SAND2016-12168R

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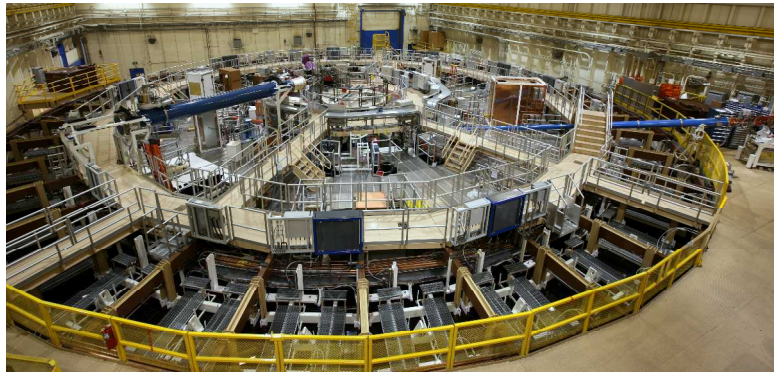

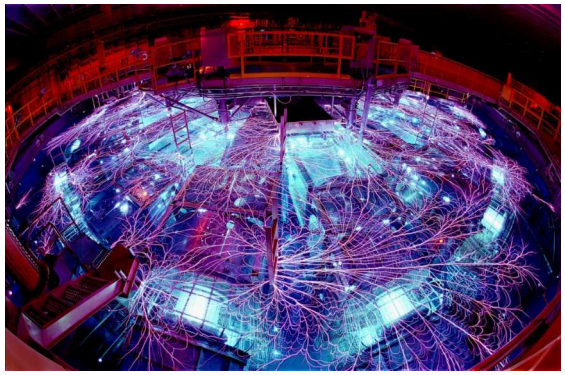

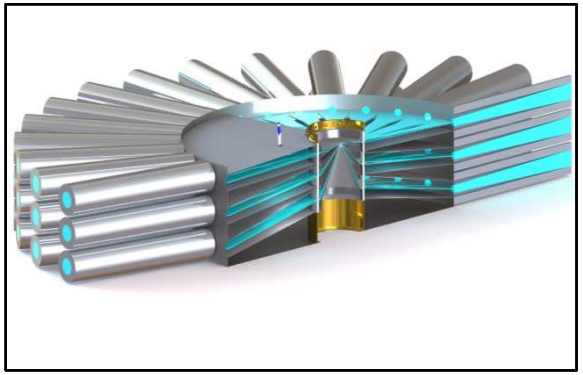

Sandia National Laboratories Pulsed Power and SF_6

