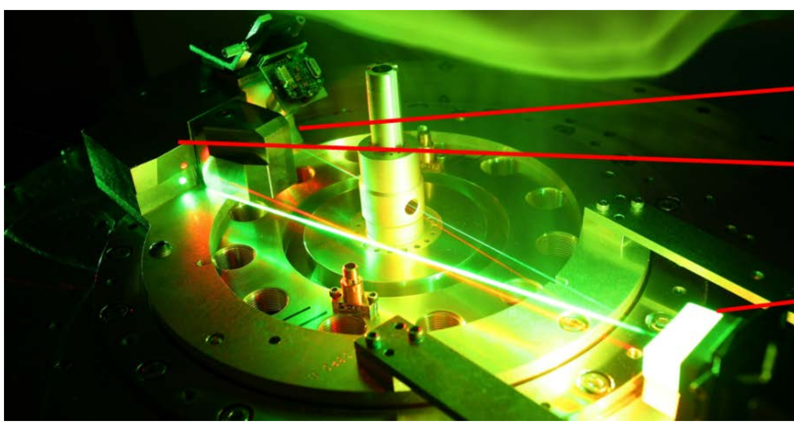
- Monochromatic Crystal Backlighting
    - Energy at 6.151 or 1.865 keV
- X-Ray Thomson Scattering
- Diffraction under study



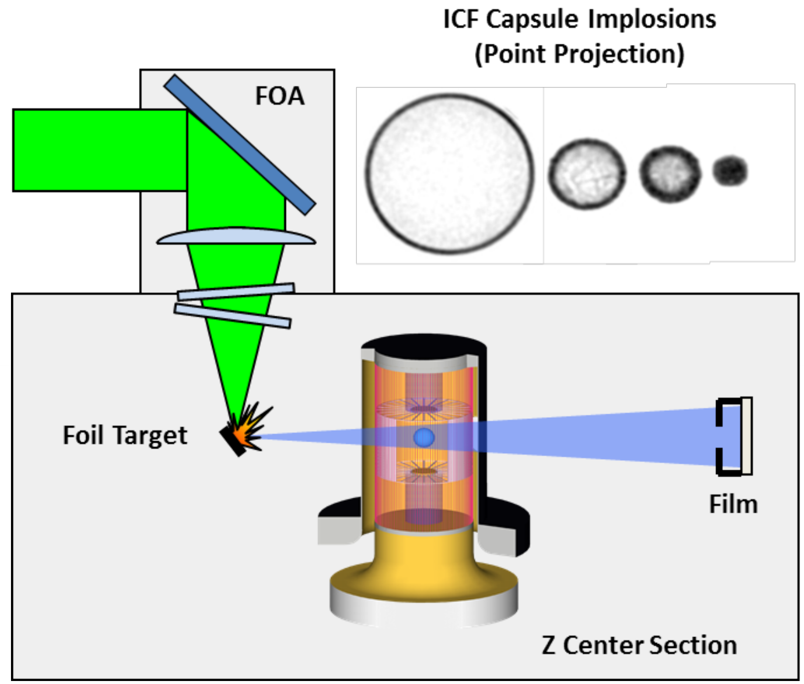
Diagnostics: X-ray Backlighting

X-Ray Bent Crystal Imaging

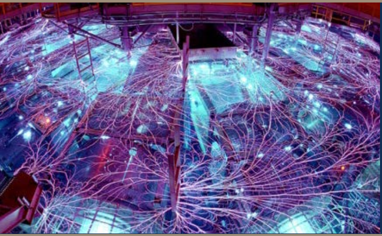
- Modifications to ZBL allow two separately timed pulses at slightly different angles.
- This allows the crystal imaging technique to take two radiographs on the same Z shot.
- Delays from 2 ns to 20 ns between frames
- Possible use of different x-ray sources and matched crystals



X-Ray Backlighting

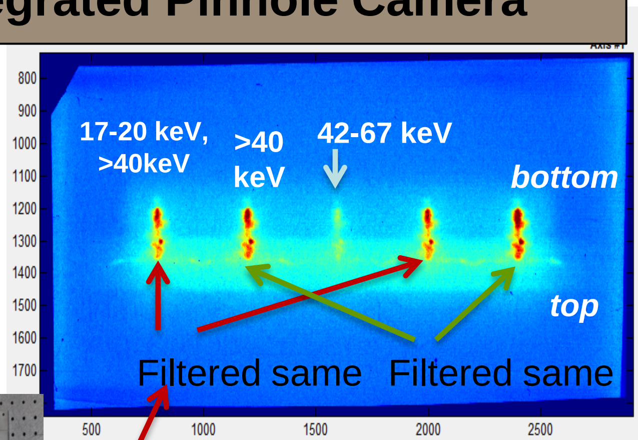


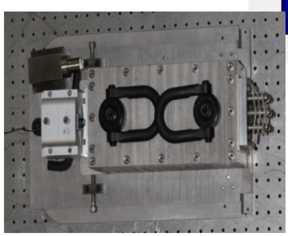
- Fast moving HEDP events are typically diagnosed in part with flash radiography (also called backlighting).
- An x-ray burst (typically 1 - 15keV range) is generated by focusing an intense laser onto a target foil to create a dense plasma x-ray emitter.

