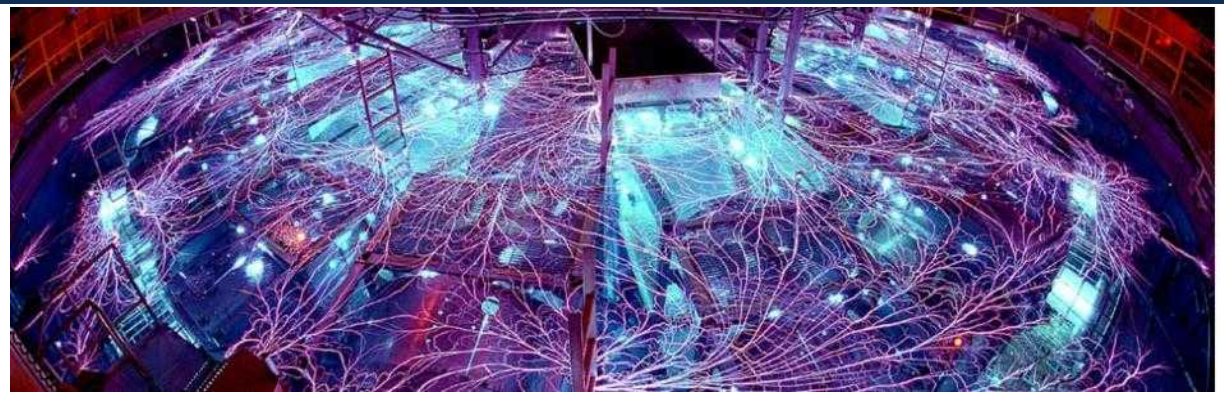
SAND2017-11242PE



Pulsed Power Operations at the Sandia National Labs Z Machine

19 October 2017

Will White, PhD

(with help from Mark Savage, Jim Moore, and many others!)

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.

Outline

- Pulsed Power Introduction
- Z Machine Overview
  - Scale comparisons
- Z Machine Operations:
  - Selected Tasks
- Pulsed Power Diagnostics
- Vacuum Stack Details
  - 2017 Rebuild Images
- References
- Summary
- Questions?

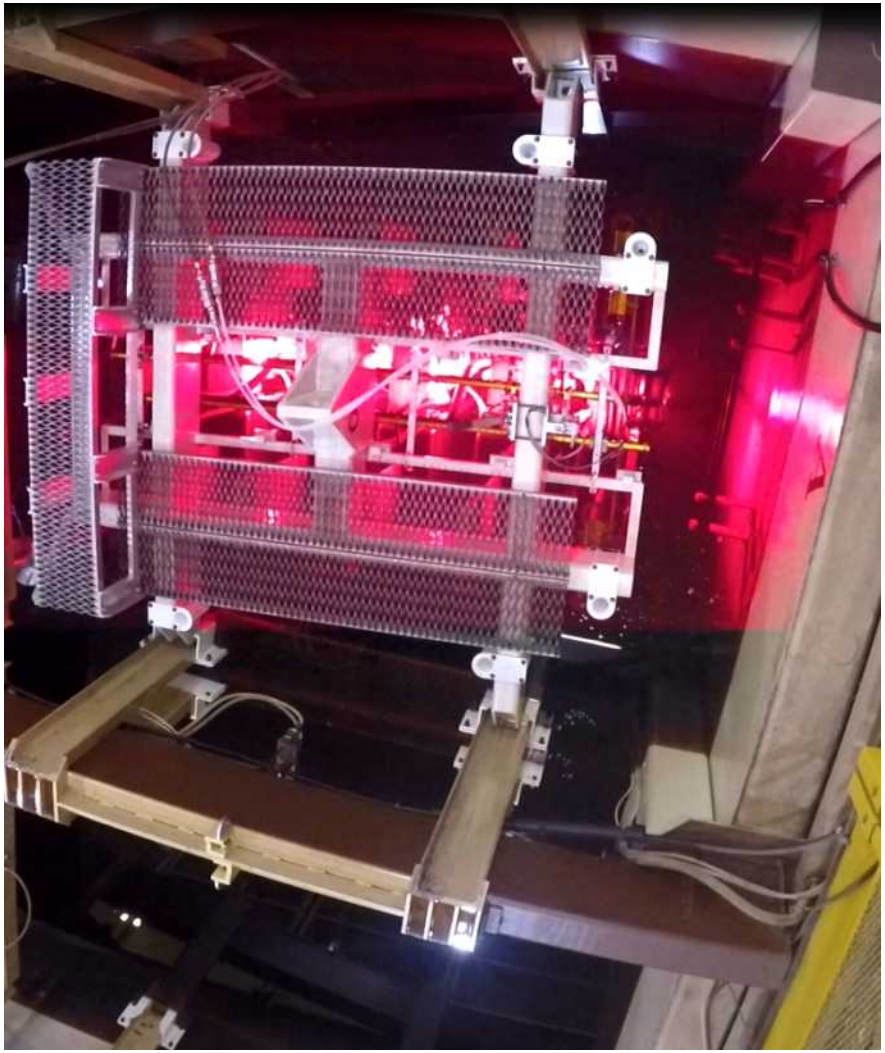
Acknowledgements

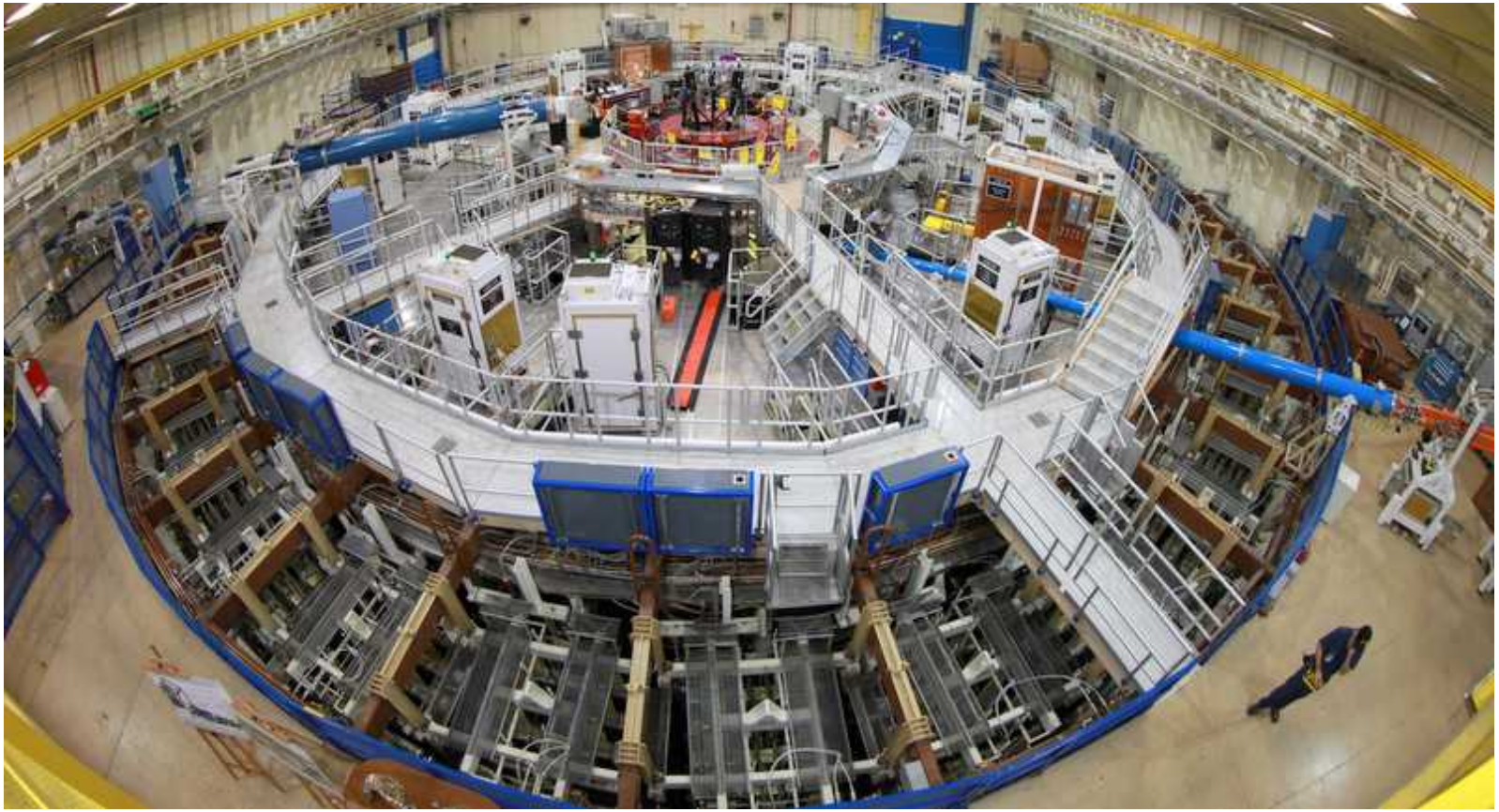
- Technologists, scientists, and engineers work together to keep Z running smoothly
- Operations Groups include ESS/PFS, Center Section, Facilities, Vacuum, CMDAS, LTS, and Diagnostics

