Lasers, Z-Pinches, and Nuclear Weapons: The Importance of Plasma Physics to the National Nuclear Security Administration

Dr. Sarah L. Nelson

Office of Experimental Sciences (on detail to NA-19)

November 18, 2020

Michigan Institute for Plasma Science and Engineering (MIPSE)

About the Speaker

A BIG thank you to:

- **HQ** – Njema Frazier, Bryan Sims, Paul Davis
- **LLNL** – Alan Wan, John Edwards, Heather Whitley
- **LANL** – Kim Scott, Brian Albright, Sean Finnegan
- **SNL** – Dan Sinars, Greg Rochau, Mike Cuneo, Matt Gomez
- **LLE** – probably someone I missed…

- **UM and MSU**, Prof. Kushner, Julia Falkovitch-Khain, for the gracious invitation and for the multiple reminders…

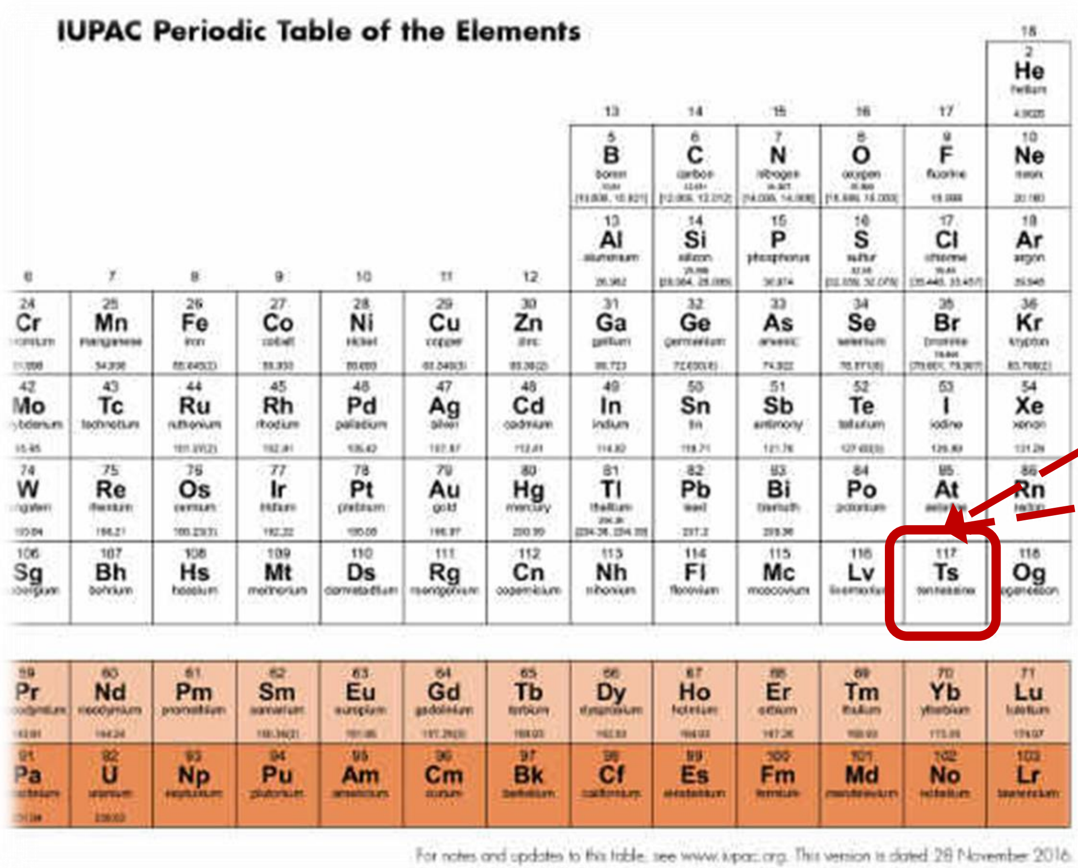
About the Speaker

- **Bachelor of Science** in Chemistry from University of California, Santa Barbara (w/Distinction)
- **PhD** in Nuclear Chemistry from University of California, Berkeley
- **Roger Batzel Postdoctoral Fellow** at Lawrence Livermore National Laboratory
- **Staff Scientist** with Pacific Northwest National Laboratory
- Joined NNSA in 2015
  - **Deputy Director** of NA-113, Office of Experimental Sciences
  - On detail to NA-19, Ofc. Of Production Modernization

