SAND2017-9067C

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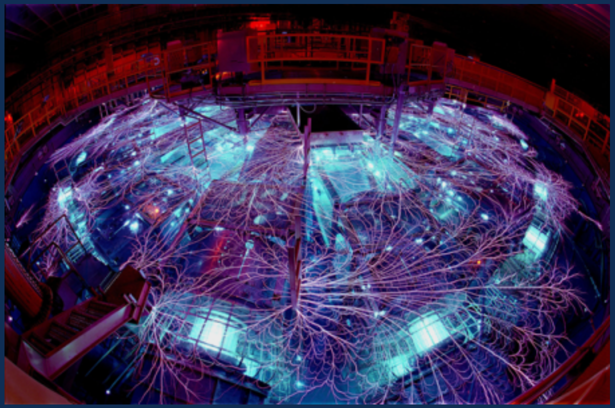
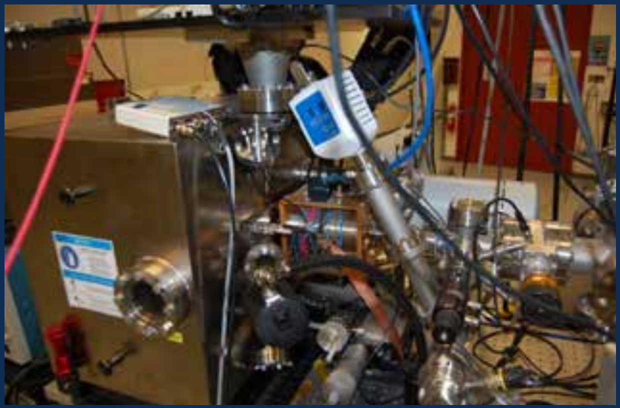




Welcome Remarks

Daniel Sinars (for Keith Matzen)

Z Fundamental Science Program Workshop
July 17, 2017

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

First, let me thank all of you for participating in our Z Fundamental Science Program workshop!

Today I want to briefly highlight areas of significant change since last year's workshop

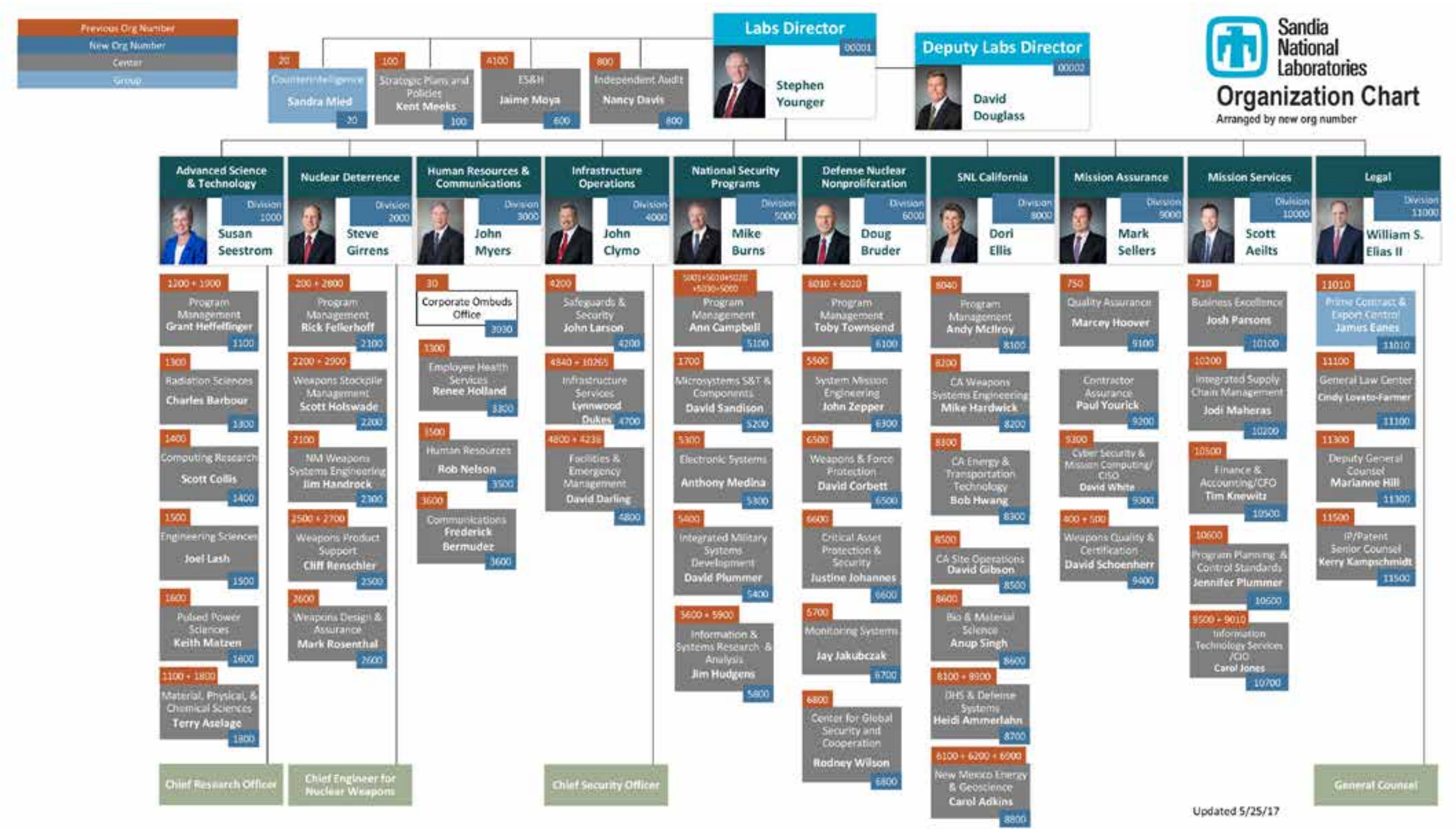
- Sandia M&O Contract Change
- Major Strategy Developments
- Significant Capability Developments
- Thoughts on the future of Pulsed Power

Since our last workshop, the senior leadership of Sandia National Laboratories has completely changed with the change in M&O contractors from Lockheed Martin to NTESS*