U.S. DEPARTMENT OF ENERGY

National Nuclear Security Administration

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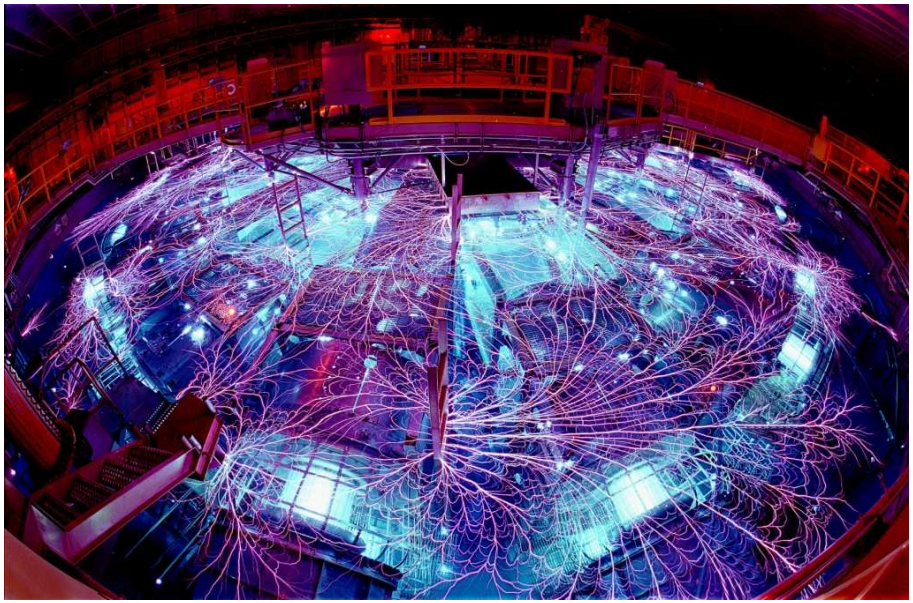
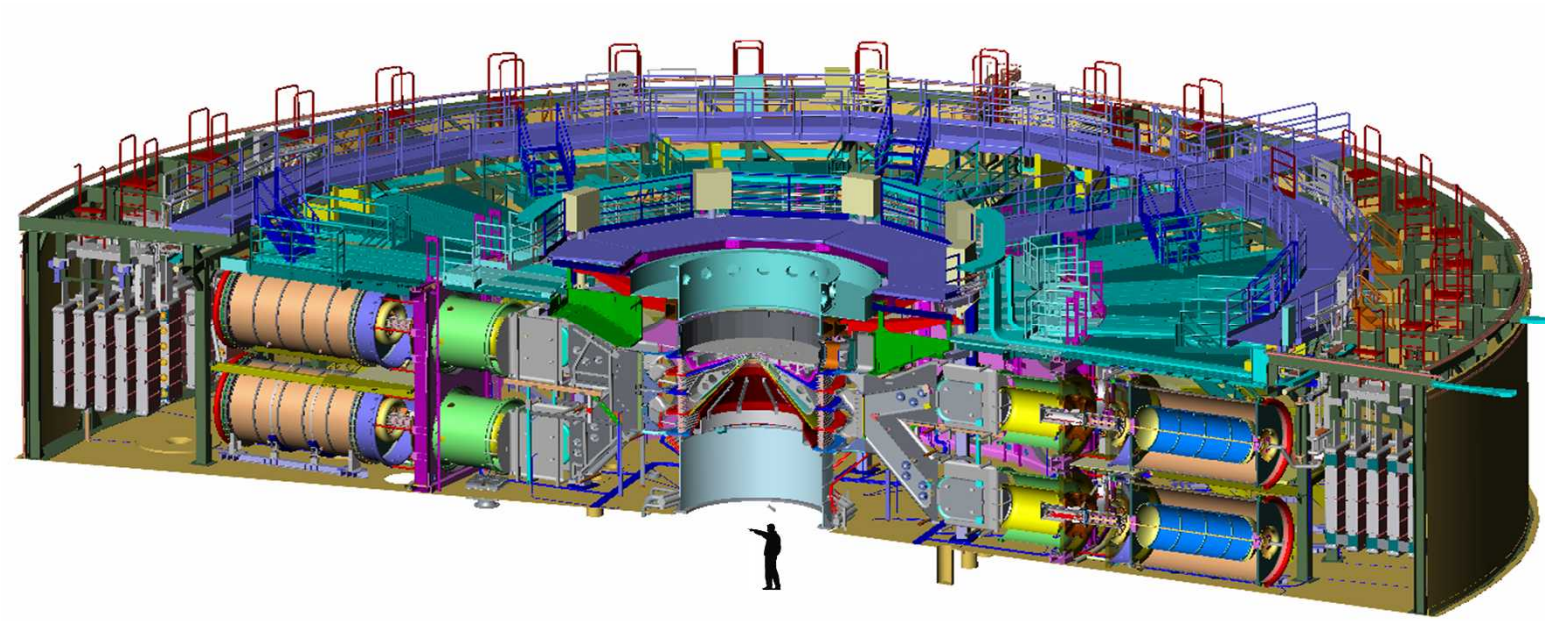
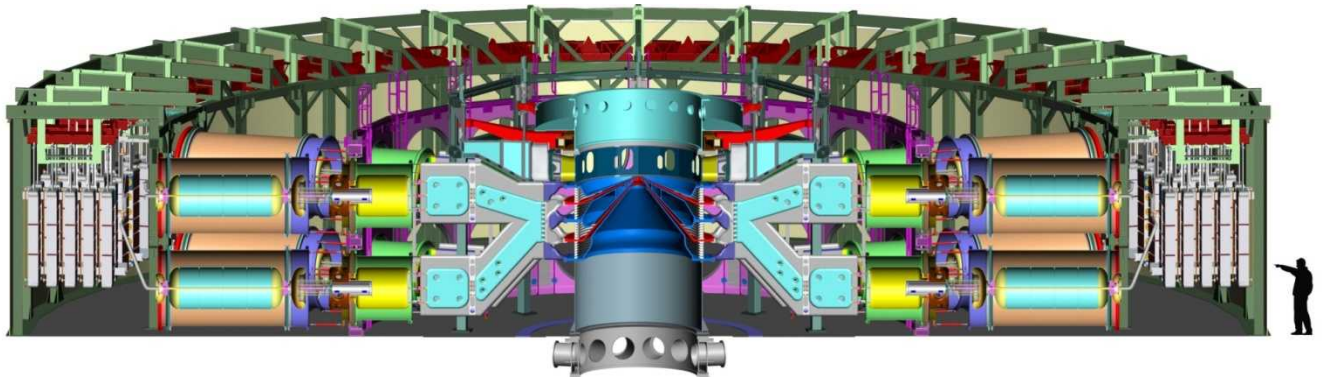




