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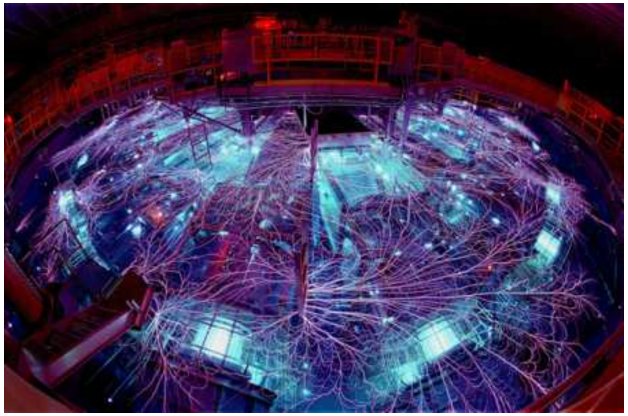
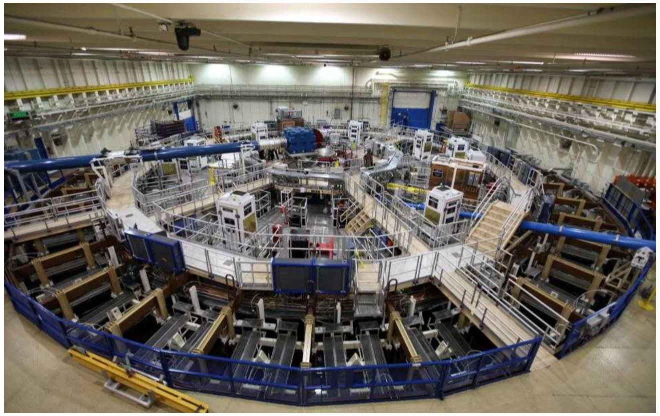


The Z Machine

Supporting The Fundamental Science Program

G. Randy McKee & Chris Bourdon

Z Facility Research and Development Group

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Outline

- The Z Machine – Quick Facts and Status
- Shot Rate Enhancement Study
- Recent Diagnostics
- Pulsed Power Future

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The Z Machine – Pulsed Power for Science