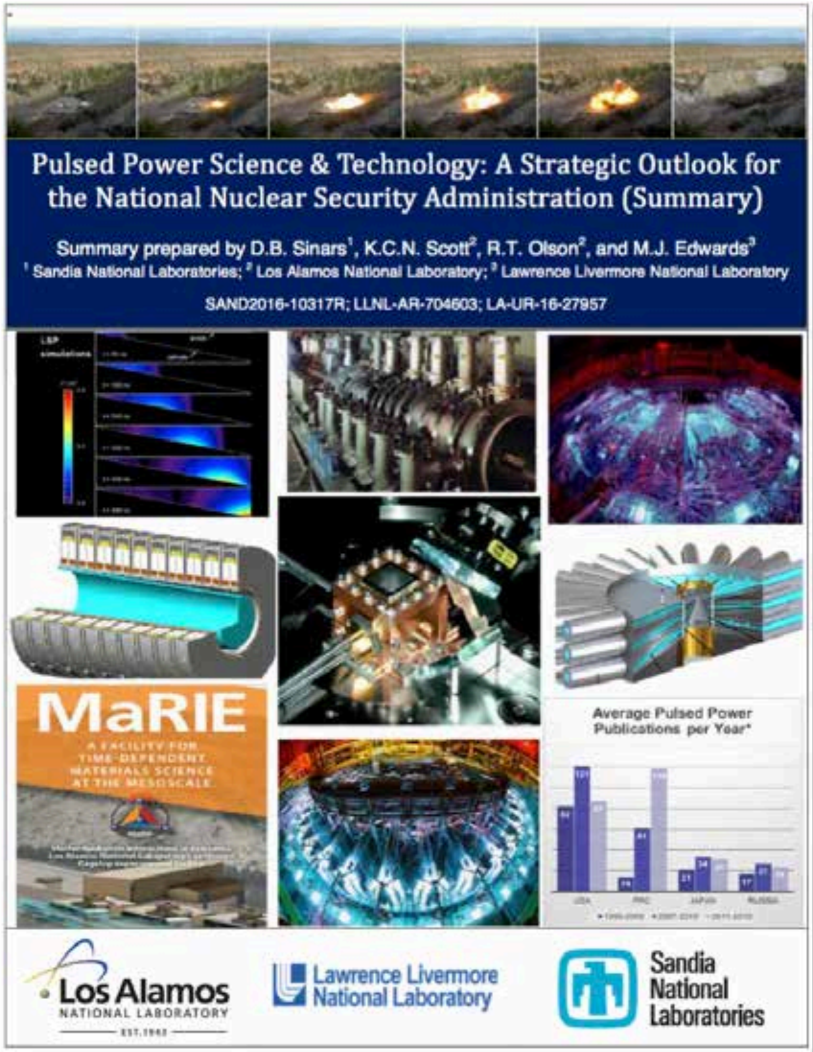
Stephen Younger	David Douglass	Susan Seestrom
		
Stephen Younger Laboratories Director	Deputy Laboratories Director	Advanced Science & Technology Associate Labs Director Chief Research Officer

NTESS = National Technology and Engineering Solutions of Sandia

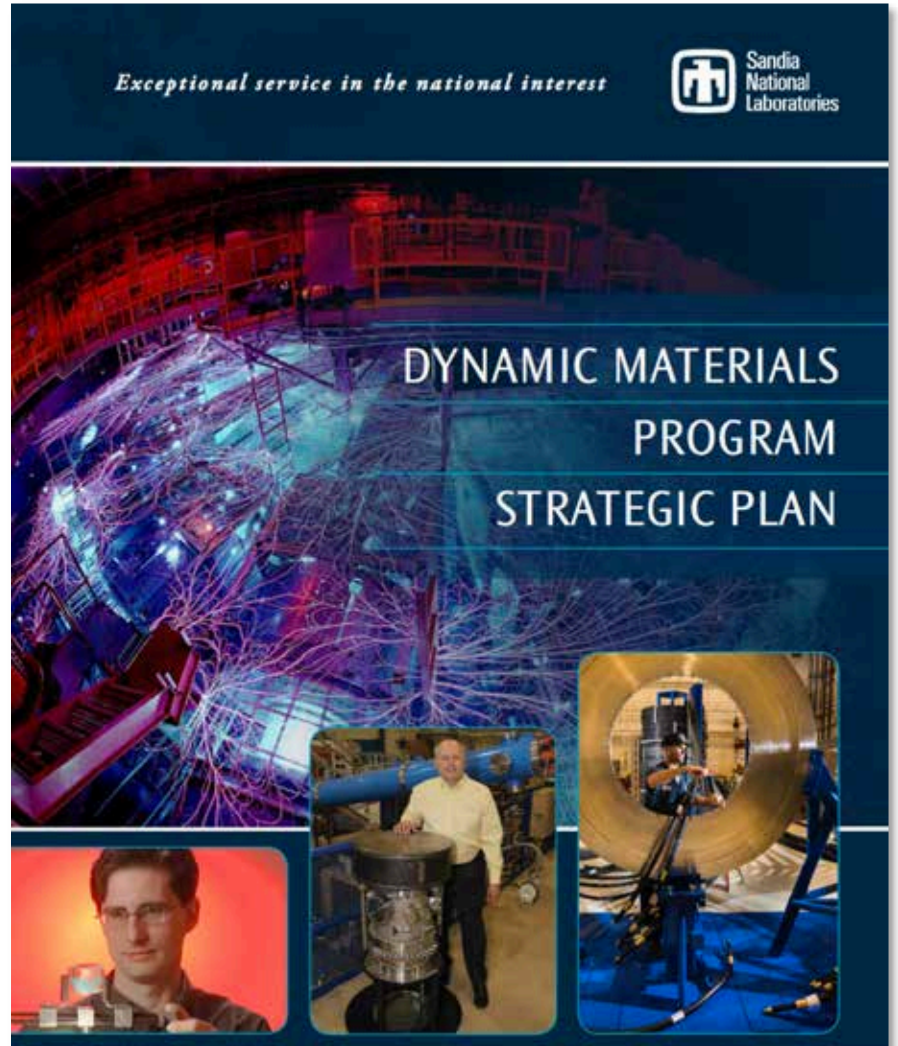
The pulsed power sciences Center remains a part of the Advanced Science & Technology Division as Center 1600



Our Center's strategy going forward is being heavily influenced by two strategic planning documents released in the past year