Why Do Pulsed Power?

- Pulsed Power Squeezes Energy in Space and Time
- Lots of Applications Require
  - More Voltage
  - More Current
  - More Power

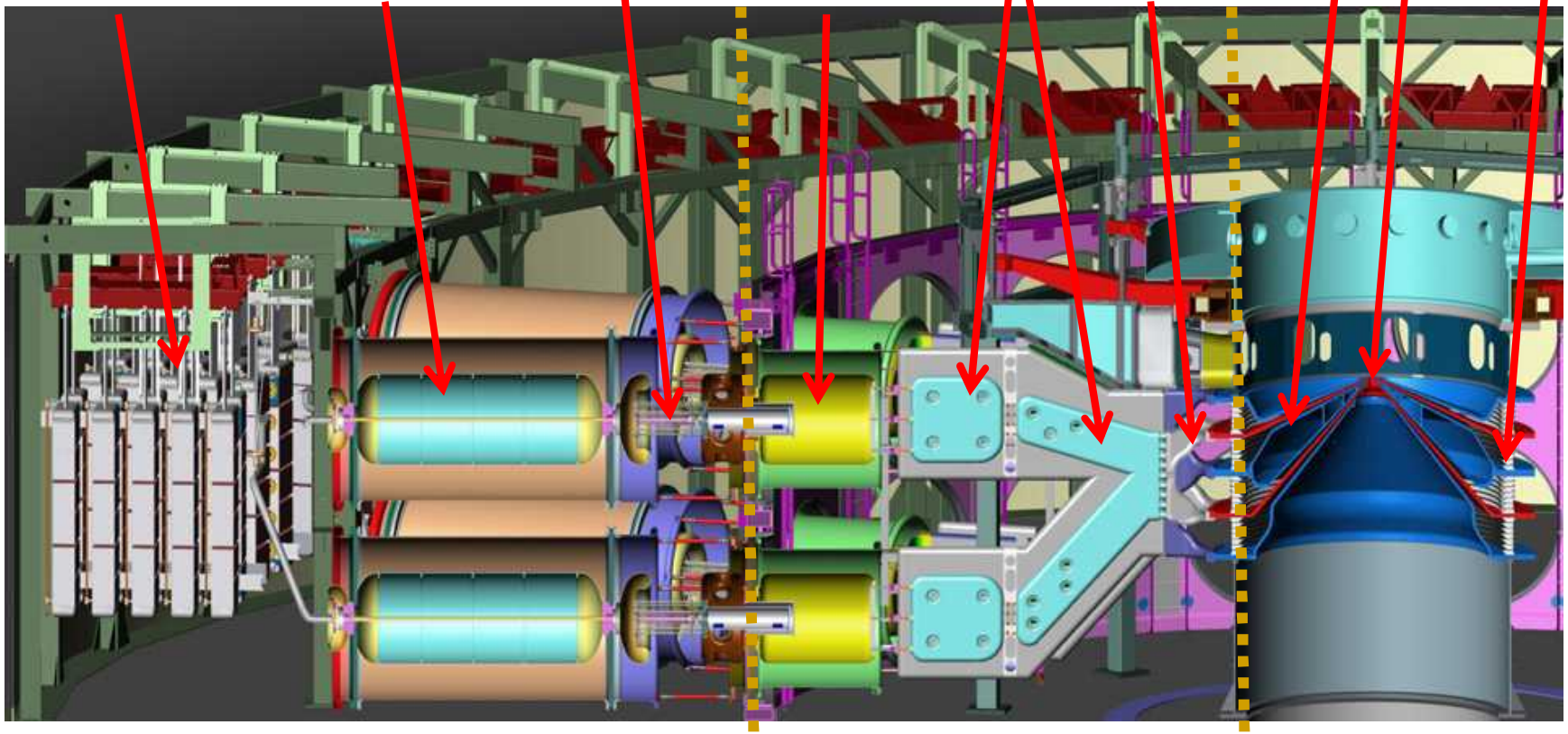
- Examples:
  - Camera Flash Bulbs
  - X-ray Sources
  - High Energy Lasers
  - Microwave Sources
  - Fusion Experiments
  - High Energy Density Physics
  - Neutron Generators
  - Particle Accelerators
  - Electromagnetic Launchers
  - Laboratory Astrophysics



