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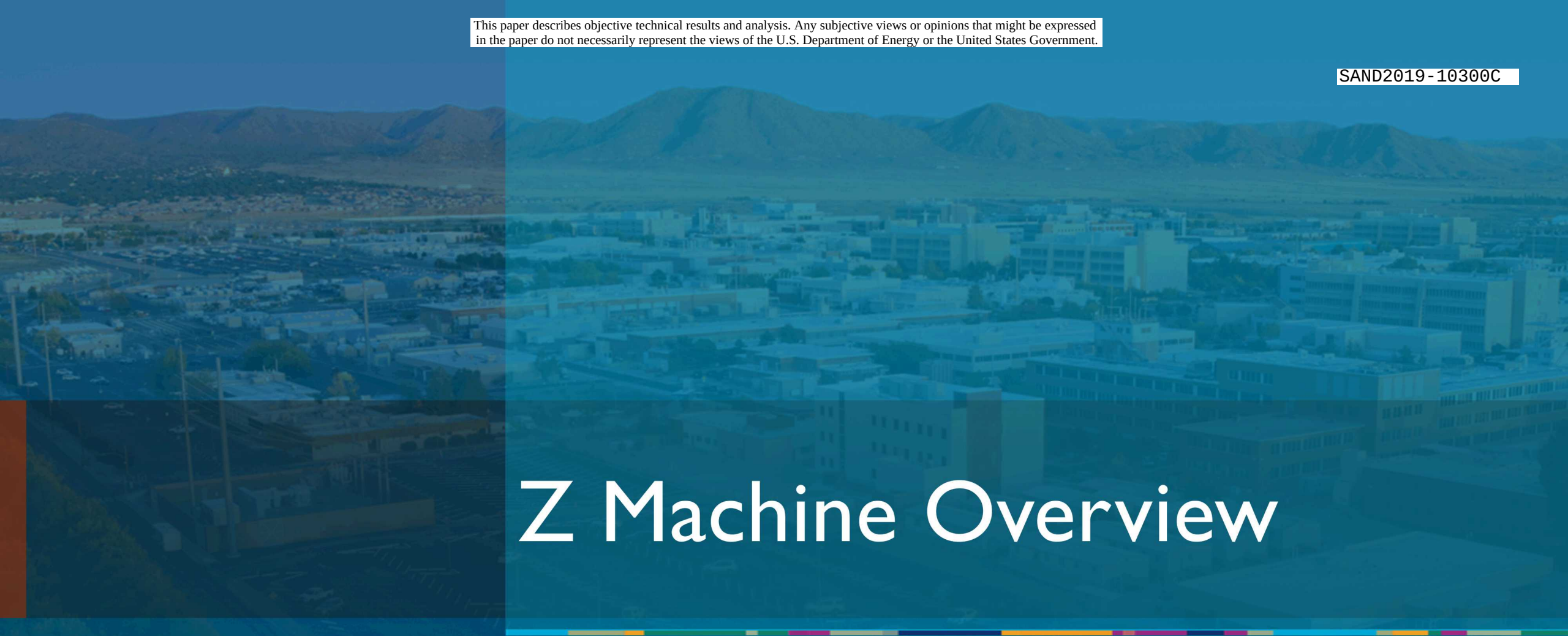


Z Machine Overview

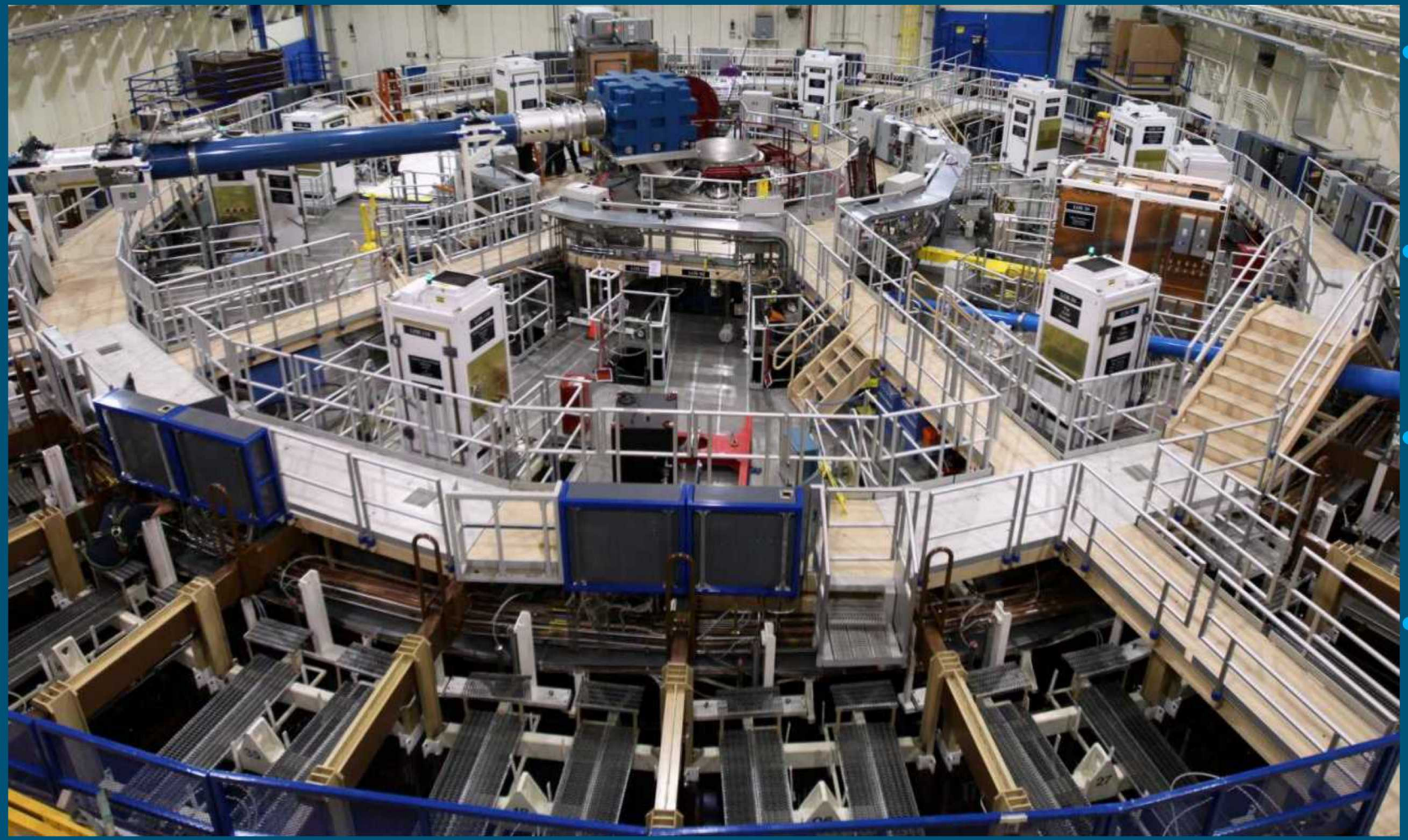
Briefing for the Z Fundamental Science Program Workshop

Chris Bourdon, Z Experimental Capability Management

8/12/2019

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & 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.