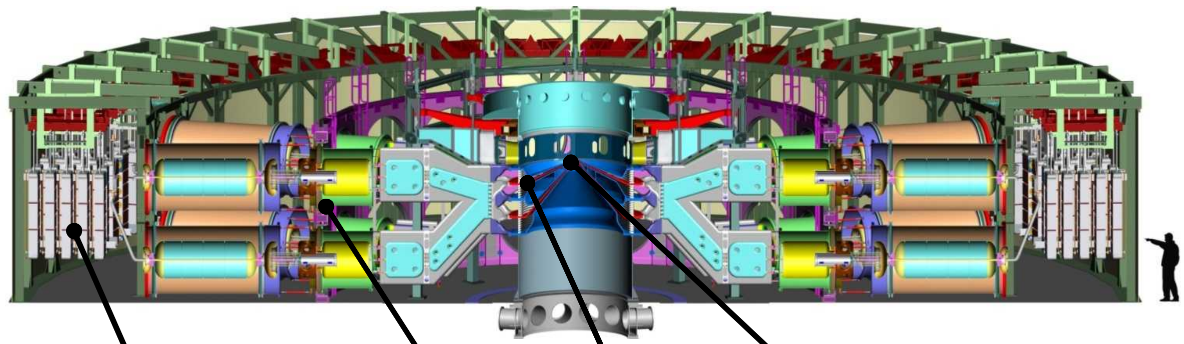
Pulsed Power

22 MJ stored energy

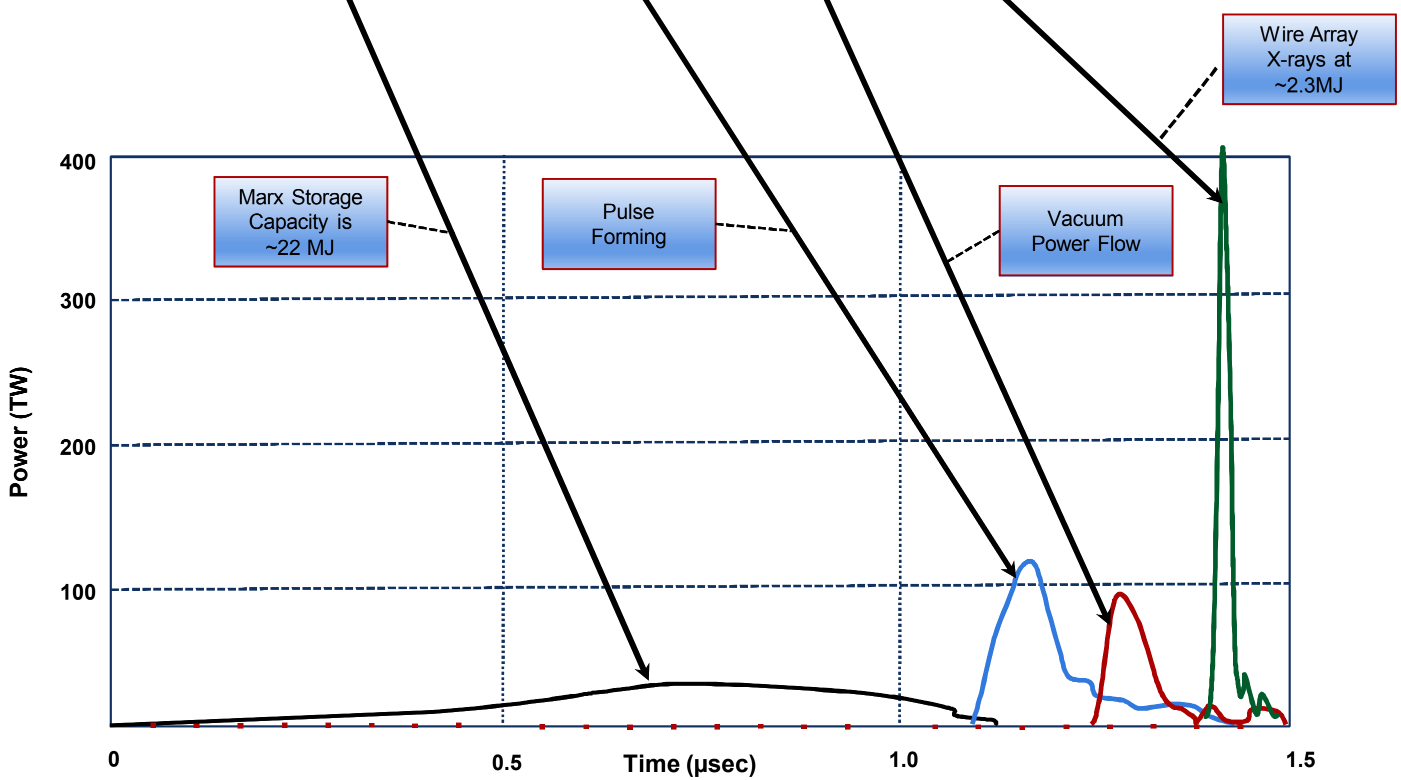
2.3 MJ delivered to the load

26 MA peak current

100 - 1000 ns pulse length



Compression of Energy In Space and Time



Unclassified Unlimited Release

The Z Machine – Pulsed Power for Science

Infrastructure

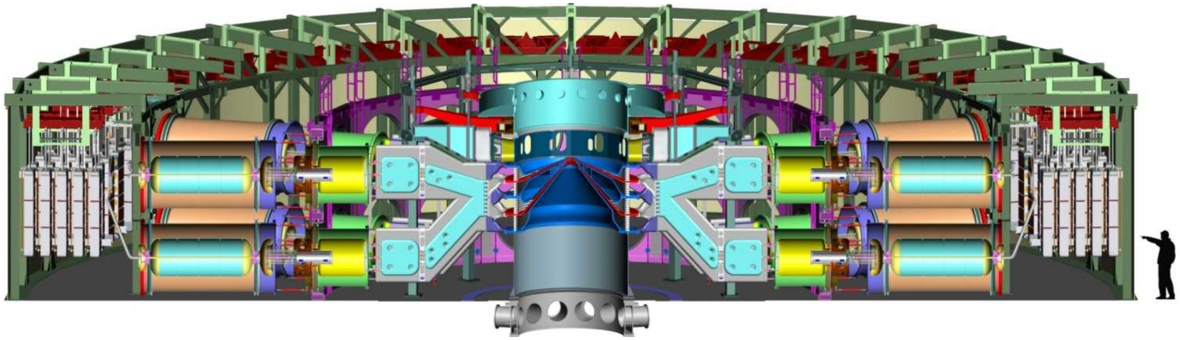
36 Marx generators

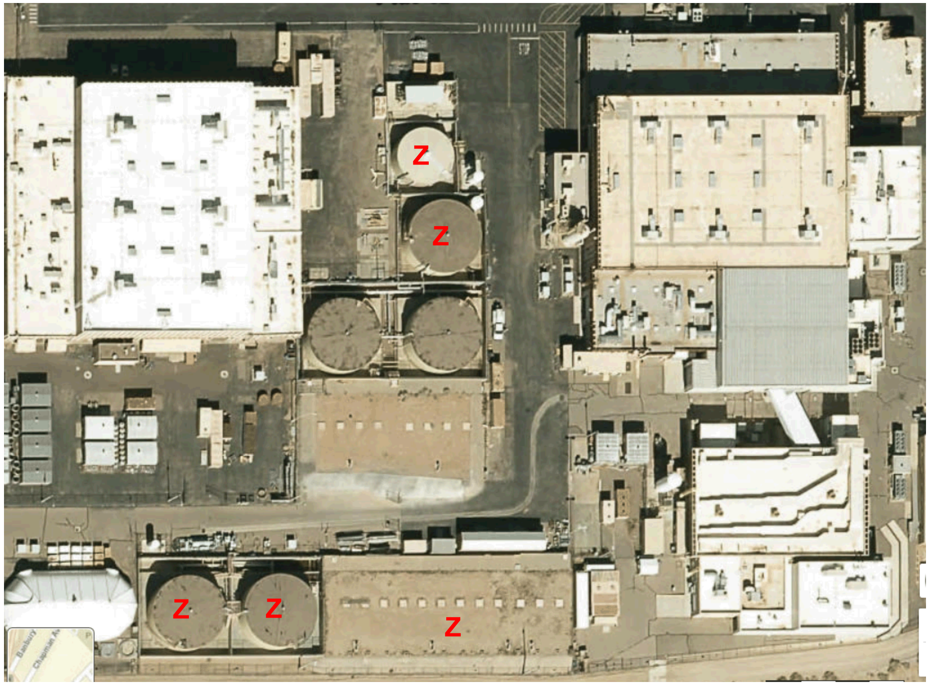
2160 capacitors

1,000,000 gallons transformer oil

500,000 gallons deionized water

100 cubic meter vacuum vessel





The Z Machine – Pulsed Power for Science

Diagnostics

Power & Energy

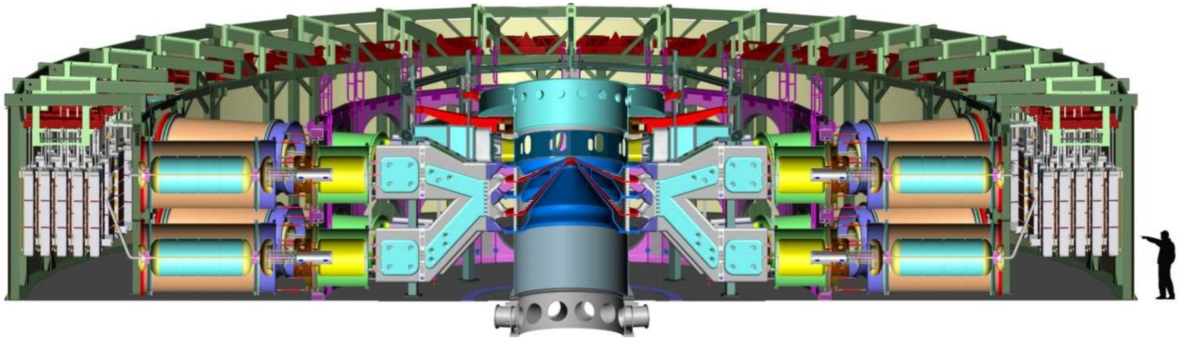
X-ray Spectrometers