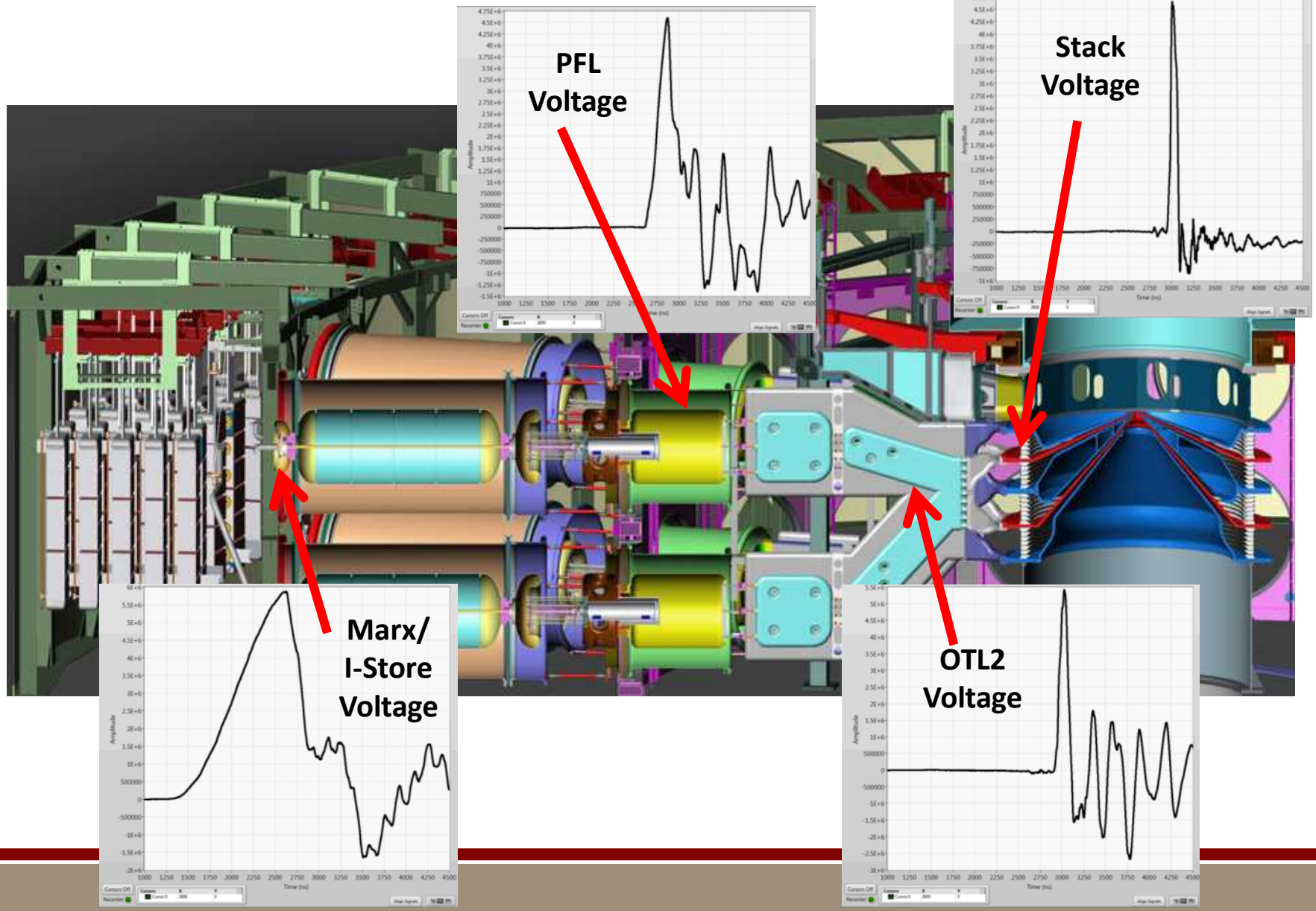


Z MACHINE OVERVIEW

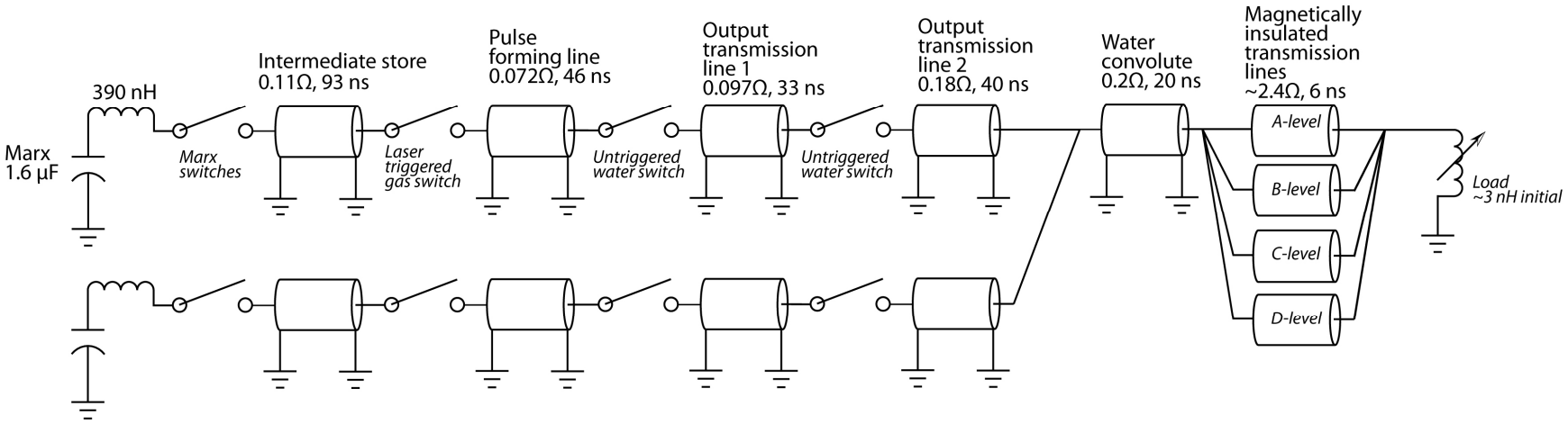
Sandia National Laboratories
Z Machine



Sandia National Laboratories
Z Machine Power Flow



The Basic ZR Schematic is Simple…



- **But complexity lies in the implementation of this circuit:**
  - Z has over 2,000 pounds of SF_6 gas, used in trigger generators, Marxes, and laser triggered gas switches
  - Z uses 600,000 gallons of transformer oil
  - Z uses 400,000 gallons of deionized water
  - 36 Marxes, with sixty 2.6 µF capacitors each, operated up to ±95 kV charge
  - 36 laser-triggered switches, designed for 6 MV operation
  - Etc....

Scale Comparisons

Sandia National Laboratories

Energy

- Z Marxes: **25 MJ**
- Z X-ray production: **2.7 MJ**
- NIF Lasers: **4MJ**
- World Electricity Use: **567 EJ per year** (2012)
- Stick of Dynamite: **1 MJ**
- Jelly Donut: **1.3 MJ**
- .30-06 rifle: **4 kJ**
- 70 mph SUV collision: **1.2 MJ**

Power

- Z Marxes: **25 TW**
- Z X-ray production: **350 TW**
- NIF Lasers: **500 TW**
- World Electricity Use: **18 TW**
- Stick of Dynamite: **120 GW**
- Jelly Donut: **60 W**
- .30-06 rifle: **4 MW**
- 70 mph SUV collision: **124 MW**

Z MACHINE OPERATIONS

So… What exactly do you do here?

Every shot day on Z we (the technologists):

- Drain both fluids
- Remove the lids
- Remove the MITLS
- Inspect the stack
- Inspect the water section
- Set water switch gaps
- Clean the MITLs
- Prep the vacuum pumps
- Clean the stack
- Assemble the load hardware
- Inspect the oil section
- Align the lasers
- Process both fluids
- Process the SF_6
- Reinstall the MITLs
- Setup diagnostics
- Set up the shot header
- Refill oil and water tanks
- Install the load hardware
- Align the diagnostics
- And more I am forgetting…

- **This does not include things that break!**
  - Tracked OTL rods, damaged Marx components, broken laser-triggered switches, grinding out flashing on the stack, damaged attenuators, etc.