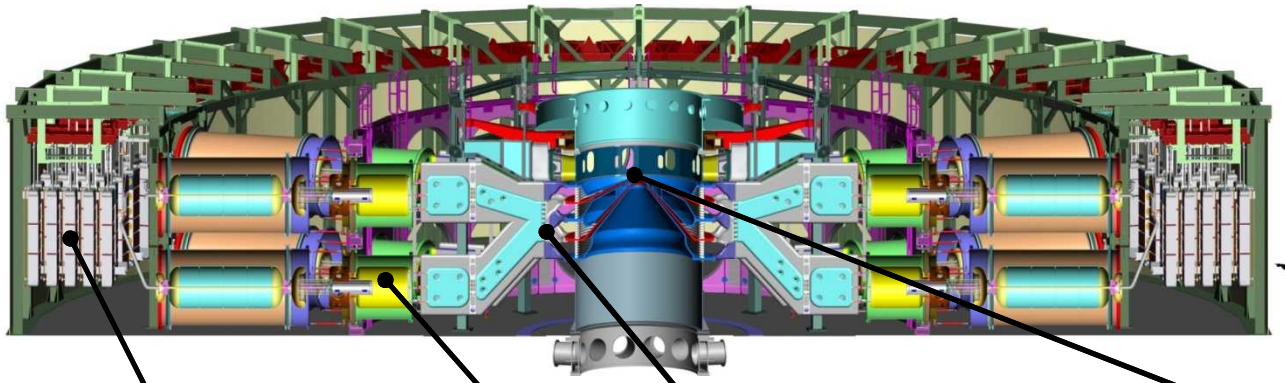
The Z Machine

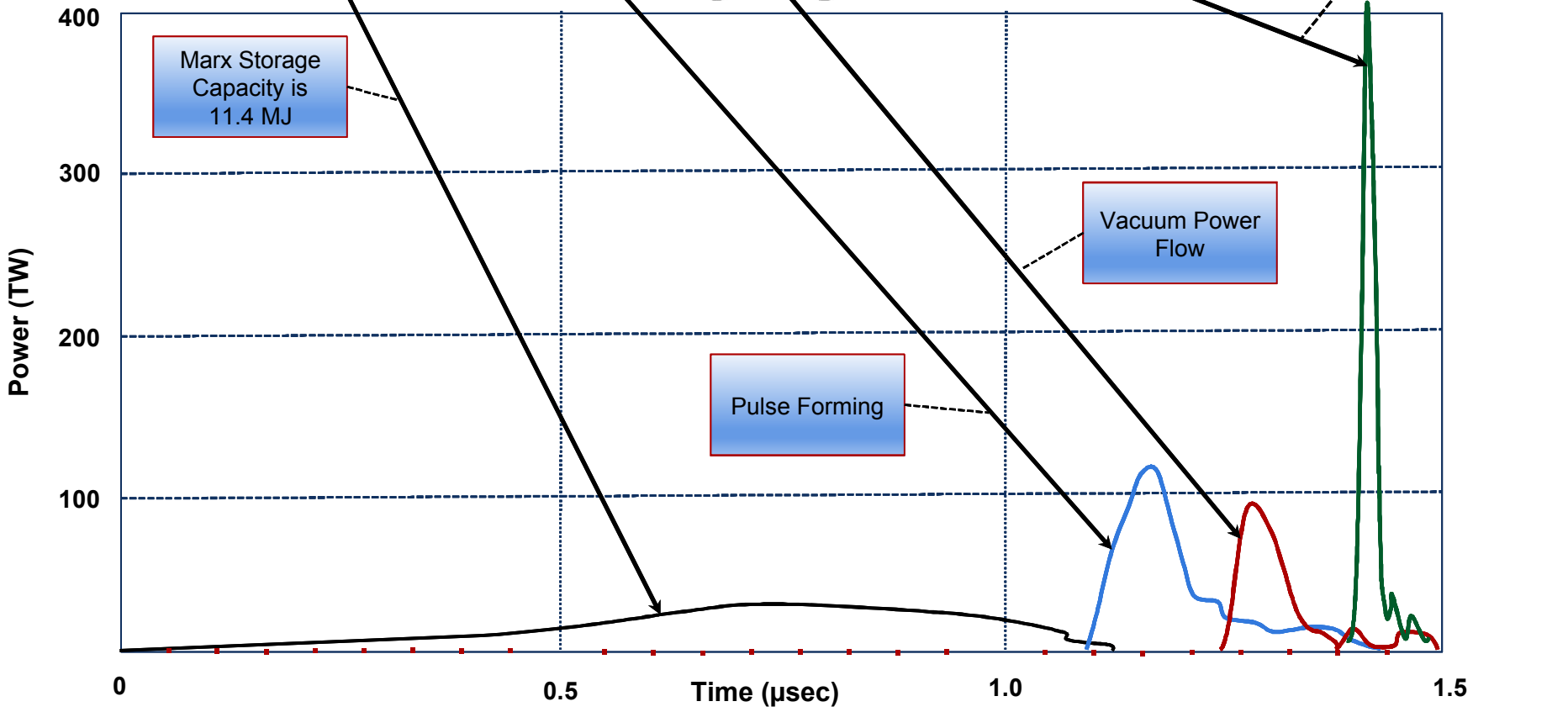


The Z Machine began operation in 1985 as the Particle Beam Fusion Accelerator 2 (PBFA-II). It was built as a high voltage driver to generate light ion beams in support of the Inertial Confinement Fusion (ICF) Program. In 1996 PBFA-II was converted to a high current mode to investigate recent advances in imploding wire-array X-ray generation that Sandia scientists had made at the Saturn facility. Sandia planned to split the machine's time between the high voltage ion beam mode and the high current X-ray generation mode, but the initial tests were so successful the machine was kept in the high current configuration. The machine was renamed the 'Z Machine' and scientists developed a number of experimental uses for the extremely high current outputs of Z, including dynamic material studies and the Isentropic Compression Experiments (ICE).

In 2007 the Z Machine was refurbished to update machine components, many of which were original to the 1985 PBFA-II configuration. During the refurbishment project new technological improvements were incorporated nearly doubling the output power of the machine without increasing its overall size.

Compression of Energy In Space and Time





SF_6 Is Critical To Z's Precision

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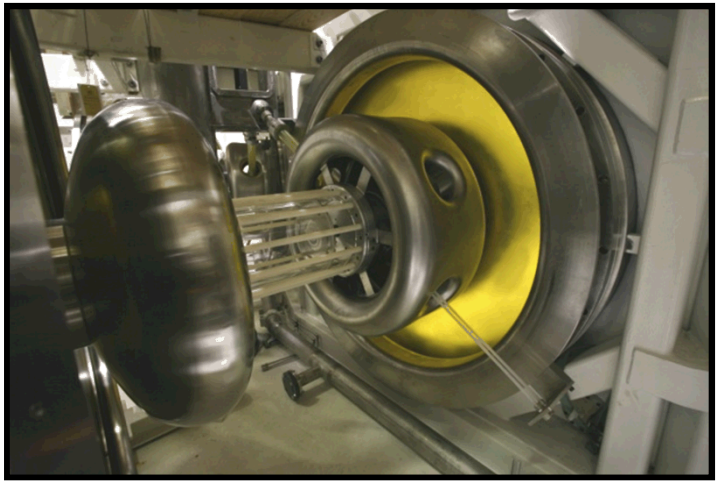
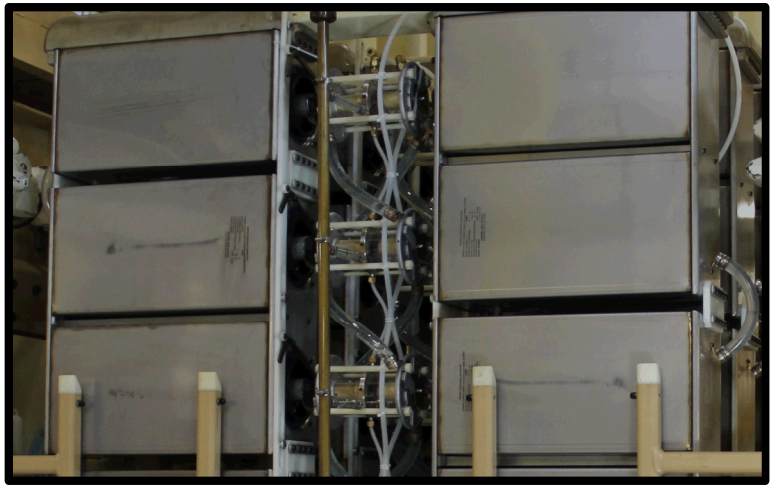
SF_6 is critical to the Z Machine and its precision operation

- It enables nanosecond time frame operations (runtimes and jitter) of three critical components:
  - Marx Switches
  - Laser Triggered Gas Switches
  - Laser Cross Over Tubes



