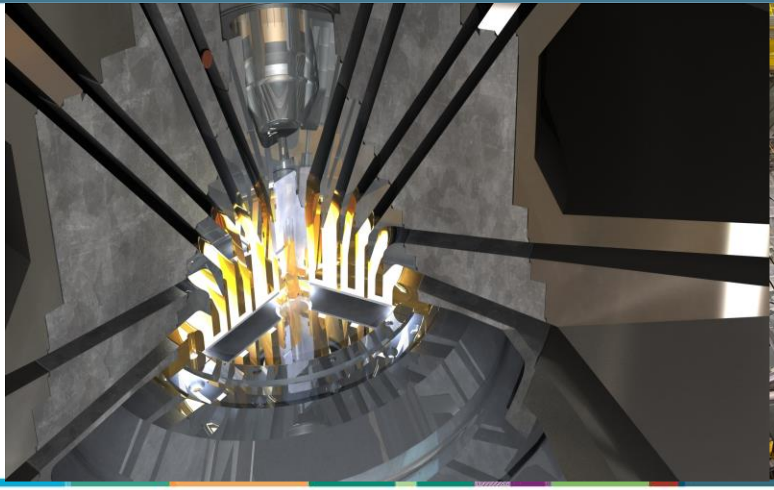
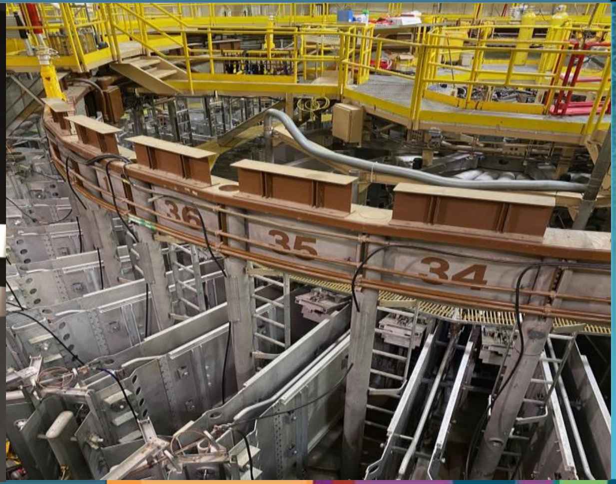
This paper describes objective technical results and analysis. Any subjective views or opinions that might be expressed in the paper do not necessarily represent the views of the U.S. Department of Energy or the United States Government.

SAND2023-05560C

Sandia National Laboratories

Pulsed Power: The Enabler for Radiation, Electrical and High Energy Density Science





Bryan V. Oliver

SAND2023-XXXXX

2023 IEEE International Pulsed Power Conference.
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Ju

Sandia National Laboratories | U.S. Department of Energy | NNSA

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.

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

The Peter Haas Award

Peter Haas was a pioneer in the field of nuclear weapons effects beginning in the mid 1950s. He proposed and conducted some of the landmark experiments on nuclear electromagnetic pulse (EMP) and transient radiation effects on electronics at the Nevada and Pacific Nuclear Test

Peter H. Haas
1921-1986

He was a strong advocate for laboratory simulation facilities and it was under his direction that some of the early electronic effects research was done in pulsed nuclear reactors and x-ray generators.

From the study of intense beams, inertial fusion plasmas and radiation effects, my career has been aligned with Peter Haas' vision and I am truly grateful for this recognition

Acknowledgments

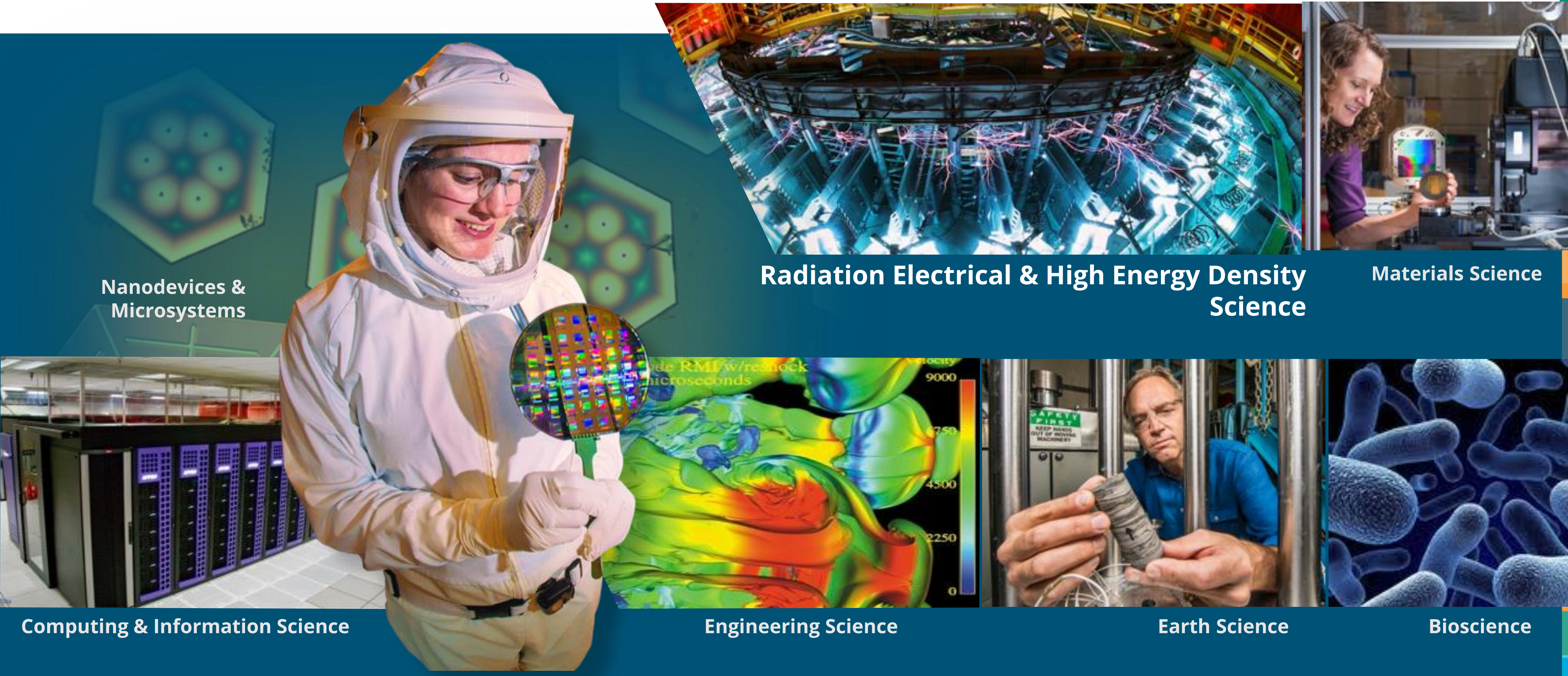
Many people have provided content for this presentation.

Keith Cartwright
Peggy Christenson
Bob Commisso
Greg Frye-Mason
Steve Glover
Chris Grabowski
Michael McLain
Israel Owens
Tim Renk
Mark Savage
Dan Sinars
Peter Sincerny
Ben Ulmen

I'll try not to botch it!

Sandia Has 7 Research Foundations that Steward Our Core Science and Technology Capabilities.

Purpose: Conduct fundamental/discovery research in disciplines germane to our national security missions, advance the frontiers of knowledge, explore innovative solutions, and build/maintain technical capability.

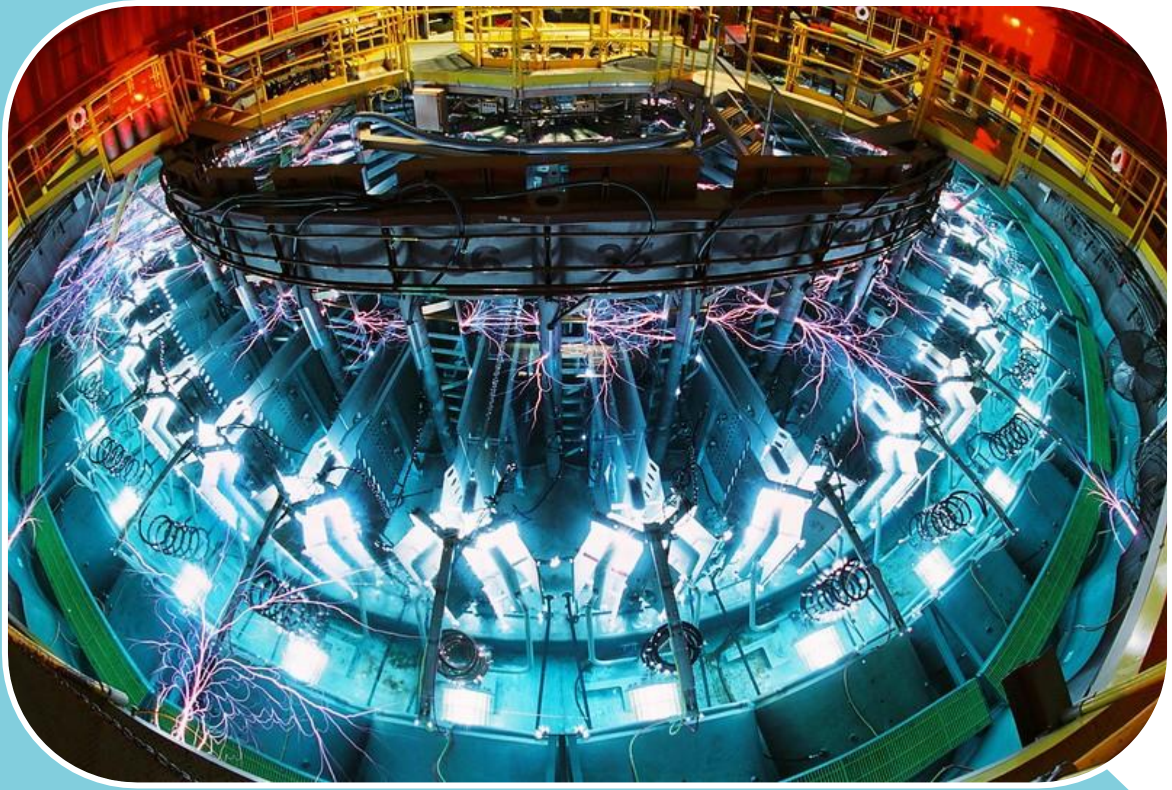


Radiation, Electrical, and High Energy Density Science (REHEDS) Research Foundation

The research foundation seeks to advance the fundamental understanding of the science of nuclear weapons and their effects for the DOE's Stockpile Stewardship Program

Radiation Effects Science

- Understanding the effects on materials and electronics caused by single and combined radiation environments (photon and particle).



Saturn Accelerator

Electrical & Electromagnetic Science

- Understanding the effects of electromagnetic radiation, with a particular focus on electrical and electro-optical circuits.
- Research, development and application of computational and physical simulation capabilities.

High Energy Density Science

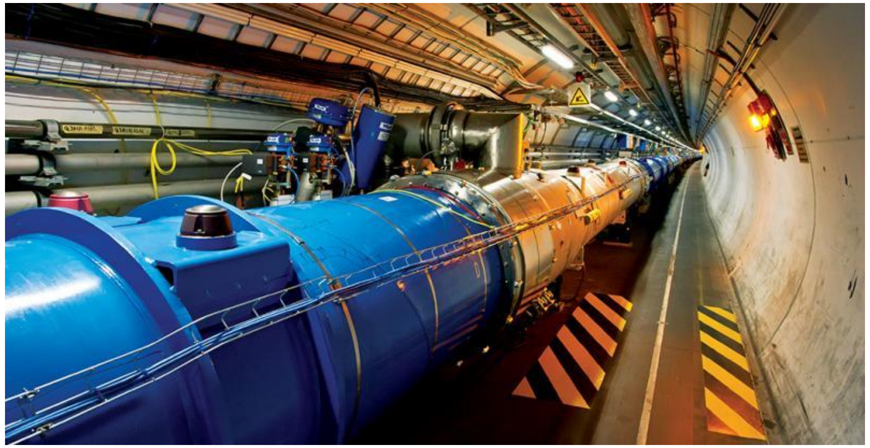
- Studying material properties, inertial confinement fusion, radiation transport, and other physical processes at extreme temperatures, densities, and pressures.

Pulsed Power Science & Technology

- Understanding the physical principles that underlie the efficient creation and application of electrical energy through pulsed power technologies.

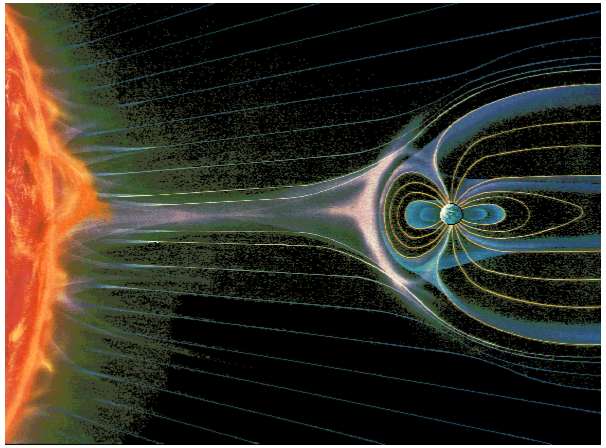
Radiation and Electrical Sciences: Why We Care?

(After nuclearweaponarchive.org)



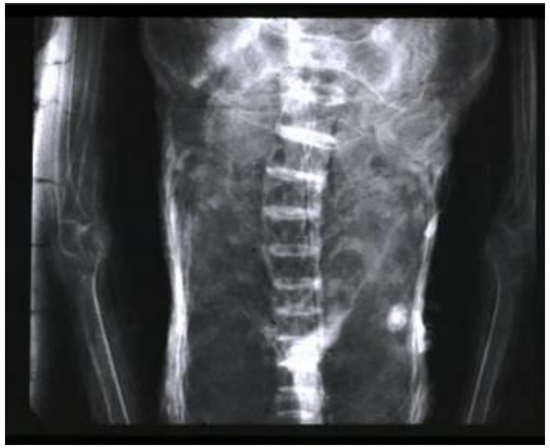
(After home.cern/topics/large-hadron-collider)

(After wikipedia.org)



(After Endo, Nikkei Science, Inc. Japan)

(After www.stratcom.mil/Newsroom/Images)



(After oncampus.richmond.edu)

Many systems require radiation hardness and/or an understanding of the response to radiation and electrical stimulus

Radiation Effects Sciences: What We Do!

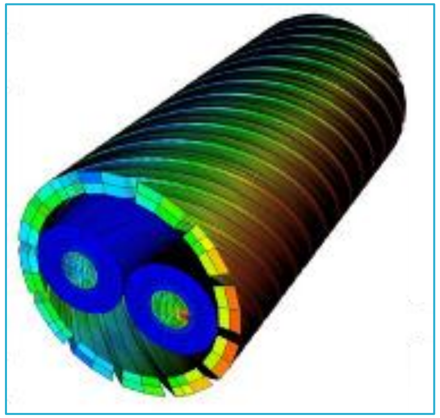
- Work spans research, development, and application in the field of radiation hardening design and qualification
- Activities range from fundamental radiation effects research to qualifying the performance of materials and electronic systems to severe radiation environments
- Utilize state-of-the-art photon, neutron, ion, electron, and laser sources located at Sandia and other laboratories throughout the United States
  - Operate pulsed power accelerators
  - Develop critical radiation, electrical, and plasma diagnostics to characterize our test environments
  - Perform research in accelerator technologies
- Develop theory, analytical techniques, and computer codes to model the effects of radiation on materials, electronics, and conduct pulsed power research

National Security Applications

X-ray effects experiments

Z Target Chamber

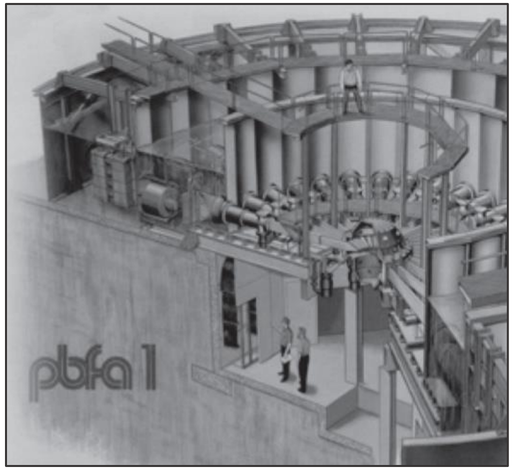
Model of Energy Deposition in a Cable

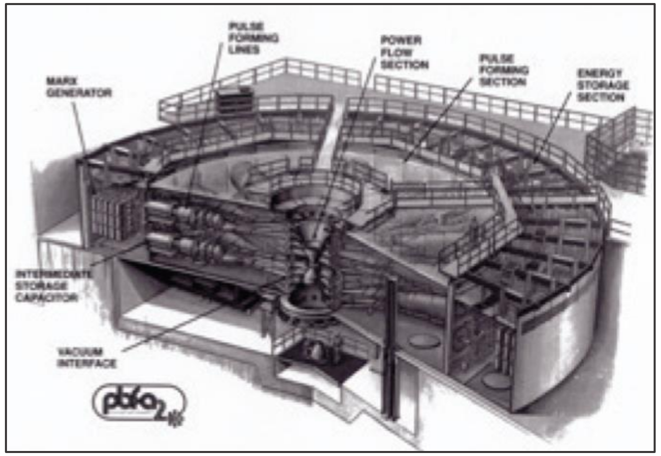


We support the national security missions using world-class experimental and computational capabilities

Sandia Laboratories is the home to three of the world’s largest radiation generating pulsed power accelerators.