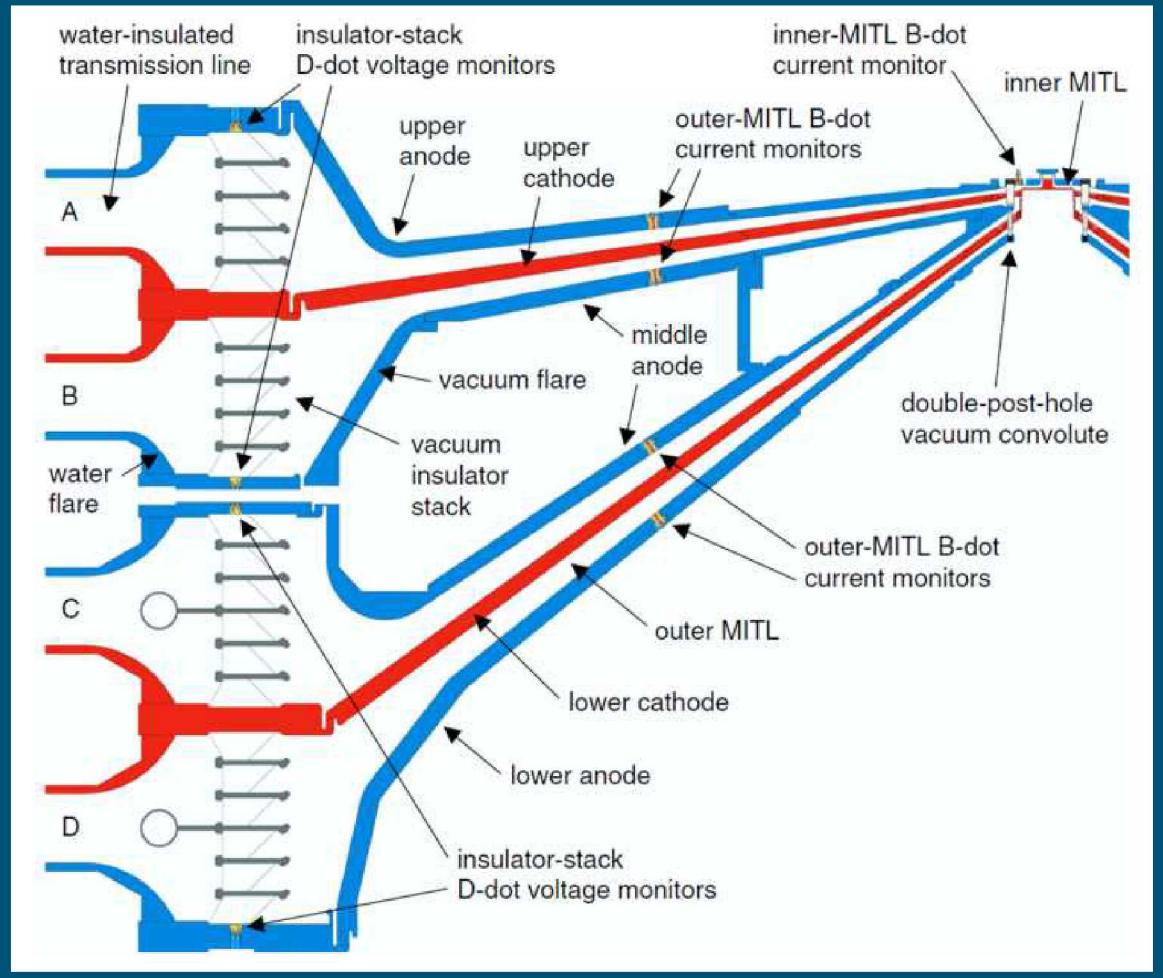
Z is a unique world class pulsed power facility at Sandia National Laboratories



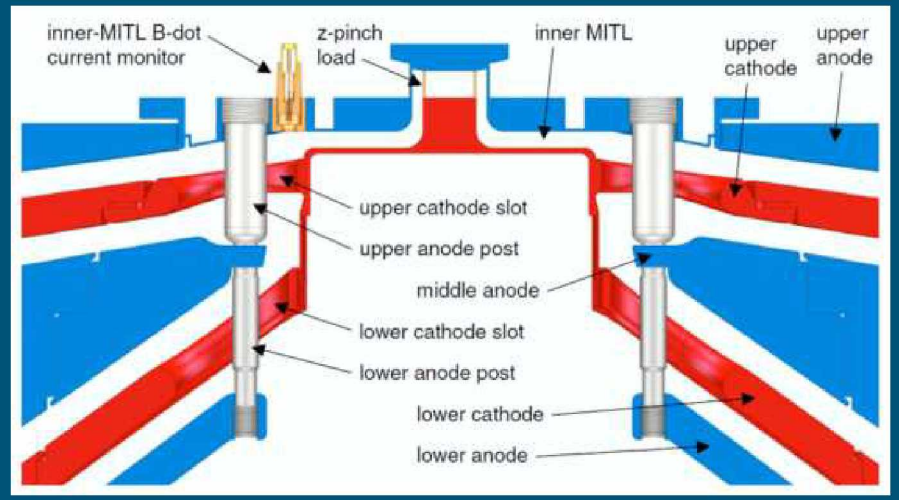
- 36 Marx generators
  - 2160 capacitors
- ~ 1M gallons of transformer oil
- ~ 0.5M gallons of deionized water
- 66,000 liter vacuum vessel

A complex series of conductors combine currents for the load

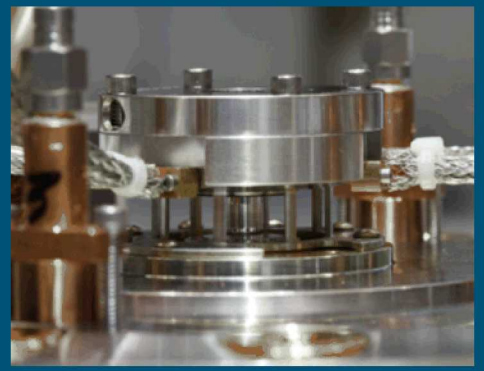
Z vacuum insulator stack and MITLs



Post hole convolute system and load



ICF liner load



DMP load

Pulse Shape Flexibility and Reproducibility

Z was designed to drive dynamic hohlraum experiments.