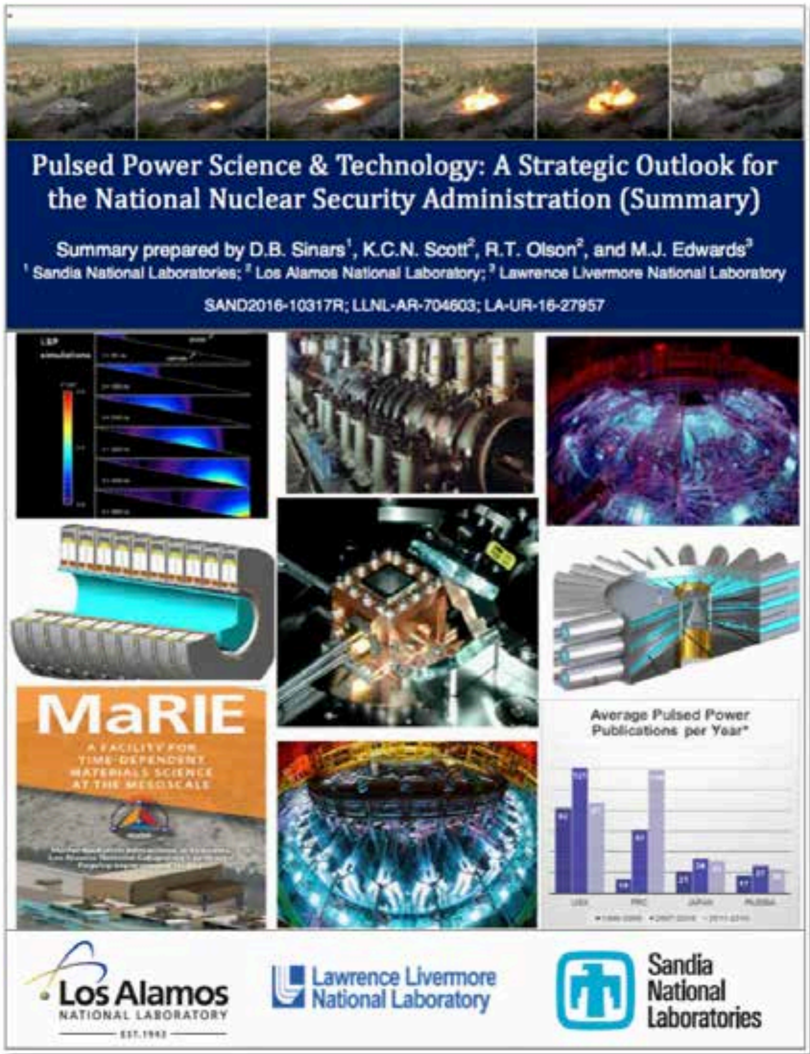


Pulsed Power Science & Technology Outlook (Oct. 2016)



Dynamic Materials Program Strategic Plan (May 2017)

The PPS&T report responded to a request from the NNSA asking broadly for how pulsed power could address high energy density physics applications for the Stockpile Stewardship Program



- NNSA request made to three weapons labs
- The memo identified five key strategy elements
  - Dynamic Material Properties (Mission)
  - Nuclear Survivability & Radiation Effects Science (Mission)
  - Thermonuclear Burn Physics and ICF (Mission)
  - Next-generation Codes for PPS&T Design (Enabling capability)
  - Academic & Industry engagement in PPS&T (Enabling capability)
- An implicit element is pulsed power technology development
- Official unclassified summary and transmittal letter to NNSA on Oct. 11, 2016

Visions emerging from the PPS&T planning process; In 20 years we would like to:

- **Dynamic Material Properties**
  - Have impacted NCT assessments and pit production decisions, which will require about 150 high-hazard materials experiments at moderate pressures with large sample sizes and time scales (highest impact if within 10-12 years)
  - Have the capability to validate key material model predictions at very high pressures in a small number of experiments per year
- **Radiation Effects Science**
  - Have revitalized key existing nuclear survivability facilities to ensure the continued qualification of our stockpile
  - Establish new capabilities for warm x-rays, 14 MeV neutrons, and combined hostile environments for qualification and model validation
- **Inertial Confinement Fusion:** Be able to produce tens of MJ yields in the laboratory on a path to >250 MJ yields in the future for weapons and effects testing
- **Codes:** Have validated, integrated code capabilities sufficient to design and engineer the power-flow, target physics, and containment systems needed to achieve these visions
- **Academia & Industry:** Have the U.S. national laboratories recognized as world leaders in pulsed power science and technology, underpinned by strong integration with academia and industry, and thoughtful engagement with international partners