Gas Switches and Cross Over Tubes



Marx Switches

Pulse Shaping Enabled By SF_6

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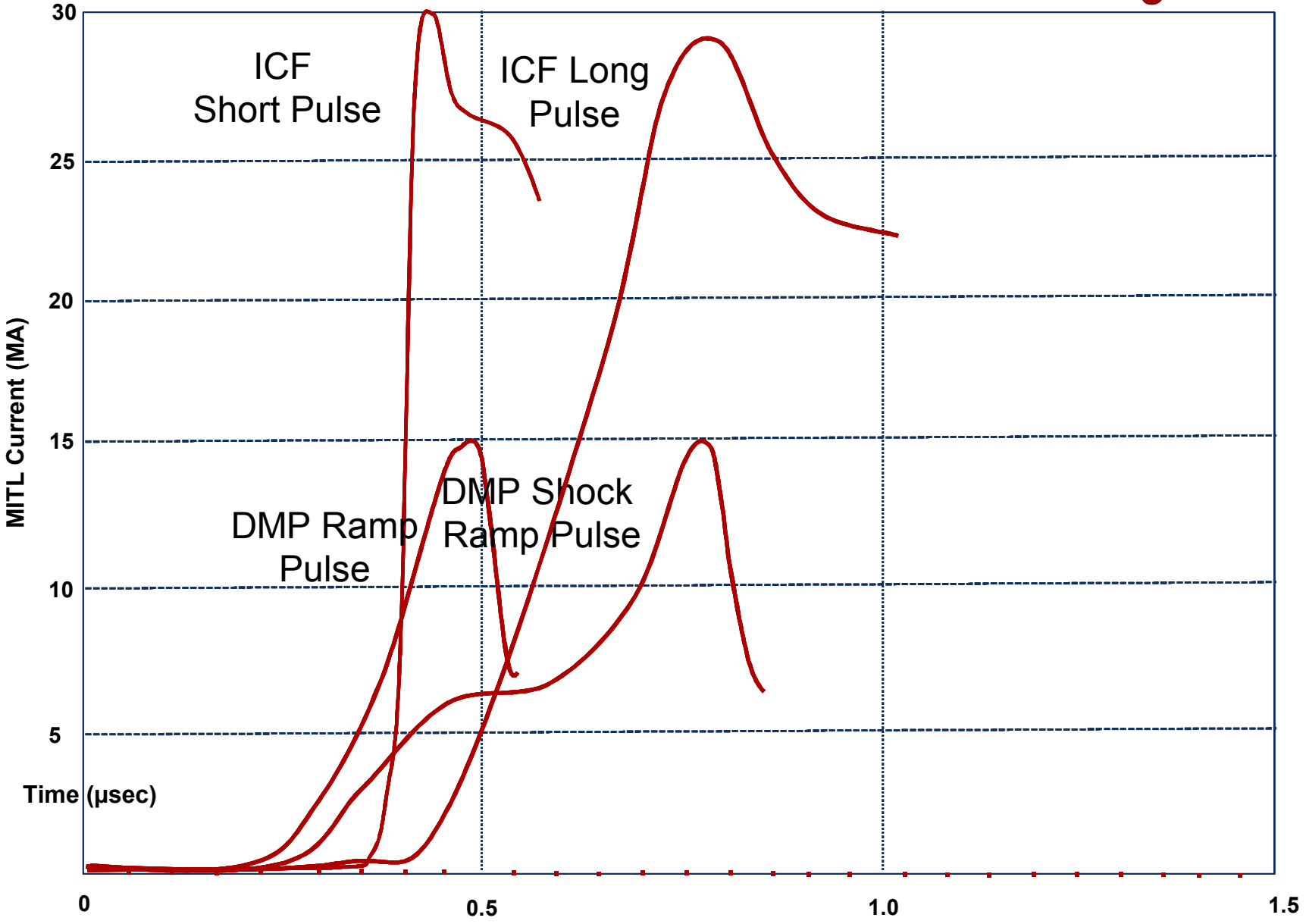
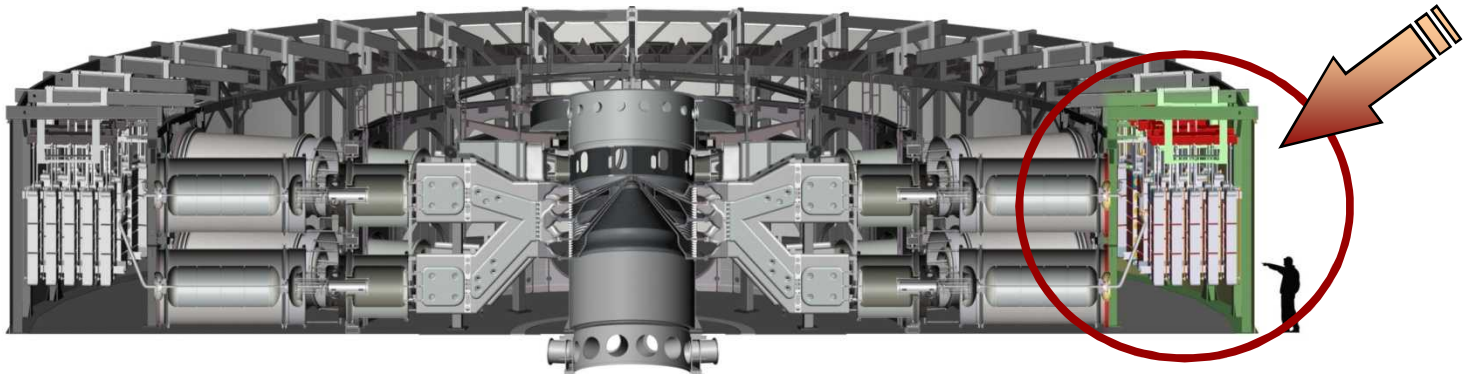


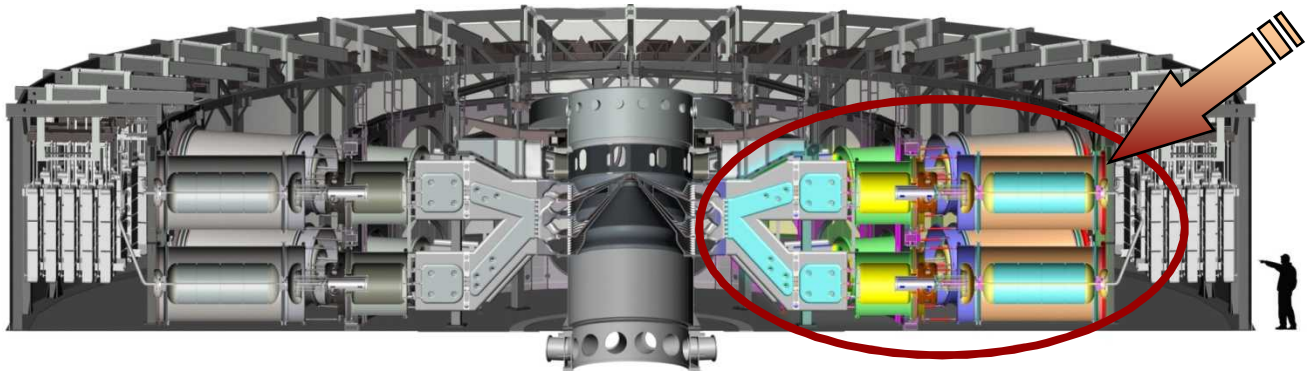
Energy Storage Section



The Energy Storage Section houses an array of 36 large capacitor banks called Marx generators. These generators are used to multiply output voltage and compress the output pulse in time. Each Marx generator is approximately eight feet wide by eight feet deep by fourteen feet high and weighs about 20,000 pounds. The Marx generators are submerged in transformer oil to provide electrical insulation. During operation, this section of the machine is filled with a total of 750,000 gallons of transformer oil.

During the firing sequence, the Marx generators are charged to a maximum of 95,000 volts over a period of about 2 minutes. Once the machine is charged and the fire command is issued, the Marx generators deliver a 6 million volt pulse to the next section of the machine in about one millionth of a second. At a factor of 100,000,000 to 1, this is by far the largest time-compression stage in the machine.