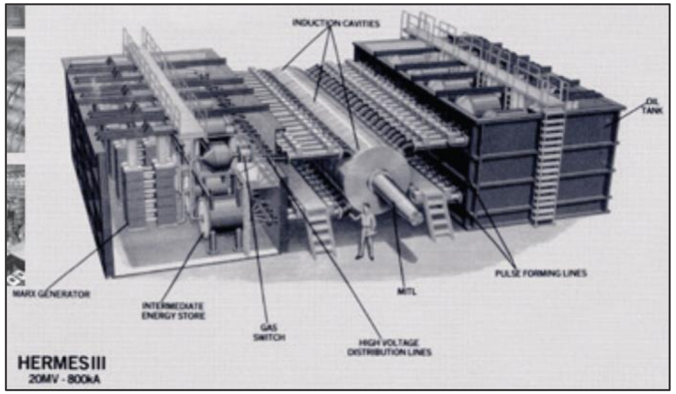
Particle Beam Fusion Accelerator 1 (1980): Built to study e-beam and light ion beams for fusion target research





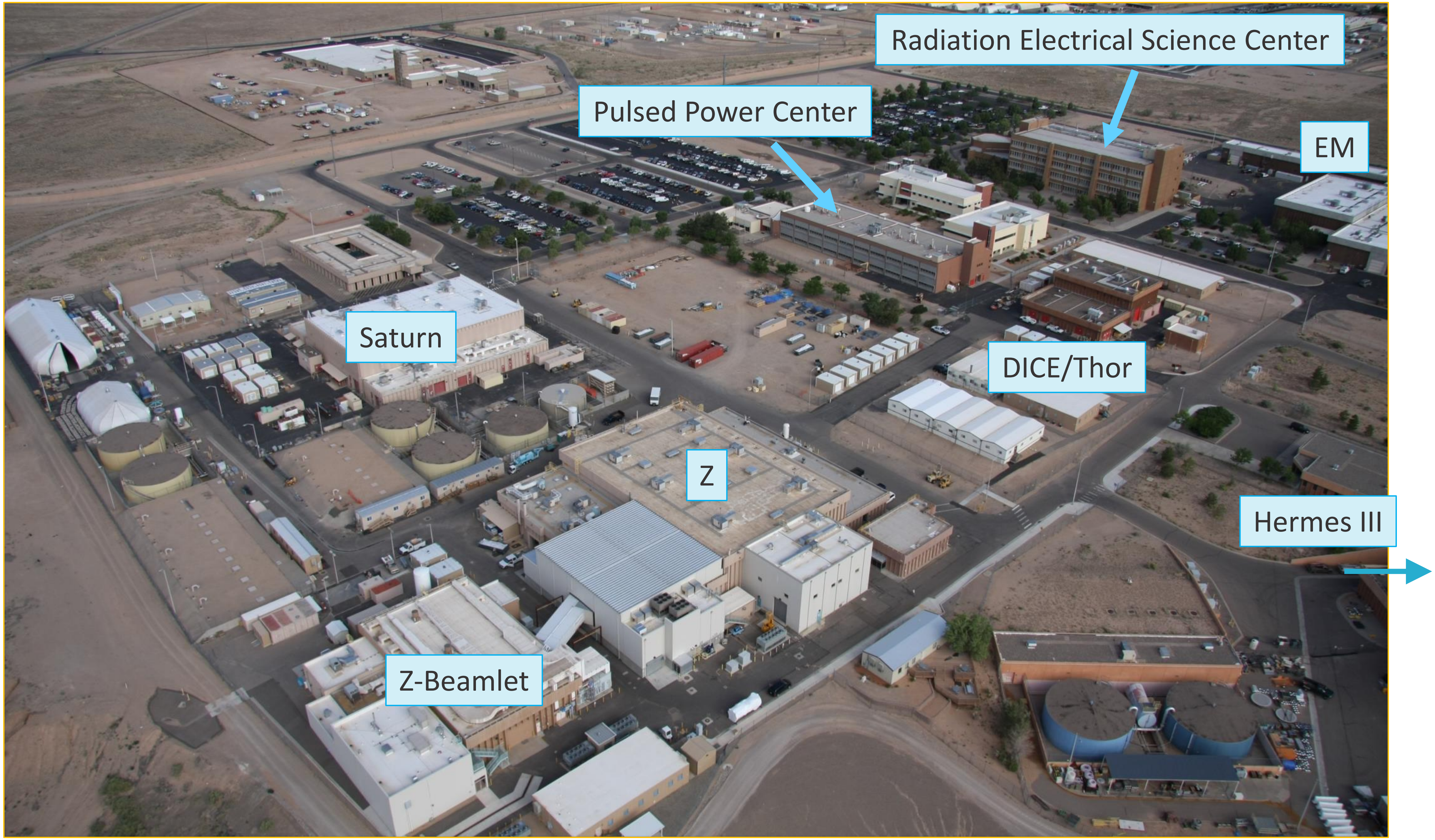
PBFA-2 (1985): Largest pulsed power machine in the world, converted to “Z machine” in 1996

PBFA-1 converted into Saturn (1987): The world’s largest, large-area hot x-ray simulator

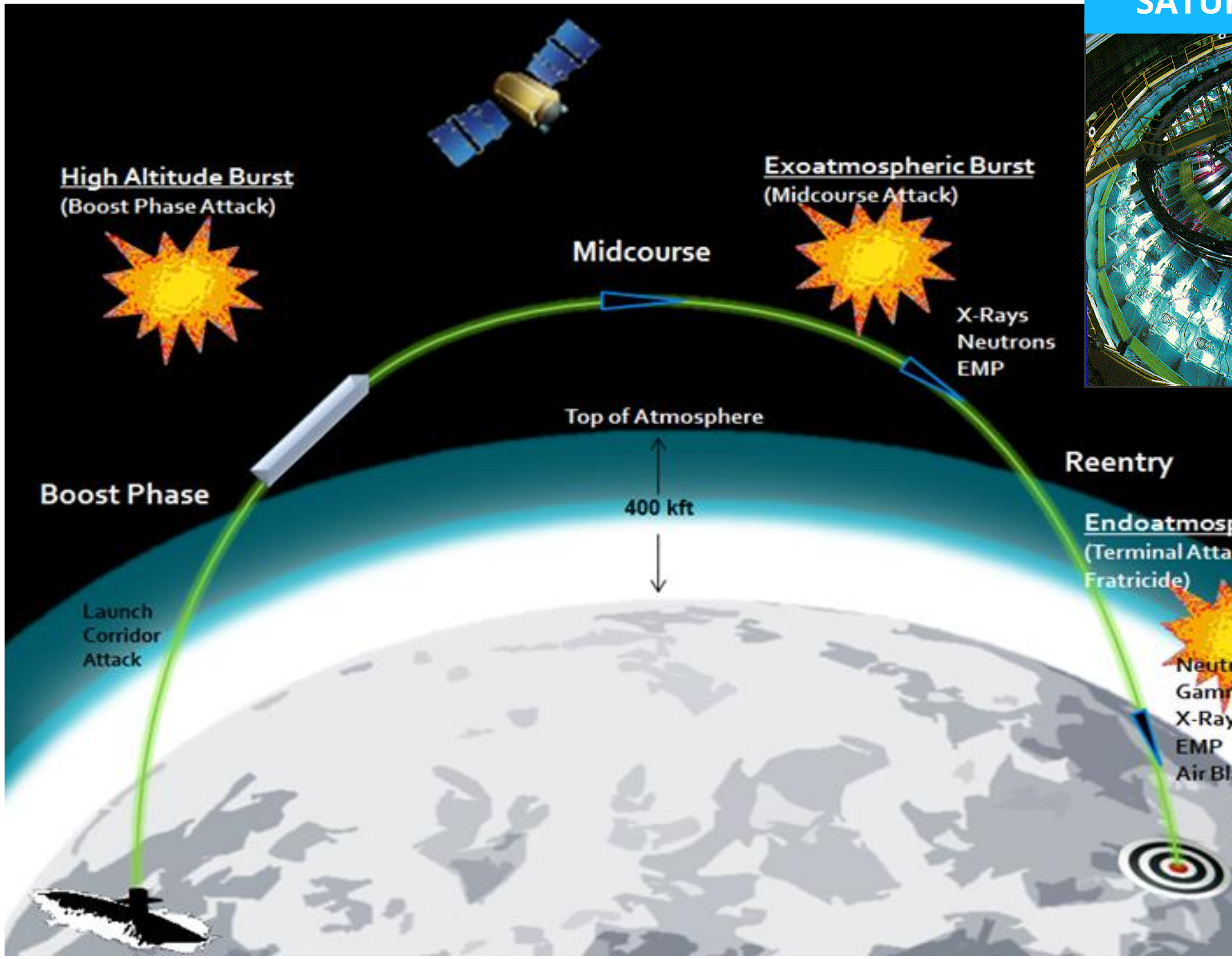


Hermes-III (1988): The world’s most powerful gamma-ray accelerator

The Infrastructure for Such Capabilities is Large

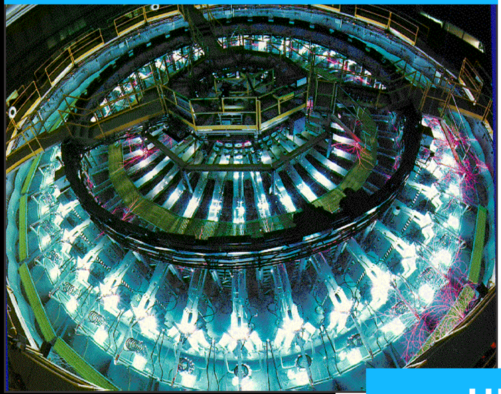


We Use The Pulsed Power Capabilities to Generate Relevant Environments for Science Based Stockpile Stewardship

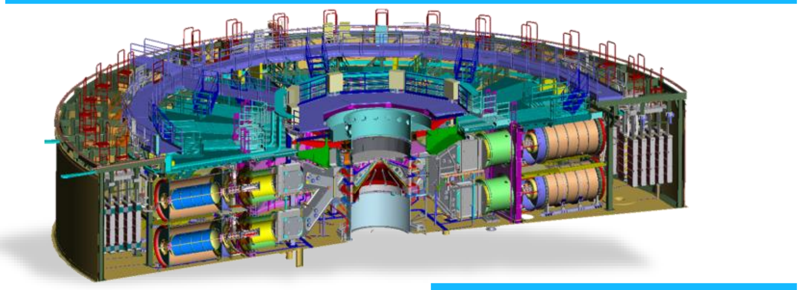


B.V. Oliver et al, *Nuclear Survivability*, Stockpile Stewardship Quarterly, **6**, 2 (2016)

SATURN (Hot X-rays)

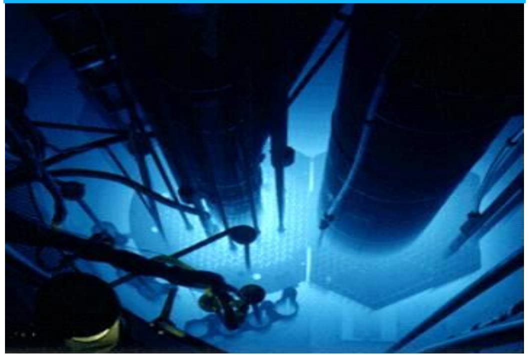


Z (Cold/warm X-rays; fast fusion neutrons)

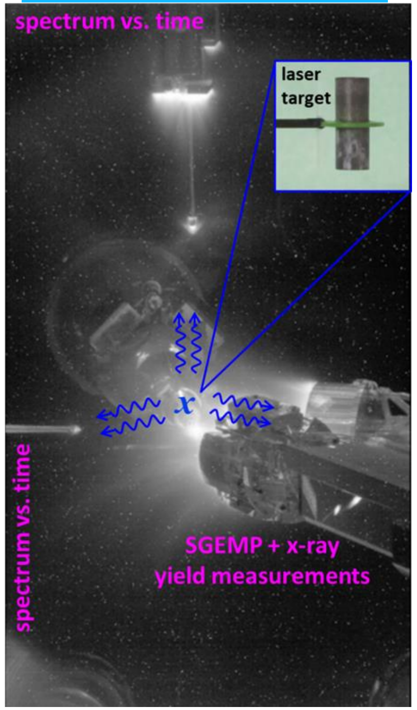


HERMES III (γ-ray)

ACRR (neutrons/γ-ray)



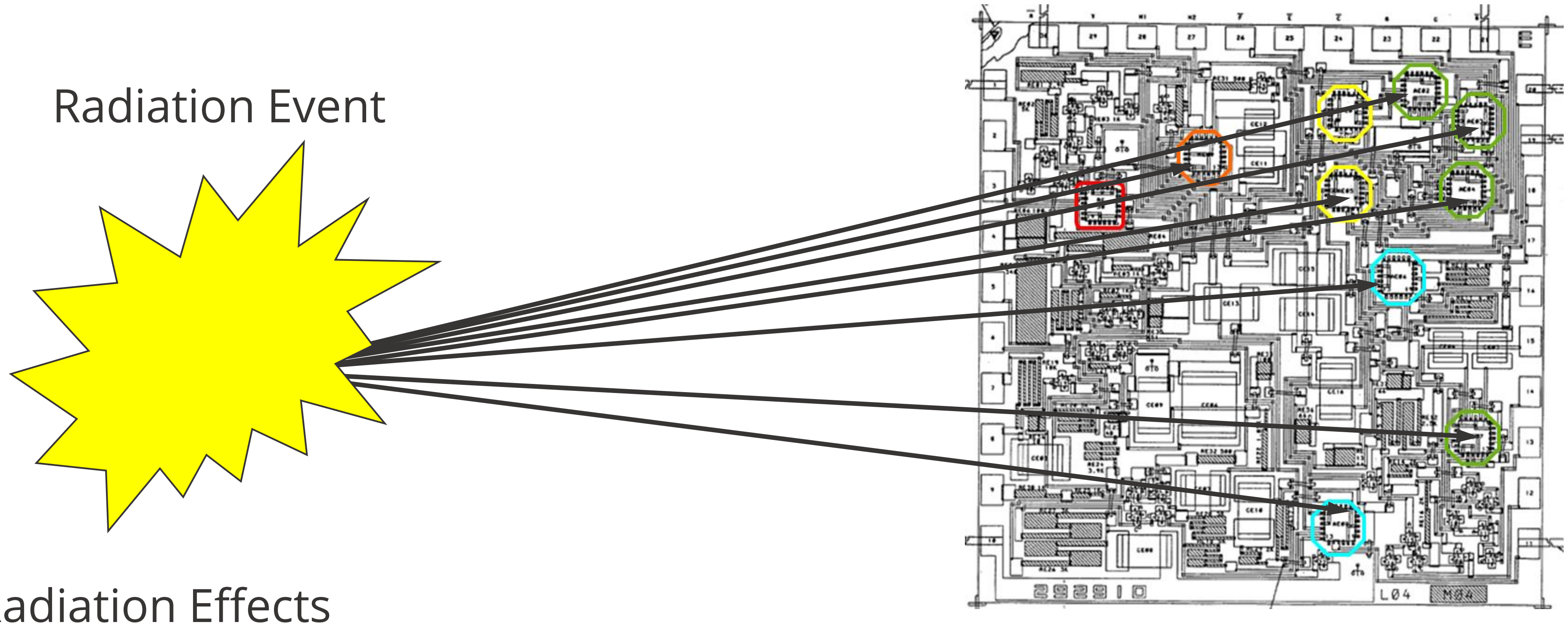
NIF (14 MeV neutrons, x-rays)



Radiation Electrical and High Energy Density Science (REHEDS) Activities

Electrical Sciences: We study the response of electrical systems to various radiation environments

Radiation Event



Radiation Effects

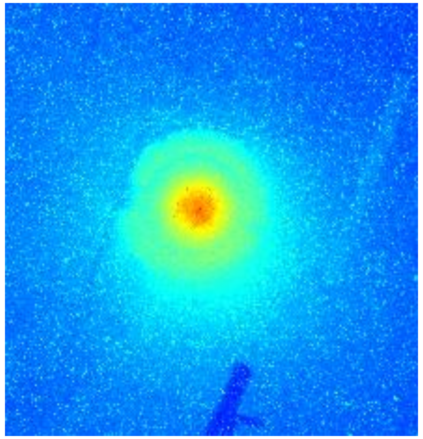
- EM shielding effectiveness
- Total Ionizing Dose (TID)
- Dose Rate Effects ($\dot{\gamma}$ and $\dot{X}$)
- Displacement Damage (DD)
- Single Event Effects (SEE)

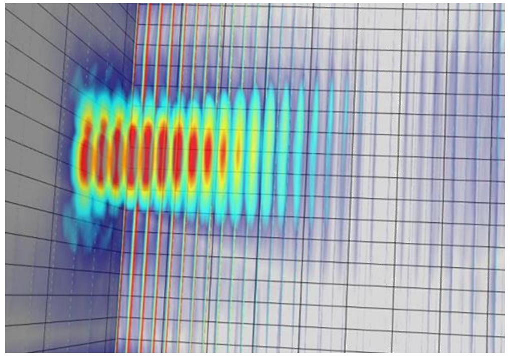
System Response

- Device Response
- Circuit Effects
- Signal Integrity/Board Effects

Radiation response depends on the environment and the technology affected. Proper characterization of the environment is essential

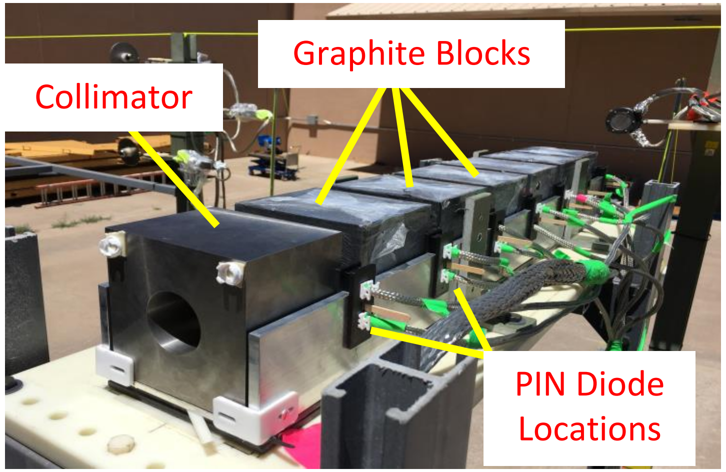
Advances at HERMES for Electronic Effects Testing





Optical dose mapping and tomographic reconstruction

Hermes III Gamma-ray simulator (18 MeV, 600-800kA)



High fidelity spectral characterization

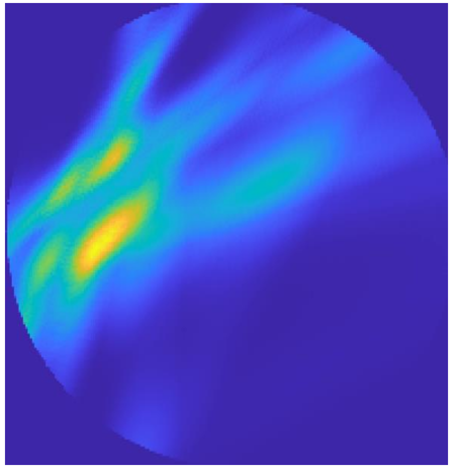
C. Grabowski et al., 23rd Pulsed Power Conf., 2021

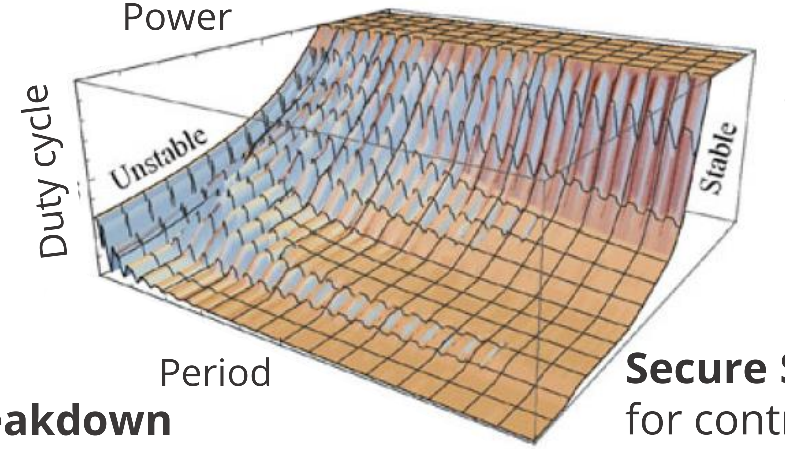
Indoor and Outdoor configurations allow for a broad range of electronic effects testing from circuit boards to simulated power grids!