This talk is unclassified. DC - SLN

Research Background, Nuclear

PRL 104, 142502 (2010) PHYSICAL REVIEW LETTERS week ending 9 APRIL 2010



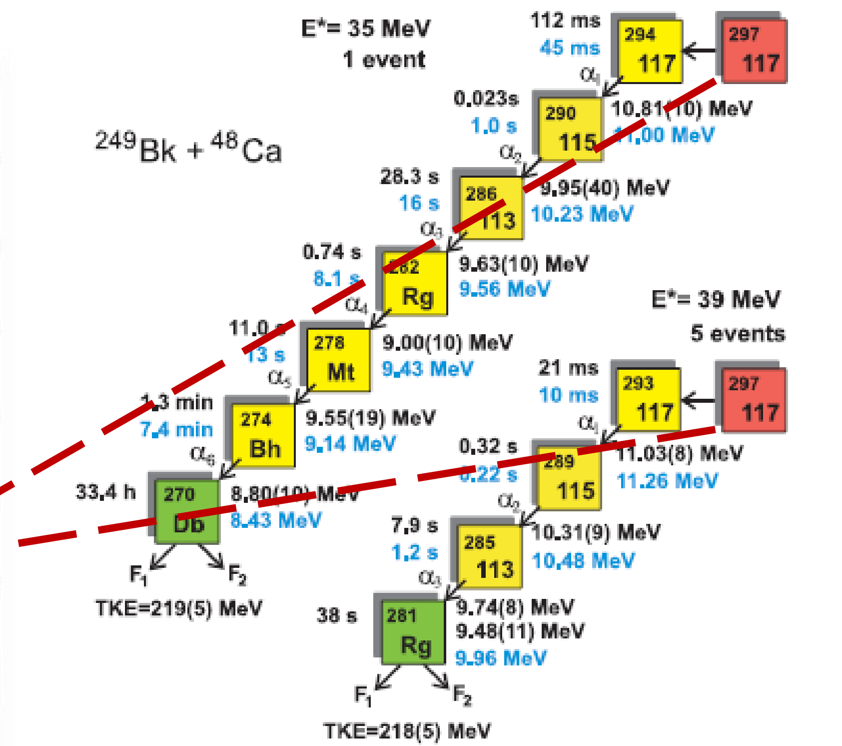
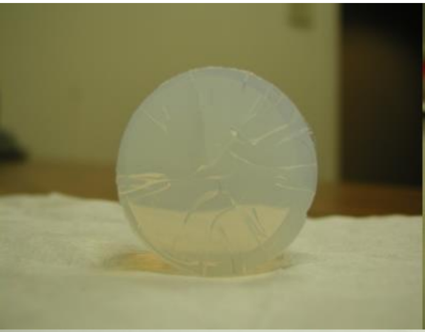
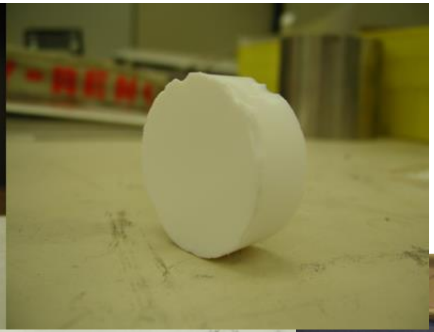
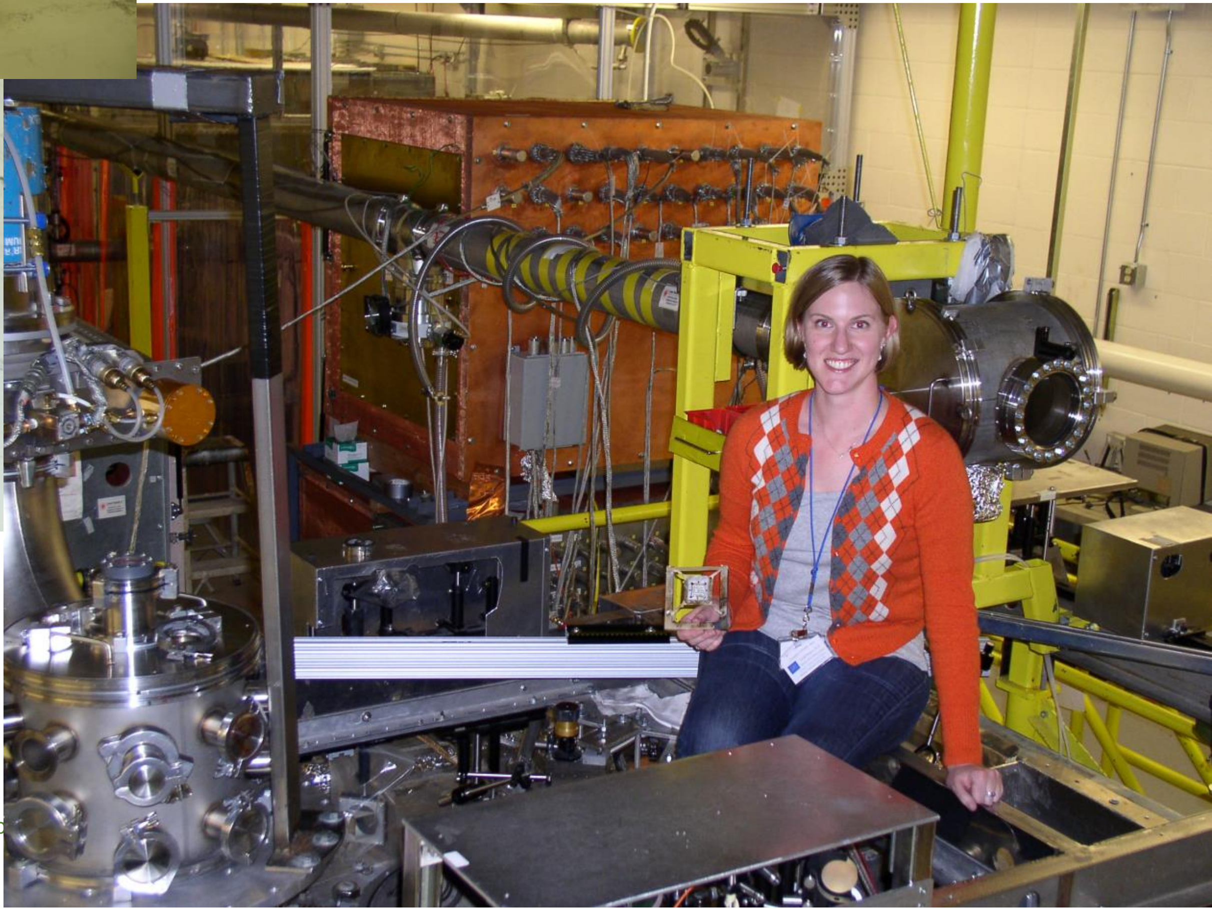