Oil Section Operations

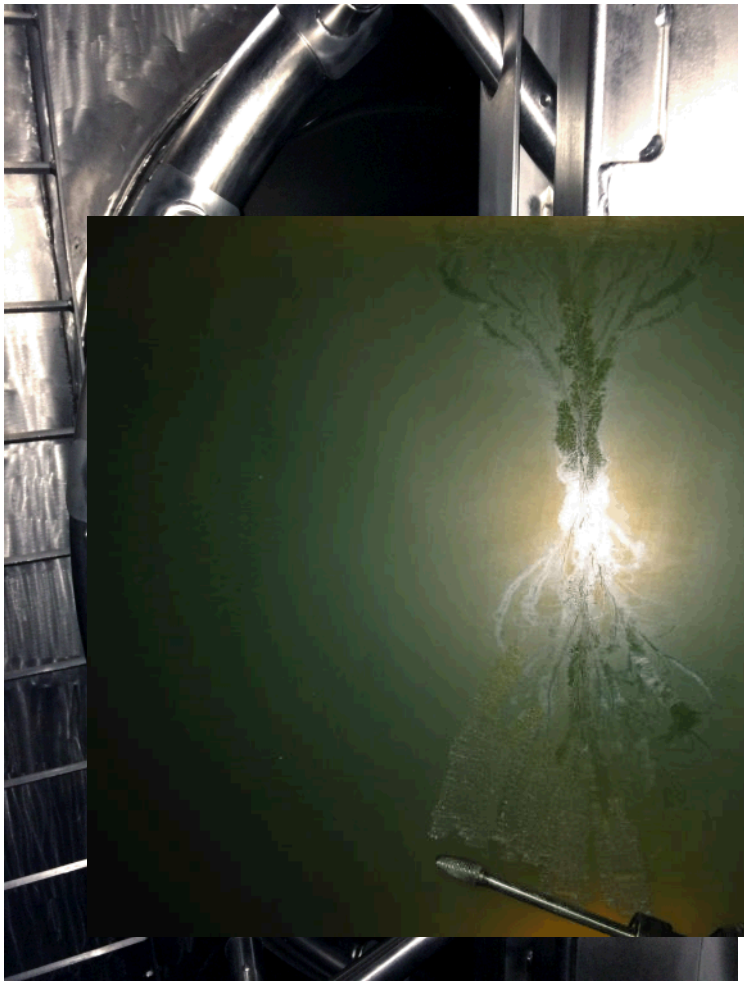
After draining the oil, need to inspect all 36 Marx banks, I-Stores, and Laser-triggered switches.

Sometimes, we do track or even crack a barrier (doh!)

Damaged components are repaired offline where possible

Water Section Operations

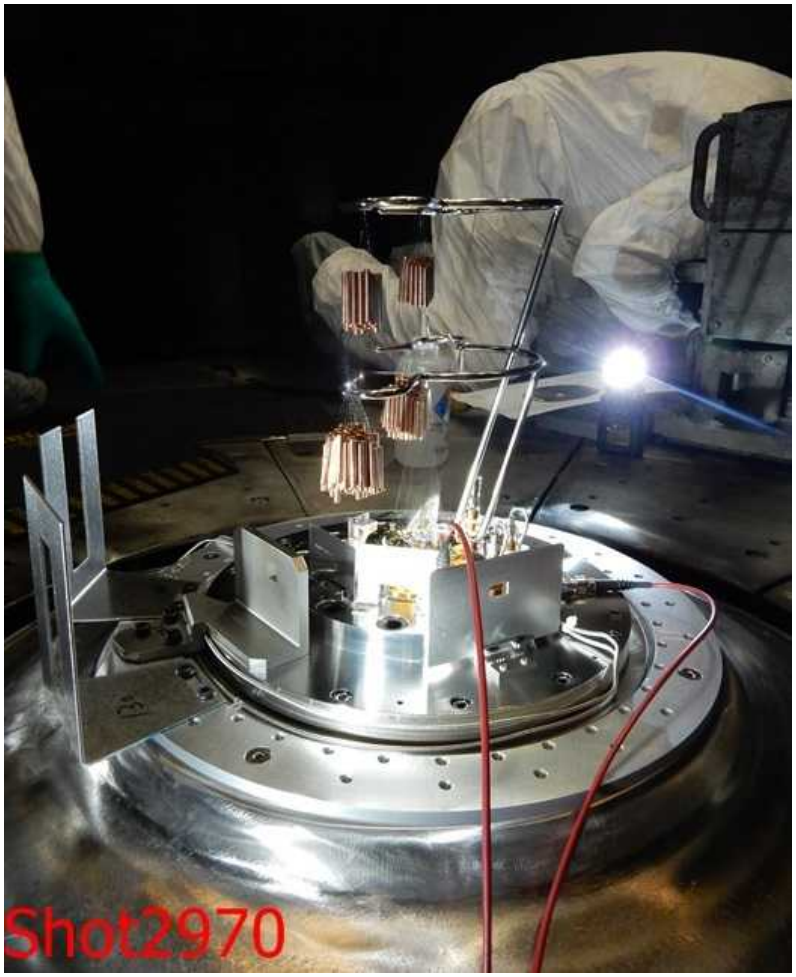
After draining the water, need to inspect OTL rods and PFL barriers, and water switch gaps may have to be set



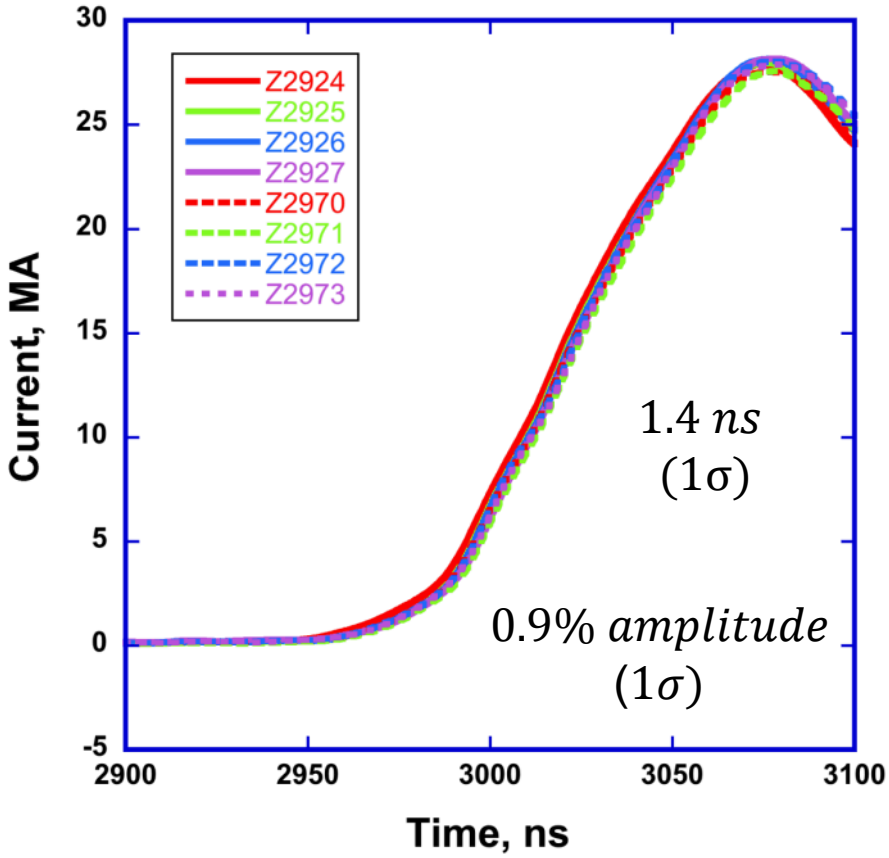
Center Section Operations

Center section has to refurbish the MITLs, clean and inspect the stack, install the load hardware, and help with diagnostic alignments