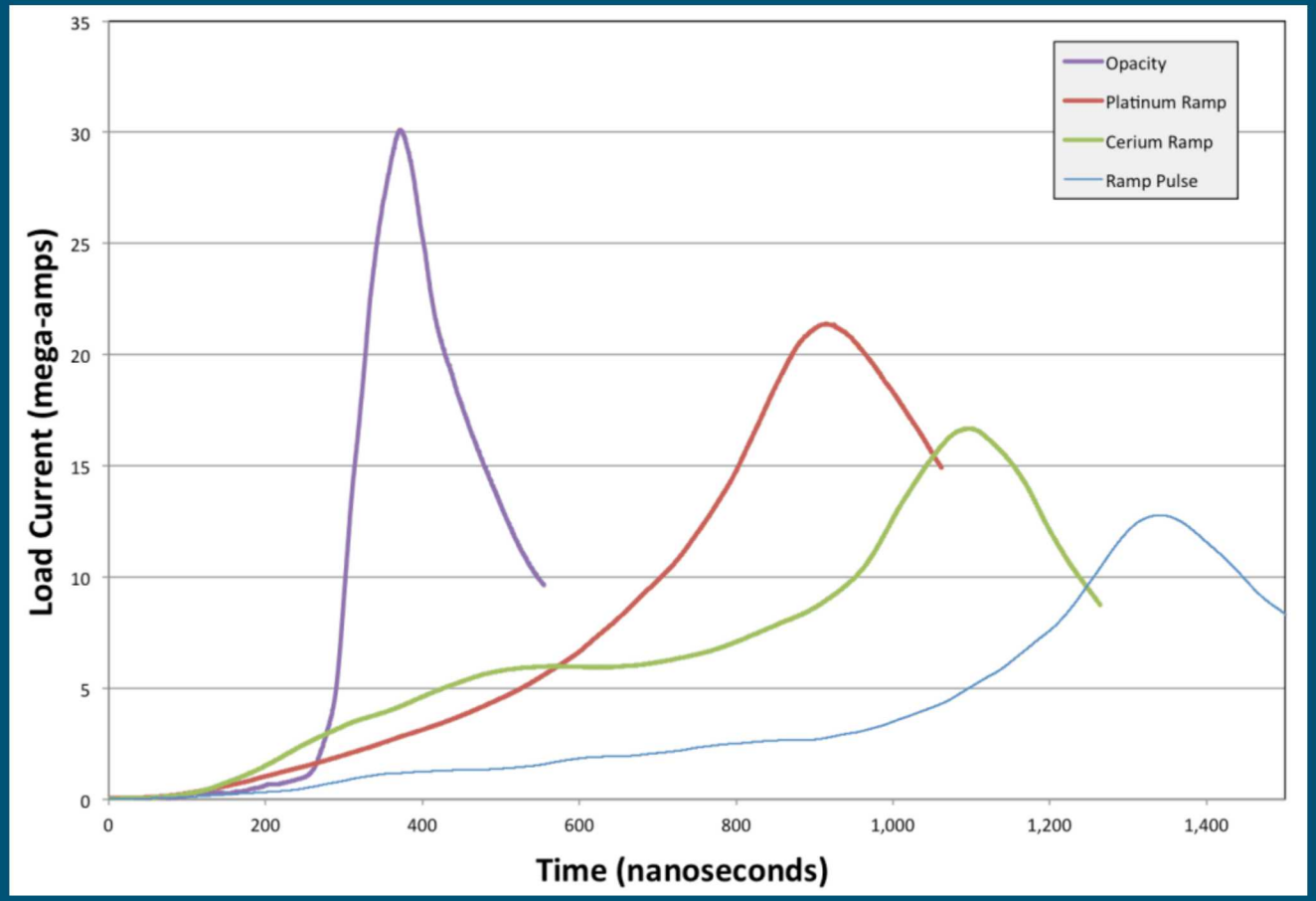
- ~150 ns current rise times

System improvements have enabled precisely tailored pulse shapes with multiple distinct drive characteristics

- E.g., both shock and ramp drives can be produced by a single pulse shape
- Up to ~1 μs current rise times

Each of Z's 36 transmission lines have multiple triggers and switches that can be employed to produce a given pulse.

- The Sandia developed Laser-Triggered Gas Switches (LTGSs) are central to our pulse shaping capabilities.

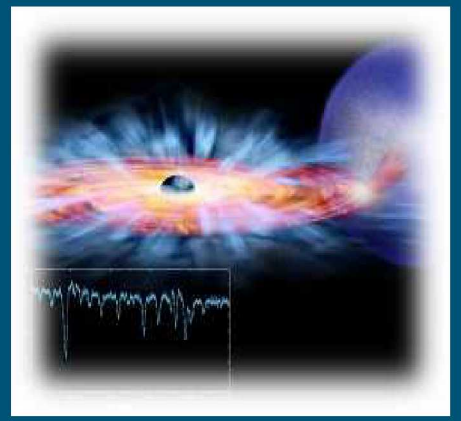


The purpose of facilities like Z is to provide the capability to answer questions that are not always possible to anticipate in advance

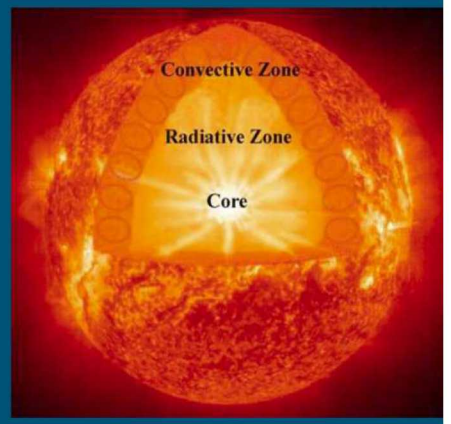
Z has evolved dramatically since 1996

- >90% of shots on Z in 2019 use experimental platforms that were not clearly envisioned in 1996
- As new platforms are developed, we are able to address new missions and answer new questions
  - e.g., capability to study dynamic materials + capability to use explosive containment vessels → Study of hazardous materials
  - e.g., fusion research leads to opportunities in radiation effects, HED opacity
  - e.g., laser backlighting capability + magnetic field capability → Study of new fusion physics regimes

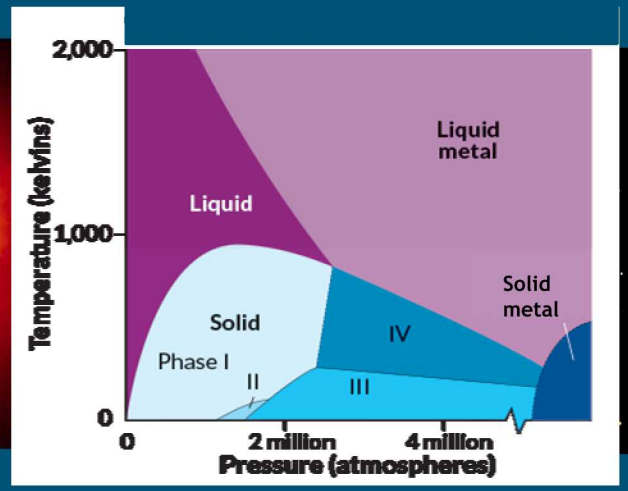
Z Fundamental Science Program benefits from this evolution