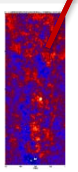


Diagnostics: New Deployments

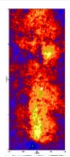
Time-Integrated Pinhole Camera







Subtracting images that are filtered the same

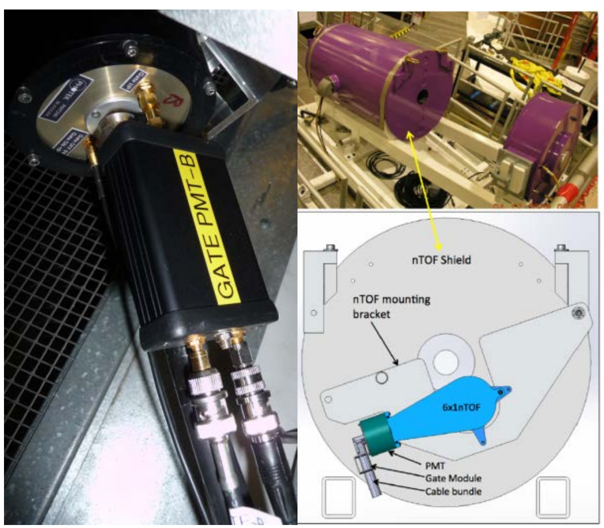


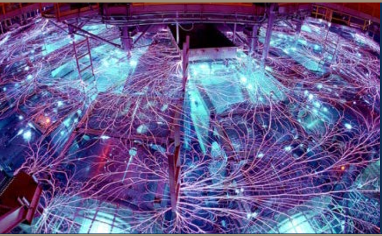
Subtracting different filtered images to get 17-20 keV window

- In-chamber pinhole camera designed for imaging warm x-rays (15 -100 keV)
- 5 filtered pinhole images per experiment
- Developed under hostile environments LDRD to identify where in the source warm x-rays are produced
- Currently used broadly in ICF and RES programs

Gated nTOF detectors

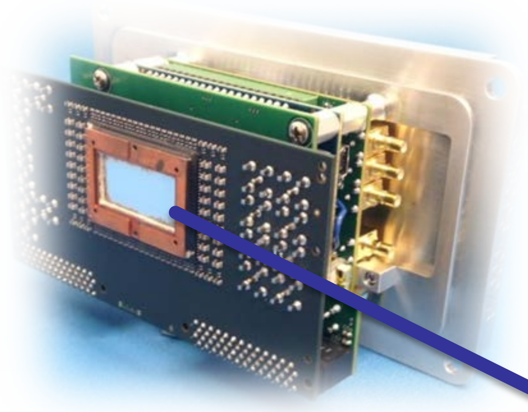
- Collaboration with LLE based on Omega fielding experience (Glebov), and NSTec to implement Z detectors
- Gating out brems pulse will allow higher signal-to-noise measurement of secondary DT spectrum
- Improved BR measurement for MagLIF
- Gate unit function has been demonstrated in Z electromagnetic environment