Center Section Operations



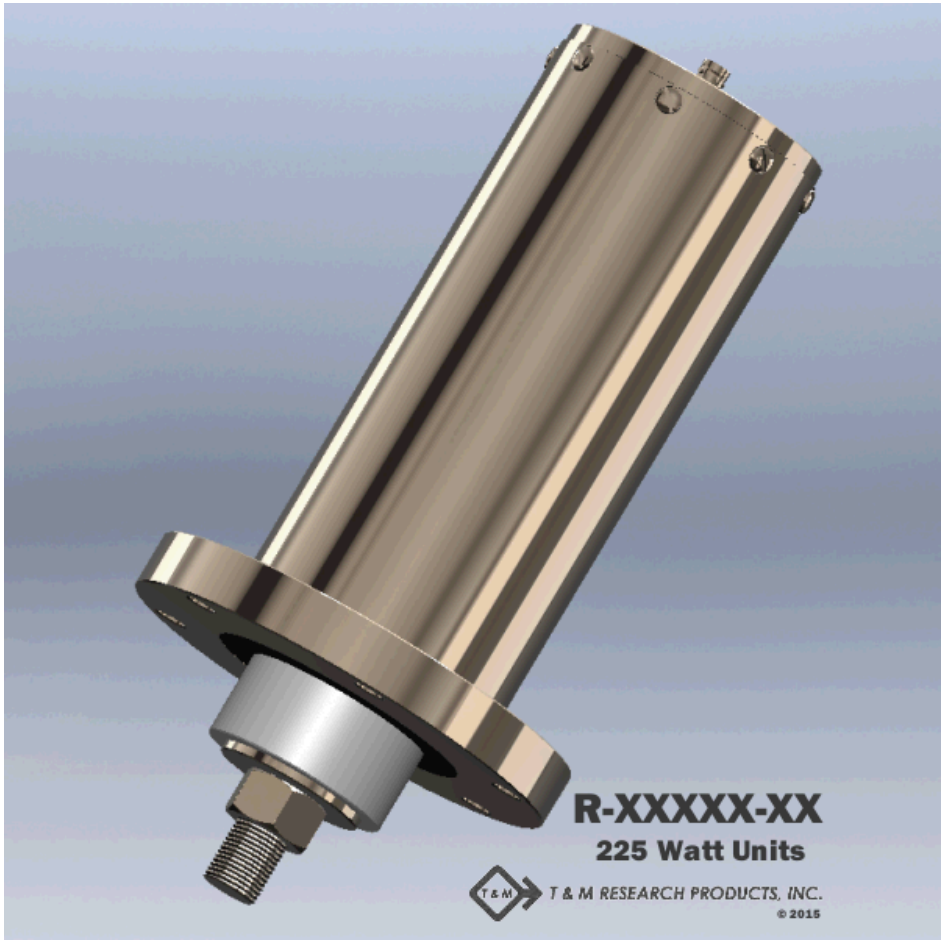
All that hard work to make that pretty wire array…



Z PULSED POWER DIAGNOSTICS

Current Viewing Resistors (CVRs)

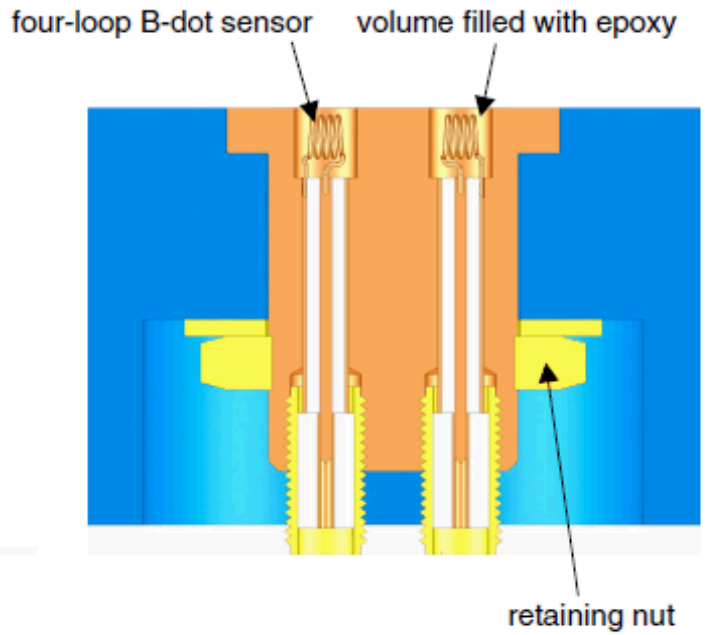
- Marx and MTG CVRs mounted on ground connection for respective bank
- Marx connection is made automatically upon installation (through Row 1 ground pedestal)
  - Breeze cables bring the signal to the oil/water wall feedthroughs
  - From there the signal goes through the water floor ports to DAS



B-dot (dB/dt) Monitors

- A thin (0.005 mm) nichrome film covers the detector
  - Allows penetration of **B** field, but isolates **E** field
- Two probes, wound in opposite directions (CW/CCW) are used in the stack and MITLs
  - The common mode noise can be eliminated by use of a balun

Ref: T.C. Wagoner, et al; PRSTAB 11, 100401 (2008)