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



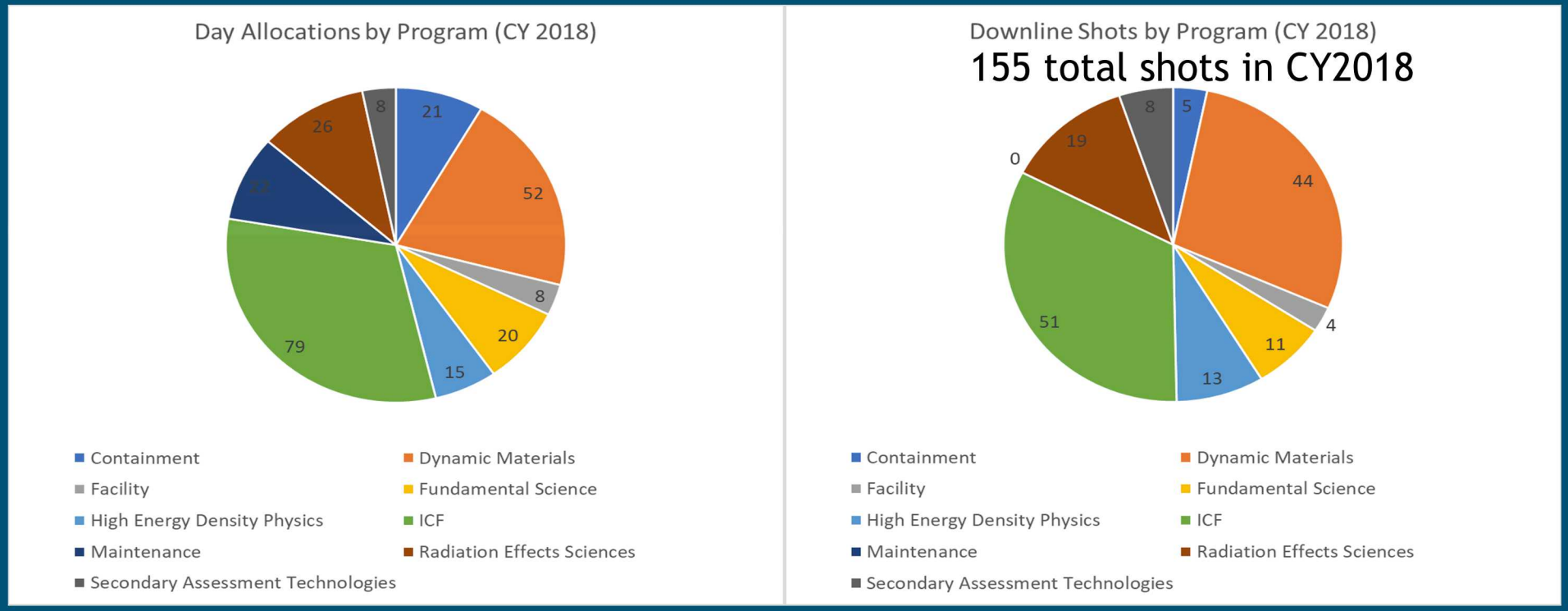
Opacity of Iron
SNL, University of Nevada- Reno, Ohio State University



Hydrogen metallization
University of Rostock, SNL

Iron Rain
Harvard University, UC Davis, SNL, LLNL,

Increasing the shot rate on Z would help ensure robust progress on the core mission and new research opportunities



Z has fielded about 150 shots/yr for the last five years, a pace dictated by multi-day hazardous experiments and single-shift operations.

M-F operation from 6 AM-6PM, excluding holidays (251 operational days)

Note that the 5 containment shots took 21 days to execute. Depending on the containment shot type we allocate 3 or 6 days per experiment.

Efforts ongoing to improve shot rate and optimizing the use of Z

Holistic approach: Look at the complete life-cycle of experiments and shots

Focus on multiple areas:

- Better planning/understanding of experiment & shot preparation and execution
- More robust hardware and target design, manufacture and procurement processes, and staffing
- Assess the shot execution operational model and implement efficiencies and/or build more timeline contingency
- Strategic activities to address Z systems maintenance needs
- Aggressively address staffing and investments as budget becomes available
- Identify and pursue game-changing technologies that improve operations (e.g., elimination of debubble dive, automated MITL refurbishment, debris catching features in MITLs)

We have been facing significant operational challenges this year

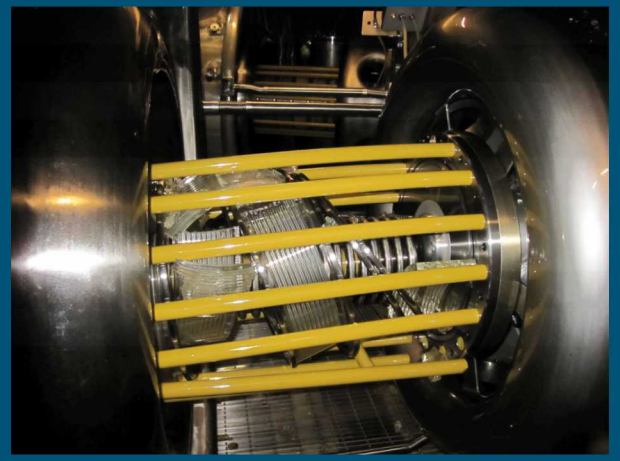
Facility Challenges encountered:

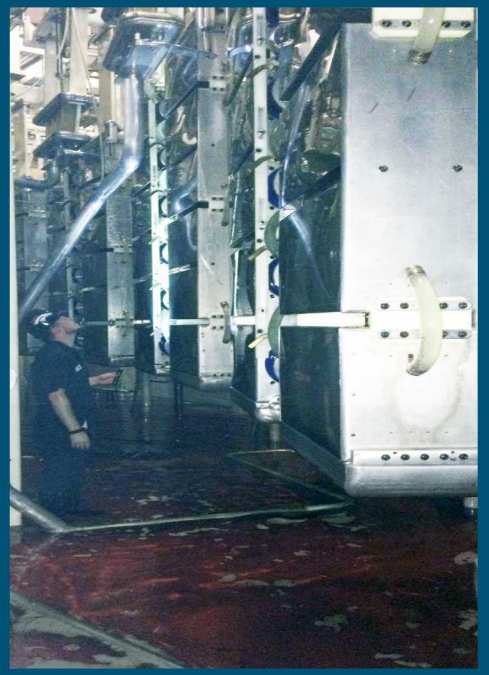
- Convolute Lift assist (4 Days) 9/17/18
- I-Store Barrier Water Supply Manifold Failure (4 Days) 10/2/18
- Franklin Lift (3 days) 12/21/18
- Unexpected Stack rebuild (31 days) 2/18/19
- Tritium Cleanup (5 days) 4/15/19
- South Elevator (2 days) 5/10/19
- Marx Failure (13 days) 6/18/19

In total, 62 operational days lost due to unexpected down-time (2X historical average) since July 2018