In May 2017 Sandia released its Dynamic Materials Program Strategic Plan

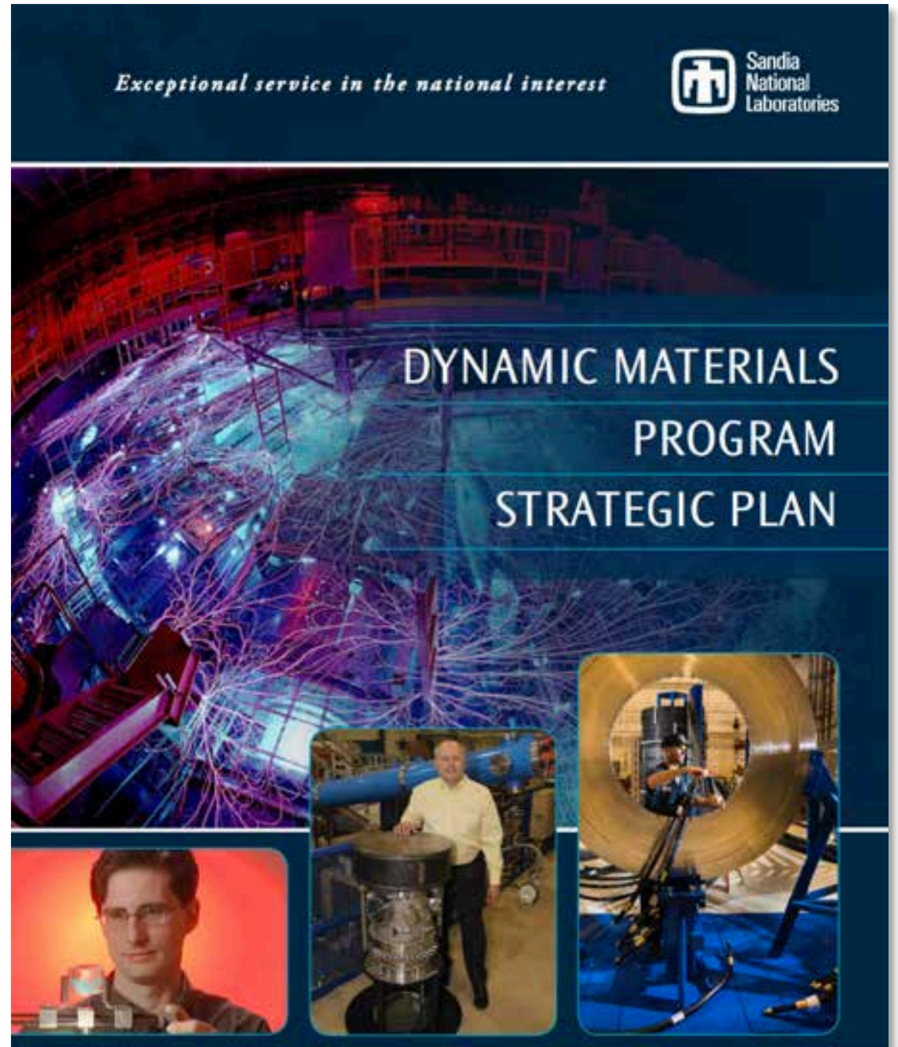
Vision

- In 10 years we will determine how kinetics, aging, and microstructure affect material response at pressures up to 15 Mbar

Mission

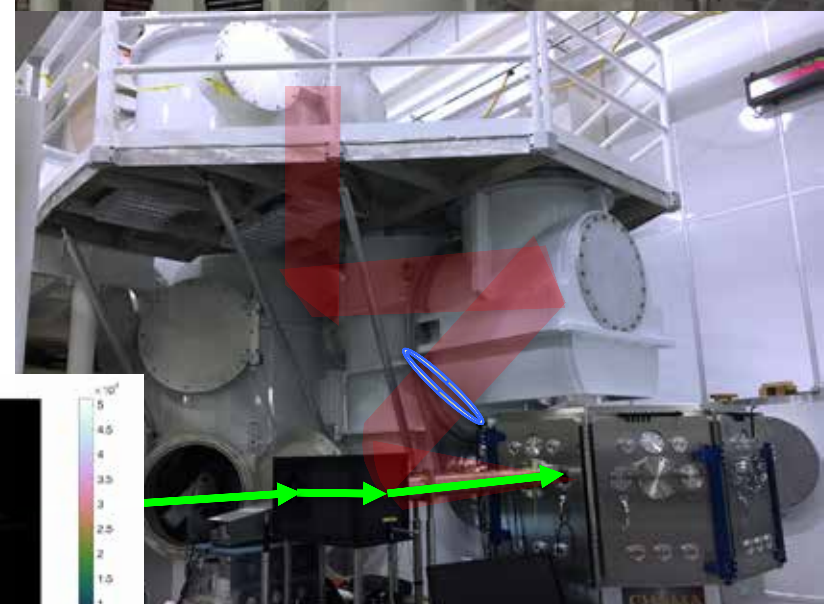
- Provide predictive capabilities for national security at high pressure and high temperature by integrating theory, simulation, and high-precision experiments on Z, STAR, DICE, and next-generation pulsed power facilities

Report outlines 13 strategic objectives for the near-, mid-, and long-term

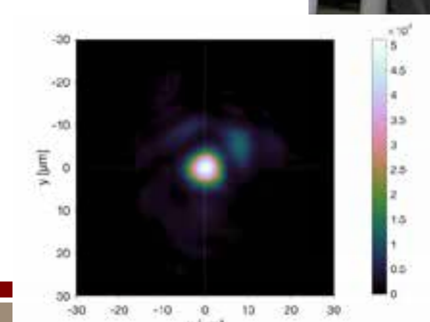


Commissioning of the Chama Target Chamber on the path to developing x-ray diffraction diagnostics for Z

- **Motivation**: Activate the last of five high energy laser target chambers in order to perform combined Z-Beamlet (ZBL) and Z-Petawatt (ZPW) experiments.
- **Approach**: Using an existing beam line, we steered the ZPW beam to the Chama chamber utilizing custom meter scale mirror mounts and in-house coated optics.
- **Outcome**: ZPW has been focused at target chamber center. This enables a large range of novel experiments, such as prototyping of dynamic diffraction experiments on the Z-machine