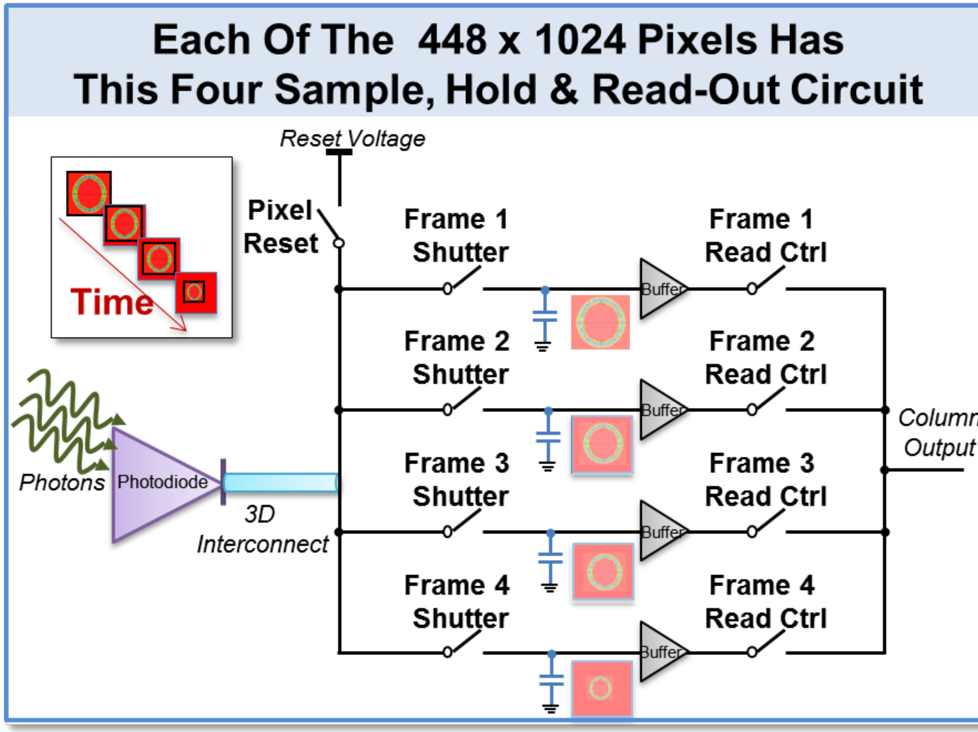
Diagnostics: CMOS imaging

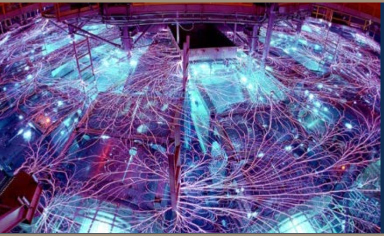
hybrid gated CMOS camera



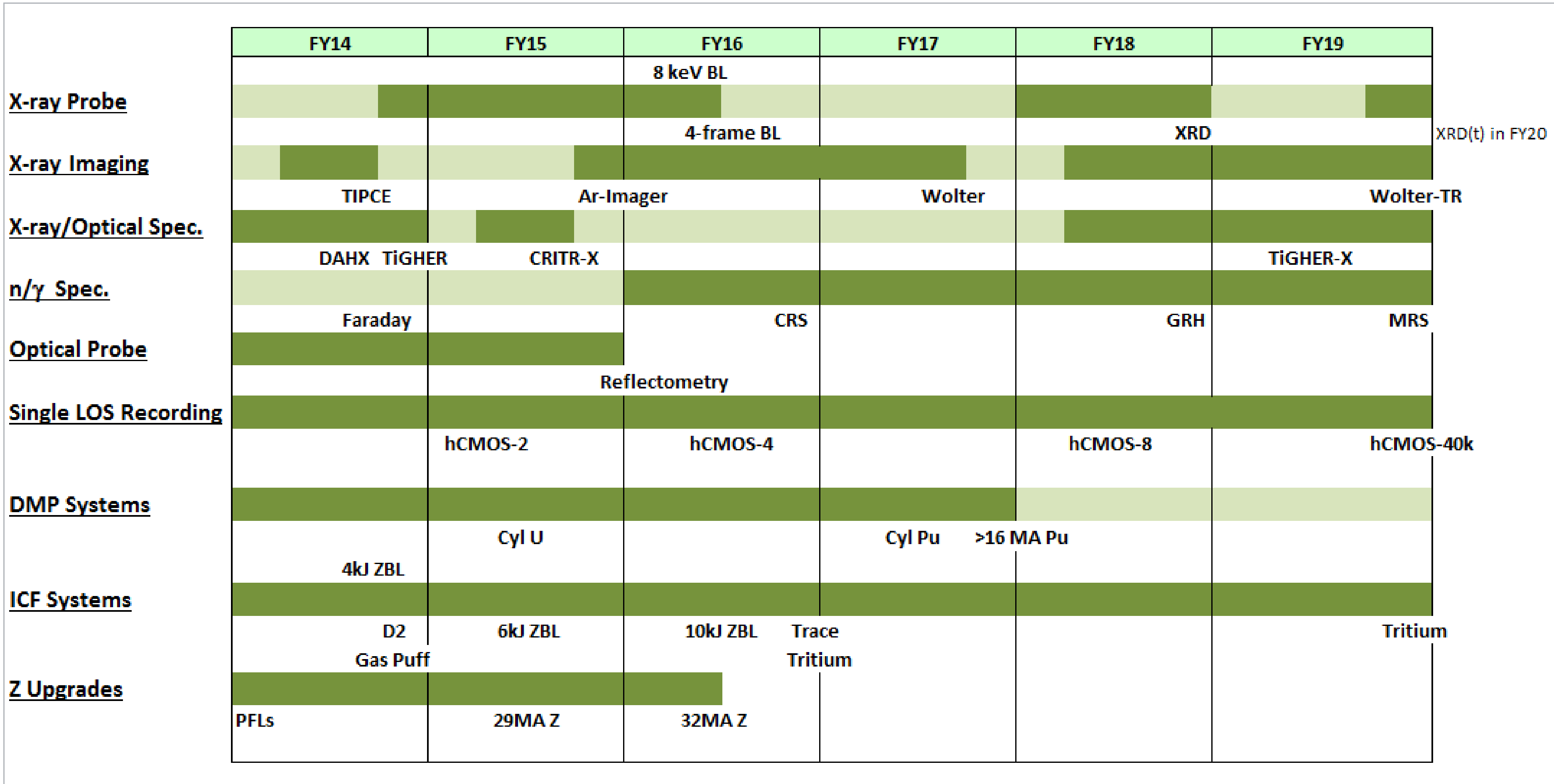
designed and built in collaboration with the MESA facility

- Up to 4 frames of data on a single line-of-sight
- 1.5 ns minimum gate time
- 448 x 1024 pixel array
- 25 um x 25 um per pixel
- Sensitive to visible light and 0.7 - 6 keV x-rays





Diagnostics: Roadmap



Questions