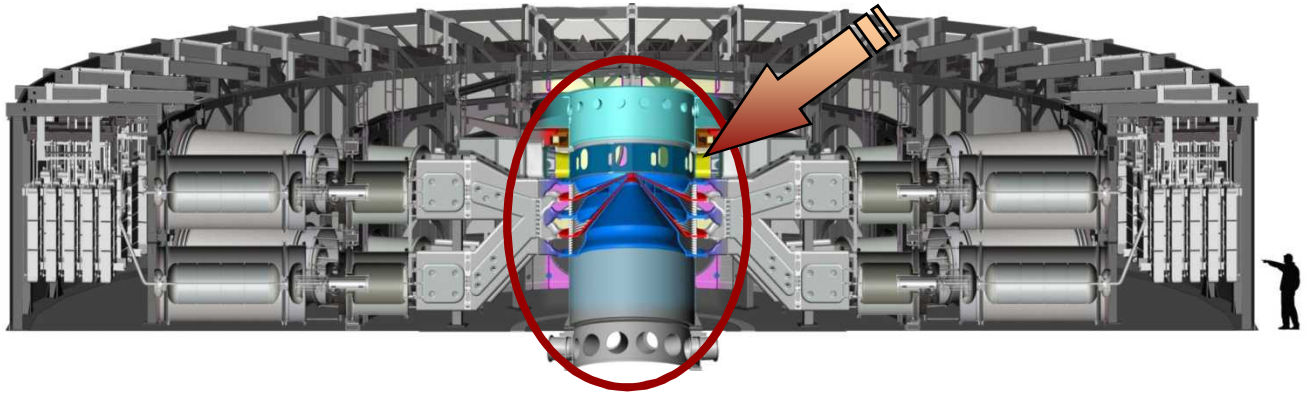
Pulse Forming Storage Section



The Pulse Forming Section further compresses and synchronizes the 36 separate pulses from the Marx generators so they can be efficiently added to make one large pulse at the center of the machine. The individual pulses must be synchronized to within a few billionths of a second for the machine to operate properly. The synchronization is performed by 36 laser triggered switches. Each of these switches controls approximately 600 kilojoules of electrical energy with less than 20 millijoules of laser energy. Each of the 36 modules delivers over 2 trillion watts of electrical power to the target chamber, this represents about half of the worlds electrical generating capacity.

The Pulse Forming Section further compresses the pulse from the Marx generators by a factor of 10. The pulse delivered to the experimental chamber lasts only 100 billionths of a second, less time than it takes light to go from one side of the machine to the other.

Center Section



The center part of the machine combines the 36 separate pulses into one large pulse and delivers it to the experiment at the very center. Z can deliver an output pulse in excess of 29 million amperes and between 80 and 100 trillion watts of electrical power.

Z has set a number of records, including launching a flyer plate in excess of 50 kilometers per second (over 110,000 miles per hour) for shock physics experiments. That would mean if we let it loose as it were fired and it headed to NYC, it would take just under 1 minute to get there……

In the X-ray production mode, the electrical energy is used to produce a “flash” of heat energy. The temperature of this flash is so high that the energy is released as x-rays. To date, the Z Machine is by far the worlds most powerful x-ray source producing over 400 trillion watts of x-ray power. This represents about 75 times the generating capacity of all the power plants on earth.

Components In the Z Machinec

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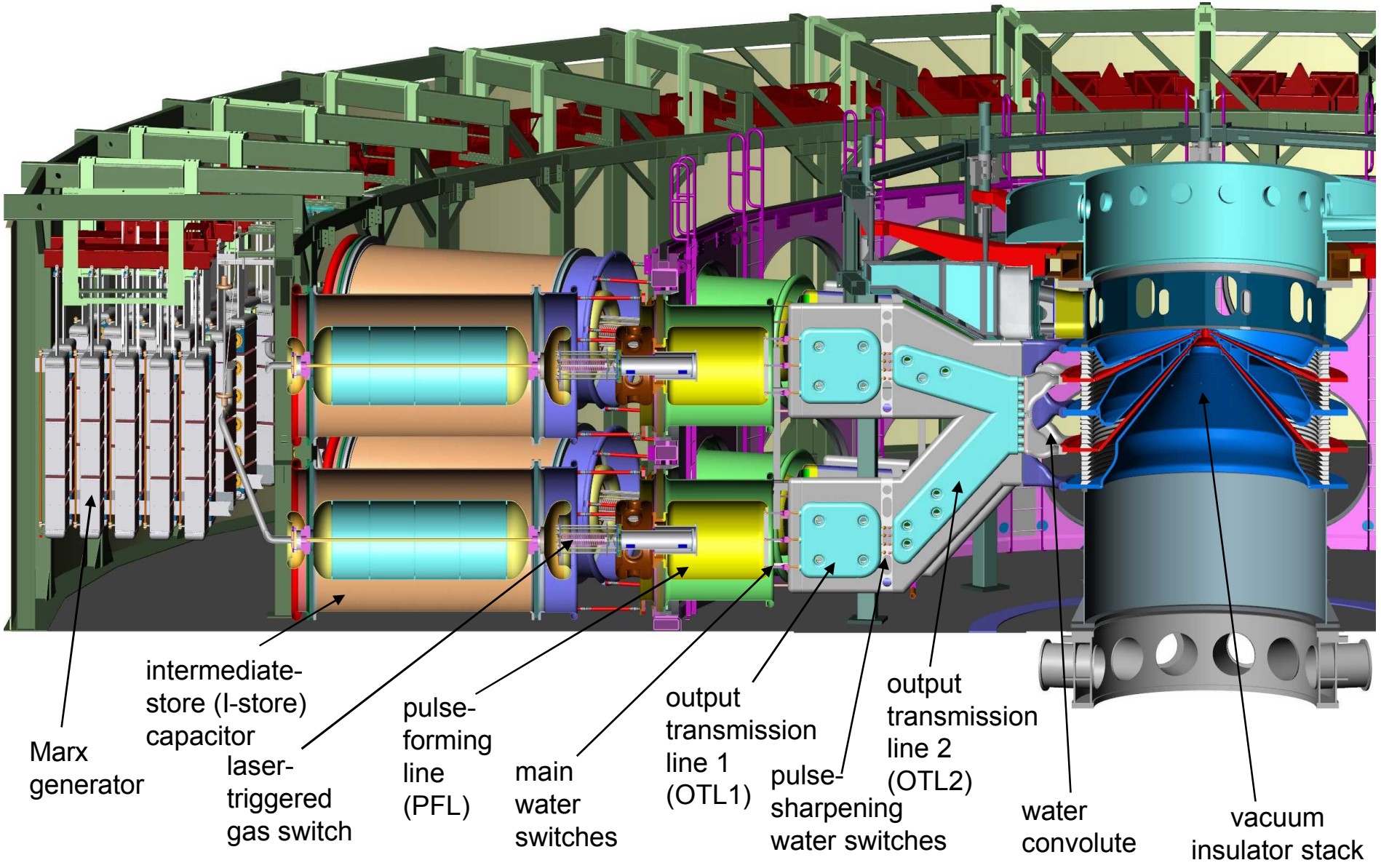
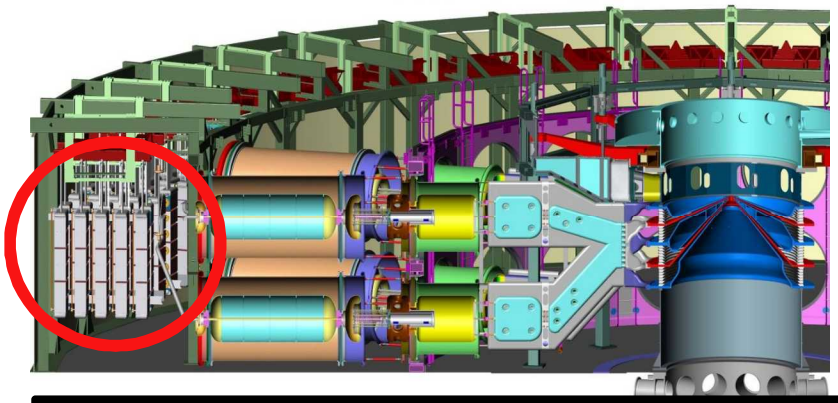