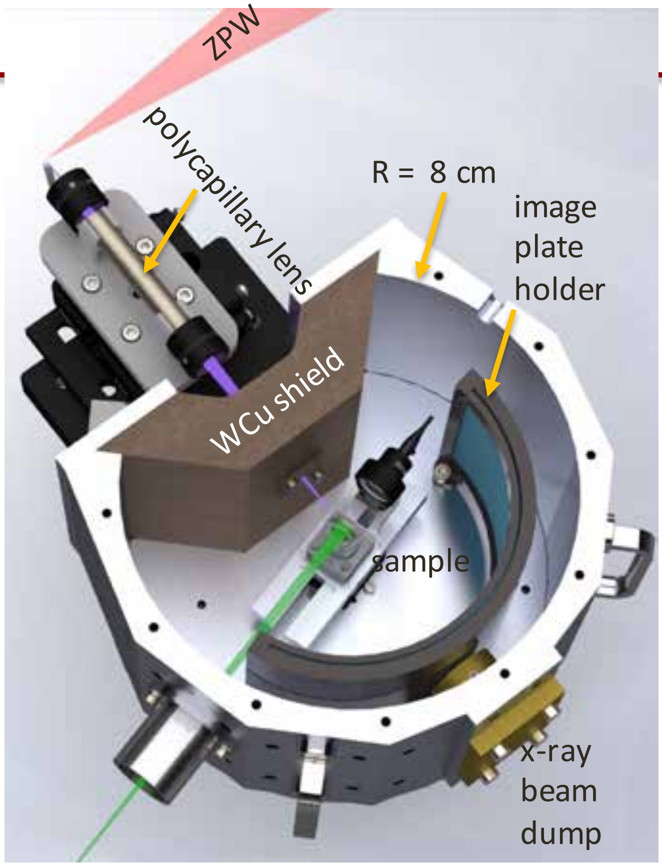


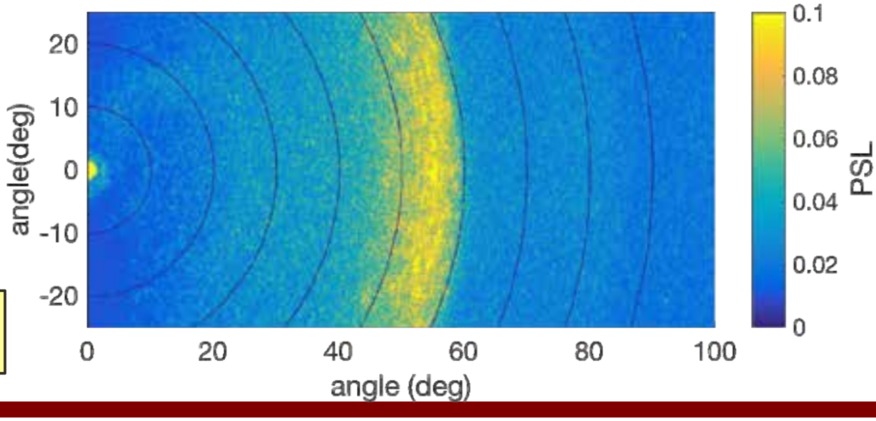
Alignment laser focus at Chama chamber: FWHM ≈ 6 μm. $I \approx 10^{18}$ W/cm^2 expected



First x-ray diffraction data with the Z-Petawatt laser

- **Motivation**: Measure phase and density changes of a dynamically compressed, high-Z sample at the Z facility with a laser-driven x-ray diffraction probe
- **Approach**: Use the Z-Petawatt short-pulse laser to create a >10 keV x-ray source; enhance x-ray flux and mitigate hot-electron background at the sample with an x-ray polycapillary lens.
- **Outcome**: The ZPW laser ($I \approx 10^{18}$ W/cm^2) was used to generate K_α x-rays from a Cu target. A polycapillary optic focused the x-rays onto a Be sample to generate a powder (Debye-Scherrer) diffraction pattern at an image plate detector.

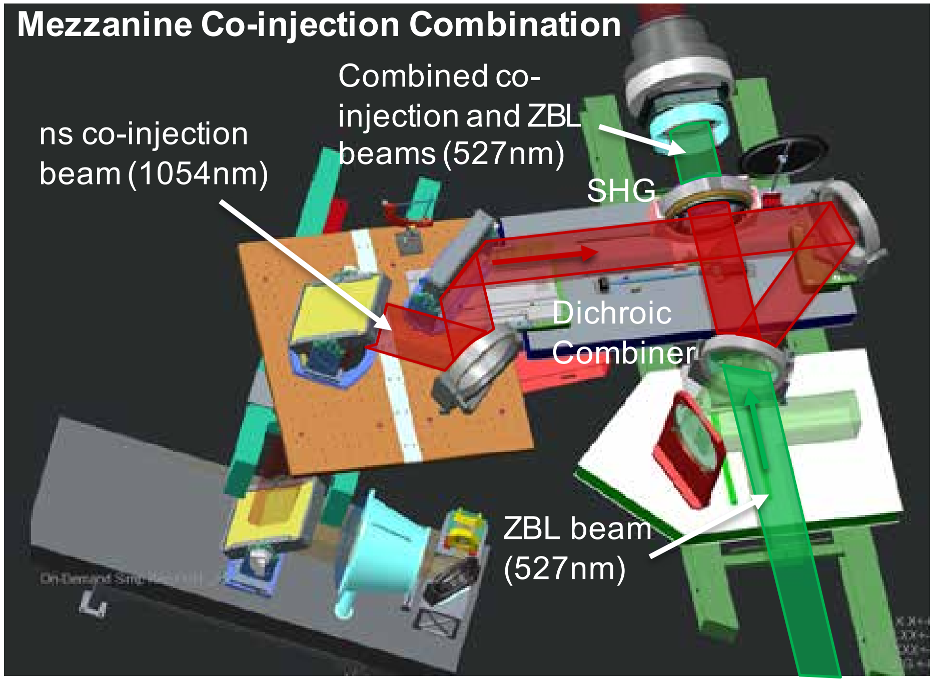




Short-pulse laser created dynamic x-ray diffraction

Z-Petawatt beam co-injected with Z-Beamlet beam

- **Motivation**: Provide a 2nd ZBL like beam for:
  - Having an arbitrarily variable temporal pre-pulse to "blow-off" the MagLIF laser entry hole,
  - Providing additional pre-heat for MagLIF, and
  - Allowing for the possibility of developing a backlighting capability for laser heated MagLIF experiments.
- **Approach**: We modified the existing Z-Petawatt short-pulse laser to operate in long pulse (ns) mode. The beam is then co-injected with a dichroic combiner and frequency doubled.
- **Outcome**: We demonstrated 168 J, 527nm, 2.4 ns FWHM pulse. Have done combined shots of ns pulse ZPW with ZBL into Pecos target chamber with controlled time delays.



Thor-48 Commissioned and Operational

- **Motivation**: Demonstrate our new unified approach to pulsed power technology development, and apply it to the advancement of dynamic materials research
- **Approach**: Single-step pulse compression and transit-time-isolated energy storage allows exquisite control and predictability of the current pulse shape at the target
- **Outcome**: Maximum synchronous pressure of Thor-48 is ~250 kbar. 200 kbar experiments in Cu at 80 kV voltage has been demonstrated.