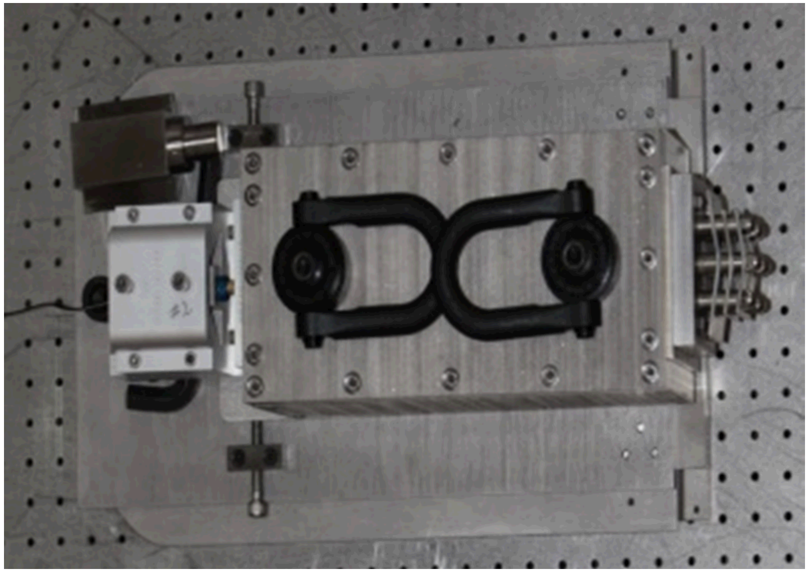
Visible Spectrometers

Neutron TOF and Activation

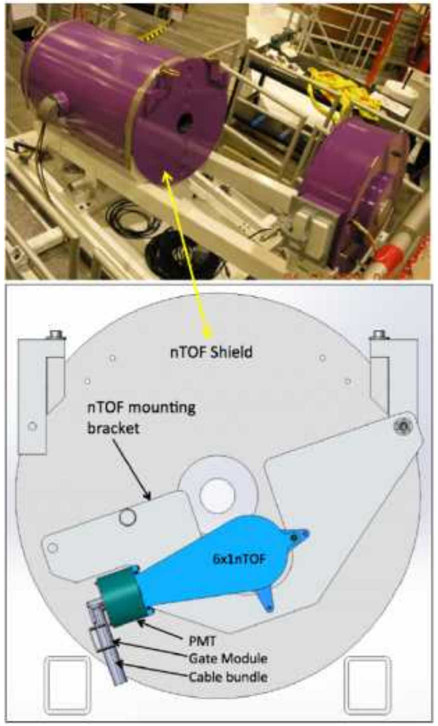
Imaging (x-ray, visible, neutron)

Axial and LOS locations



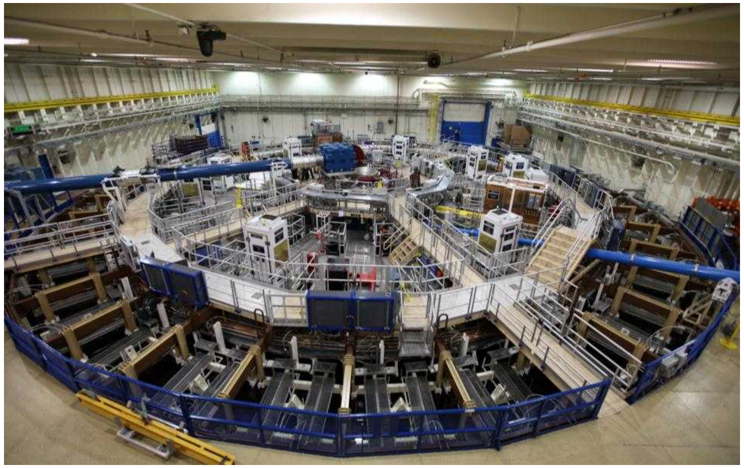


Pin Hole Camera



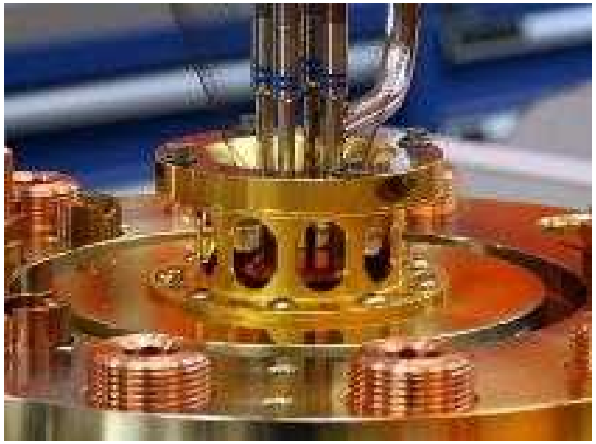
Gated Neutron Time of Flight Diagnostic

The Z Machine – Pulsed Power for Science



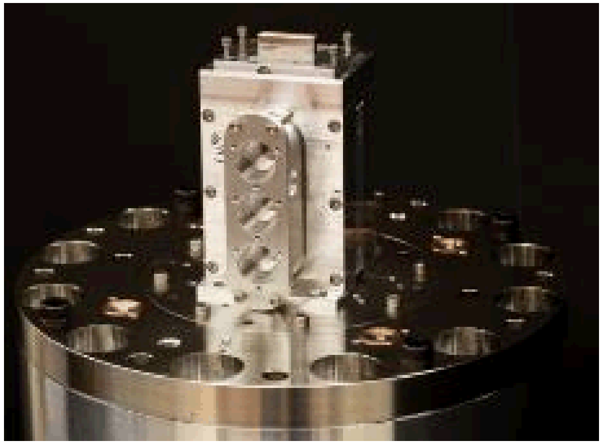
Radiation Effects Sciences (RES)

- Radiation Effects Science (RES) in Nuclear Weapons
- Fundamental Sciences



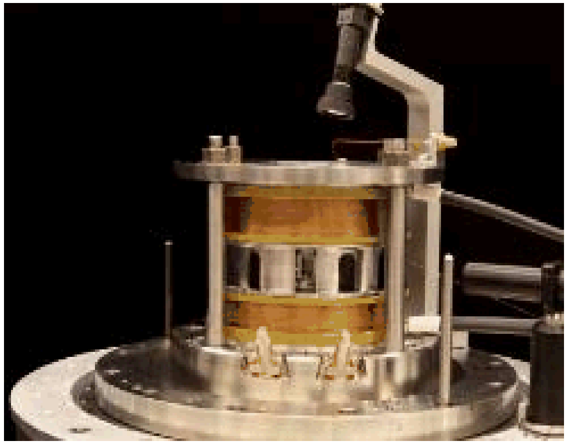
Dynamic Materials Properties Experiments

- Advanced Materials Phase Diagram Development
- Single Z Shot Hugoniot Curves
- Fundamental Sciences