$$\text{Simplified model: } V = NA\frac{d\vec{B}}{dt}$$

V = induced voltage

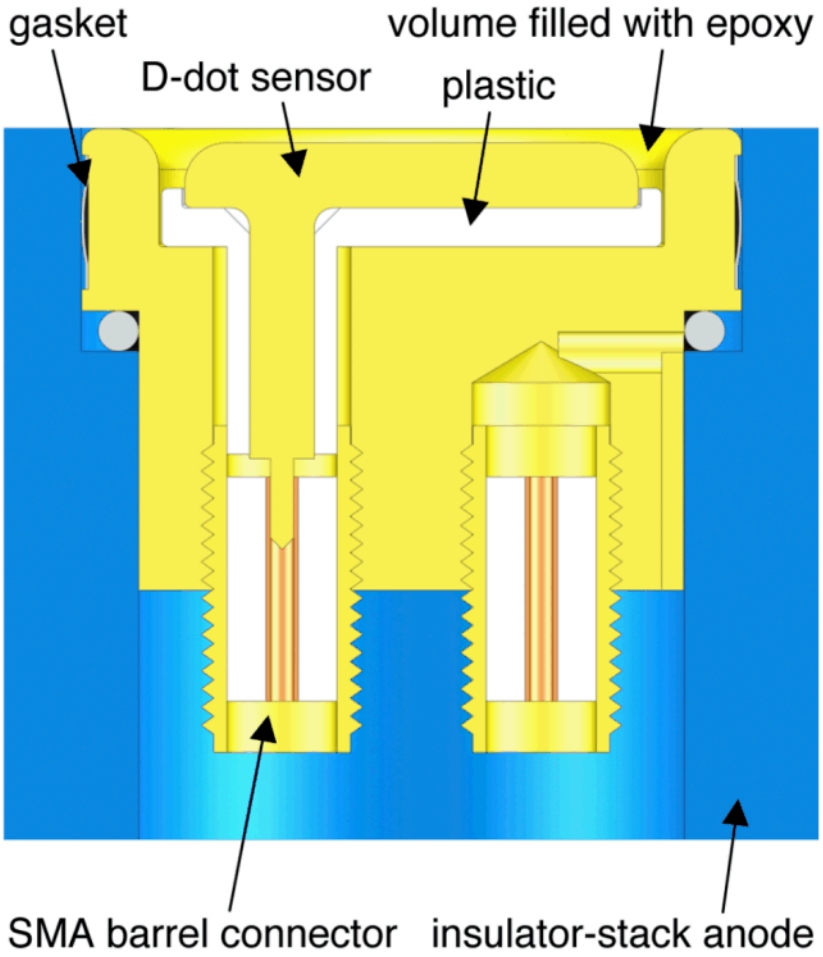
N = number of turns

A = perpendicular area of loop

$\vec{B}$ = magnetic field being sampled

V-dot (dV/dt) Monitors

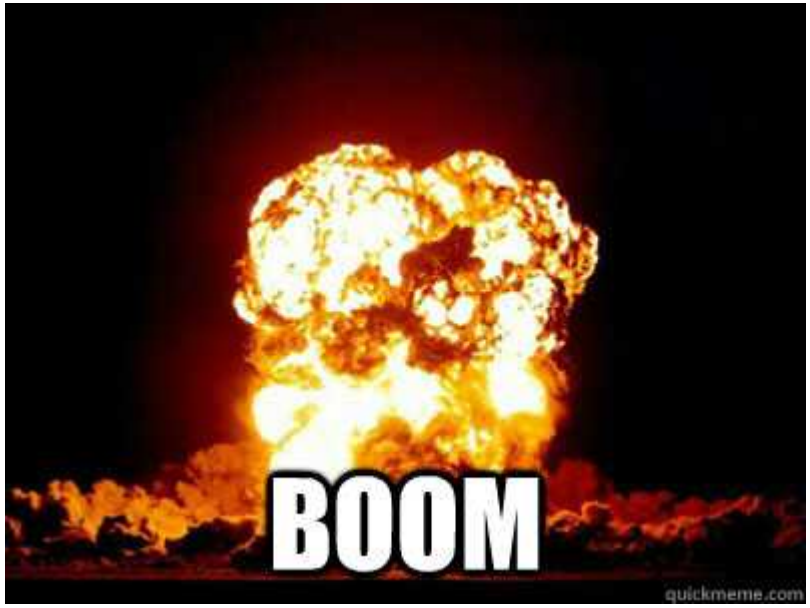
- Capacitive E-field probe
- Two probes, one shorted to the case for a noise measurement
  - Common mode noise is rejected by the use of a balun for the stack monitors
  - Other V-dots around Z do not use baluns
- ELECTRO code used to minimize perturbations of the electric field



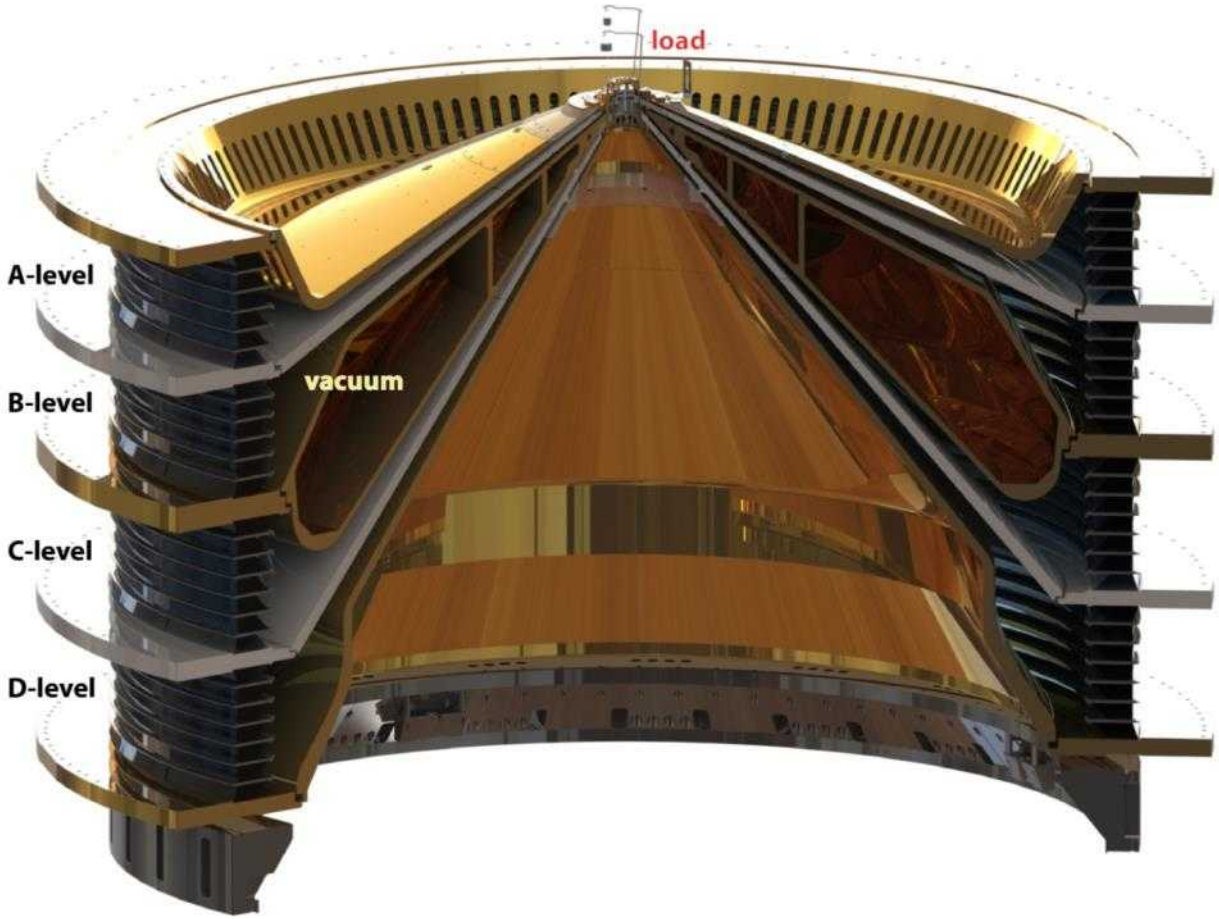
Ref: T.C. Wagoner, et al; PRSTAB 11, 100401 (2008)

Why So Many Diagnostics?

- 4 LTS 100 current probes (actually more, these are added together at the source)
- 9 MTG CVR signals
- 36 Marx CVR signals
- 36 I-Store V-dots
- 36 LTGS monitors
- 36 PFL B-dots
- 36 OTL1 B-dots
- 18 OTL2 B-dots
- 18 OTL2 V-dots



- A level: 12 Stack V-dots, 15 Stack B-dots, 8 MITL currents
- B level: 16 Stack V-dots, 17 Stack B-dots
- C level: 17 Stack V-dots, 17 Stack B-dots
- D level: 17 Stack V-dots, 17 Stack B-dots, 9 MITL currents
- Plus load B-dots and experimenter diagnostics!



Z VACUUM STACK

What does the Stack do?

- The stack provides much of the vacuum envelope for the Center Section of Z
  - It has to be a good vacuum material
- The stack provides the last high voltage insulator holdoff before the target
  - It has to have good dielectric insulating properties
- The stack provides an impedance transfer for the electrical energy coming in from the Water Section
  - It has to have good electrical properties
- The stack helps provide mechanical support for much of the Center Section
  - It has to have good mechanical properties