Electrical Science Research to Advance Performance and Protection of Grid Systems.

Improving energy transfer through multi-physics based nonlinear controls and power electronics*

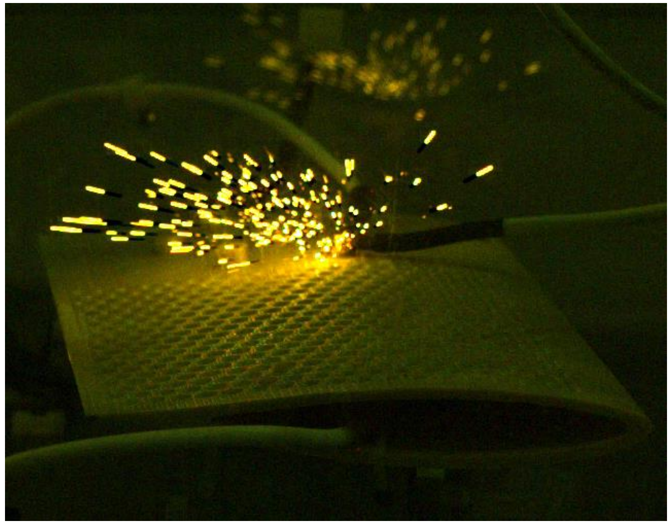
Characterizing dielectric breakdown using radio-imaging





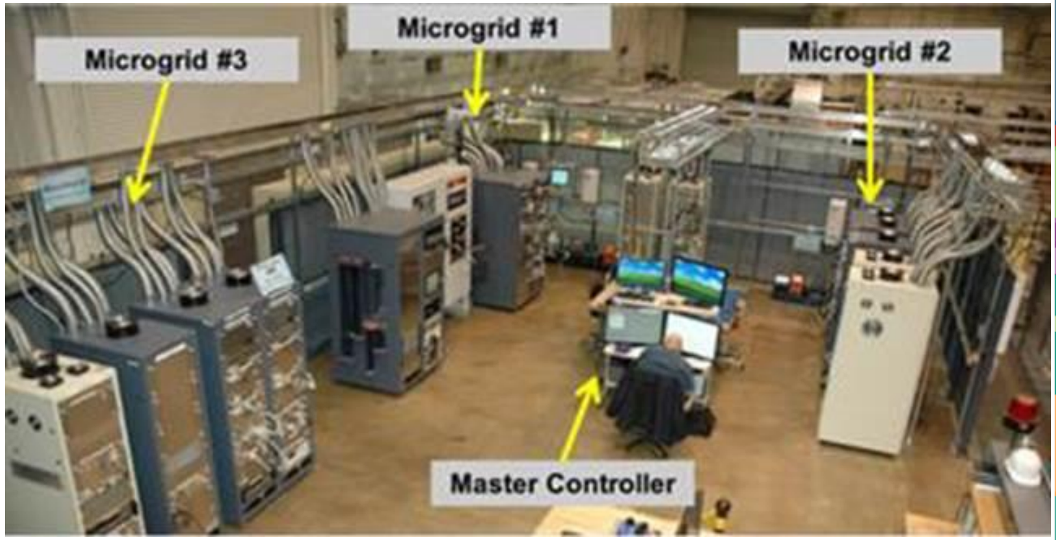
Meta-stable regions expand the operating regions beyond normal linear stability

Understanding and detection of electrical breakdown



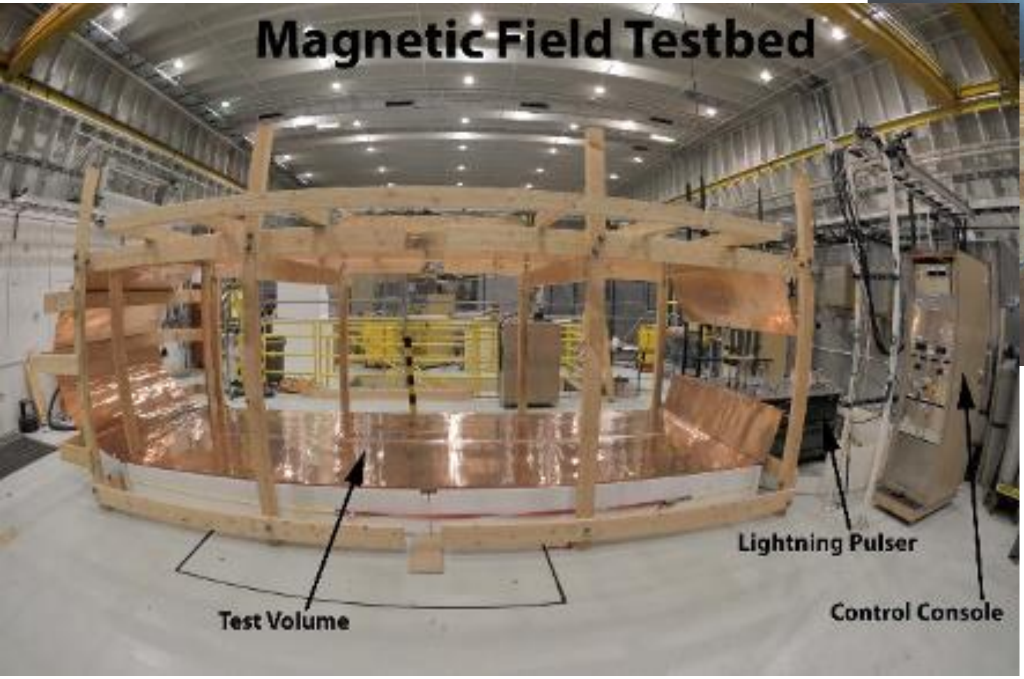
Lightning strikes to electrical systems and components such as wind turbines

Secure Scalable Microgrid: for controls and power electronics research

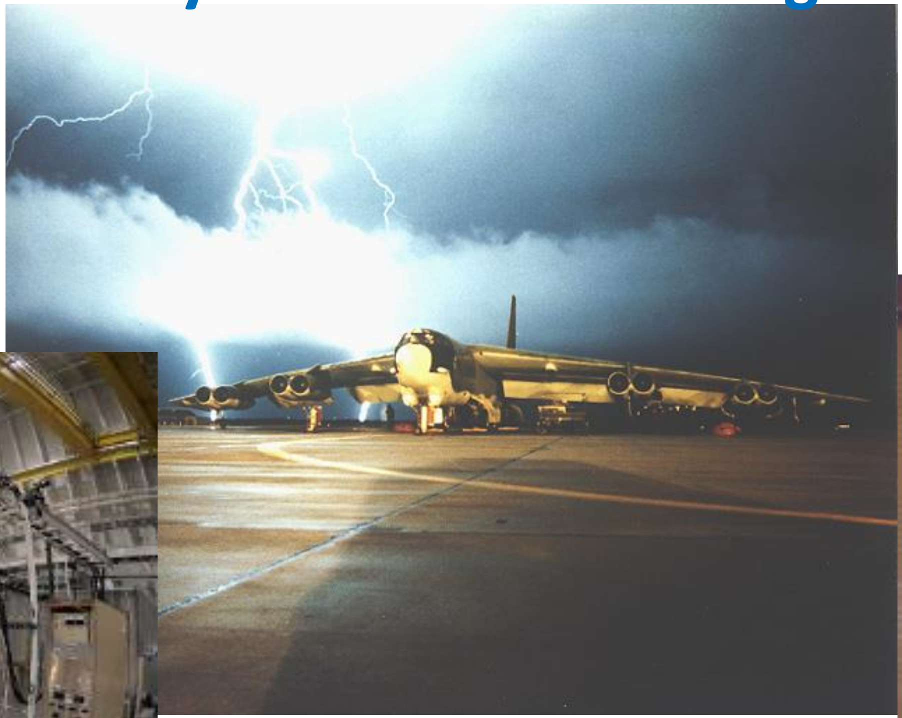


Weaver, W.W., Robinett III, R.D., Wilson, D.G. and Matthews, R.C., Meta-Stability Control of Pulse Power Loads using the Hamiltonian Surface Shaping Method, in Special Topics Journal on Electric Ship, IEEE Transactions on Energy Conversion, DOI 10.1109/TEC.2017.2652980, (2017).

Lightning Simulators for System Level Testing



Peak H-field 700 A/m
Risetime <500 ns
Pulse Width ~31 μs

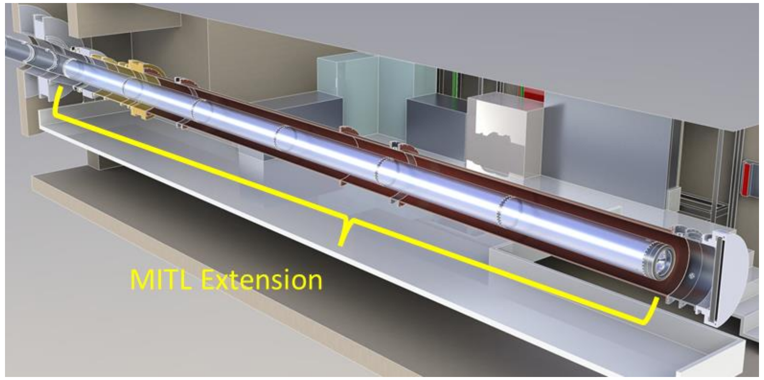


Sandia Lightning Facility

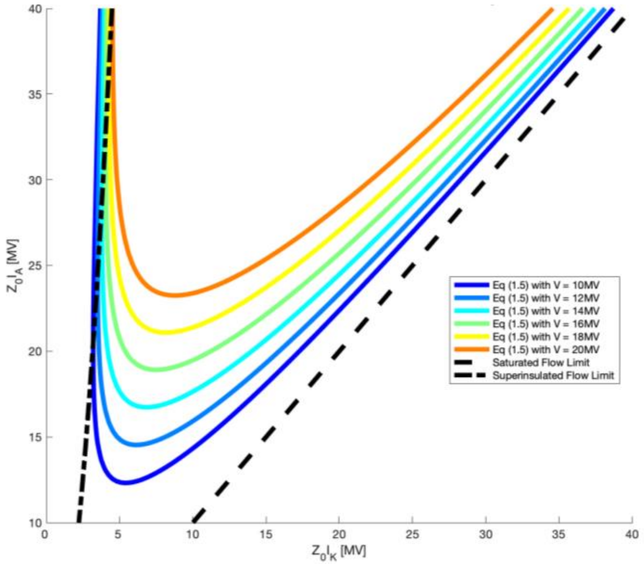
Peak Current 200 kA
Risetime 1-500 μs
Pulse Width ~50-500 μs
1 or 2 pulses

Emulation of pulsed E and B fields from Lightning strikes

Extending MITL Flow and Theory at HERMES to Improve Performance

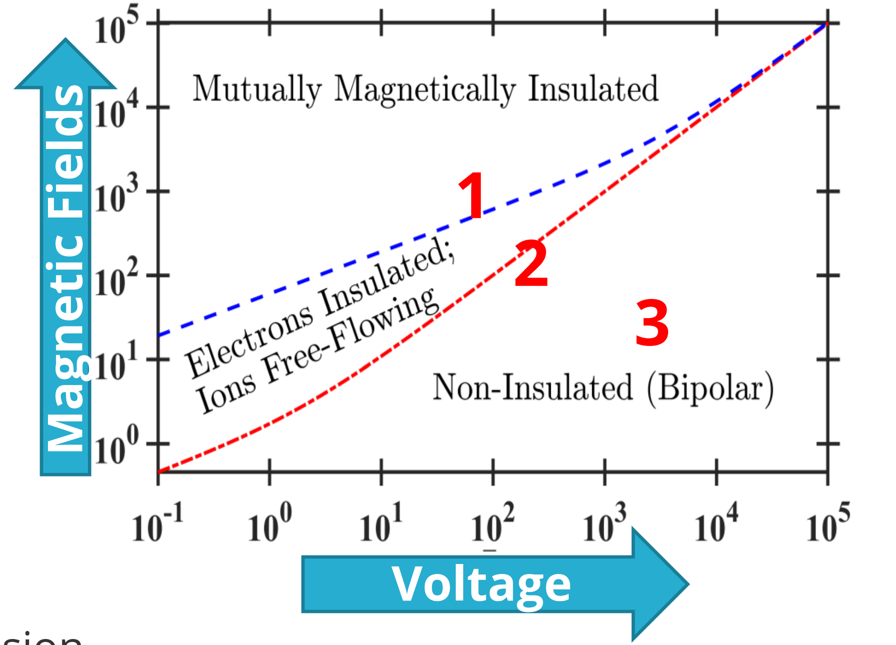


T. Powell, K. Cartwright et al., Proc. EAPPC-BEAMS, 2021



$$V = Z_0 \sqrt{I_A^2 - I_K^2} - \frac{mc^2}{2e} \frac{I_A^2 - I_K^2}{I_K^2}$$

The Magnetically Insulated Transmission Line (MITL) is a wonderful non-linear transmission line which affords some freedom in operating conditions

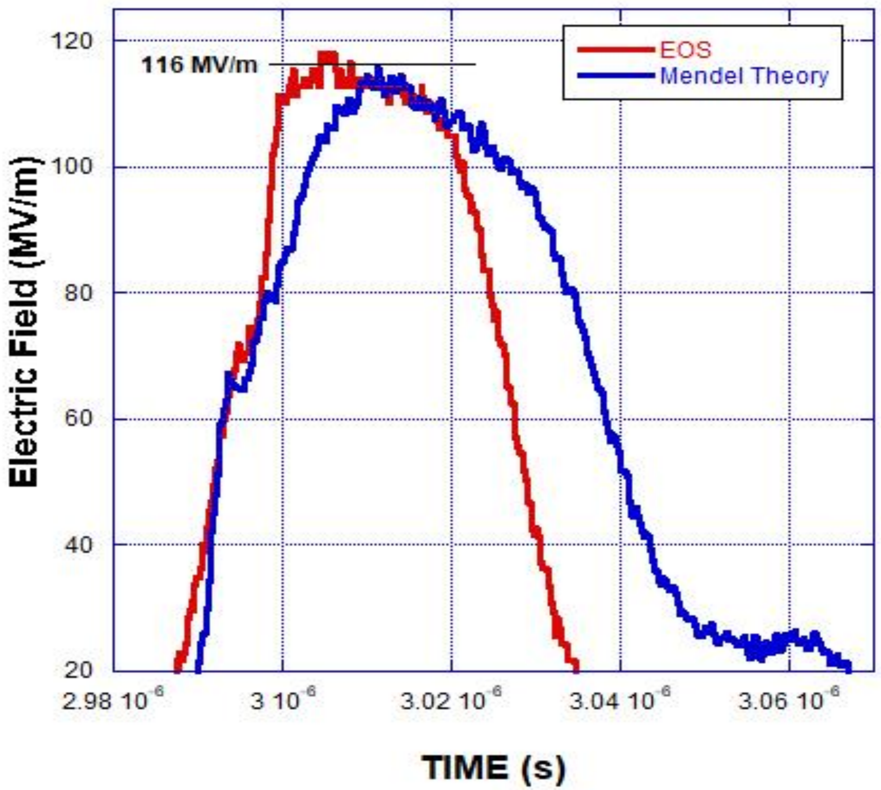


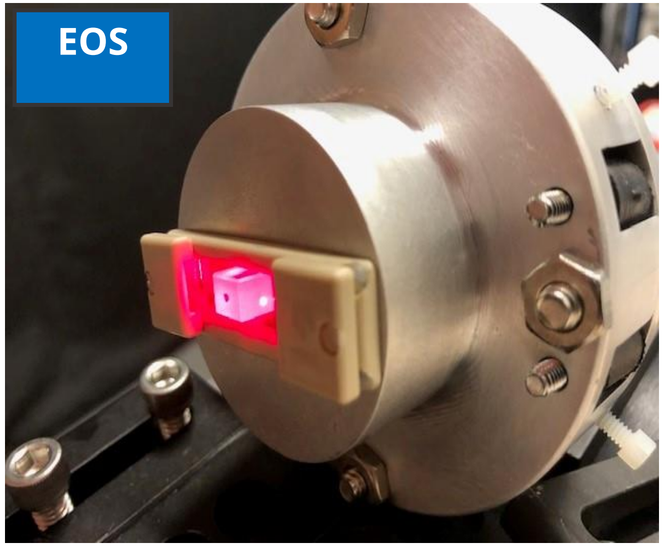
We developing multi-species insulation theories that account for time-dependence and span the regimes from non-insulated to fully insulated

*A. Darr, K. Cartwright., Phys. Plasmas **30**, 2023*

MITL Optimization and Redesign Decreased Losses and Doubled Radiation Output

New Diagnostics: Electro-Optical Measurement of Very High Electric Fields





- Electro-optical sensors (EOSs) are ideally suited to be used as a noninvasive pulse power diagnostic
- Provides a *direct absolute linear measurement of electric fields* up to 100 MV/m without the need for calibration or integration factors

"Nice idea, I doubt it will work……", Bryan Oliver, 2018

I. Owens, et al., Nature Scientific Reports, ***11****, 10702, 2021*

Demonstrated measurement of the electric field in the HERMES III MITL at full power (18 MeV)

We Develop High Performance Computing capabilities to define environments and investigate response.