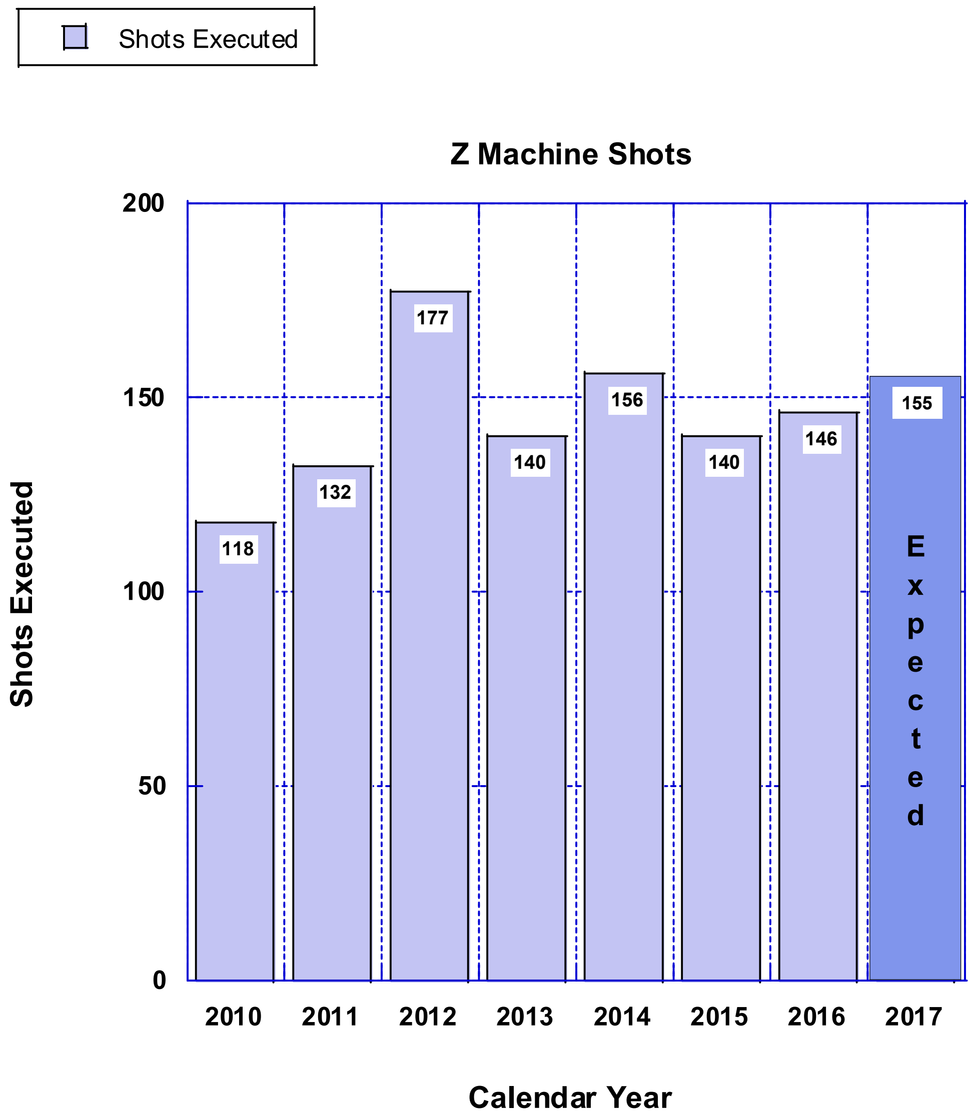


HEDP Experiments

- High Energy Density Physics in ICF



The Z Machine – Pulsed Power for Science



Z Shot Planning:

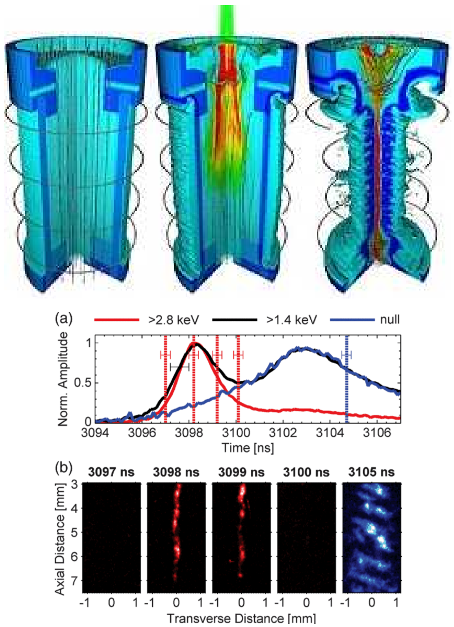
- Typically plan for 140 – 160 shots a year based on budget
- We nominally plan to execute one shot per day
- Currently we have executed 88 shots in CY17
- We are expecting to complete at least 67 of the remaining 75 planned shots on the schedule resulting in 155 shots for the year
- Nominally 1 shot per shot day
- In CY17 the Fundamental Science Program is scheduled to realize 18 shots (~12% of Z's annual shots)

The Z Machine's Core Mission

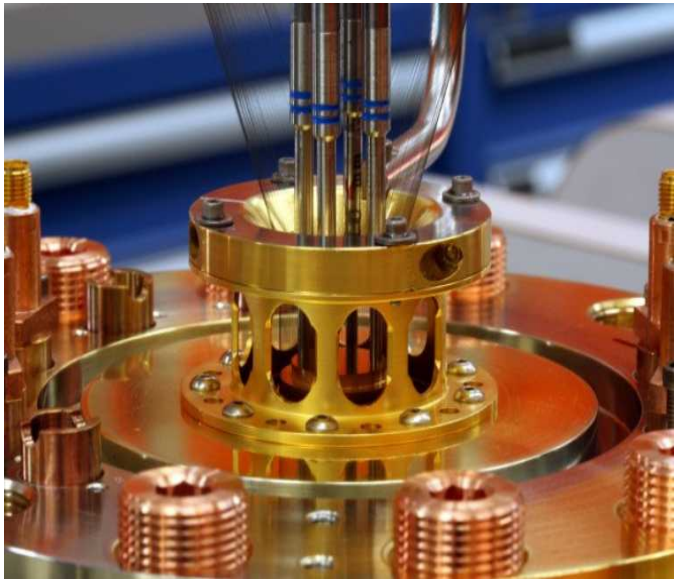
High Energy Density Physics
Radiation Effects Sciences
Dynamic Materials Properties

Science Based Stockpile Stewardship

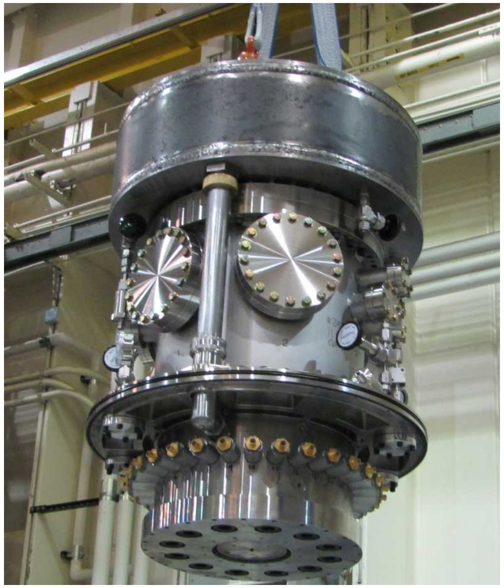
We deliver but often don't discuss outside of a few of our stakeholders



Magnetic Liner



Radiation Effects



Dynamic Material Properties (SNM containment shown)

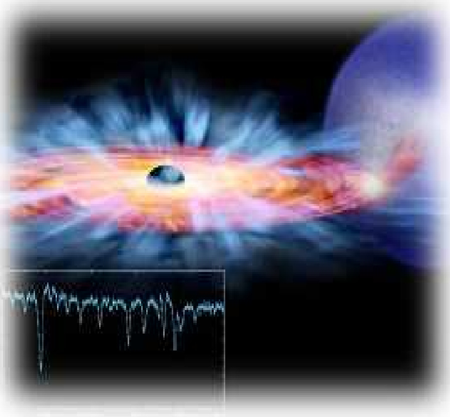
Other Z Machine Missions

Fundamental Science Program

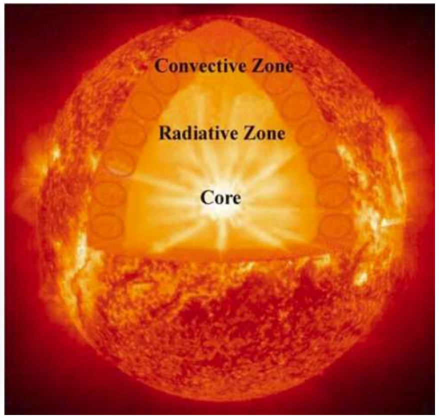
Strong collaboration with:

- Other DOE laboratories
- Universities
- Private Sector

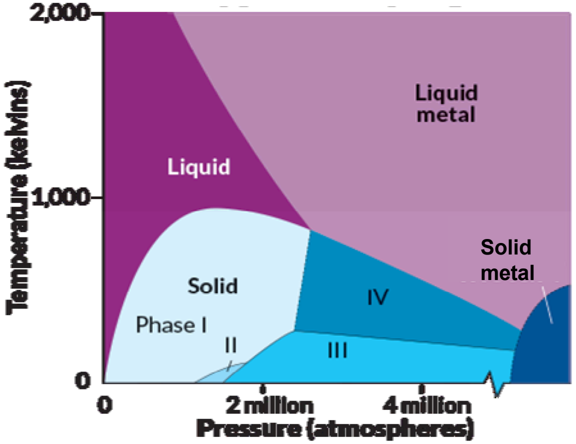
We deliver, and the results often carry a strong message of success to all of our stakeholders with a *WOW* factor.



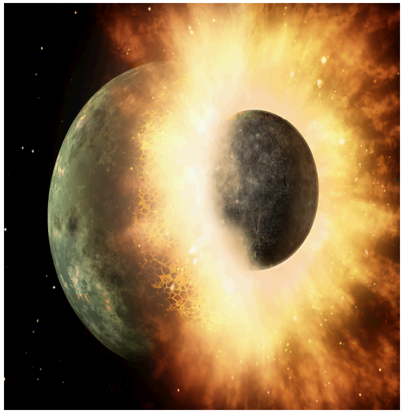
Accretion Disc
SNL, UC Berkley, University of Nevada- Reno, Goddard



Opacity of Iron
SNL, University of Nevada- Reno, Ohio State University



Hydrogen metallization
SNL, University of Rostock,



Iron Rain
SNL, LLNL, Harvard University, UC Davis

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Shot Rate Enhancement Study

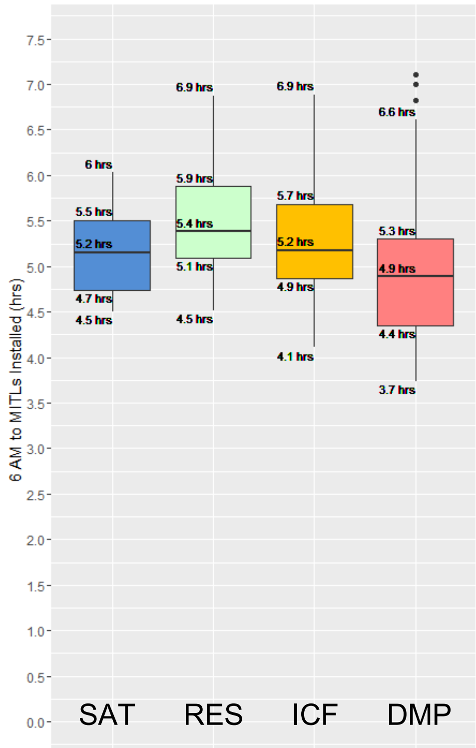
In response to a PPS&T recommendations, we assessed options to provide more Z shot opportunities

- Pulsed Power S&T Strategy Key Recommendation: Pursue an increase in the capacity of the Z facility to 250 experiments per year.
- For many years Z has been 3x oversubscribed in requested shots from LLNL, LANL, SNL and the Fundamental Science community. Currently we average ~146 shots per year (CY13-CY17) within ~250 operational days.
- Many important Science data needs are presently unmet.
- The Fundamental Science community has consistently requested greater access to Z – they are important advocates for Z's future.
- We are realizing more and more insufficient days for testing and commissioning activities
- Z deferred maintenance continues to grow and operational reliability can may become more unpredictable which will require attention.
- An internal study evaluated investment options for increasing the shot rate and shot capacity.

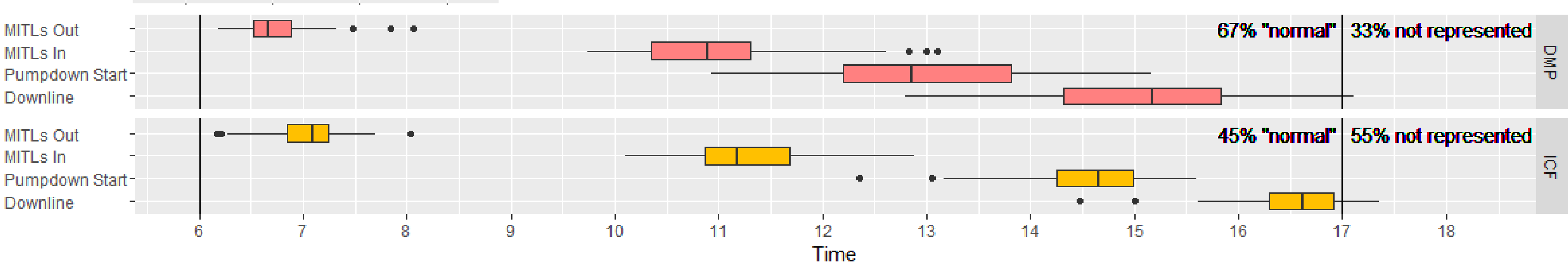
Shot Rate Enhancement Study

Sandia National Laboratories

Given the complexity of most every Z shot, operational variability is significant and unpredictable



- As an example, the time for MITLs to be installed varies due to many potential factors:
  - Radiation Protection surveys and availability
  - Number of diagnostics to unload
  - Varying degrees of debris and soot to remove
  - Unexpected stack damage and repair
  - Trained personnel availability
- With ever-growing shot complexity (e.g., subsystem and diagnostic fielding), Z shots are increasingly starved for contingency for downline execution by 17:00.
  - This is especially impactful for ICF and RES shots



Shot Rate Enhancement Study

Sandia National Laboratories

$9.3M of increased annual funding and $4M for one-time purchases is needed for realizing ~180 shots/year

	Additional personnel	Annual Purchases	One-time Purchases
Add Center Section technologists starting at 4 am for increasing margin on critical path activities	$1.0M		
Create and staff roles to improve life-cycle planning and execution efficiency for individual shot series	$1.1M	$0.05M	
Add Engineering personnel to reduce deferred maintenance and reduce overnight pumps	$1.5M	$2.05M	$2.6M
Add fielding personnel and experimental consumables to support the additional shots	$0.9M	$2.1M	$0.3M
Increase General Atomics investment to provide additional targets and ensure Be machining	$0.5M	$0.1M	$1.1M
	$5.0	**$4.3**	**$4.0M**

- We anticipate realizing ~180 shots/year after 15 - 24 months
- Subsequently we will revisit options for realizing ~250 shots/year through adding capacity (e.g. 7-days per week)