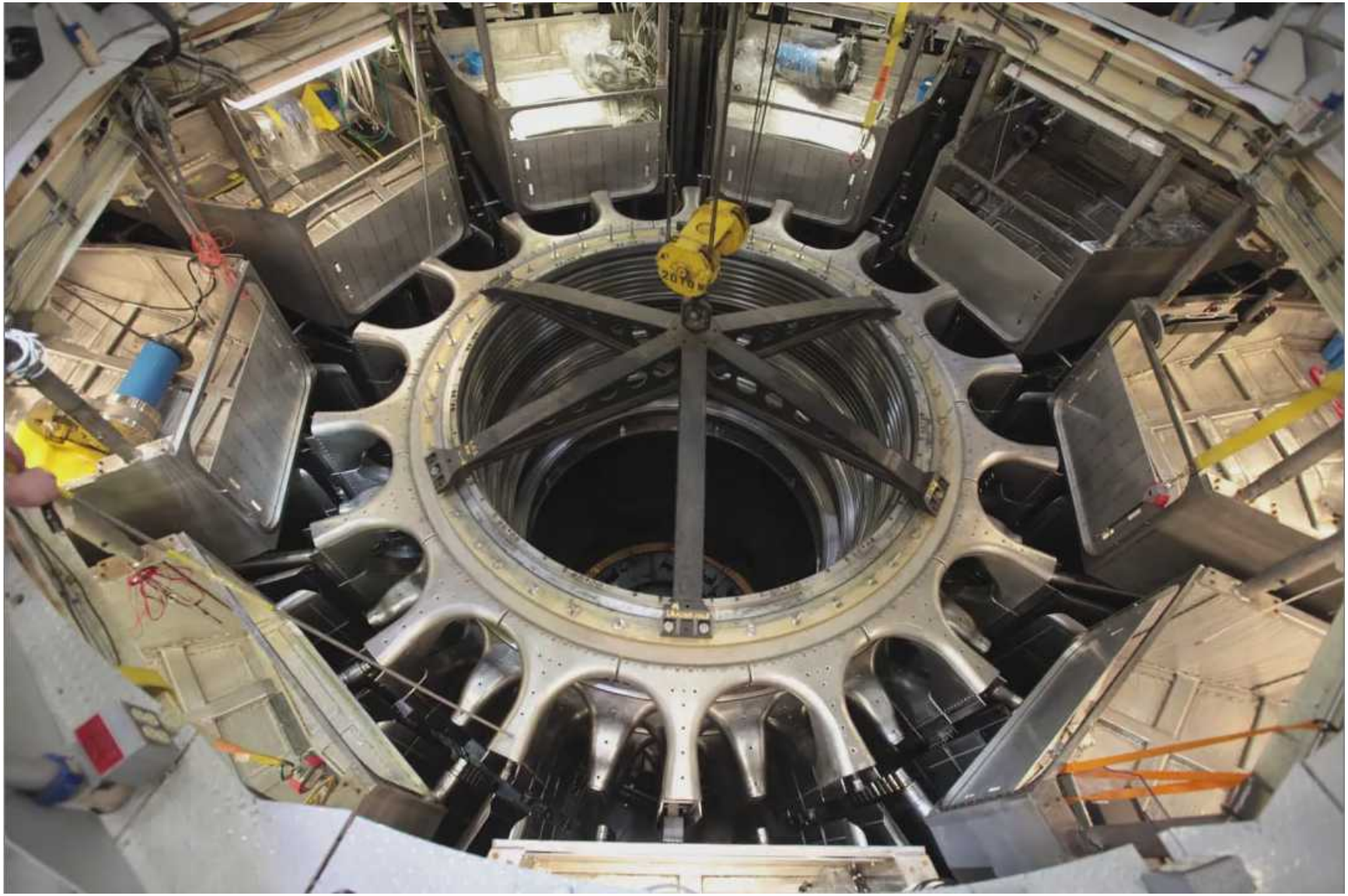
Images of the Vacuum Stack

Here is a photo of A-level, this looks pretty good! (This picture was taken before the final wipe.)

This is a photo of B-level, NOT so good.

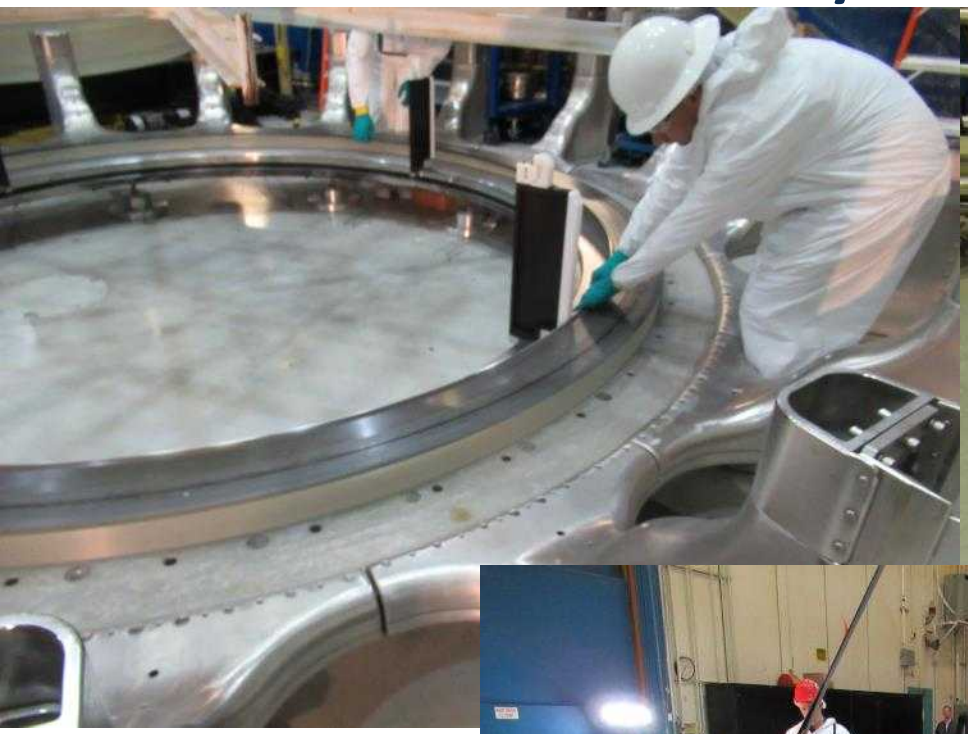
Time for a rebuild

Fly it Out of the Center



Disassemble, Clean and Inspect

Cleanliness is Key for Good Vacuum



The Finished Stack is Compressed and Moved Back into the Center!

Wow. Just… just go to the next slide…

To Learn More…

- There are lots of good books on the subject of Pulsed Power:
  - *J.C. Martin on Pulsed Power*, by T.H. Martin, et al, 1996
  - *Pulsed Power*, by G.A. Mesyats, 2005
  - *Transient Electronics*, by P.W. Smith, 2002
  - *High Speed Pulse Technology* (2 vols.), by F. Frungel, 1965
  - *Pulse Generators* (MIT Rad Lab Series), by Glasoe and Lebacqz, 1948
  - *Principles of Charged Particle Acceleration*, by S. Humphries Jr., 1999
    now available free online: http://www.fieldp.com
  - *Electronic Gadgets for the Evil Genius*, by B. Iannini, 2004

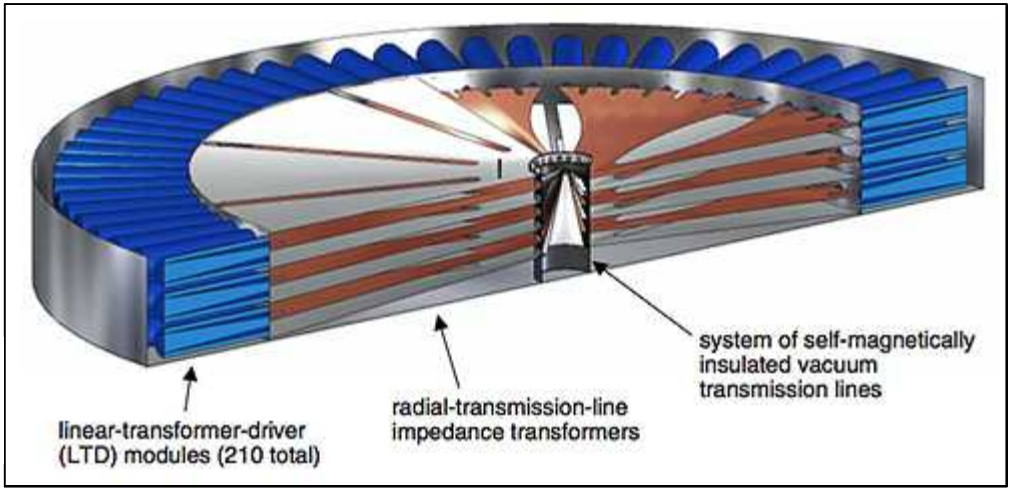
- **Come to the International Power Modulator/High Voltage conference next June (Jackson, WY):** http://www.ipmhvc.com/2018/