Approach for resolving

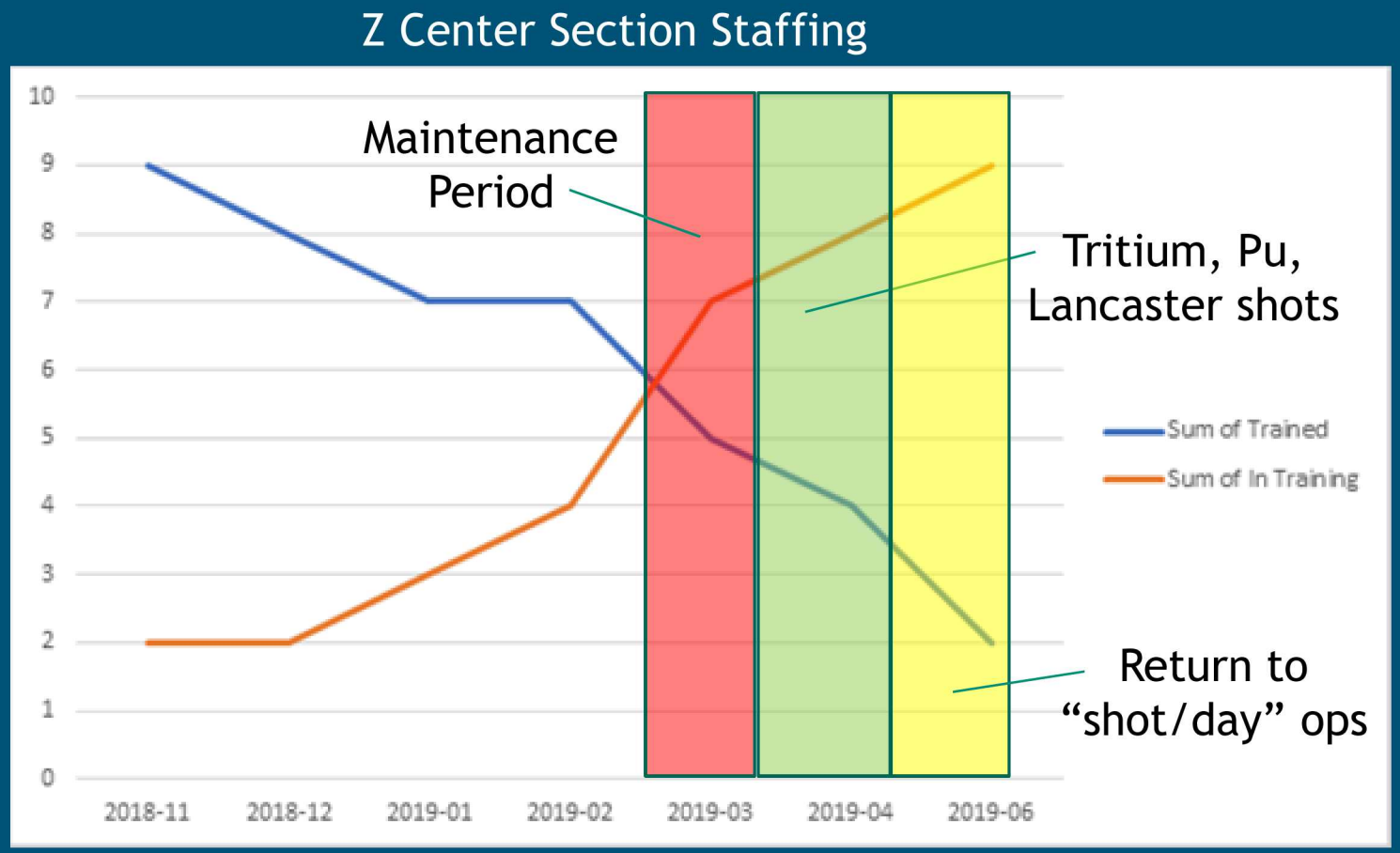
- Maintenance and infrastructure investments are ~10% of the core (machine) operations budget; and have been steadily increasing in response to age of facility
  - Many of the critical systems have been addressed (Crane, Oil process valves, Oil tanks, SF6 process valves and infrastructure, control system) in 2018 and 2019
  - Planned investments in FY20 and beyond
- Continuous improvement sought in major systems for reliability, fault tolerance, and performance
- Operations rigor and risk assessment in operations will be a priority in FY20





The experience level of our Z Center Section is our most acute staffing issue in 1670—the team now has <1 year average experience

- ~200 hours of safety and job-related training means a heavy investment is needed before workers are productive
- Many Z shots today require Q clearances to fully participate in the load and unload, which can impact the ability of uncleared staff to contribute
- On-the-job training is expected to be a ~2 year apprenticeship due to its complexity—working with both large hardware and precision hardware (targets and diagnostics) in a range of environments
- This is a unique job and a unique skill set not found almost anywhere else within Sandia



While staffing roughly constant at 10-12 members, experience level has been dropping; return to "shot per day" ops over last several weeks has exposed the difference

Short-term (through end of CY19) approach for worker training and efficiency

Current focus is knowledge sharing, building proficiency and efficiency:

- **Temporary change in operational posture**
  - FY19Q4 reduction in shot rate to enable paced, focused training with high execution effectiveness
  - Last Quarter of CY ramp up shot rate toward improved normal operations
- **On-boarding and training** team members in select critical tasks to move toward reliable execution of complex, integrated experiments (on average 1 shot/day plus efficient multi-day shots)
  - Focus on top side and bottom side refurbishment and load training
    - Individual skill assessments – baseline completed in July, will reassess each month
  - Shot schedule for Q4 is built currently to enable OJT to occur during shot execution
    - Extended timelines for execution
    - Sequencing of shots to give exposure to all varieties of experiments while creating repetition of similar experiments
    - Ensures all diagnostics are kept to achieve maximum knowledge gain
  - Leveraging former Center Section technologists' expertise (those still in the 1600) – strengthening bonds of past and present
    - Adam York ad Kelly Seals tapped frequently – general help, containment, etc.
    - Creating a framework for coverage on high-risk days due to Kraig being away, multiple members in training, etc.
    - Engaging with Mike Sullivan on more in-depth diagnostic training in preparation of and during high complexity shots; reaching out to K. MacRunnels
    - Collecting ideas for improved processes
  - Process and documentation improvements
    - Capturing improved instructions in documentation
    - Capturing suggestions for overall process improvements
- Capturing and using activity level **metrics** and improving **communications**
  - Measuring team's performance
  - Improving communications approach to keep larger community informed

We are also gathering data to better enable planning

- Prototype shot timelines based on complexity and risk
- Define the 'complexity levers' to enable better informed decision making from broader community
- Identify knowledge gaps earlier so that we can plan in advance

On the job Training

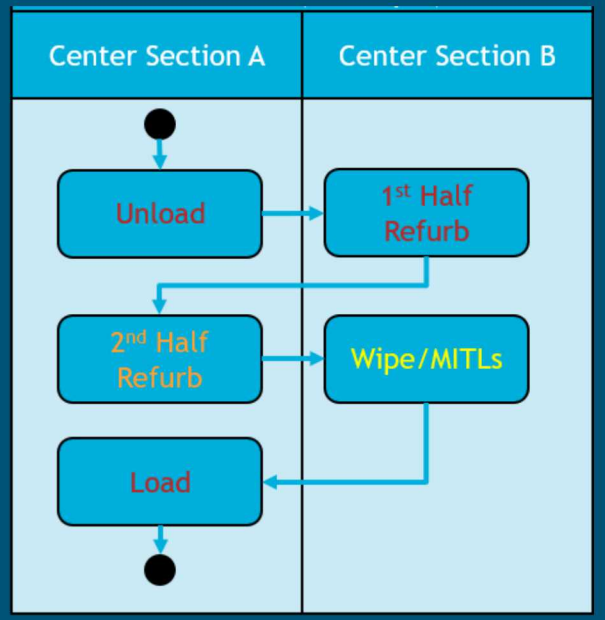
Key milestones for assessing progress

By the end of the **fiscal** year:

- Successfully executing 3 planned shots on average per week
- 10 trained technologists proficient in bottom and top refurbishment, wipe, loading the MITLs
  - Able to reliably complete these activities without injury or defects in an efficient manner
  - Reduce variability in timing to just refurbishment
- Top Side Load
  - 1 independent
  - 1 proficient
  - 1 emerging
- Bottom Side Load
  - 3 independent
  - 2 proficient
  - Many emerging
- Crane Operator
  - All certified
  - 3 independent
  - 2 proficient
- 3 new technologists hired, completed required certifications for Radiation and Beryllium work activities

By the end of the **calendar** year:

- Successfully executing 4 planned shots on average per week
  - Continuous shot activity
  - Reduced ergonomic hazard
- 3 new technologists proficient in bottom and top refurbishment, wipe, loading the MITLs
  - Able to reliably complete these activities without injury or defects in an efficient manner
- Top Side Load
  - 3 proficient or higher
- Bottom Side Load
  - 7 proficient or higher
- Crane Operator
  - 3 new technologists certified
  - 7 proficient or higher



We have authorized increased staffing levels for Z Operations, but attrition to other parts of Sandia has been an ongoing problem

- Attrition from Group 1670 has mainly been a combination of retirements and employees migrating to other parts of Sandia, and is a significant fraction of total
- Lab-wide hiring boom over last two years created a "buyer's market" for highly-trained and cleared members of the workforce. This is expected to slow down in FY20 as the laboratory population plateaus.
- As of late 2018, Group 1670 has been authorized to expand its staffing levels in order to begin working toward more reliable and eventually higher shot rates
  - We have added staff to review and update our work planning documents to improve job training aids
  - We have added two shot planning experts to the team in the last month, along with a schedule planner
  - Studies done over the previous year (e.g., "Benage" study) have identified improvements to the shot planning process leading up to the day of the experiments that we will be working on.