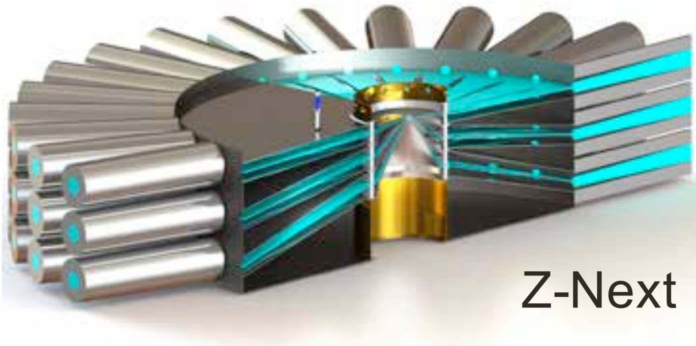
Components for Thor 72 will be in house for FY18
maximum pressure = 600 kBar (Cu) at 4 MA

Pulsed power technology can address scientific opportunities and threats to our nuclear stockpile

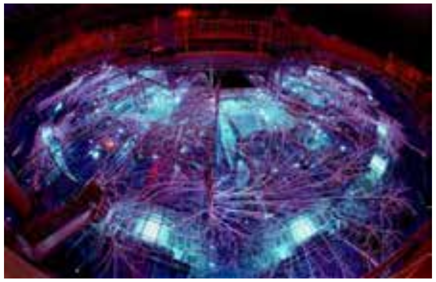
Sandia National Laboratories

- **Opportunities: A Z-Next facility capable of 10-30 MJ yield could address key physics gaps**
  - Provide combined neutron and x-ray hostile environments
  - Achieve higher-pressure capabilities for actinide dynamic material properties
  - Address critical nuclear weapon primary and secondary physics issues

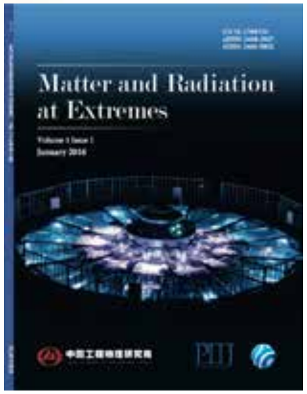
- **Threats: New technology developments abroad driving a reassessment of threats; U.S. preeminence in pulsed power could be lost in 5-10 years**
  - Changing threat landscape in nuclear survivability
  - Both China and Russia have active plans to build larger pulsed power (and laser) facilities than the U.S.
  - China has a larger pulsed power program than the U.S. and is catching up technically
  - Z has been an “engine of discovery”: Do we want to risk technological surprise?



Z-Next



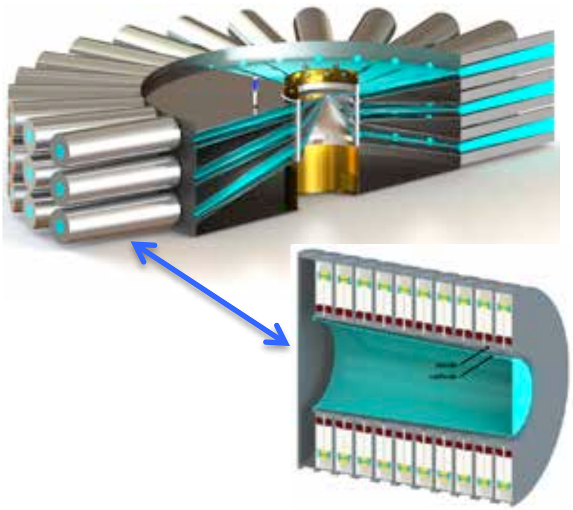
Z Arcs & Sparks

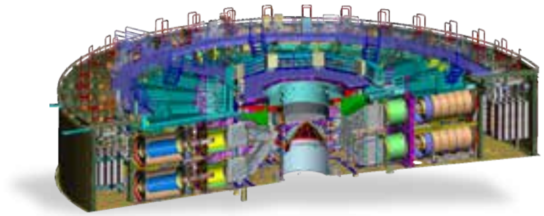


CAEP 10 MA Primary Test Stand

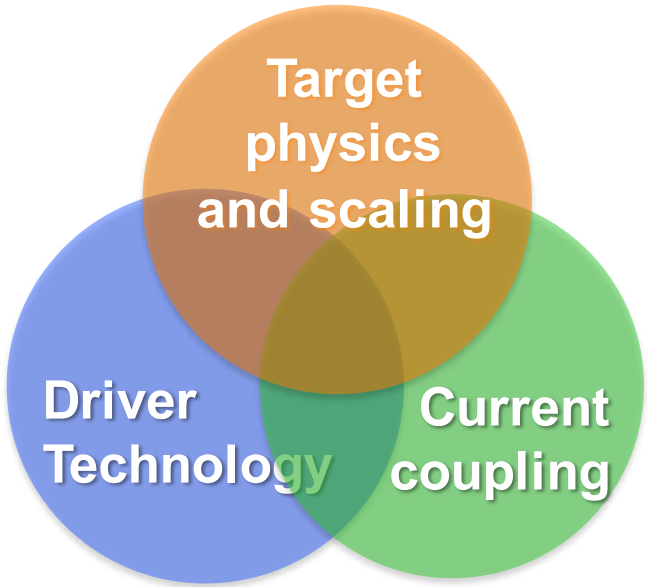
We aspire to advance pulsed power science and technology to address these opportunities & threats

Build a Z-Next Module
Demonstrate technology & develop supply chain

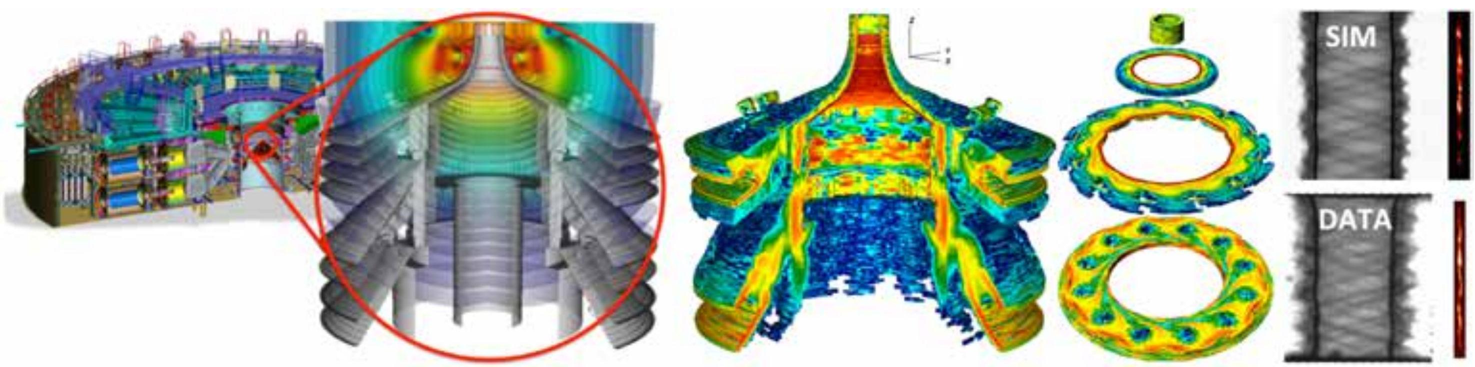




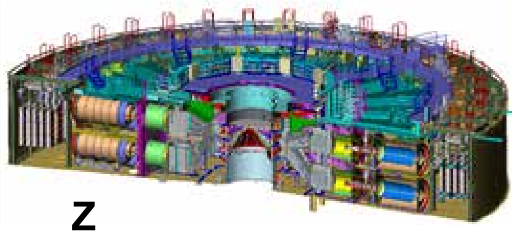
Increase the shot capacity of the Z facility
Timely evaluation of new magnetic drive targets while supporting stockpile today