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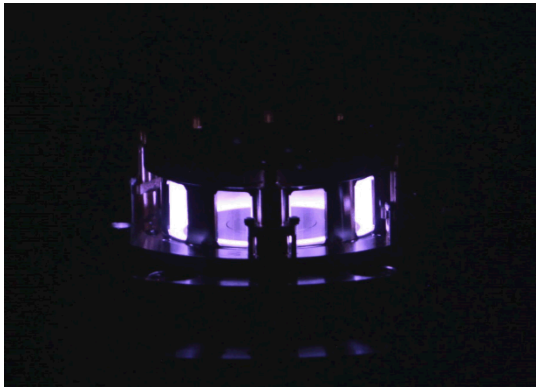
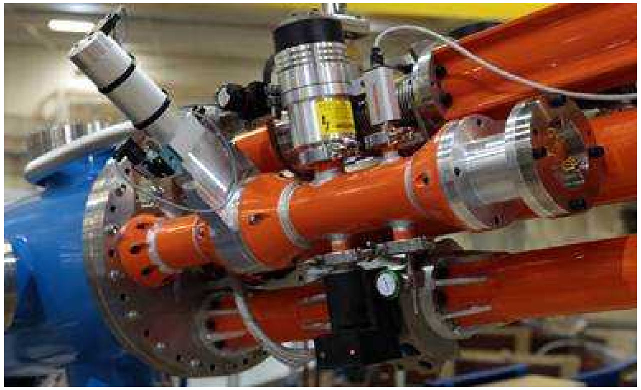
Recent Additions To Z's Capabilities

Highlights of a few of the upgrades and Z capability enhancements implemented over the past 18 – 24 months

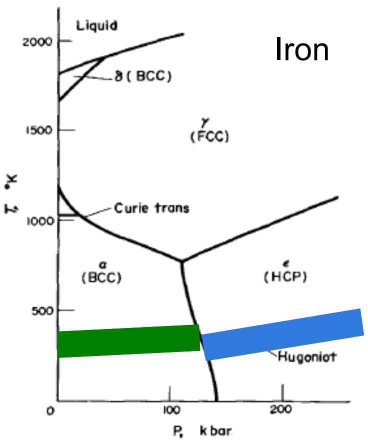
- Enhanced Applied Magnetics (ABZ) – dual bank operation authorized
- Power, energy and mechanical response diagnostics added or upgraded
- Cryo-target capabilities enhancements
- Improved SF6 gas management
- Increased facilities automation and connectivity to CM-DAS
- CM-DAS Upgrades
- Implemented post shot air exchange on vacuum stack
- Plasma cleaning integration onto Z
- In chamber vacuum gauge (vacuum insulator stack)
- Vacuum insulator stack de-bubble upgrade

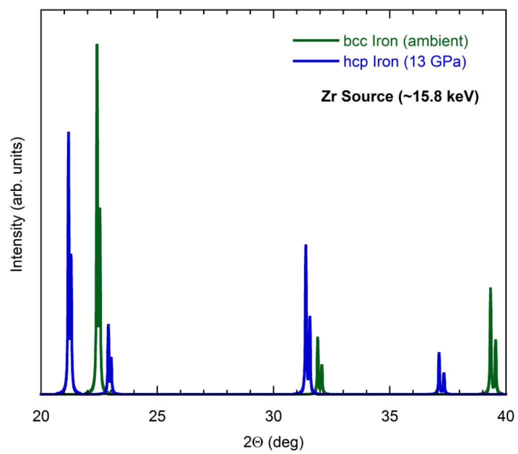




X-Ray Diffraction (XRD) on Z

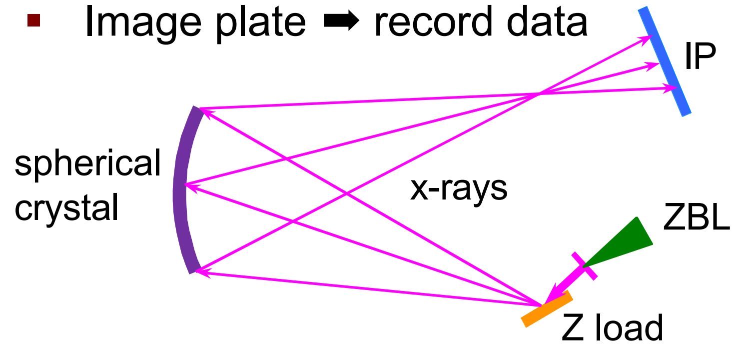
- Scientific needs
  - Characterize phase transformations of dynamically compressed matter
  - Diagnose material lattice dynamics



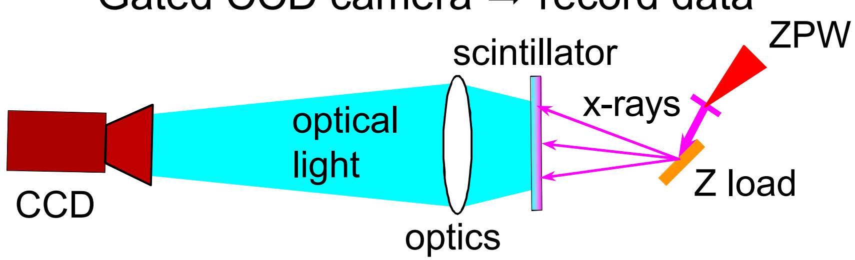


- Experimental requirements and challenges
  - Shock/ramp compress material to high-pressure phases
  - High-energy, short-duration x-rays
  - Detection and recovery of x-ray diffraction data
  - Destructive environment of Z load
  - X-ray background and EMP

- Near-term scheme
  - Z-Beamlet laser ➡ 6-8 keV x-rays
  - Spherical crystal imager ➡ collect diffracted x-rays
  - Image plate ➡ record data



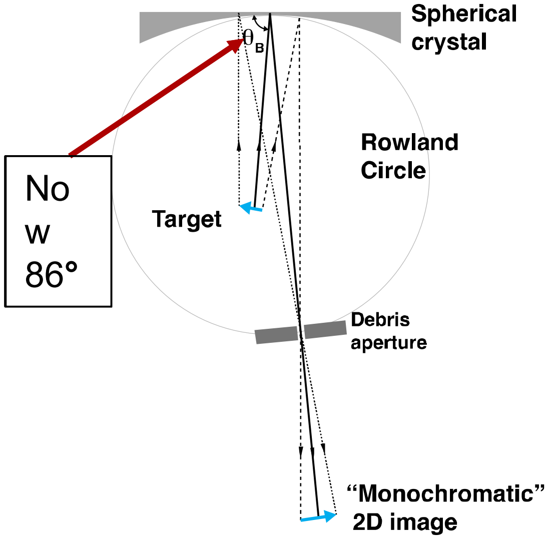
- Long-term scheme
  - Z-Petawatt laser ➡ 15-20 keV x-rays
  - Scintillator ➡ collect diffracted x-rays and convert to optical light
  - Image relay optics ➡ transport light outside Z center section
  - Gated CCD camera ➡ record data



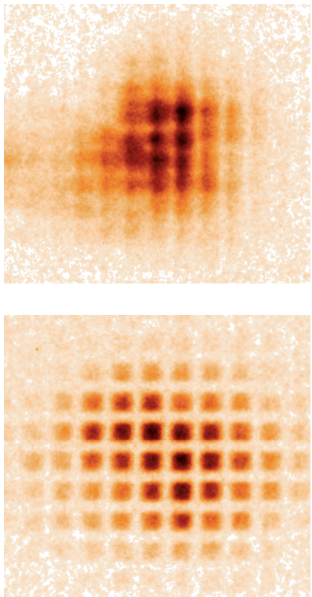
Improved X-Ray Crystal Imager

The radial emission profile of the stagnation plasma from a MagLIF implosion is now measured with greater accuracy using an improved x-ray crystal imager.