"Monte-Carlo used to be embarrassingly parallel…now it's just embarrassing!", Greg Valdez, 2014

- The RAMSES (Radiation Analysis, Modeling and Simulation for Electrical Systems) tool suite attempts to cover our broad physics and engineering needs
- Radiation transport, electromagnetic (EM), plasma, and electrical component/system response
- Our pulsed power facilities allow us to induce and measure response on test articles for the purpose of validating our codes.

" Bryan, the future of plasma physics is that you'll do the same problem on a bigger computer", Rod Mason (LANL), 1994

RAMSES

Charon CHEETAH EMPHASIS EIGER EMPIRE
Gemma ITS NuGET Q SCEPTRE Xyce

Particle Radiation Transport Codes

ITS CHEETAH MC SCEPTRE NuGET

Device and Circuit Simulators

CHARON Xyce

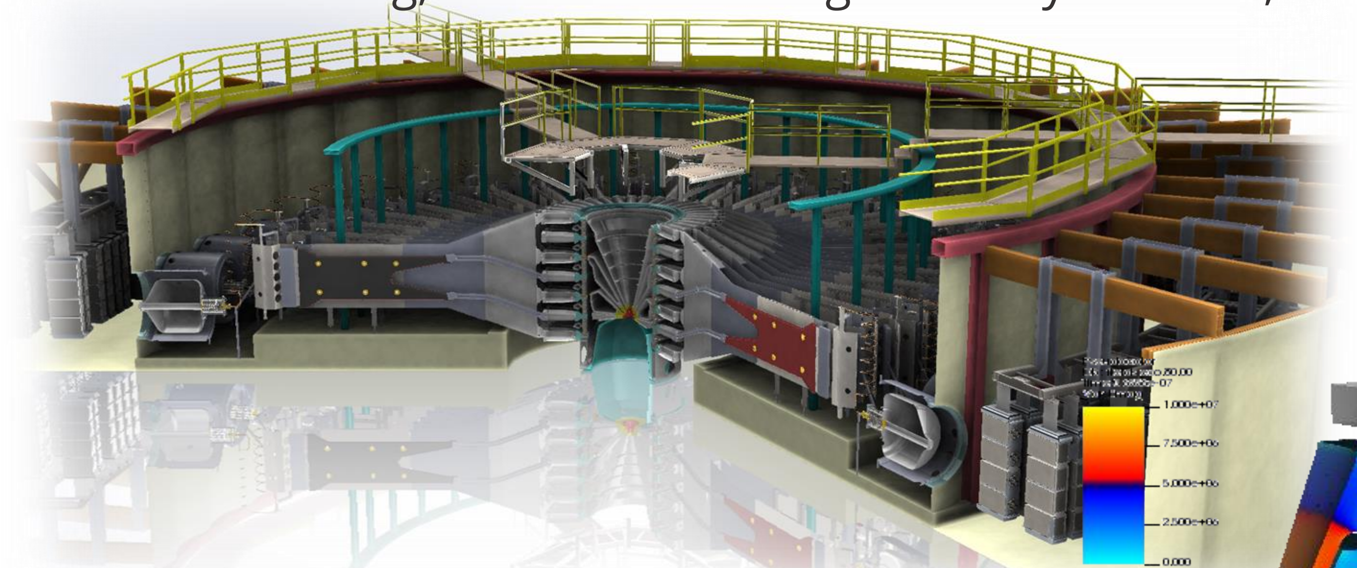
Electromagnetic/Plasma Codes

Gemma EMPIRE

There is a strong need to develop accurate and efficient workflows to couple the codes and to reduce the complexity to enable fast turn solutions

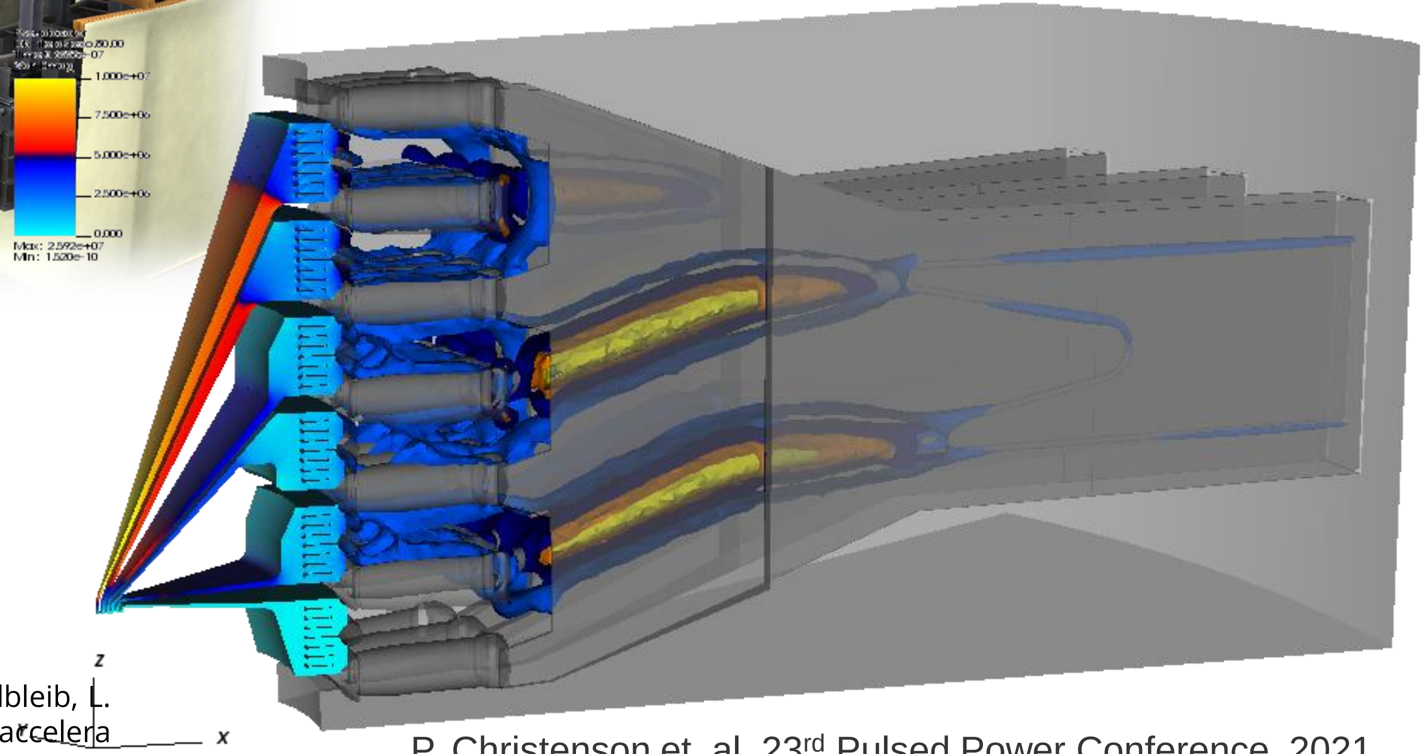
New Code Capabilities Allow for Full 3D Electromagnetic Simulations to Inform Pulsed Power Design

Simulations of 3 tri-plate water lines in Saturn can be analyzed to determine power flow characteristics such as timing, current and voltage delivery to diode, as well as effects on symmetry.



SATURN: A Modular, variable-spectrum, pulsed-power accelerator (10 MA, 1.6 MeV,40 ns power-pulse and ~25ns radiation pulse width)

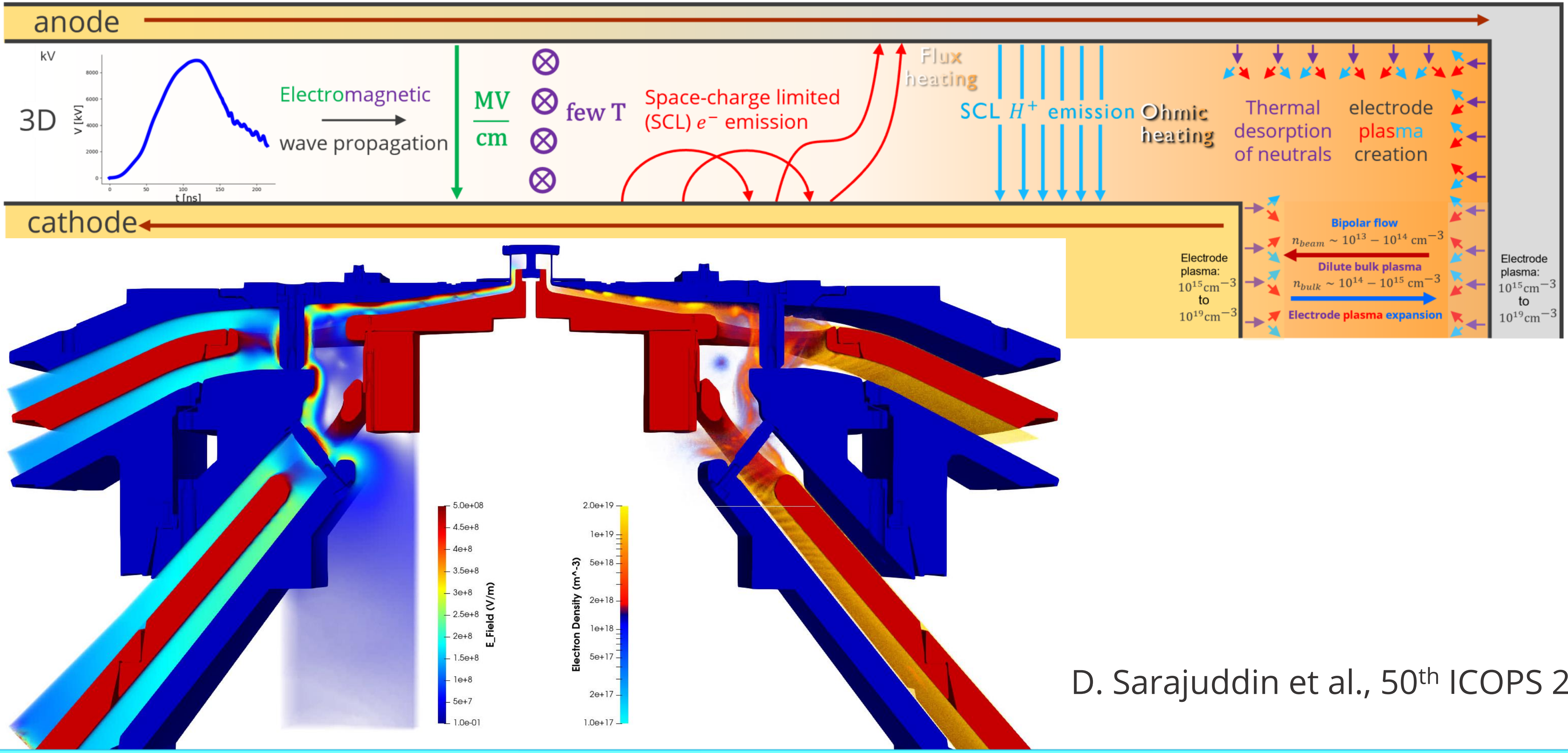
EMPIRE



D.D. Bloomquist, R. W. Stinnett, D. H. McDaniel, J. R. Lee, A. W. Sharpe, J. A. Halbleib, L. G. Schlitt, P. W. Spence, and P. Corcoran. "Saturn, a large area X-ray simulation accelerator." In Proc. 6th IEEE Pulsed Power Conference, Arlington, VA, p. 310. 1987

P. Christenson et. al. 23rd Pulsed Power Conference, 2021

High Fidelity Hybrid PIC/Fluid Simulations Inform Power Flow and Guide Diode Designs



D. Sarajuddin et al., 50th ICOPS 2023

Models couple upstream TEM wave propagation described by 1D transmission lines to downstream 3D electromagnetic particle-in-cell domain (centimeters) which include detailed processes near the load

Intense Beam Propagation in Gas, Validation Studies

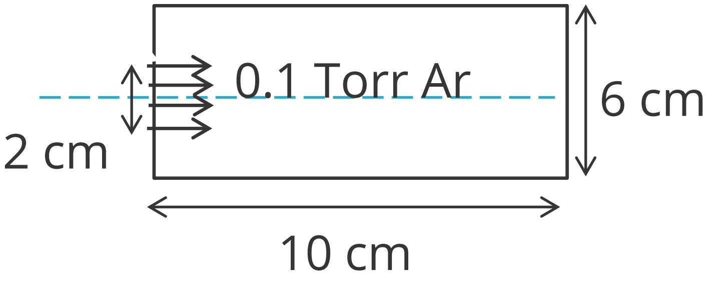
Benchmarking simulations: EMPIRE (SNL) and GAZEL (CEA)

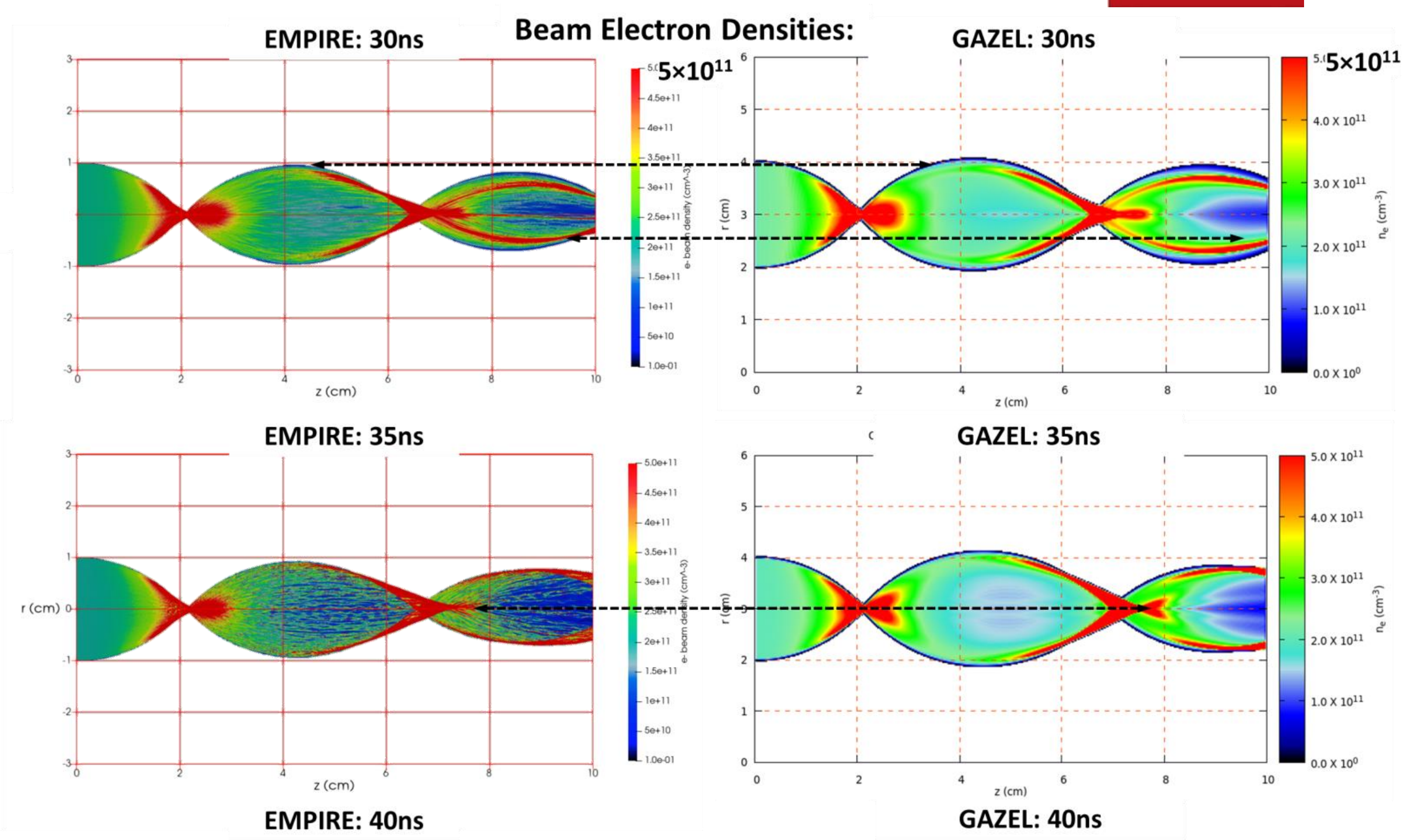
Data taken on the SPHINX pulsed e-beam generator