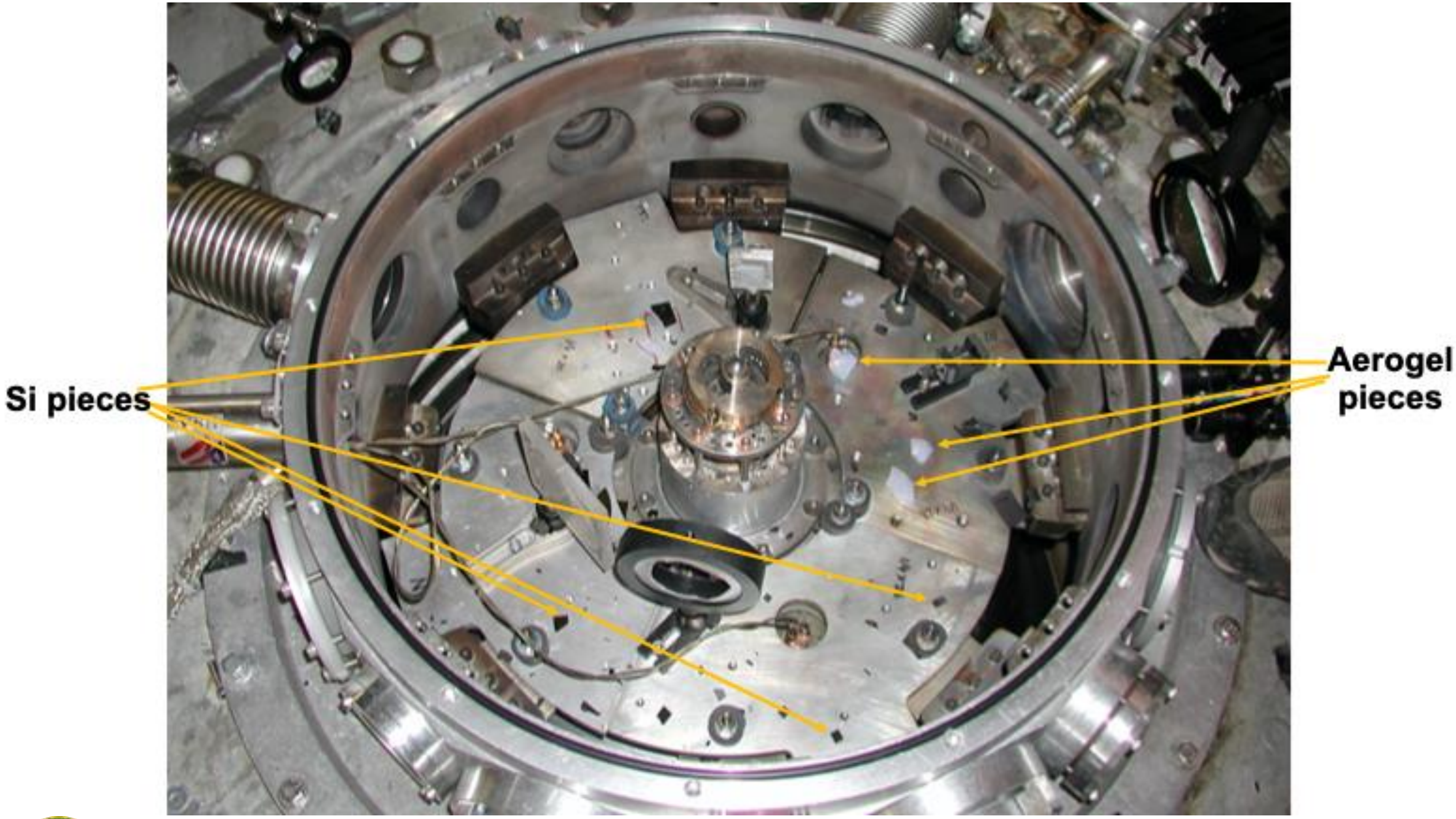
FIG. 1 (color). Observed decay chains interpreted as originating from the isotopes $A = 294$ (single event) and $A = 293$ (average of five events) of the new element $Z = 117$. The deduced and predicted [9] lifetimes ($\tau = T_{1/2}/\ln 2$) and α-particle energies are shown in black and blue, respectively.