Develop next-generation plasma science & engineering code
Reduce risks for scaling to a Z-Next

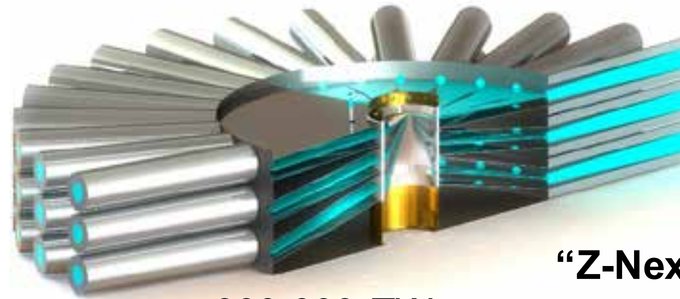


We aspire to build a demonstration module to mature the pulsed power technology needed for a Z-Next



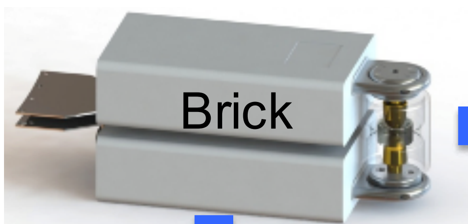
Z

- 80 TW
- 33 Meter diameter
- 22 MJ Stored Energy
- 0.2 to 1 MJ to target

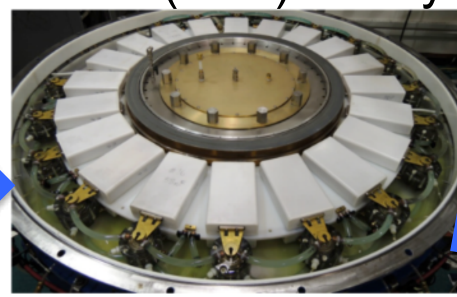


"Z-Next"

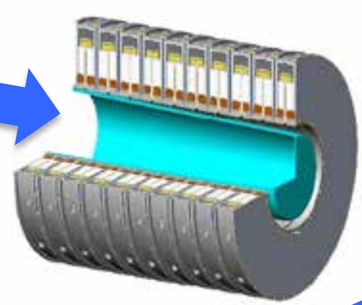
- 300-900 TW
- 35-52 Meter diameter
- 50-130 MJ Stored Energy
- **~10 MJ to target**



Linear Transformer Driver (LTD) Cavity



LTD Module



Thor (Cable pulser)

Impedance-matched Marx Generator (IMG) Module

Pick one to build out as a full Demo Module

The high-quality work being done across all areas on Z has not gone unnoticed—NNSA aspires to significantly increase our budget

SNL WEAPONS ACTIVITIES	FY2016 ENACTED	FY2017 ENACTED	FY2018 PBR	FY2019 PPBE	FY2020 PPBE	FY2021 PPBE	FY2022 PPBE	FY2023 PPBE
Science								
Advanced Certification	4,139	4,739	4,139	4,139	4,809	4,809	4,917	5,028
Primary Assessment Technologies	8,274	9,300	9,732	13,929	16,385	18,644	19,061	18,844
Dynamic Materials Properties	11,060	11,774	14,266	18,587	19,738	18,836	19,265	19,703
Advanced Radiography	11,367	10,920	7,650	14,131	15,692	18,792	19,578	20,566
Enhanced Capabilities for Subcritical Experiments			6,827					
Secondary Assessment Technologies	5,062	6,257	5,257	5,467	5,587	5,714	5,843	5,843
Science	39,902	**42,990**	**47,871**	56,253	62,211	66,795	68,664	69,984
ICF								
Ignition								
Support of Other Stockpile Programs			500					
Diagnostics, Cryogenics, and Experimental Support	3,250	3,949	7,500	10,942	10,666	10,433	9,792	9,994
Pulsed Power ICF	4,849	5,529	7,500	8,320	9,000	9,000	9,409	9,620
Facility Operations and Target Production	36,291	37,900	41,978	45,744	45,103	46,434	47,963	48,931
ICF	44,390	47,378	57,478	65,006	64,769	65,867	67,164	68,545
Science + ICF Total	84,292	**90,368**	**105,349**	121,259	126,980	132,662	135,828	138,529

Extras

The $57.5M ICF Congressional Budget Request will allow us to stabilize shot rate decline and make some investments

Inertial confinement fusion ignition & high yield	Omnibus FY17	NNSA FY17 Budget Request FY17	NNSA FY17 Budget Request FY18
Diagnostics, cryogenics and experimental support	3.9	7.1	7.5
Pulsed power inertial confinement fusion	5.5	5.5	7.5
Facility operations and target production	38.0	38.0	42
Support of other stockpile programs	0.0	0.0	0.5
Total: Sandia ICF Program	**47.4**	**50.6**	**57.0**