500keV Beam

$I_{max} = 180\text{kA}$

τ =20ns

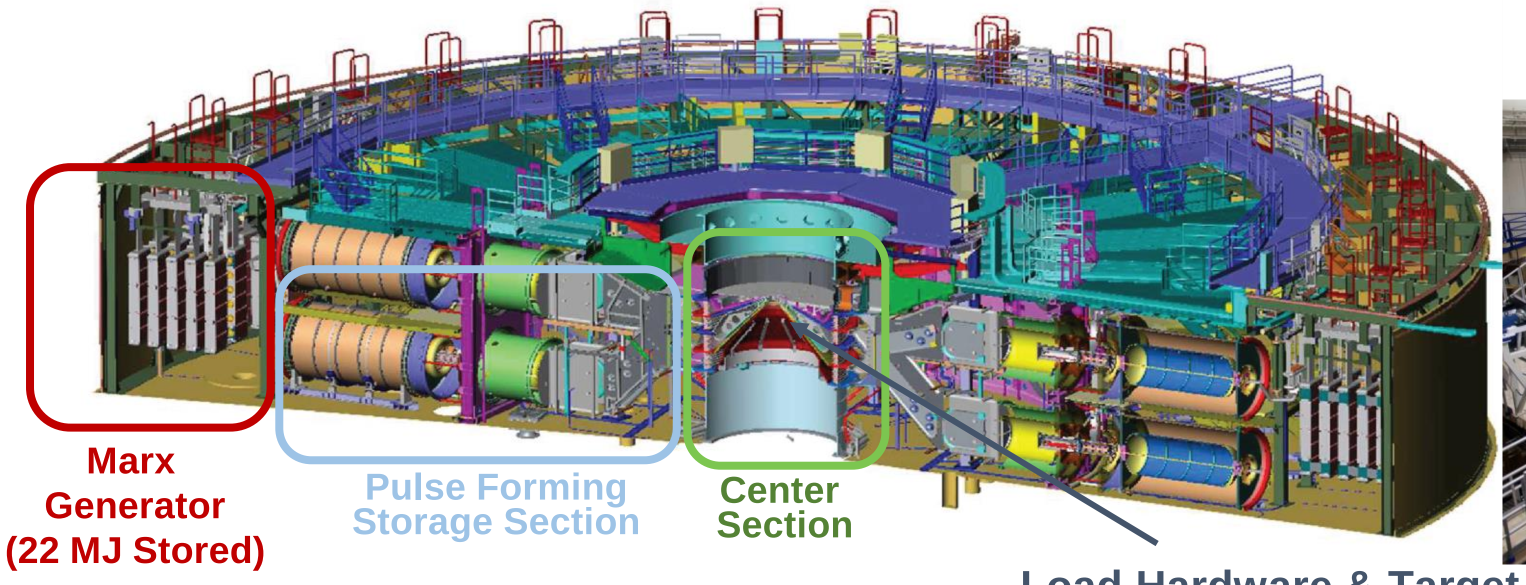


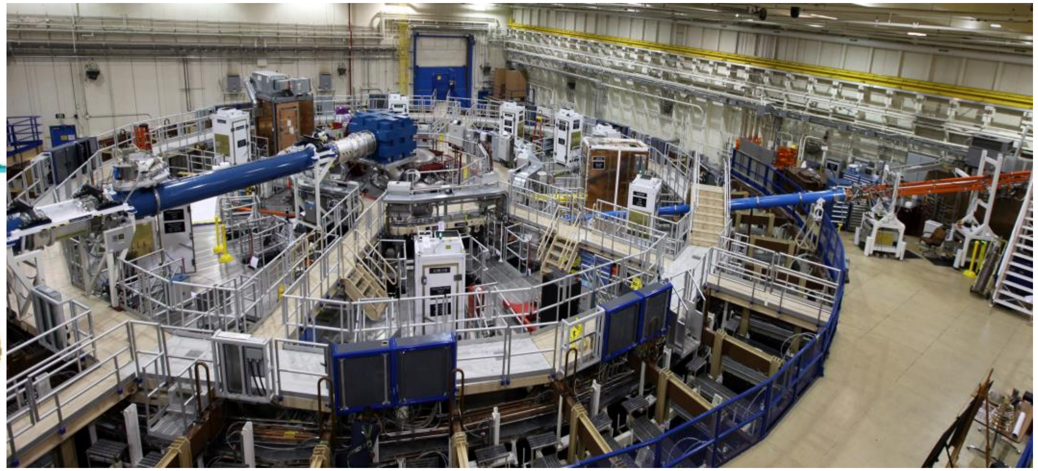


Medina et al. Verification and benchmarking relativistic electron beam transport through a background gas, Comp Phys. Comm. 288, 108721 (2023)

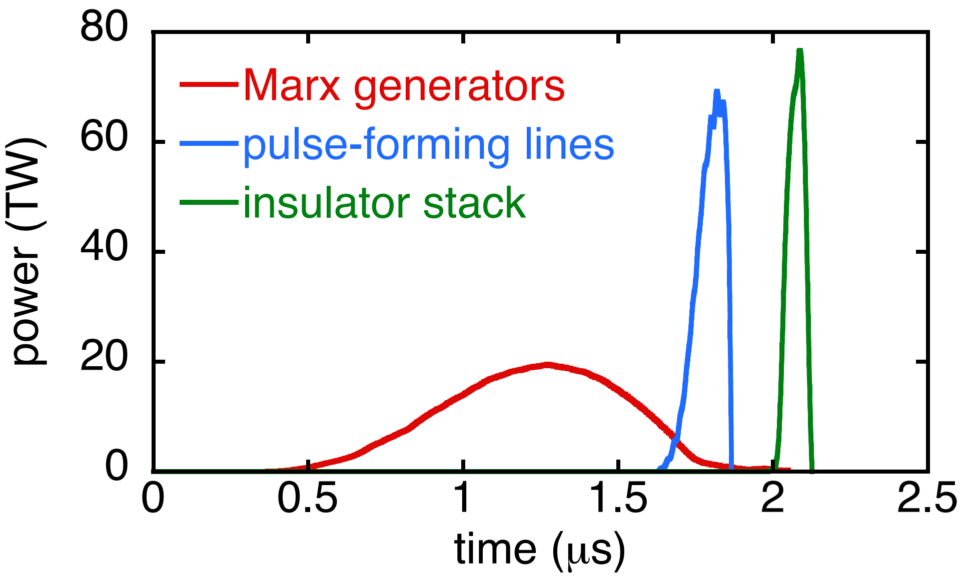
E. Rhodes et al., 24th PPC., PS30-07 (2023)

The 'Z' Facility: world's largest pulsed power machine, delivering 80 TW and 6 MJ of electrical energy to the load region





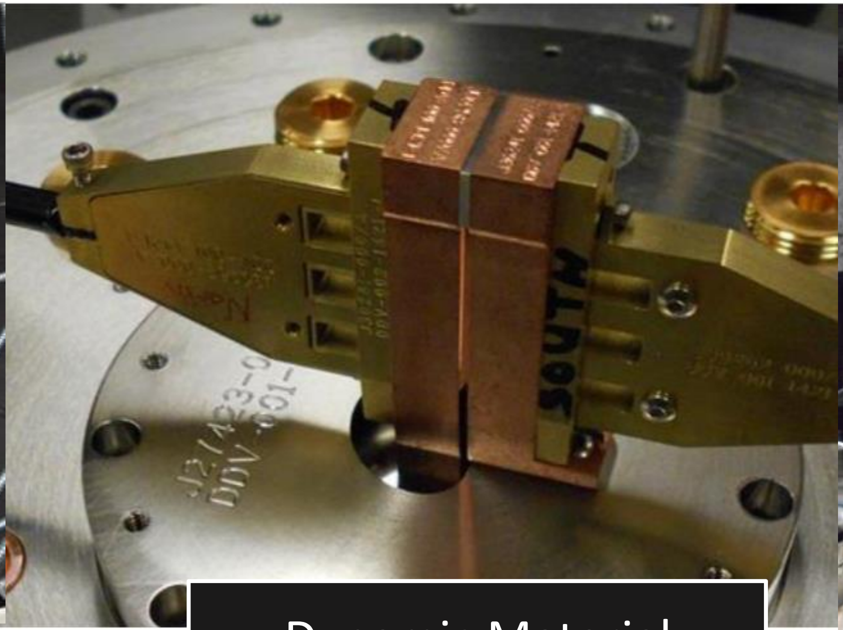
(post-shot)



Z today couples several MJ out of 22 MJ stored to the load hardware region at the machine center.

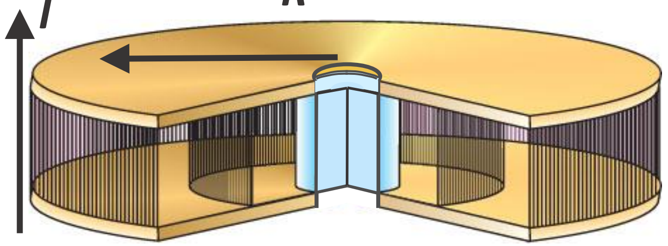
Z is a precision tool for high energy density science

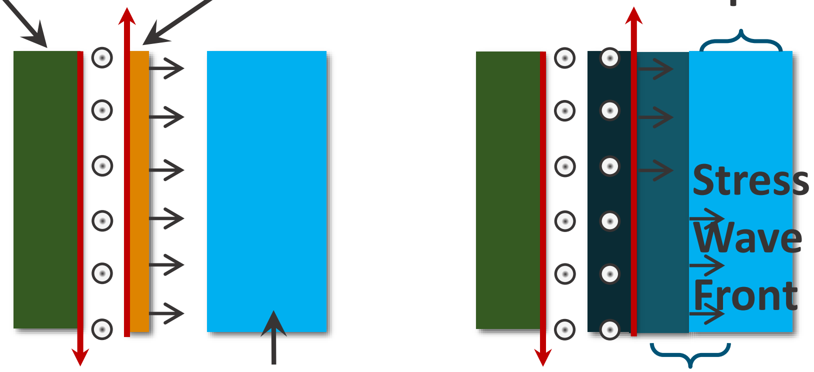
Radiation Science

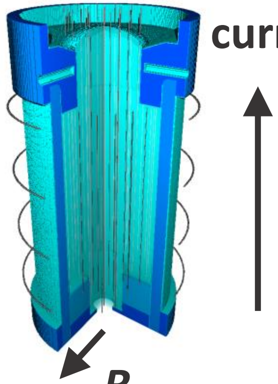


Dynamic Material Properties

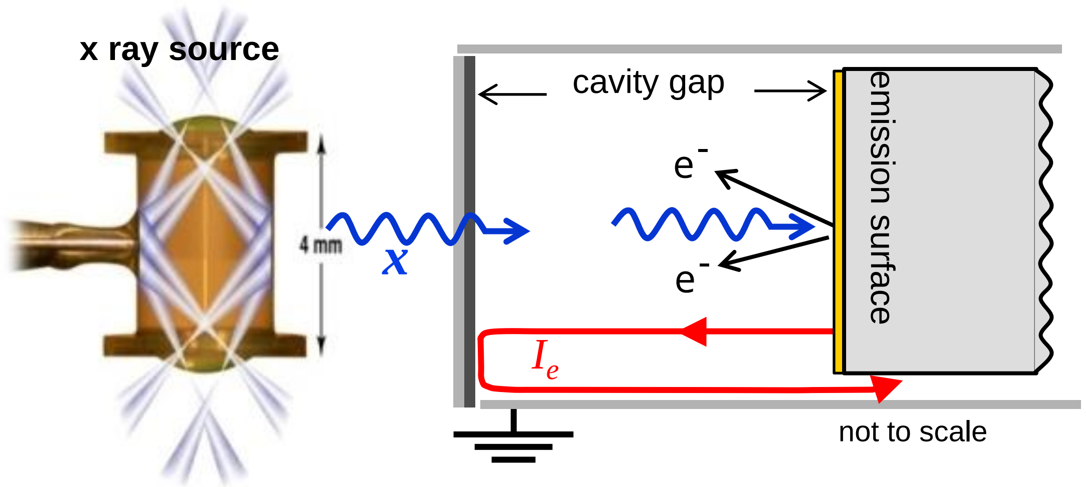
Inertial Confinement Fusion

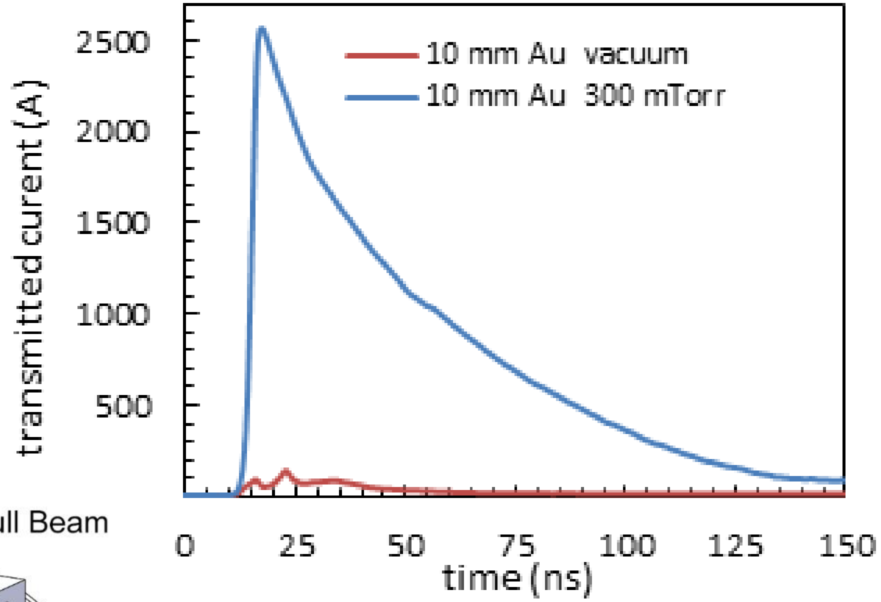


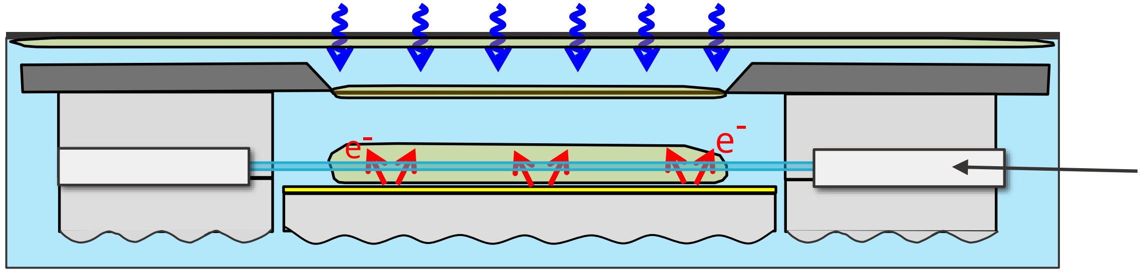




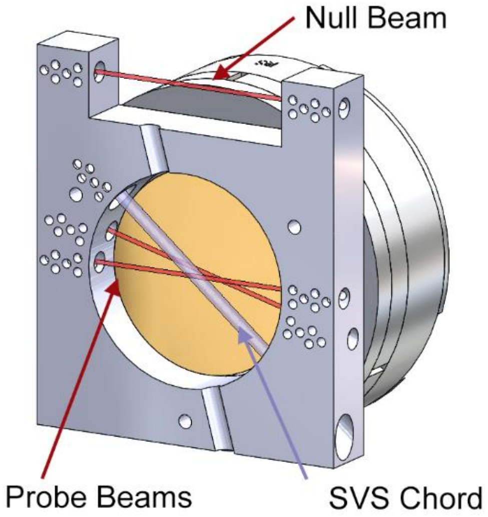
We Can Generate Sufficient X-rays to Study High Current Diodes Driven by the Photo-electric effect in Vacuum and in Gas







Interferometric density measurements, K. Cartwright, K. Bell, T. Flanagan et al, APS DPP (2019)



Peak current response:

Vacuum = 120 A

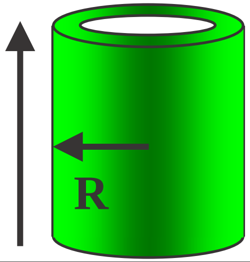
300mTorr N_2= 2.6 kA

With Pulsed-Power x-ray sources we can drive sufficient emission off Au to induce space-charge limited currents in vacuum and gas for beam physics code validation

‘Z’ can generate ~100 Mbar drive pressures to study materials under intense dynamic loads

Magnetically Driven Implosion

$$P = \frac{B^2}{8\pi} = 105\left(\frac{I_{MA}/26}{R_{mm}}\right)^2 \text{ MBar}$$



100 MBar at 26 MA and 1 mm

1 Mbar ≈ 10^6 atmospheres

Pressure equivalent to Energy Density (J/m³)

1 Mbar = 10^{11} J/m³, threshold of High Energy Density regime

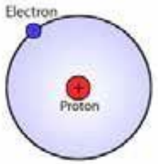
Z Storage capacitor

2e-6 Mbar

TNT

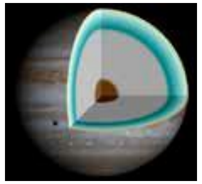
0.07 Mbar

Internal Energy of H atom



1 Mbar

Metallic H in Jupiter’s core

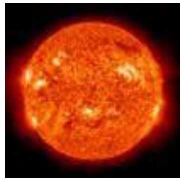


30 Mbar

Z Magnetic Drive Pressure

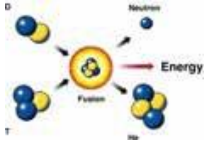
~100 Mbar

Center of Sun



250,000 Mbar

Burning ICF plasma

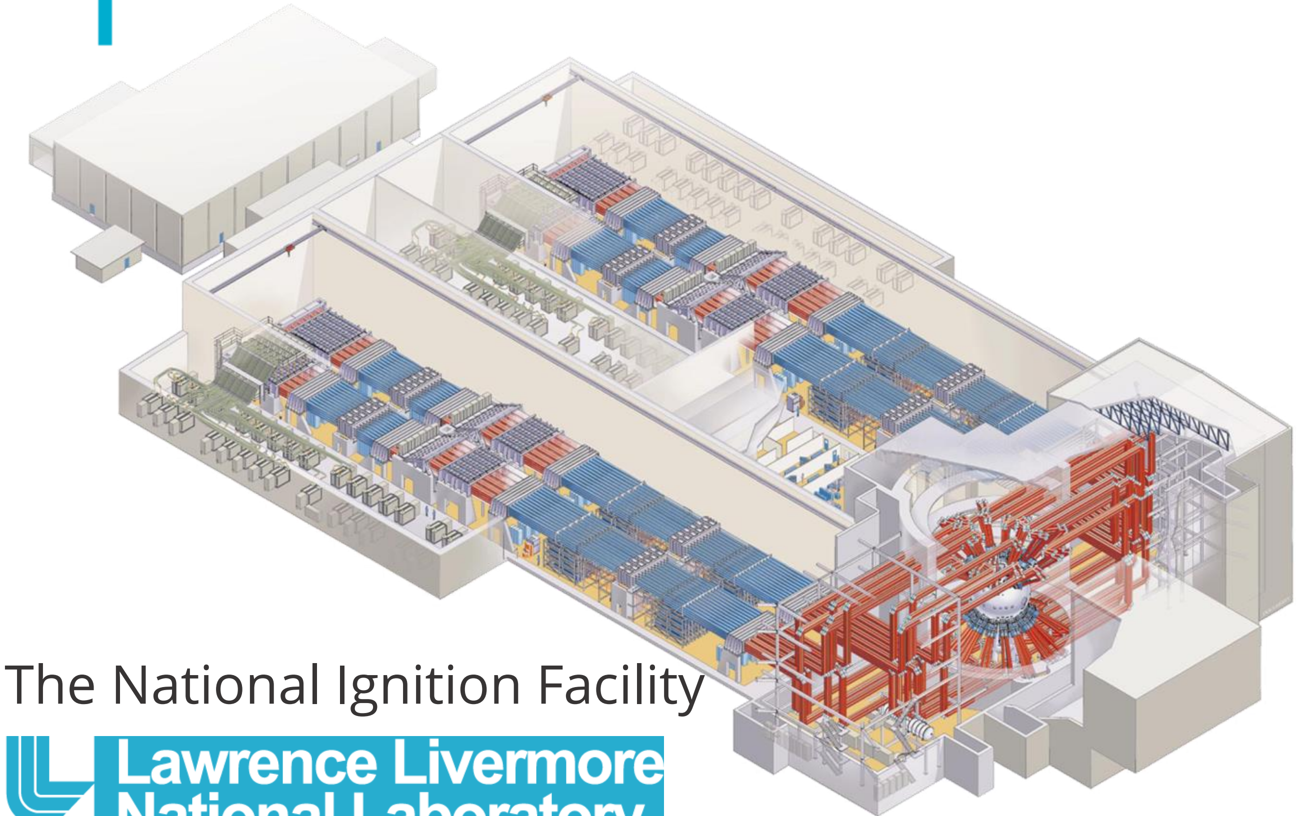


800,000 Mbar

Push on samples

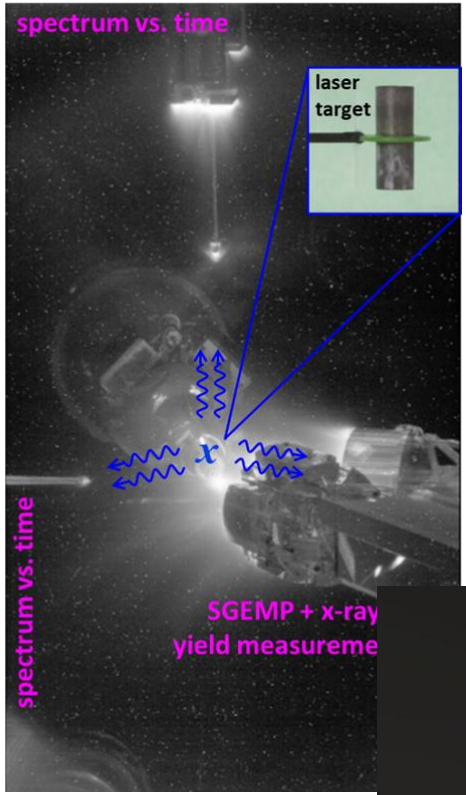
Compress fuel at high velocity

And Lest I Forget: A Very Large Pulsed Power Facility is a Laser!