Organization 1670 Years of Experience (Does Not Include Students)

Fiscal Year	Average Years of Experience
FY19	6.9
FY18	8.7
FY17	9.0
FY16	9.1
Average	**8.4**

Organization 1670 Gains and Losses (Does Not Include Students)

Fiscal Year	Gains	Losses	Net Gain or (Loss)
FY19	18	15	3
FY18	20	23	(3)
FY17	14	20	(6)
FY16	13	11	2
Grand Total	**65**	**69**	**(4)**

- 1670 size at end of FY18 was 60 people
- FY19 Data Is As Of 4/12/19
- FY18, FY17, and FY16 Data Is As Of End Of Each FY

Keeping Z a vibrant scientific facility ("Z-2030")

Given the time scale for a net-gen power facility, nearer-term investments in Z are needed to keep it scientifically vibrant through 2030

Keeping Z a vibrant scientific facility ("Z-2030")

- Continuous development of our workforce
- Sustainment investments in Z pulsed power infrastructure
- Z pulsed power capability improvements
- Improved scientific capabilities (to support scaling physics and ongoing stockpile stewardship activities)

Laying the groundwork for a next-generation pulsed power capability (2032 or later)

- Continuing to improve credibility of target scaling from Z to "Z-Next"
- Refining exemplar problems for multi-MJ through GJ yield capabilities
- Maturing pulsed power driver technology readiness levels for various pulsed power architecture options
- Investments in power flow (driver-target coupling physics tools and diagnostics

Our strategy for moving forward over the next several years continues many of these initiatives

Sustainment investments in Z pulsed power infrastructure

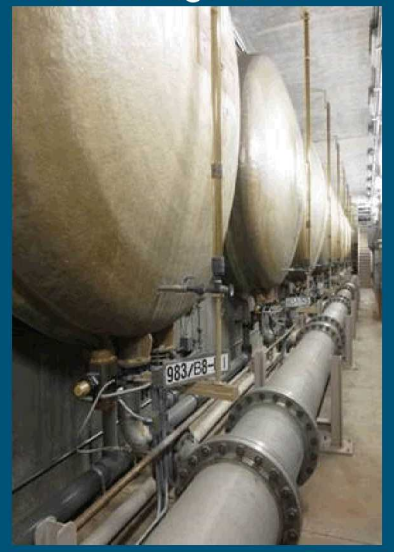
Z capability improvements

Improved scientific capabilities

Marx capacitor banks

Oil filtration systems

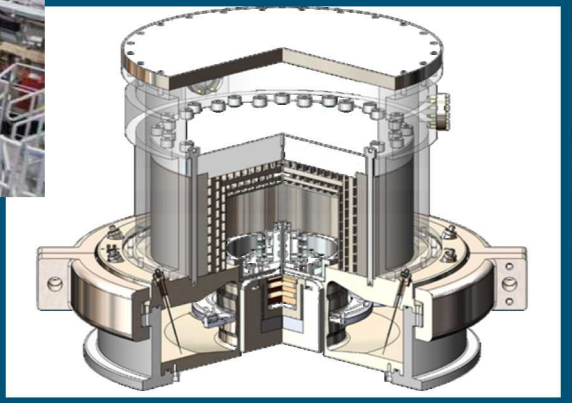
Water storage tanks



Beryllium mitigation planning

Advanced diagnostics,
e.g., Z Line VISAR (joint with LLNL)

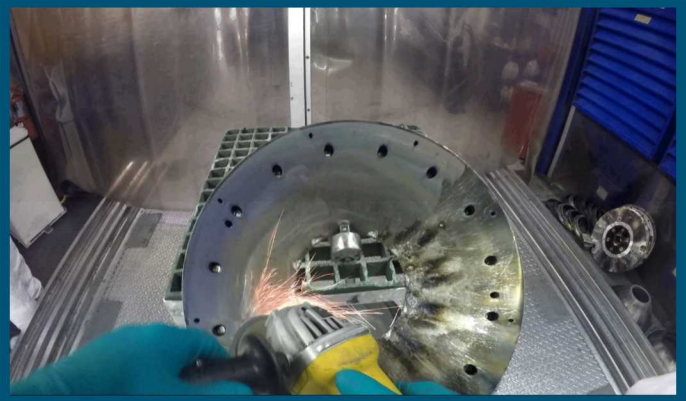
Next-generation containment systems



Examples of Z facilities and infrastructure investments that are needed to sustain our existing capabilities, including safety improvements

Beryllium Exposure Mitigation programs

- Reduce worker exposure by improvements to MITL & center stack refurbishment processes (e.g., robotics)
- Z offers the opportunity to prototype ideas in advance of a NGPPC



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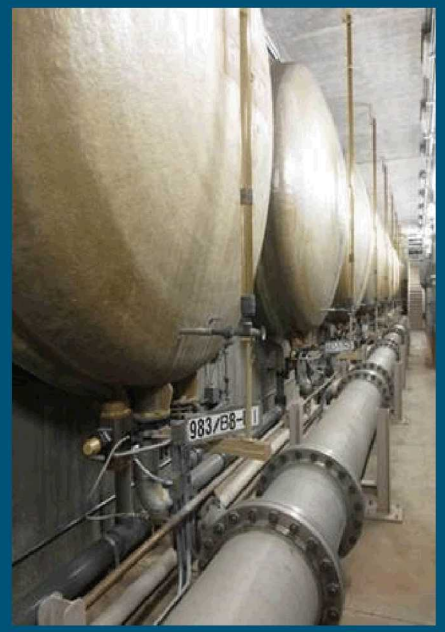
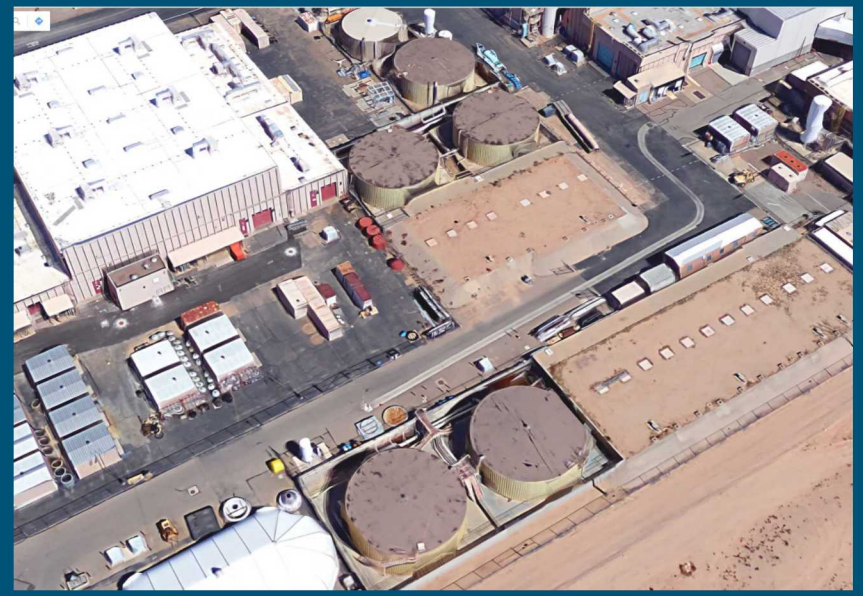
Oil tank system sustainment & storage facility containment upgrades