To reduce astigmatism and improve resolution we increased the reflection angle from 83° to 86°.



Resolution tests were performed using an Au grid and a laser (ZBL) heated foil.

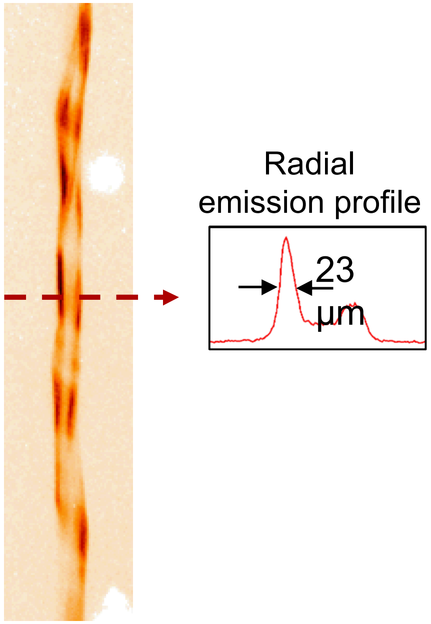


Old imager
Resolution
~ 60 µm

New imager
Resolution
~ 17 µm

Assuming bar width = 25 µm

Recent MagLIF experimental data (PI: Matt Gomez, z3120)



E.C. Harding and M.R. Gomez

TiGHER Pin Hole Camera

Next generation version of Time-Gated High-Energy Spectrometer though it is a pin hole camera.

Purpose: high-resolution, high-sensitivity 2D imaging of Z load x-rays (e.g. MagLIF)

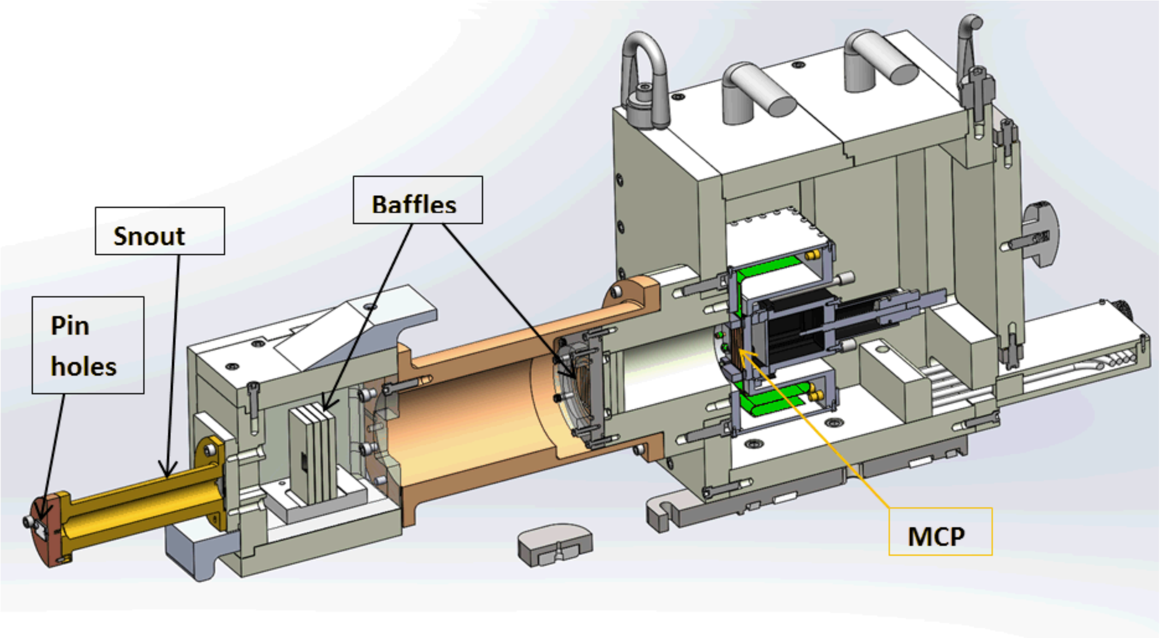
In commissioning phase at Z.

Located in the Z vacuum chamber, detector is 880 mm from the Z load.

Eight MCP channels (Gen II, < 1 ns width gates). Independent vacuum system for MCP.

0.5X, 1.0X, or 3X magnification

MLM-style pin holes



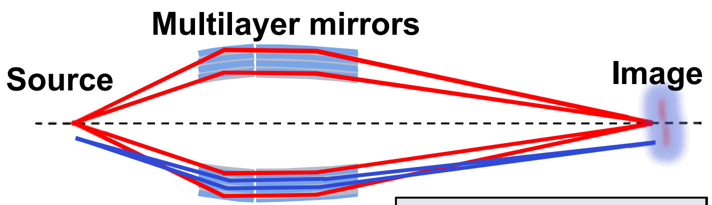
Shown: 3X mag configuration. Lower magnifications achieved by effectively moving pin holes closer to the detector with alternative hardware.

Wolter Optic Imager

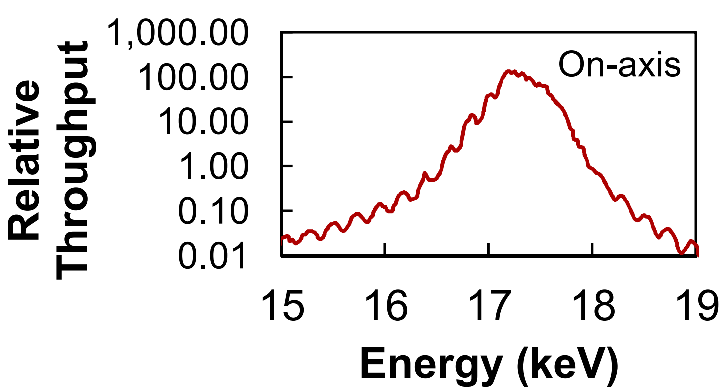
Wolter optic imager will provide improved capability to study dynamics of >10-keV x-ray sources on Z

Part of National Diagnostics Plan in collaboration with LLNL

Wolter optic forms narrow-band image by focusing x-rays with multi-layer mirrors:



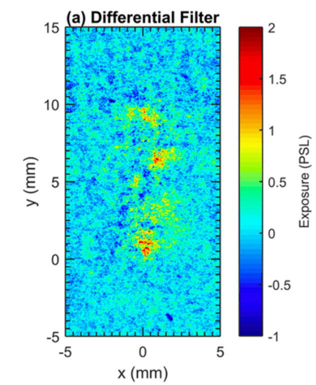
100-μm resolution over 5-mm FOV



Wolter optic imager provides several advantages over pinhole cameras:

- Natural band-pass enables higher S/N
- Higher collection efficiency from focusing geometry
- Large stand-off distance allows for **compatibility with hCMOS detectors**

Low S/N in Ross-pair pinhole image of Mo wire array:*



Diagnostic Status:

- **Current:** Optic multilayer surface characterization
- Diagnostic housing and alignment system being finalized
- **September:** Optic arrives at Sandia for calibration/imaging characterization and hardware in fabrication
- **December:** Full scale 17.5-keV optic to be commissioned on Z!
- **2018:** Commissioning of 22-keV
- **2019:** hCMOS integration

*McPherson, RSI (2016)

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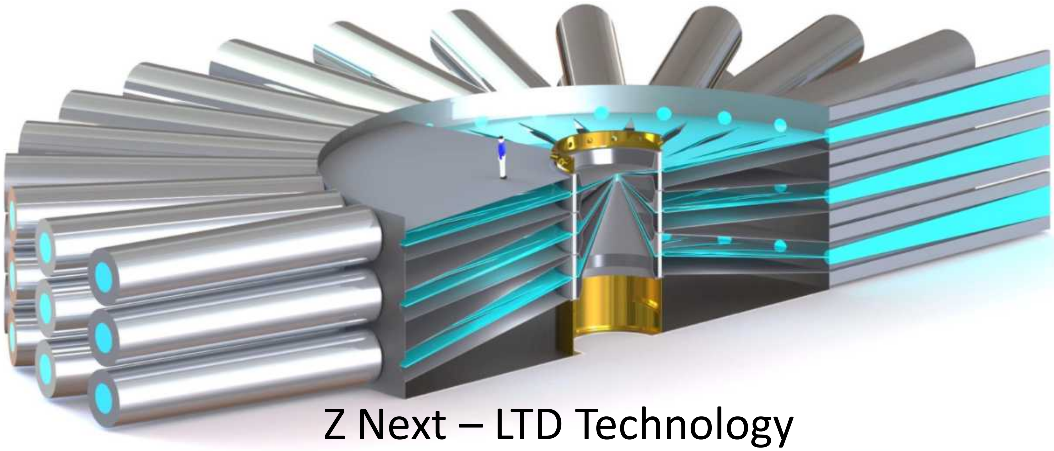
Pulsed Power Future

The Next Generation of Pulsed Power Machines Are Based In Linear Transformer Driver (LTD) Technology



Z Next – LTD Technology

Mykonos – LTD Technology

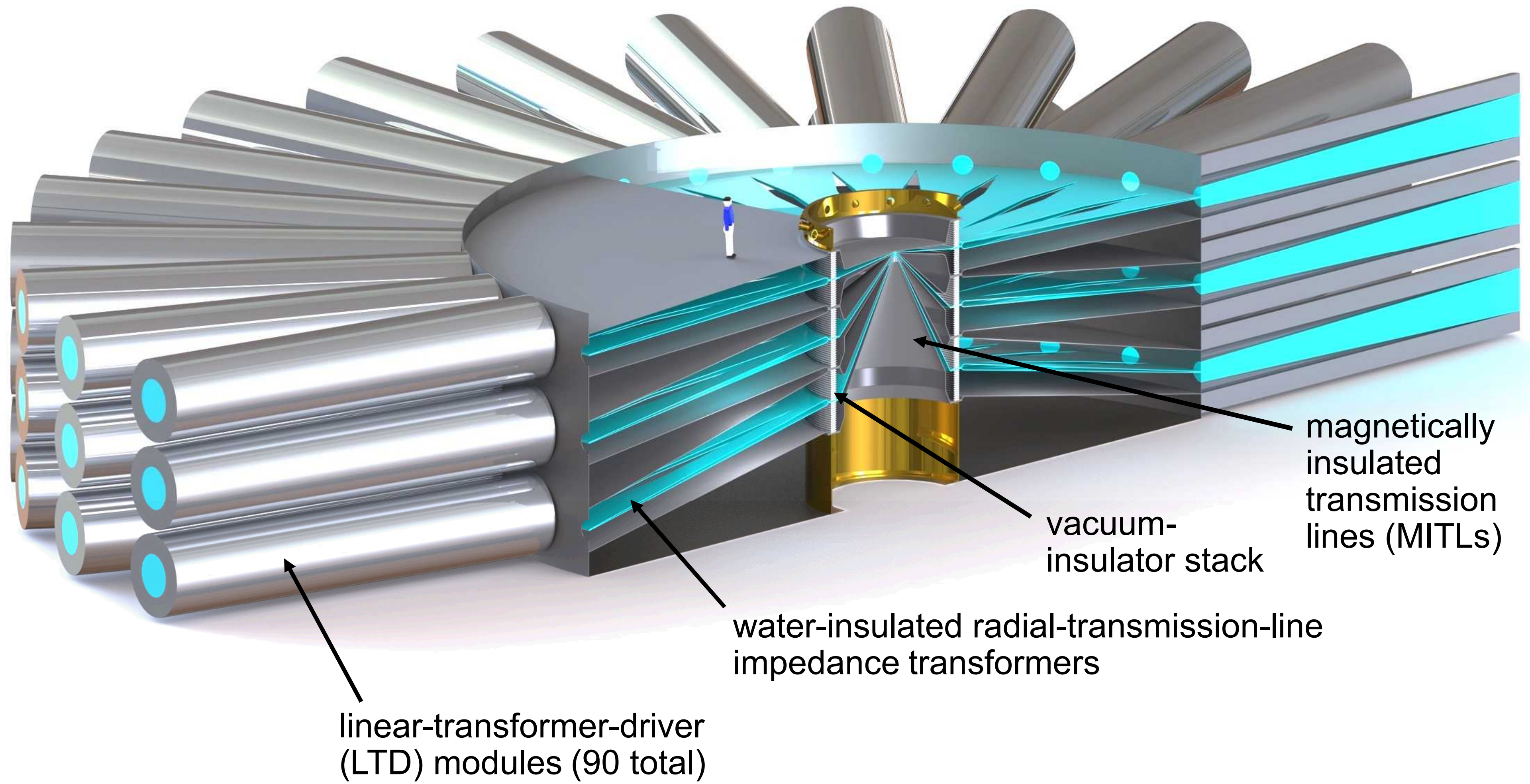
Radiography– LTD Technology

One of the proposed next pulsed power machines: Z 800.

E_{LTDs} = 130 MJ
V_{stack} = 15 MV
I_{load} = 65 MA
P_{load} = 2500 TW

P_{LTDs} = 890 TW
L_{vacuum} = 20 nH
$\tau_{implosion}$ = 113 ns
E_{load} = 8.0 MJ

diameter = 52 m



Thank you for your dedication and hard work in being of part of the success of the Z machine.