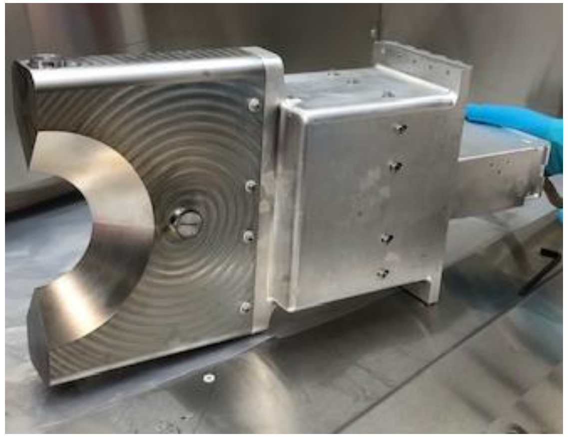


The National Ignition Facility

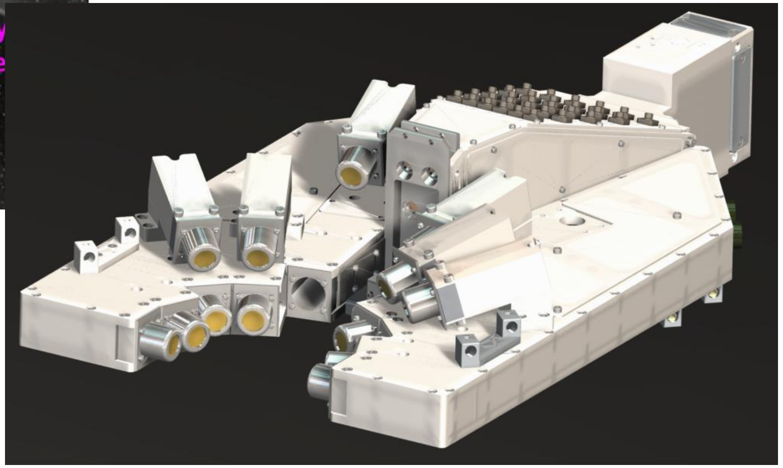
Lawrence Livermore National Laboratory



SGEMP platform



Energetic neutron platform



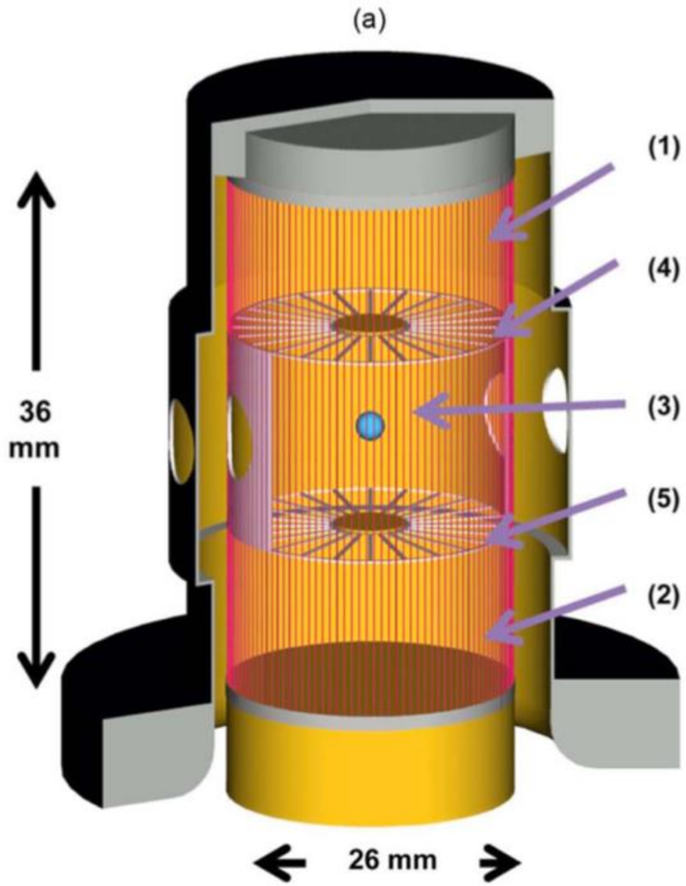
STAR materials platform

400 MJ stored electrical energy

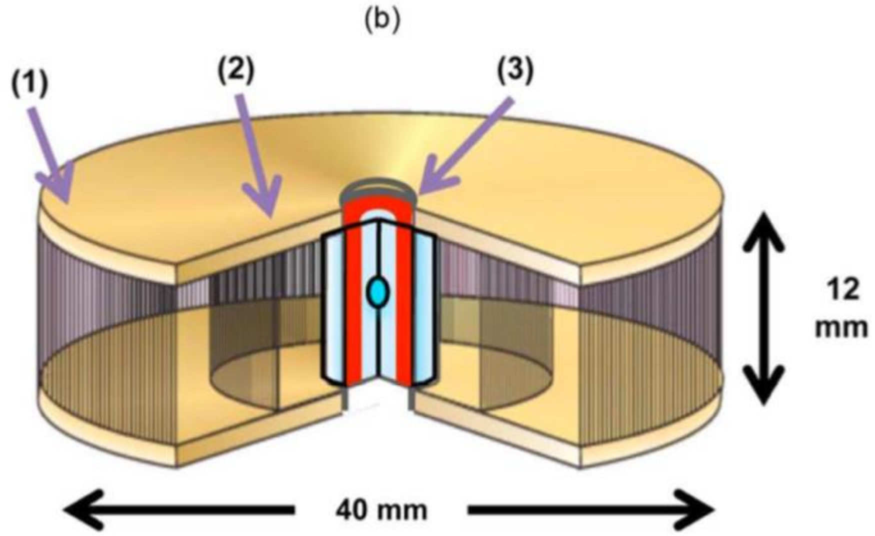
Coupled 2.15 MJ of UV laser energy to the target chamber and achieved fusion ignition in Dec. 2022.

We have developed platforms for studying materials and electronics subject to x-ray and neutron radiation drives

Magnetic drive (radiation-driven) inertial fusion remains an option for a future high-current facility to build on the success of NIF

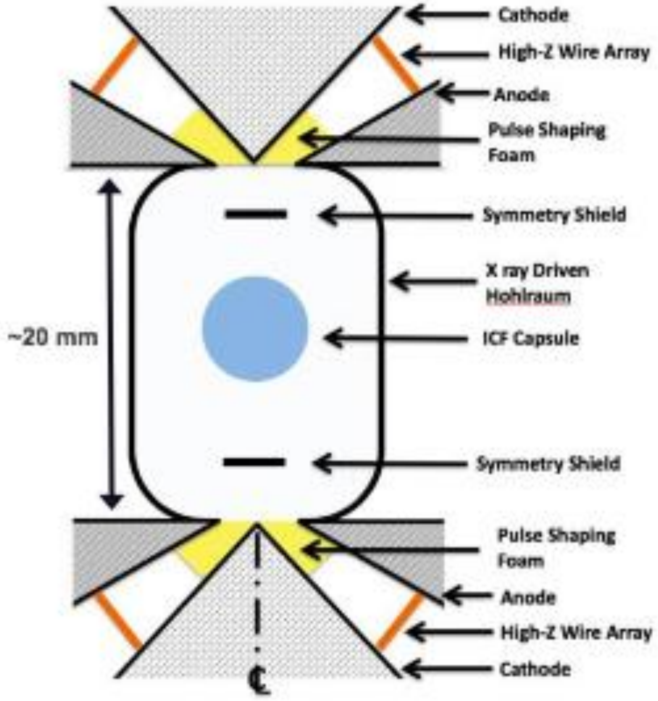


Double-ended Hohlraum



Z-pinch Dynamic Hohlraum

M.E. Cuneo *et al.*, IEEE Trans. Plasma Sci. (2012).



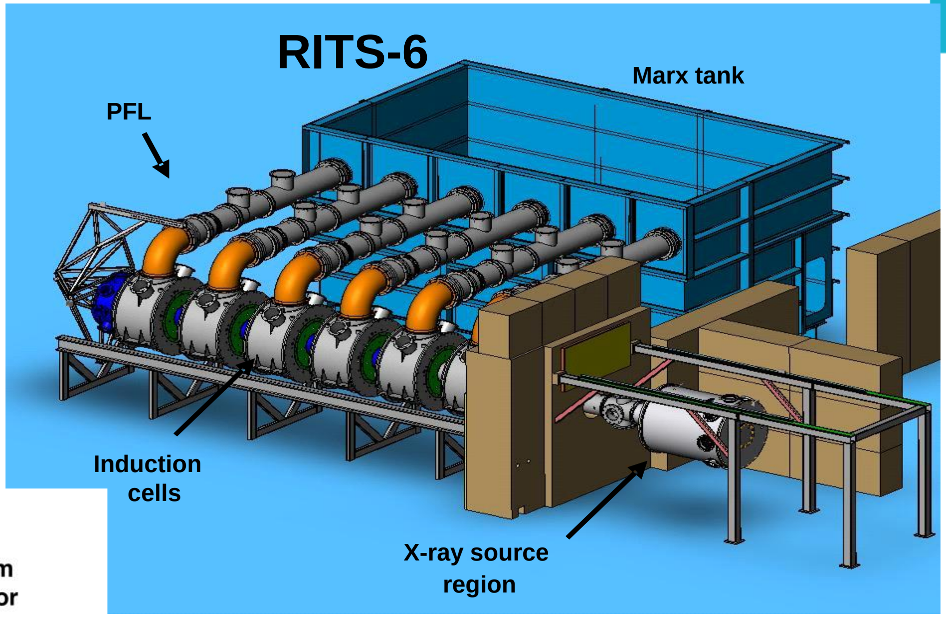
R.E. Olson *et al.*,
High Energy Density Physics (2020).

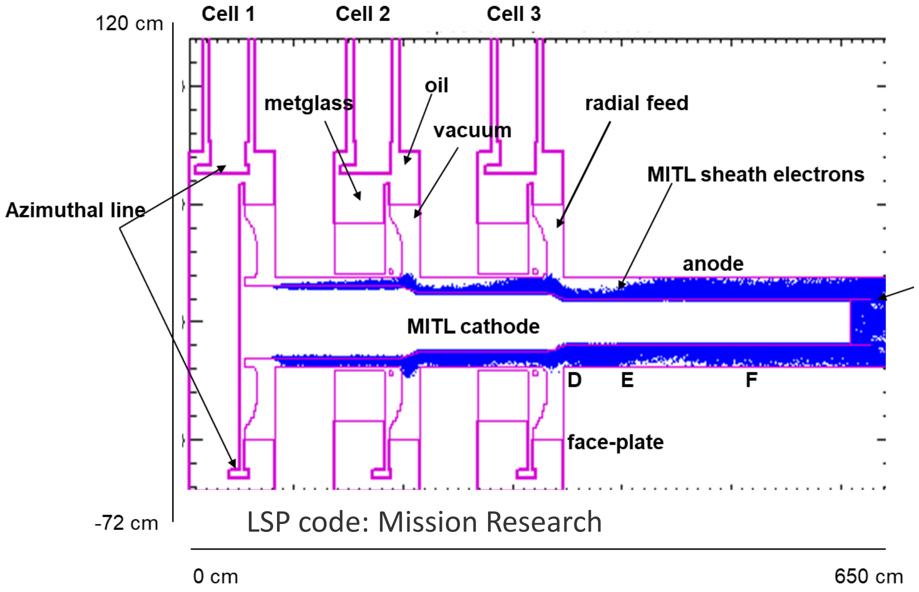
Induction Voltage Adders for Pulsed X-ray Radiography

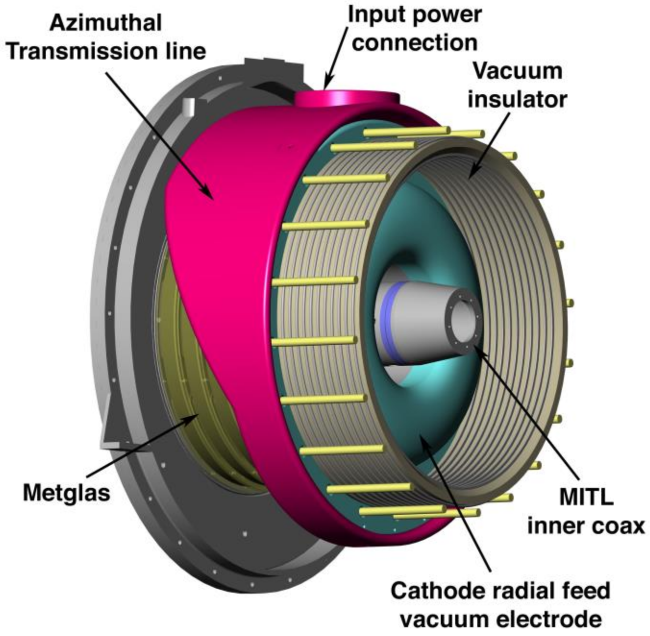
E-beam driven flash x-ray radiography drivers

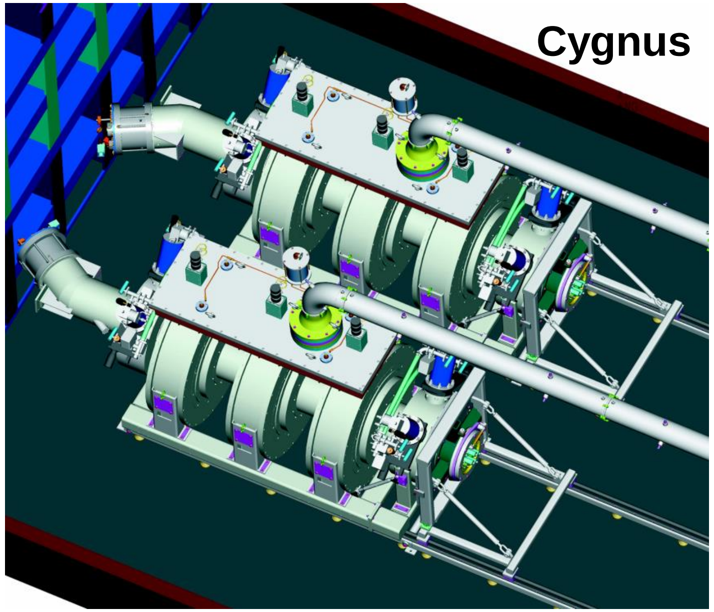
RITS: Flexible accelerator architecture with exchangeable MITLs producing: 4.5-11 MV, 125-190 kA, 70 ns pulse.

CYGNUS: dual axis, pulsed radiography for subcritical expts. First single-point feed IVAs.