De-ionized water tank farm and processing





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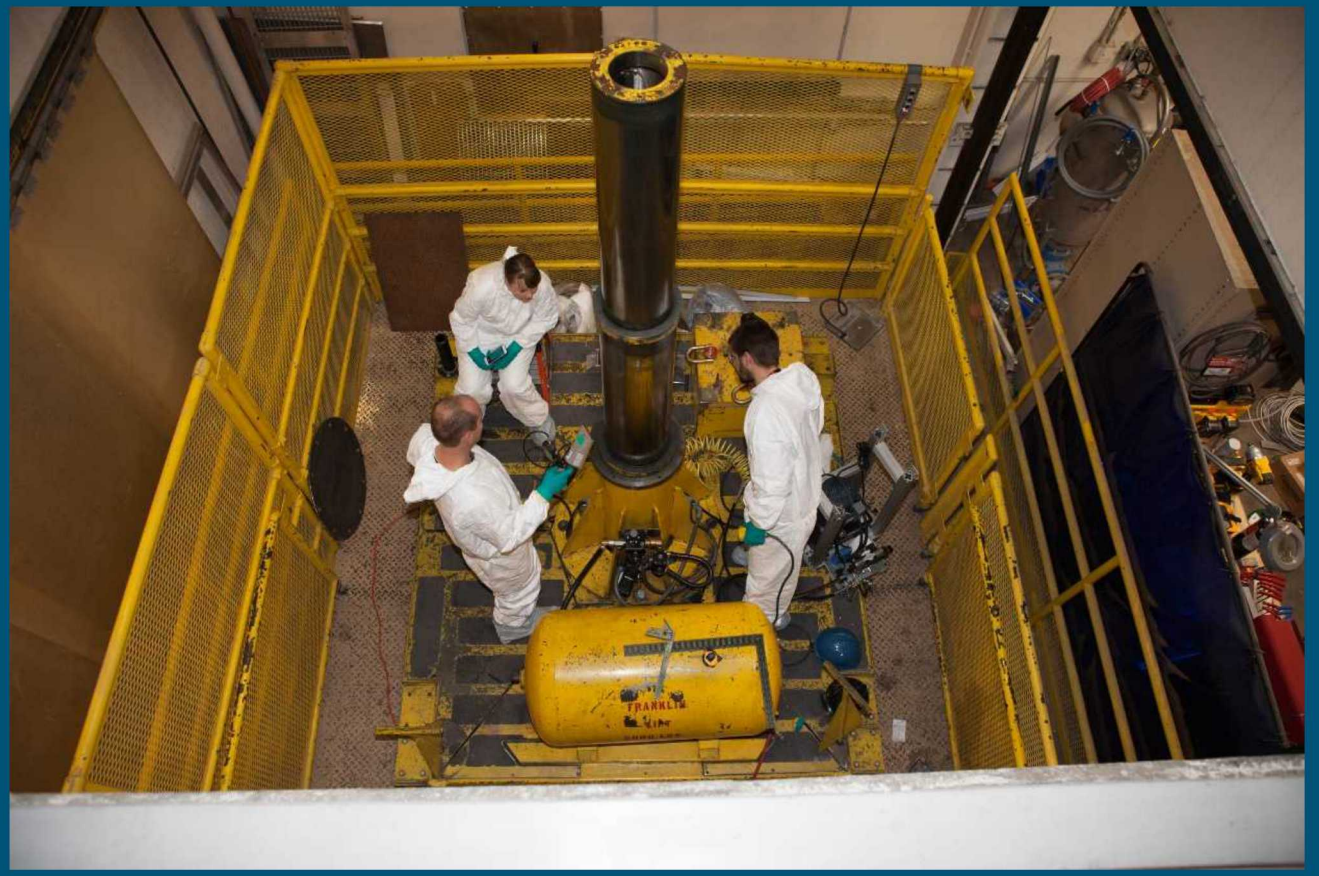
Elevator sustainment

- Both elevators have age-related and containment compliance issues

Sealing & Airlocks for Z High Bay

- Part of long-range plan for higher T inventory



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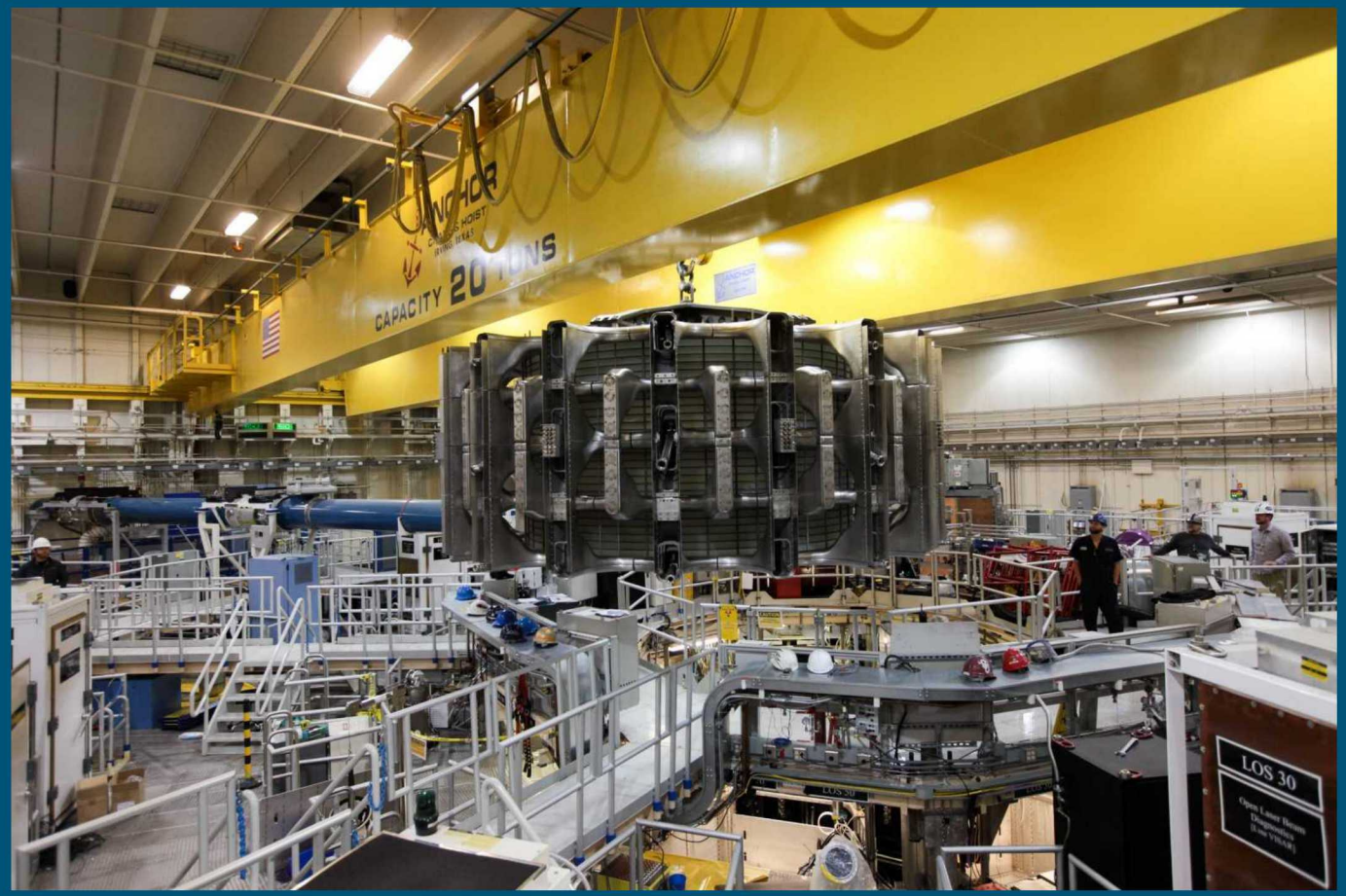
Improved stack rebuild infrastructure