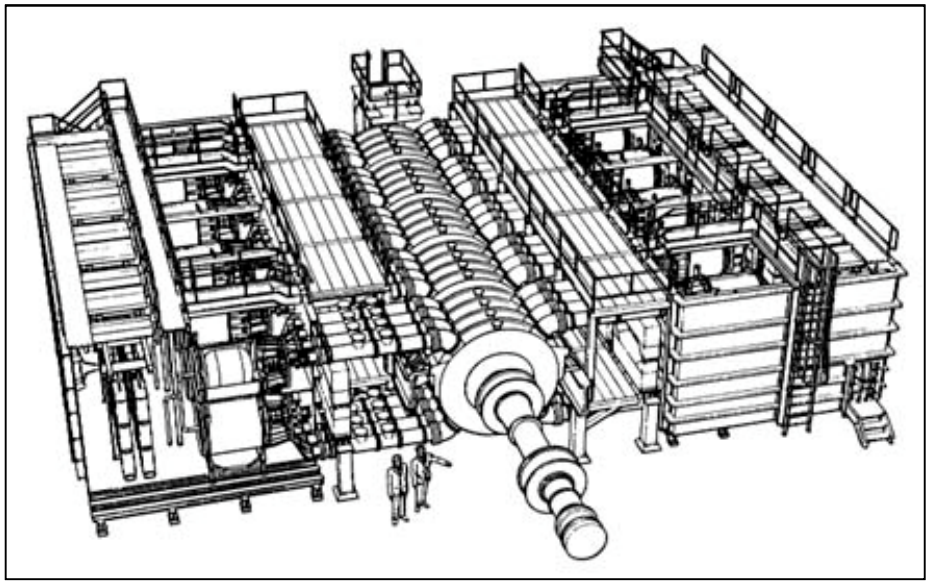
- Texas Tech has their annual short course: http://www.p3e.ttu.edu/shortcourse2015/
- The Pulsed Power Formulary is available for free online: http://www.highvoltageprobes.com/_literature_89707/Pulsed_Power_Formulary
- As is material from the US Particle Accelerator School (e.g.): http://uspas.fnal.gov/materials/09VU/VU_PulsedPowerEng.shtml

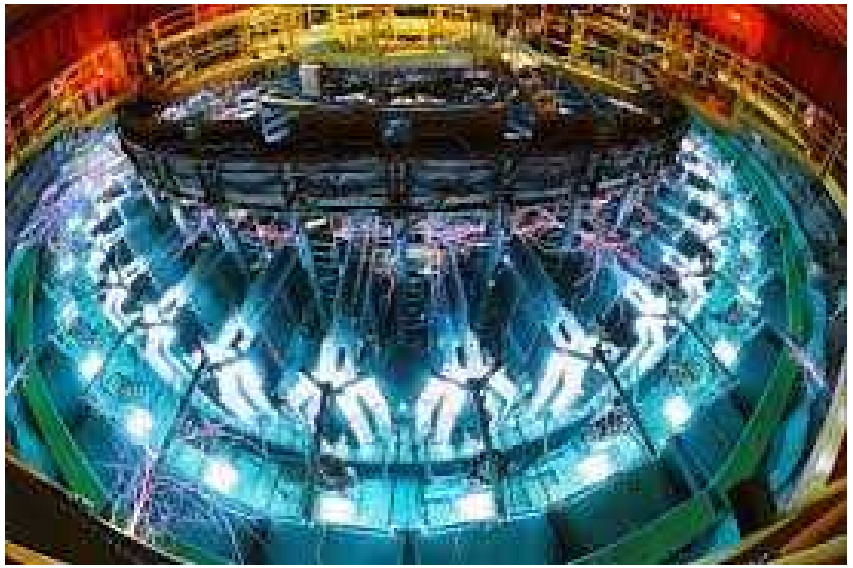
Want to do Cool Stuff Like This?

- Few schools in the US do pulsed power research… can you guess the name of one of the best?

GO BLUE! MICHIGAN







Careers at Sandia National Labs

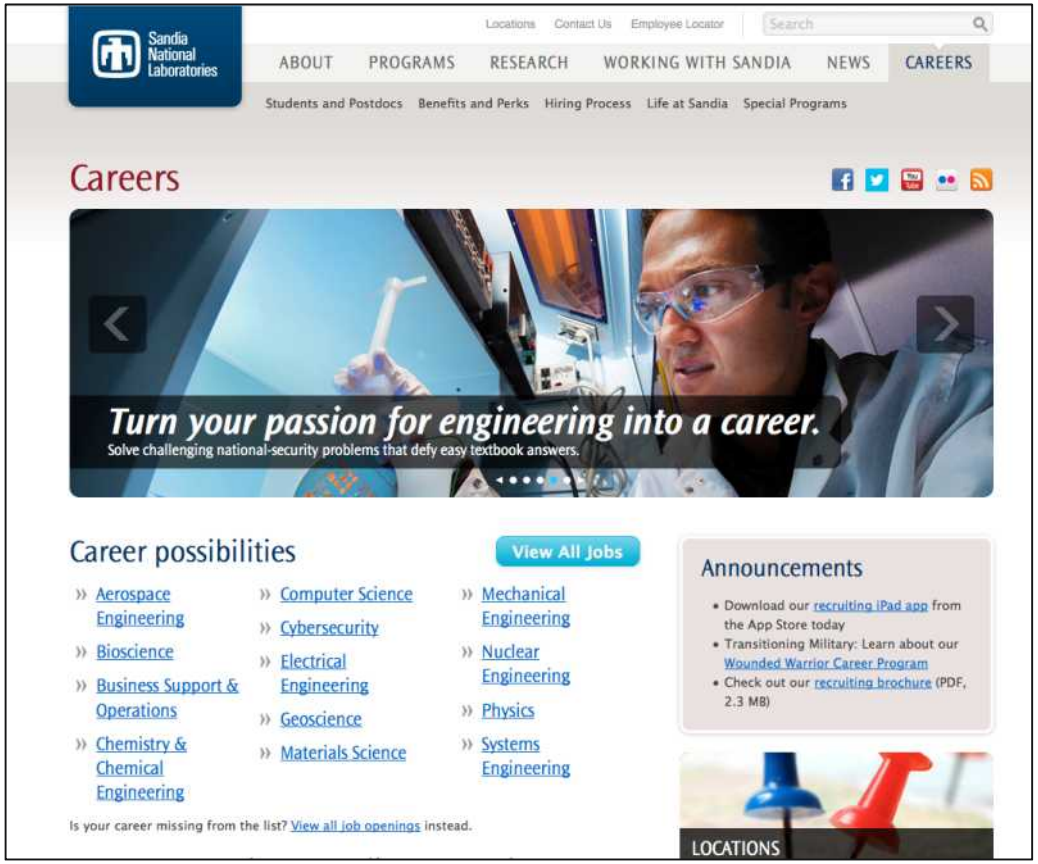
Come by the SNL booth at the Career Fair tomorrow

Or check out our website: *http://www.sandia.gov/careers*

Forbes | 2017
AMERICA'S BEST LARGE EMPLOYERS
POWERED BY STATISTA

#1 in Aerospace & Defense
#20 out of 500 large companies

We're honored to be named by Forbes as one of America's Best Employers



Questions?