*J.E. Maenchen et al., Proc. IEEE **92**, 7, 2004*
B.V. Oliver et al, Proc. 14th PPC, 2003
B.V. Oliver et al, Proc. 17th Pulsed Power conf. (2009)
J. Smith et al., 24th Pulsed Power Conf., 03A-1

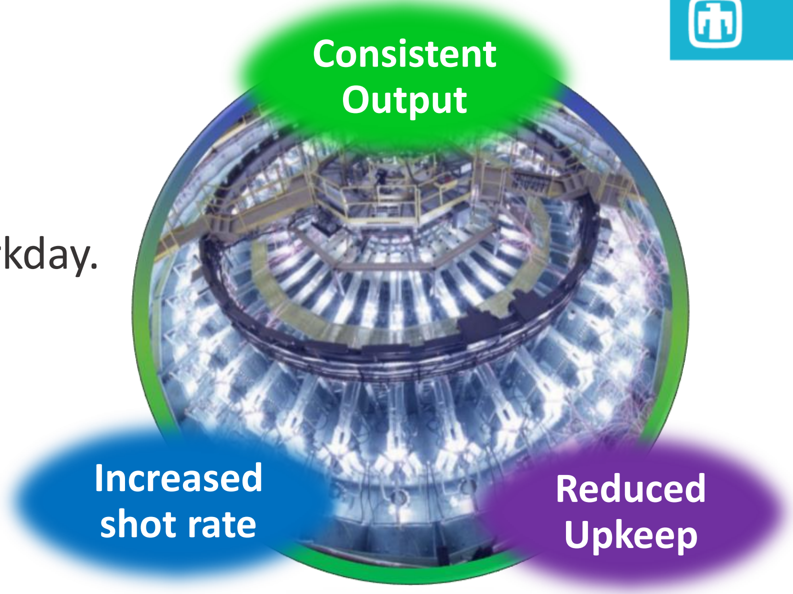
Mission Research Corporation | TITAN SYSTEMS CORP PULSE SCIENCES DIVISION | Sandia National Laboratories | Voss Scientific | Los Alamos NATIONAL LABORATORY | National Security Technologies LLC Vision • Service • Partnership

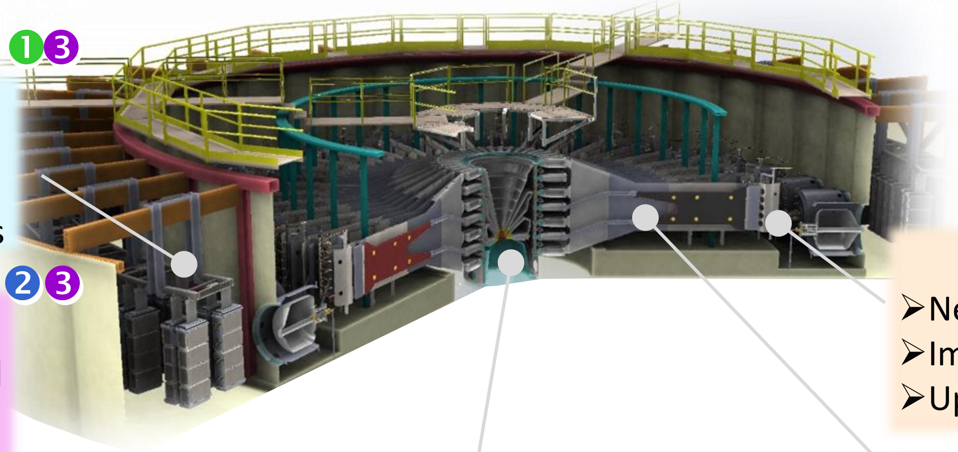
New Initiatives

Saturn Recapitalization Project: ~$50M NNSA Investment

SATURN RECAP

1. Provide Consistent Radiation Output
   Radiation output to ~ 10% shot-to-shot variation
2. Increase Facility Shot Rate
   Enable consistent execution of one shot per 10-hour workday.
3. Reduce Time Needed for Facility Upkeep
   Enable routine evaluation of machine performance.





1 3

Energy Storage Section:
- Upgrade MTGs
- Laser Trigger MTGs
- Z-Based Operational & Safety Features

2 3

Technical Utility Systems:
- Improve Water/Oil Fill & Drain Control
- Stainless Steel DI Water Piping
- SF6-Based Components Gas Isolation
- 24 VDC Water/Oil Actuators, Controls

2 3

Facility:
- 8-Ton Crane
- MITL Fixtures Improvements
- Dry Compressed Air
- Paint High Bay
- Access Control System Enhancements

1 2 3

Stack/Vacuum Power Flow Section:
- Improve MITL Alignment & Concentricity
- Design Hard-Set Diode
- Reduce Inductance
- Incorporate Stack Debubbling System
- Stainless Steel MITLs
- Stack & MITL Current/Voltage Monitors

1 2 3

Pulse Forming Section:
- New Triggered Gas Switch
- Improve Gas Switch Trigger System
- Update Diagnostic Monitors

1 2 3

Transmission Section:
- Addition of Water Diverters
- Stainless Steel Components
- Improve Connecting Rod Design

1 3

Data Acquisition System:
- Repair/Upgrade Data Ports in Floor
- Fiber Optics Communications Capability
- Stack & MITL Monitors Infrastructure

B.V. Oliver et al, 23rd Intl. Pulsed Power Conf. 2021, *M. Savage, PPC 2023, 02C-5*

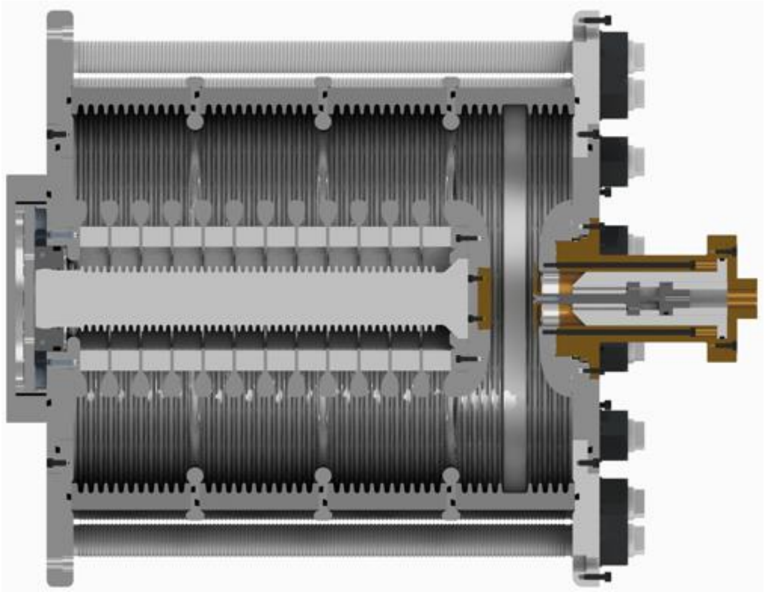
A New output Gas Switch is Designed, Tested and Fielded at Saturn

Designed by M. Savage

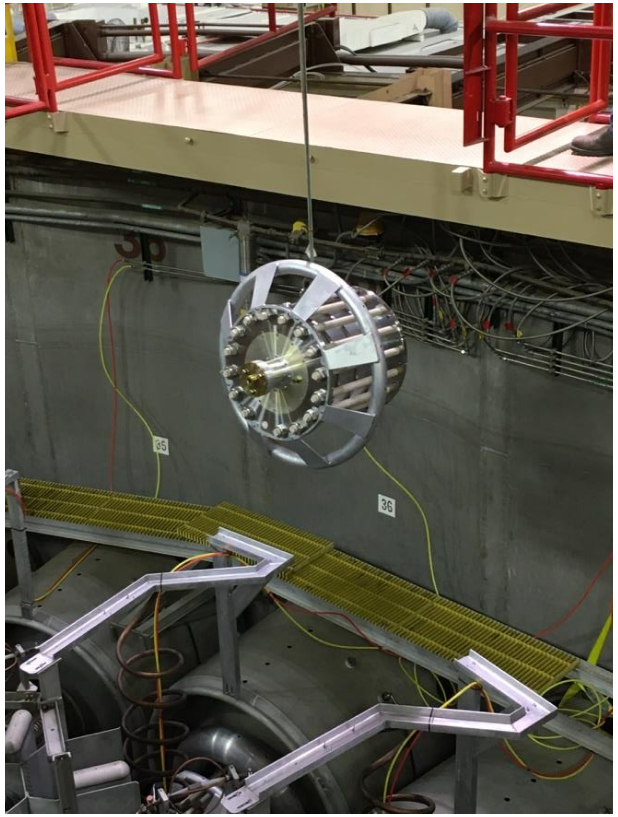
Tolerate >2.6 MV before closure

Electrically triggered with a ~80 kV forward wave in high voltage cable

New Saturn Switch



New optical diagnostic
for timing fiducial



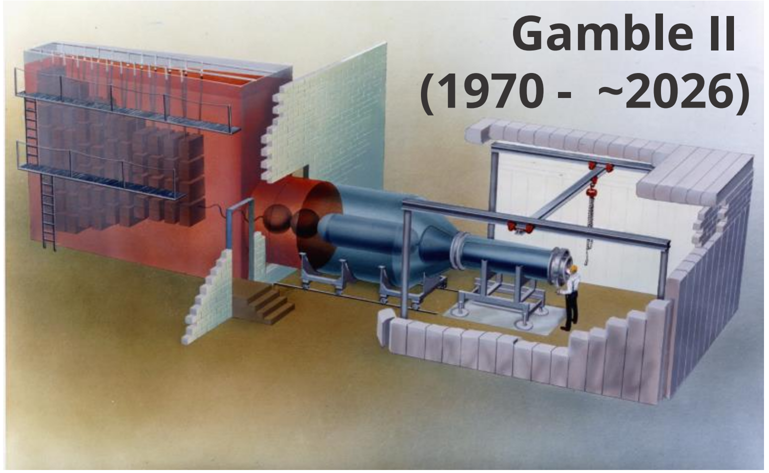
- Improve jitter to ~ 4ns
- Reduced pre-fire rate
- Maintenance lifetime of ~200 shots
- Retain electrical triggering for simplicity, with option to laser-trigger if needed

C. Grabowski et. al. "Characterization of a New 3-MV Gas Switch for Saturn", Pulsed Power Conf. 2021

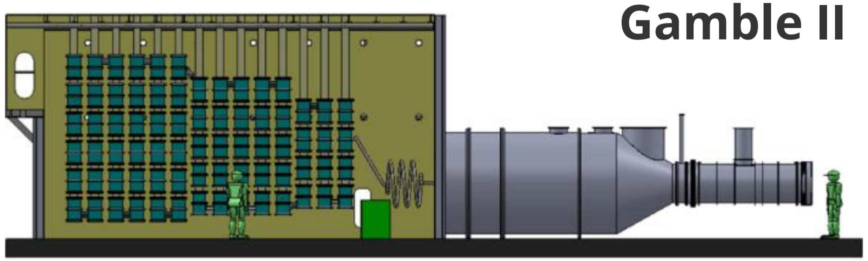
B. Ulmen et. al. "Optical measurement of the new Saturn gas switch as a timing fiducial", Pulsed Power Conf. 2021

Naval Research Labs’ Gamble III Accelerator

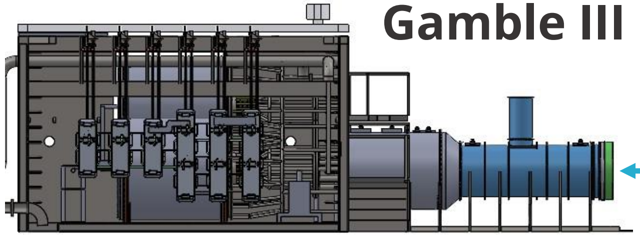
- Sandia Z machine Marx technology and output line enhancements significantly reduce the footprint and increases reliability.
- Increased current will allow Gamble III to produce higher fluence, enabling testing of larger, 3D test objects
- Design provides more efficient operations and maintenance to further reduce downtime and shot-to-shot turnaround times



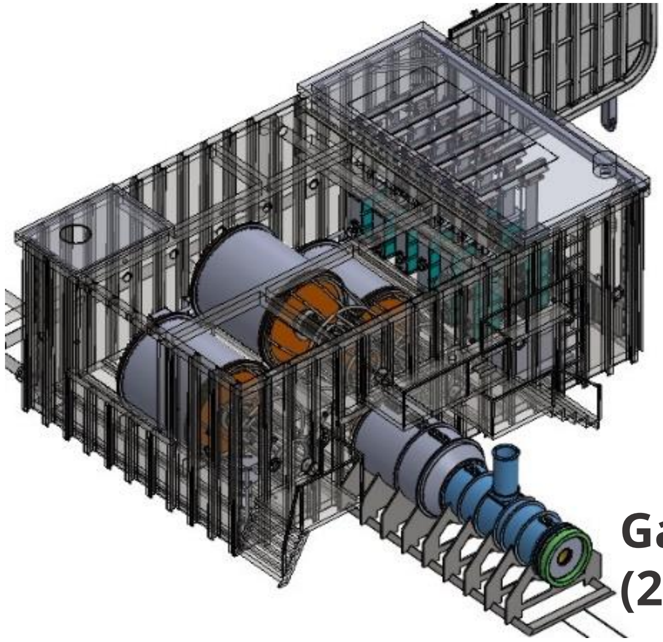
Gamble II



Gamble III



Reduced footprint



Gamble III
(2026 - ~2056)

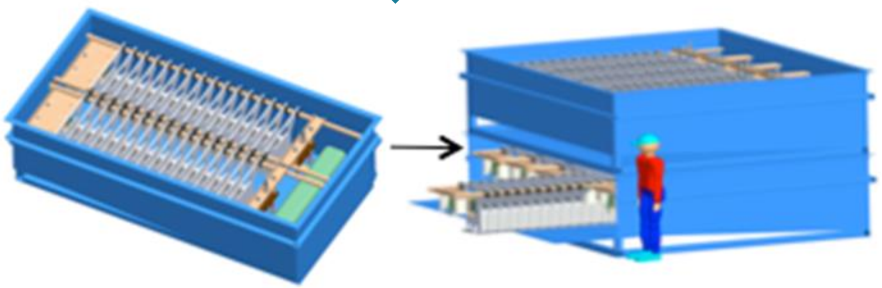
Increased capability, test area, uniformity, and reliability.

Exciting New Capability Using Fast Marx Technology: Quad-EAGLE

Transfer Fast Marx technology from successful Short Pulse Gamma simulator

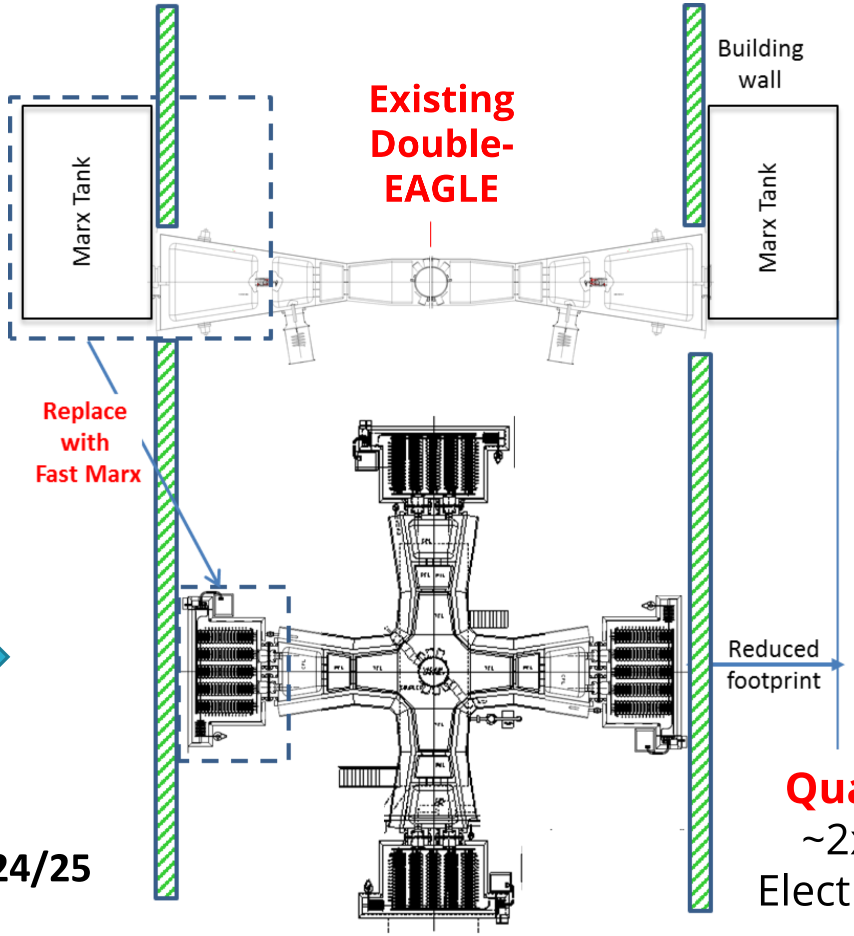
Fast Marx Test Bed

Full-scale Fast Marx



Standard Marx banks' inductance slows the discharge time and requires a second stage of energy transfer via an intermediate storage capacitor and triggered output switch.

Because of its low inductance and fast rise-time, the Fast Marx allows for the elimination of the first stage of the pulse forming lines



Quad EAGLE
~2x Output Electrical Power

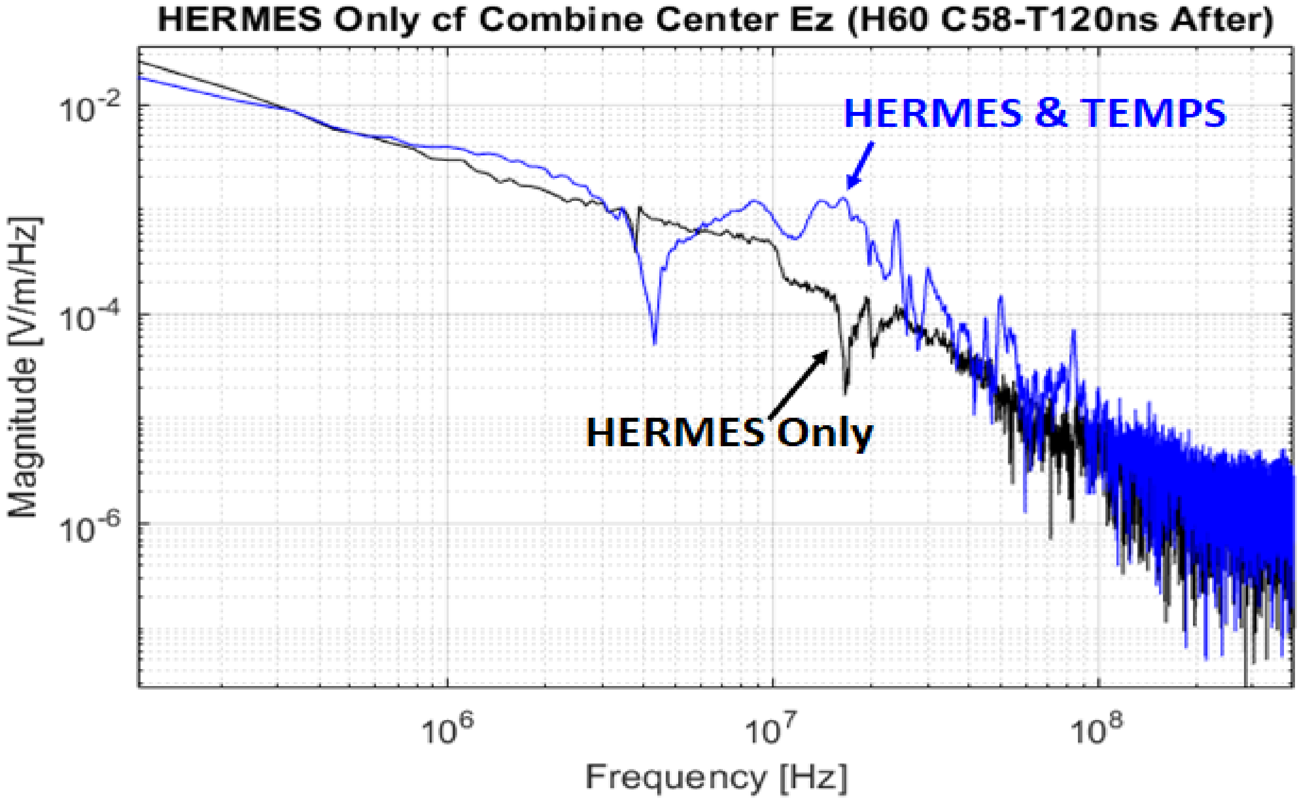
L3HARRIS™

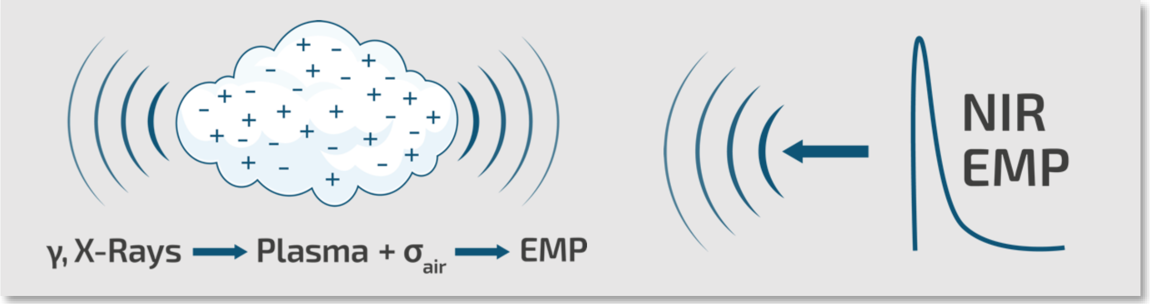
- **Quad Eagle (QE) will replace Double-EAGLE (DE): Planned for 2024/25**
- **It will eliminate the use of SF6**