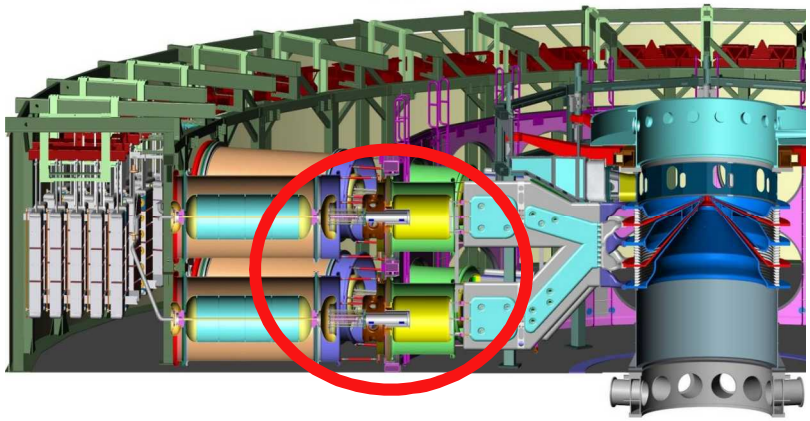
Marx Generators

100 second “input pulse”

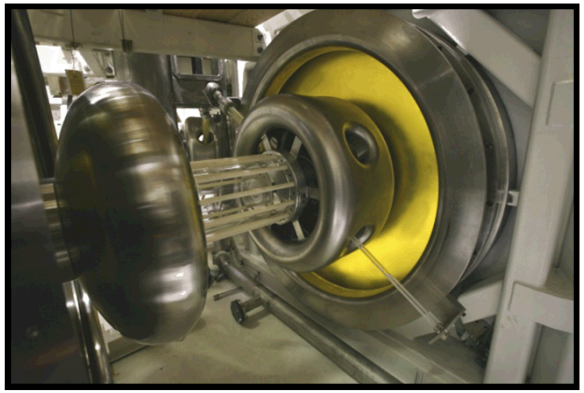
1 microsecond output pulse

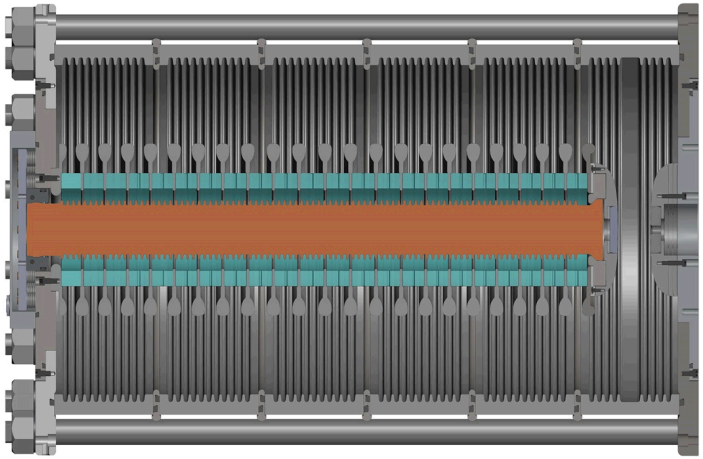
Store energy during charge sequence which is enabled by the SF_6 in the Marx switches

Deliver output to Intermediate Storage Capacitor



Intermediate Store And Gas Switch



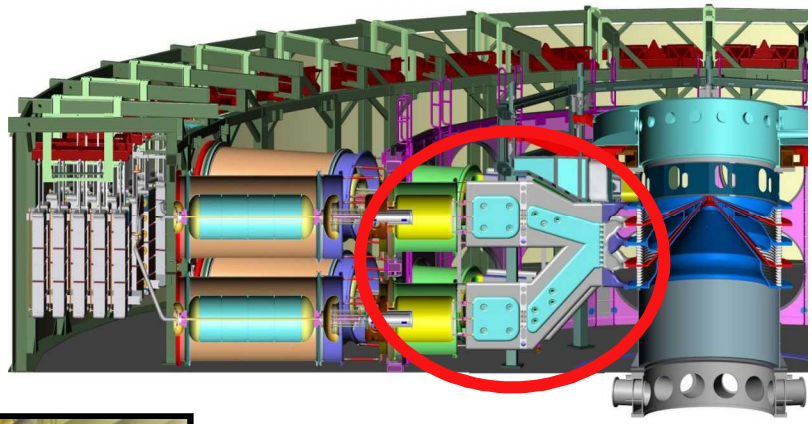


1 microsecond input

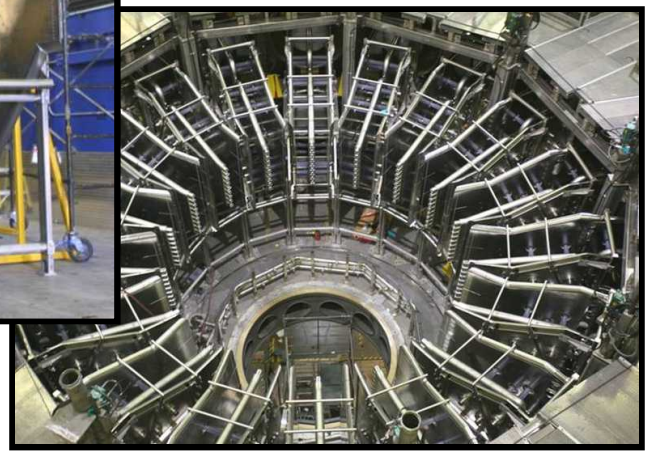
200 nanosecond output pulse which is enabled by the SF_6 in the Laser Triggered Gas Switches and the Cross Over Tubes