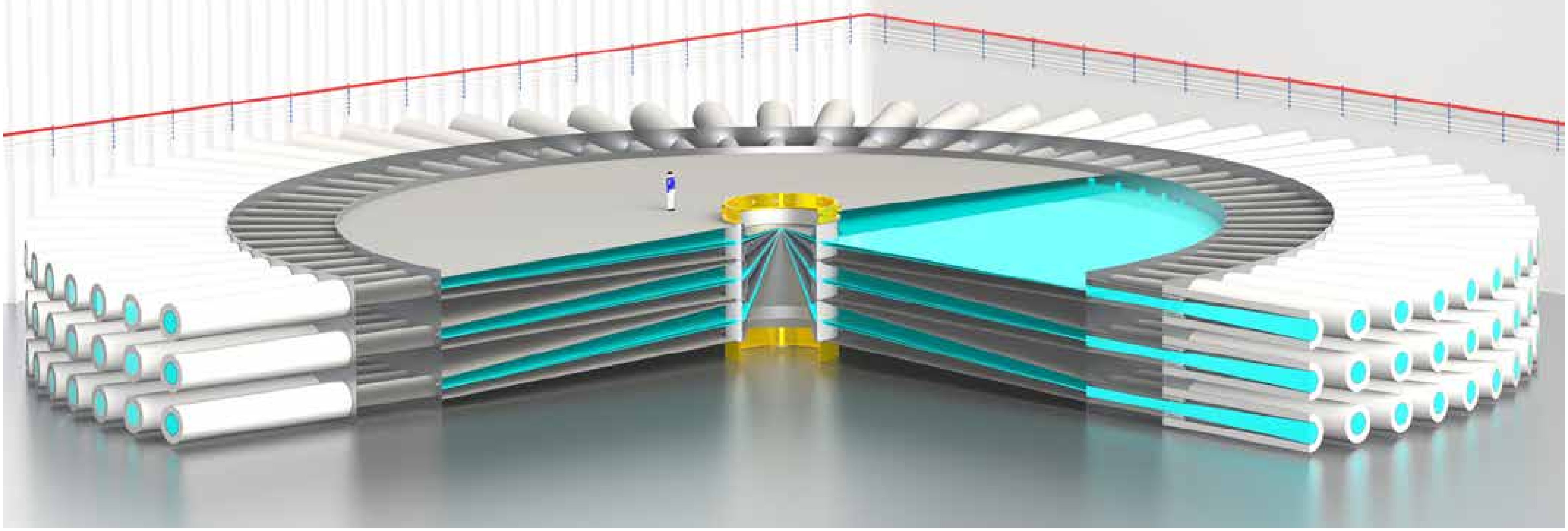
		FY18
FY18 Sandia ICF Program (from NNSA FY17 Budget Request)		**57.5**
ICF Program needs	Possible funding source	
Enhance Z shot capability to ~200 shots/year[1]	ICF Facility operations	9.5
Address deferred maintenance on Z[2]	ICF Facility operations	4.1
	Total	**71.1**
	Total over NNSA FY17 Budget Request	**13.6**
Continuing support from Science Program		
Maintain Z shot rate at 140-150 shots/year[3]	Science Program	6.0
Additional Program needs		
Start next-gen pulsed power module (single test beam)[4]	PP ICF Program	5.0

We have started working through a Center 1600 structure change that we hope will make workloads more manageable and position us for growth

		Flicker	Cuneo	Sinars	New Sr. Mgr. (McKee, Actg.)	New Sr. Mgr.
Program	Deputy Role	Deputy role: - Science Program	Deputy roles: - ECSE - Sci: C3 - ARTT - SCE Council	Deputy roles: - ICF Program	None at this time	None at this time
Program	Program & National Focus Areas	Dynamic Materials and Boost Related Planning and Capability Development	LDRD Advanced PPS&T Development Plans ICF: Driver-target coupling	National ICF and RES Related Planning and Capability Development Sci: SAT	Shot Solicitation & Prioritization Process Target Fabrication Interface System Eng. Rqmts. for Adv. Pulsed Power Experimental Capabilities	Manage CD process for Advanced Pulsed Power Technologies (growth with new funding realized)
Program	Integration	**Teaming for Cross-Program Integrated Strategies & Plans**				
Center	Line Mgmt.	**1640 High Energy Density Material Physics Group**	**1650 Pulsed Power Accelerator S&T Group**	**1680 Radiation & Fusion Physics Group**	**1670 Z Experimental Capability Management Group**	**1690 Pulsed Power Engineering & Design Group**
Center	Experimental Capability Mgmt. / Stewardship	• Star • DICE • Thor • VELOCE	• ECSE • Mykonos • Component Test Stand • Ursa Minor • Switcharoo #1, #2 • Centipede • Z-Next Module • Cleaning	• ZBL • SITF (with 5400)	• Z • ABZ	• Containment Systems
Center	Integration	**Teaming for Center-Wide Integration, Optimization, and Assurance**				

We have developed a conceptual design of an accelerator that is optimized for high-yield thermonuclear-fusion research.

- Outer diameter: 72 m.
- Power source: 210 impedance-matched Marx generators.
- Energy storage: 140 MJ.
- Peak electrical power at the output of the IMGs: 960 TW.
- Peak current delivered to a fusion target: 67 MA.
- Electrical energy delivered to a fusion target: 9 MJ.



Thermonuclear & ICF Opportunities

- Mature the required pulsed power driver engineering and technology needed to achieve 10-30 MJ yields within the next 20 years
- Establish a combined experimental and computational program in driver-target coupling (power flow physics)

Yield	High Energy Density Science Applications
~0.01 MJ	• Interplay of thermonuclear fusion burn and mix • Nuclear physics data (Reaction-in-flight, fission, and radiochemistry)
>0.1 MJ	• Transport of charged particles in plasmas • Threshold for fusion-fission physics
~few MJ	• Threshold for enabling complex mix physics studies. • Robust radiation and charged particle transport • Robust fusion-fission experiments
20-30 MJ	• Higher fidelity versions of the above experiments are possible • Neutron sources for outputs and environmental studies
>500 MJ	• Use of fusion targets to drive complex experiments • Use of fusion targets for material properties (EOS, opacity) research • Combined neutron and x-ray environments for outputs and effects studies

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We have recently converted Sandia's Mykonos accelerator to a user facility.

- Mykonos is a five-cavity linear-transformer-driver (LTD) module.
- Mykonos was first used to support LTD-pulsed-power experiments.
- Mykonos is presently being used to drive vacuum-power-flow, automag (MagLIF), and z-pinch experiments in support of the ICF program.
- We expect to increase the Mykonos capacitor-charge voltage from 70 kV to 90 kV in FY18.
- At 90 kV, Mykonos will generate a peak electrical power of 0.4 TW.

- Number of LTD cavities = 5.
- Number of bricks per cavity = 36.
- Capacitor charge voltage = 70 kV.
- Peak load voltage = 350 kV.
- Peak load current = 700 kA.
- Peak load power = 0.245 TW.
- Output power variation = 1% (1σ).
- Module jitter = 2 ns (1σ).
- Number of shots to date = 2000.