Examples of Z pulsed power capability improvements that would improve our ability to execute our stockpile science missions and scaling physics work

95 kV Insulator Stack Upgrade

- Allow higher currents for short-pulse experiments
- Improve technology readiness level for Z-Next design options

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Marx Capacitor Bank Upgrade

- Go to 3.5 microfarad caps and/or add bottom row
- Correspondingly, upgrade the Marx trigger switches
- Expect to reach nominal lifetime of Z capacitors close to 2030

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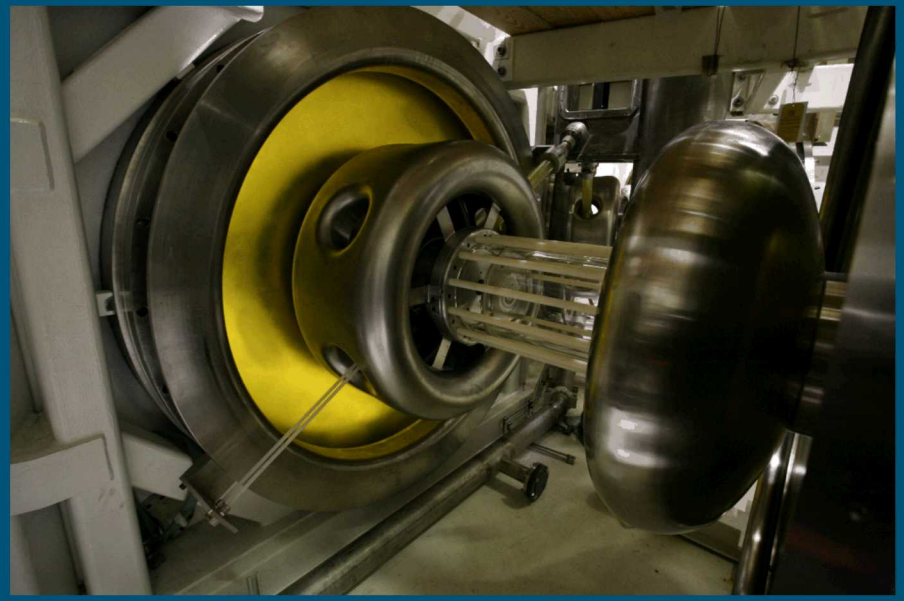
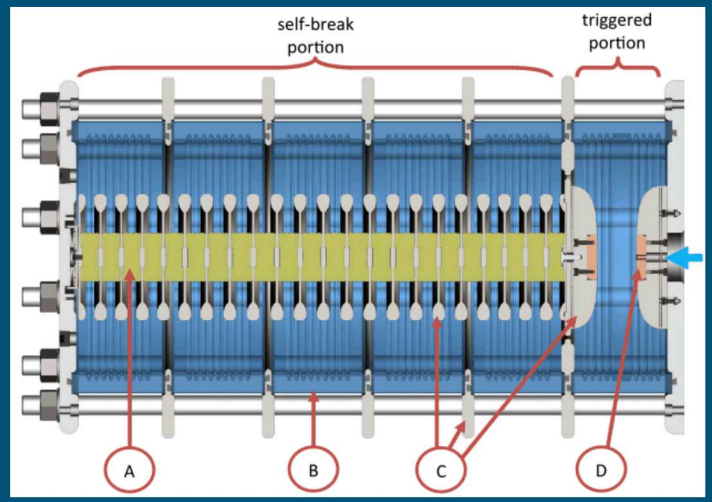
7.5 MV Gas Switches

- Increase switch performance to 7.5 MV capability while retaining performance
- Improve technology readiness level for Z-Next design options





Examples of Z science capability improvements that are a high priority to keep our stockpile science and research program vibrant

Improvements to tritium infrastructure
- Support higher T fractions than 3%

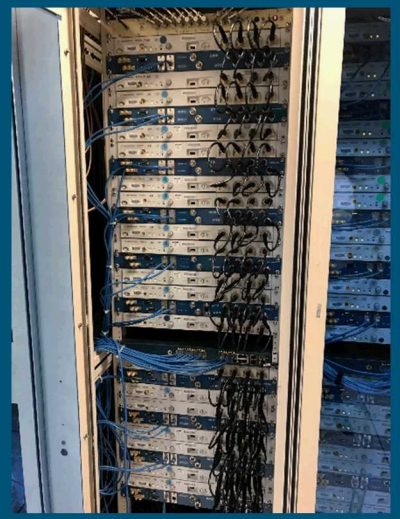
Improved neutron hazard modeling and engineered mitigations
- Increase facility yield limit above 1e15 (2.5 kJ) (above 5e15 integral annually)

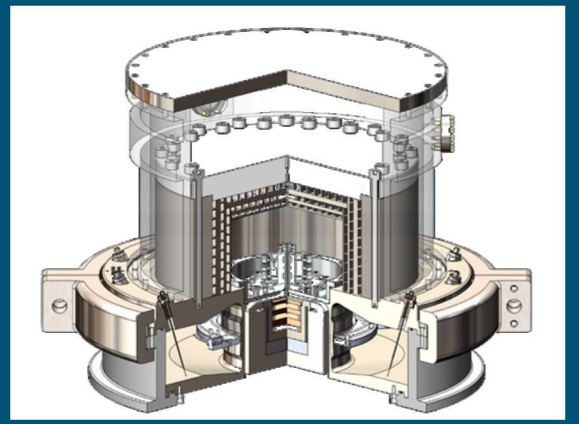
Improved cryogenic target capabilities

Improved data acquisition infrastructure

Improved data acquisition infrastructure
- More diagnostics; lower noise floor

Improved containment capability
- Not just for materials experiments, but also for possible fusion/fission experiments





Examples of laser system capability improvements that we are evaluating as options to keep our stockpile science and research program vibrant

Modifications to ZBL Front End

- Some parts date back to 1980s
- Enable longer laser pulses for MagLIF

Conversion to 3w light

- Non-trivial replacement of existing optics
- Would increase annual operating costs

Updated Final Optics Assembly for Z-Petawatt short-pulse operations

- Likely needed to support long-term development plans for x-ray diffraction

Questions?