Allows faster transfer than Marx generator

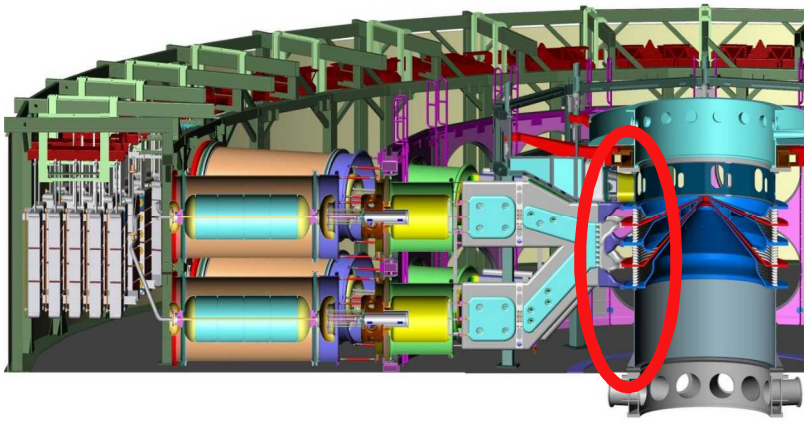
Laser Triggered Gas Switches synchronize pulses from 36 separate modules



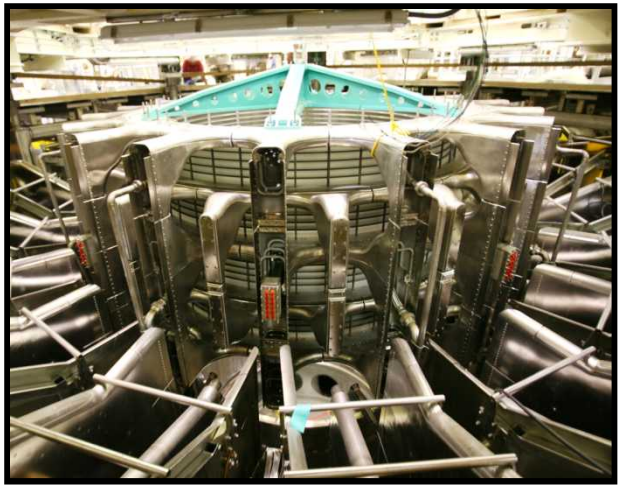
Pulse Forming
And
Transmission Lines



- 200 nanosecond input
- 100 nanosecond output pulse
- Compress output pulse in time and space
- Deliver “18” pulses to the water-vacuum interface

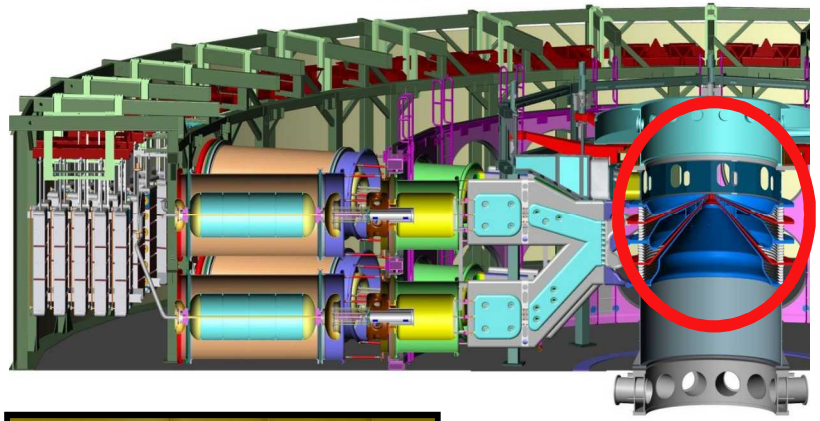


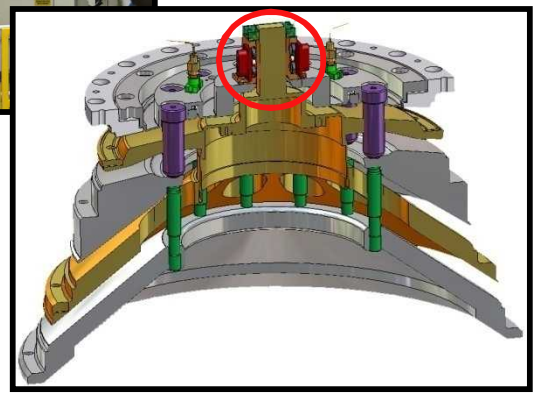
Water Convolute
And
Vacuum Insulator Stack



Allows smooth transition from pulse forming lines to vacuum transmission lines

Establishes boundary for experiment chamber





Magnetically Insulated Transmission Lines And Target Region

Carries machine output to experiment package

Spatially compresses pulse to a few cubic inches

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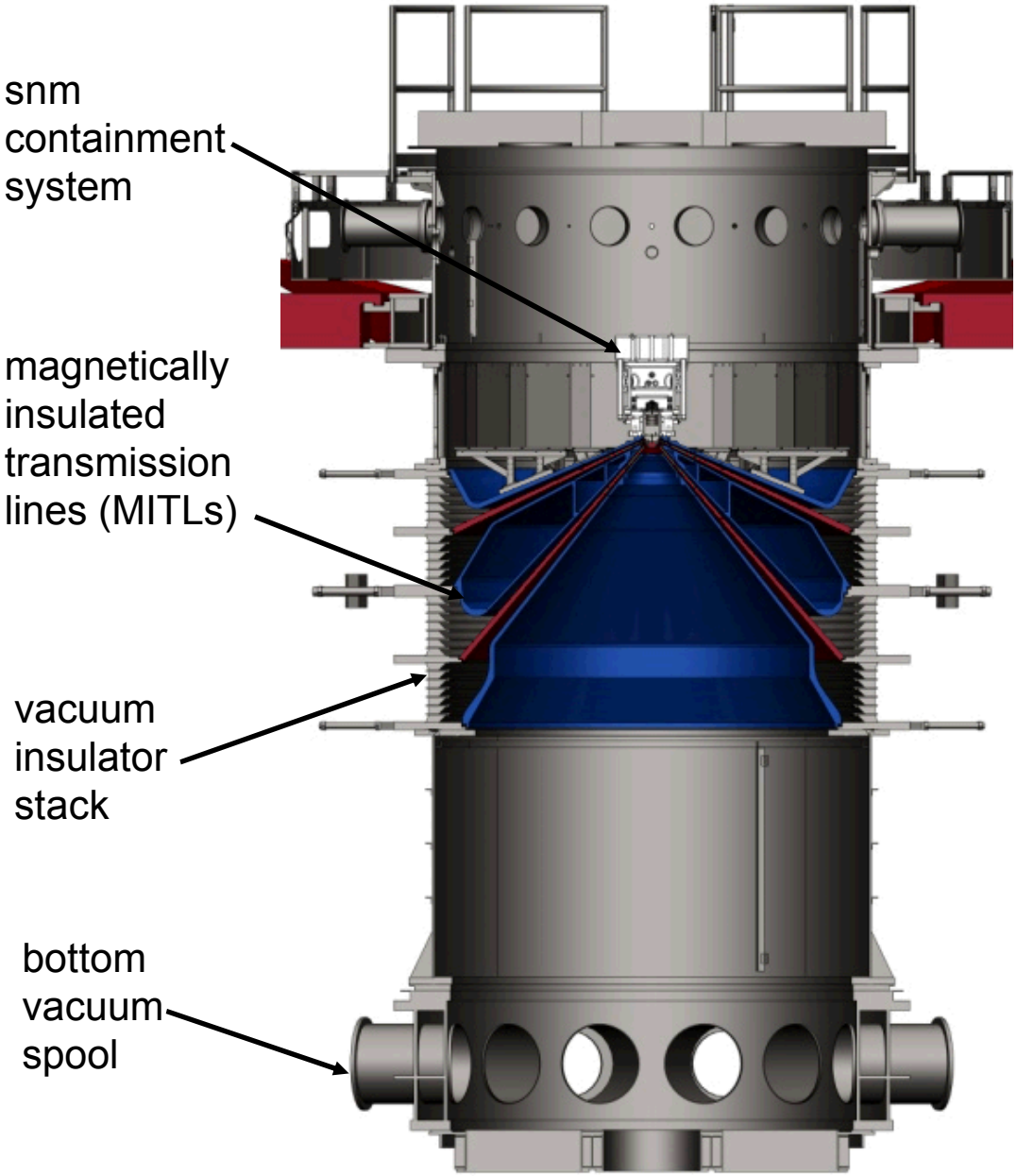
Magnetically Insulated Transmission Lines And Target Region