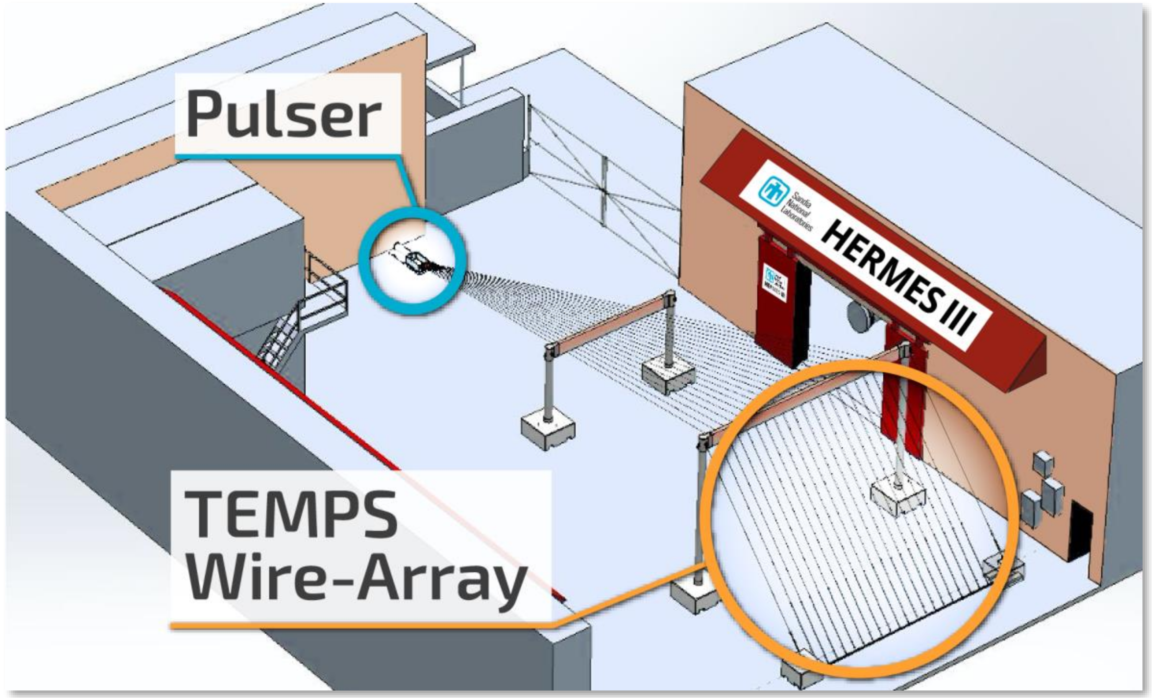
A new Sandia platform for gamma ray & EMP environments by integrating capabilities

Challenge:

- Capability to explore electrical system effects using a combined-simultaneous ionizing and non-ionizing environment



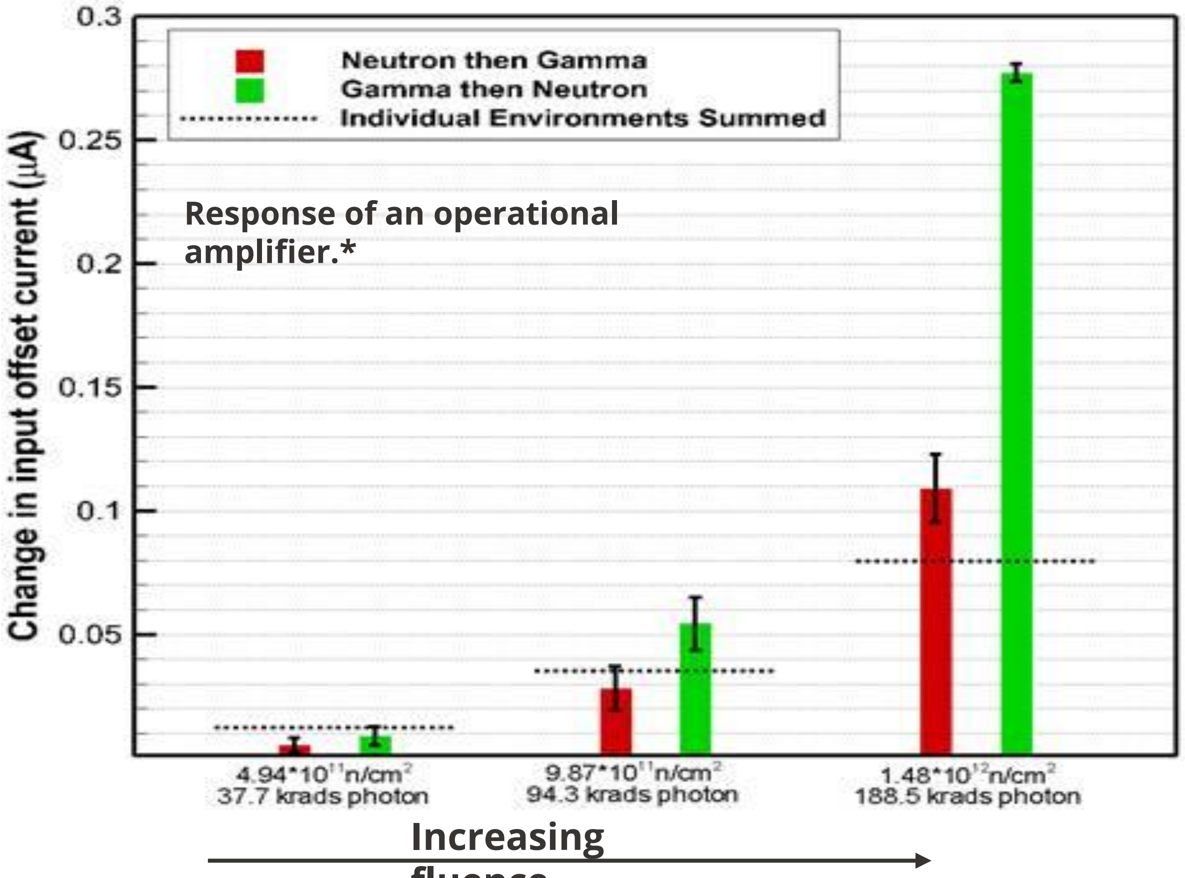




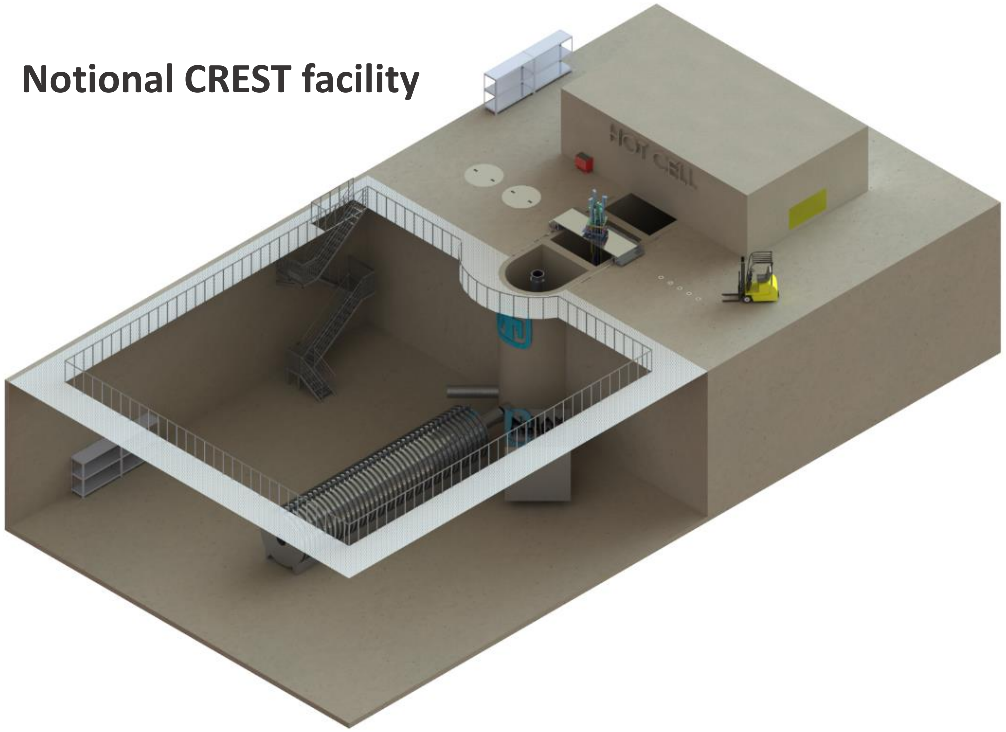
Looking to the Future: The CREST Facility

CREST is *Combined Radiation Environments for Survivability Testing*

- A new facility for the pulsed neutron Annular Core Research Reactor (ACRR) facility to ensure continued reactor-based research and testing at Sandia
- Add a gamma-ray accelerator to allow study of synergistic effects in combined radiation



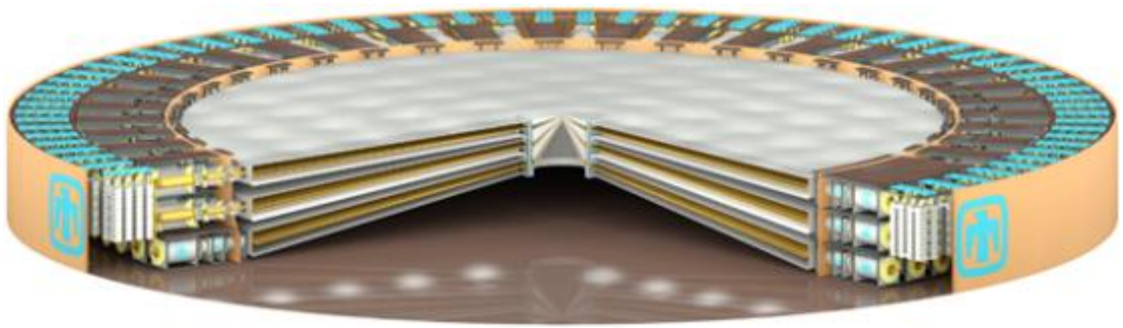
Notional CREST facility



Through Critical Decision-0 and Analysis of Alternatives. Preparing for Conceptual Design

*Data taken in collaboration with U.T. Austin Nuclear Engineering Teaching Laboratory

Looking to the Future: A Next Generation Pulsed Power (NGPP) Machine



NGPP will:

Be the world's most powerful warm x-ray source

Support fusion yields up to ~100 MJ

Provide advanced capability for high energy density physics (e.g., dynamic materials)

Advance the state-of-the-art for fast pulsed power technology

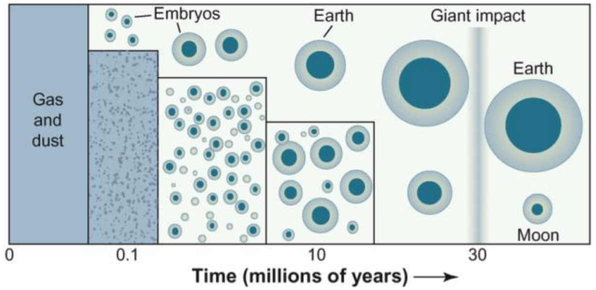
Provide a venue for scientific and technical innovation for national security

Parameter	Example NGPP Option	Z
Diameter	300'	108'
Marxes	75 @ 2400 kJ (180 MJ)	36 @ 600 kJ (22 MJ)
Capacitors	13,500 @ 2.95 µF	2,160 @ 2.65 µF
Power at Stack	600 TW	85 TW
Forward Energy at Stack	54 MJ (short pulse)	6 MJ (short pulse)

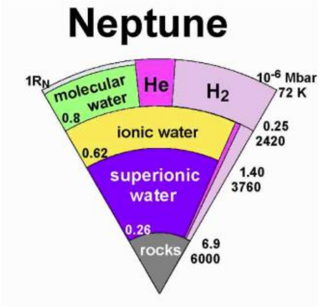
The National Nuclear Security Administration is working with Sandia to define the requirements

Sandia is looking for additional lab, academic, & industry partnerships going forward

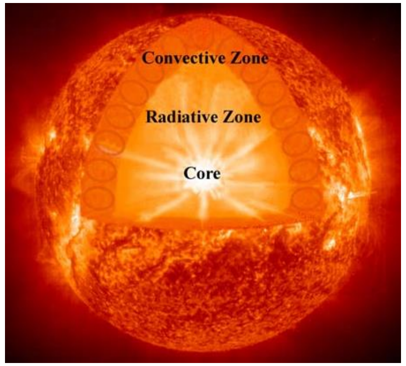
Z Fundamental Science Program



Earth and super earths
Properties of minerals and metals



Jovian Planets
Water and hydrogen



Stellar physics
Fe opacity and H spectra

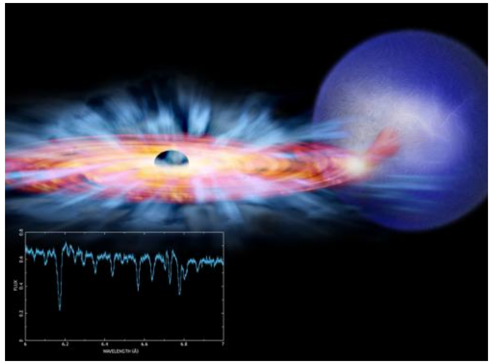


Photo-ionized plasmas
Range of ionization param. ξ

NNSA Laboratory Residency Graduate Fellowship

Students can complete residency projects with us

Laboratory Research and Development Funding

Radiation, Electrical, and High Energy Density Science Research Foundation ($9.5M annually)

Assured Survivability and Agility with Pulsed Power (ASAP) Mission Campaign ($40M FY20-26)

New Maxwell Fellowship opportunity (2 awarded in 2022, 1 in 2023)

Other Avenues for Student Engagement: The Science of Extreme Environments Research and Innovation (SEERI) Internship Program

- Foster the search for future researchers, engineers, and operators in radiation effects, pulsed power, and high energy density sciences
- Students (at all levels) are offered hands-on, flexible, challenging, interesting, and cutting-edge research opportunities
- Technical work supplemented with seminars and facility tours which expose students to the broad range of engineering and scientific disciplines

Contact: Patricia St. John, plstjoh@sandia.gov

Some Musings

My Only Words of Advice

When the Theory doesn't match the Experiments…….Check the Vacuum!

Controlling the vacuum on SuperSwarf, AWE (2004)

Nothing good can come from a theorist having oversight of pulsed power facilities in the 1-100 TW range.

I'm sure J.C. Martin would concur

The Berkeley Liberal In Me

"Bryan V. Oliver was born in San Francisco, CA on Sept. 6th, 1965. Immediately thereafter he was taken across the Bay and raised in Berkeley, where he became environmentally Green and politically Left"

Biography,

PhD Dissertation, Nov. '94

We need your innovations for SF_6 free pulsed power switching

SF_6 is excellent for high voltage switches, but is a potent greenhouse gas (GHG)

Every pound of SF_6 is equivalent to ~24,000 lb CO_2

SF_6 advantages for switches:

- High breakdown strength
- Chemical stability
- Compatible with materials
- Low jitter
- Compatible with laser triggering
- Well known, existing infrastructure

SF_6 emissions from the Z, HERMES & Saturn facilities result in ~30% of total GHG emissions for the Sandia New Mexico site!

Executive Order 14057 requires a 65% reduction in federal facilities' greenhouse gas emissions by 2030, net zero by 2050

Next generation pulsed power needs Marx, laser triggered and self break switches with:

- High reliability and low maintenance

  Potential for ~ 100,000 switches at 100keV, dependent on architecture

- High voltage (~ 5-10 MeV)
- Low jitter (< 5 ns)

The challenge! Provide it all without using SF_6

And….

Thank you PPS&T Committee for the recognition! It is an honor to be listed amongst the previous winners for which I have great respect and admiration.

I encourage all of us to continue to recognize the accomplishments of our peers. And, to pursue the advocacy for and the recognition of individuals that represent the diverse population of the PPS&T community.

We are stronger when we:

Appreciate all members of our community
Minimize bias and maximize acceptance
Are equitable in our reward and recognition

Thank You!

Past Haas Award Winners

1987 Magne “Kris” Kristiansen
1989 Arthur H. Guenther
1991 Gerold Yonas
1993 Alan C. Kolb
1995 Bernard H. Bernstein
1997 William L. Baker
1999 Gerald Cooperstein
2001 Dillon H. McDaniel
2003 Hidenori Akiyama
2005 Robert Reinovsky
2007 Karl H. Schoenbach
2009 John E. Maenchen
2011 Roger White
2013 Scott J. MacGregor
2015 Edl Schamiloglu
2017 Ron Gilgenbach
2019 Thomas Mehlhorn
2021 Andreas Neuber