Stewardship of SF_6 Is Critical To Z's Continued Mission

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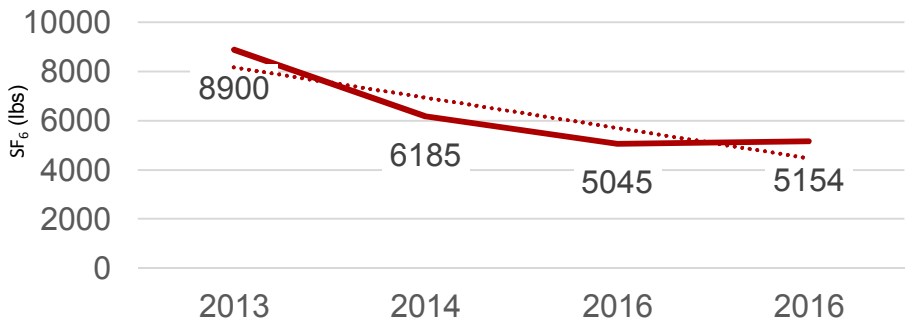
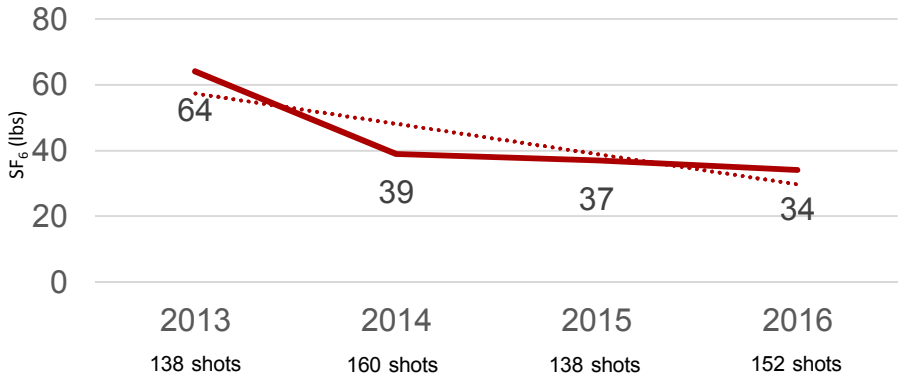
A number of SF6 gas usage reduction efforts have been underway since 2013. This has resulted in SF6 usage (measured in pounds) being reduced from 64 pounds per shot to 34 pounds per shot. We did a significant number of these efforts in FY13 and FY14. Included in these upgrades are:

- System leak identification and repair (FLIR camera used to identify leaks more efficiently)
- Removal of unused systems and processing hardware
- Effective management of gas usage post shot (faster shut off of SF6 gas to leaking components)



Annual SF_6 Usage (lbs)



SF_6 Usage Per Shot (lbs)

Stewardship of SF_6 Is Critical To Z's Continued Mission

Sandia National Laboratories

We are also upgrading components in the system to prevent accidental losses due to age and standard shot operations. Over the next year as budget permits we are doing the following to reduce use:

- Re-routing pressure relief valve exhausts to capture tanks instead of venting to atmosphere
- Adding computer control to valves and regulators to detect and stop leaks caused by damaged components
- Adding computer monitoring to pressure systems with alerts to operations staff 24/7 for leak prevention and mitigation
- Continued upgrading of aging system to prevent component failures (replacing large storage tanks)
- Upgrading gas management system (scales and mass flow monitoring) to more accurately measure gas usage
- We continue to perform leak identification and management as a daily effort using the FLIR camera system and believe that the reductions though minimal will be a component of our continued dedicated efforts to reduce the center's use of SF6.

The Next Generation of Pulsed Power Machines Designed Specifically to Eliminate the Use of SF_6

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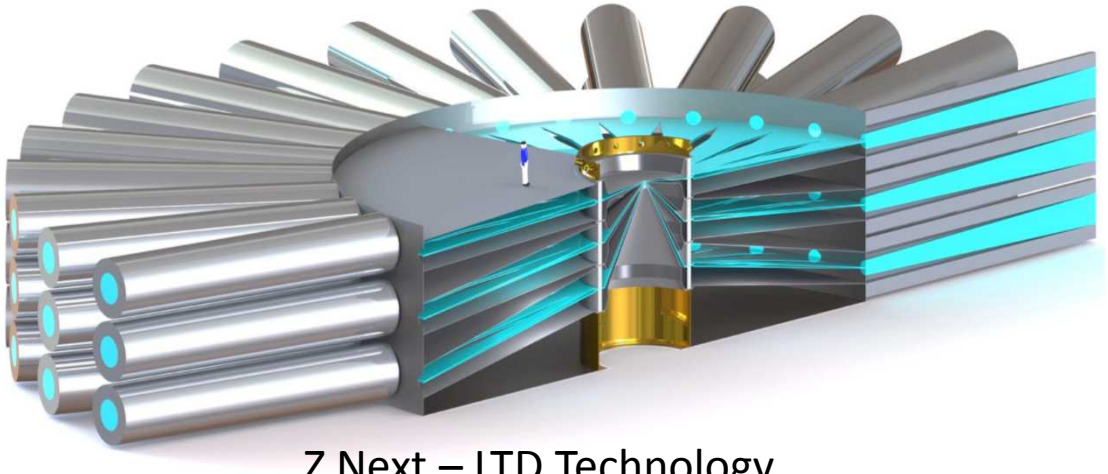

Z Next – LTD Technology

Mykonos – LTD Technology

Radiography– LTD Technology