Research Background, Nuclear + Pulsed Power - Collection of Debris



Research Background, Nuclear + Pulsed Power, con't.
- Collection of Debris



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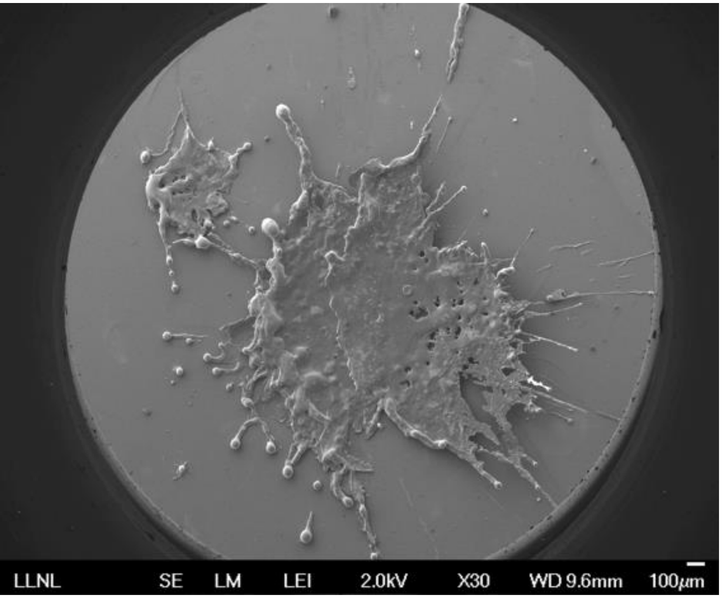
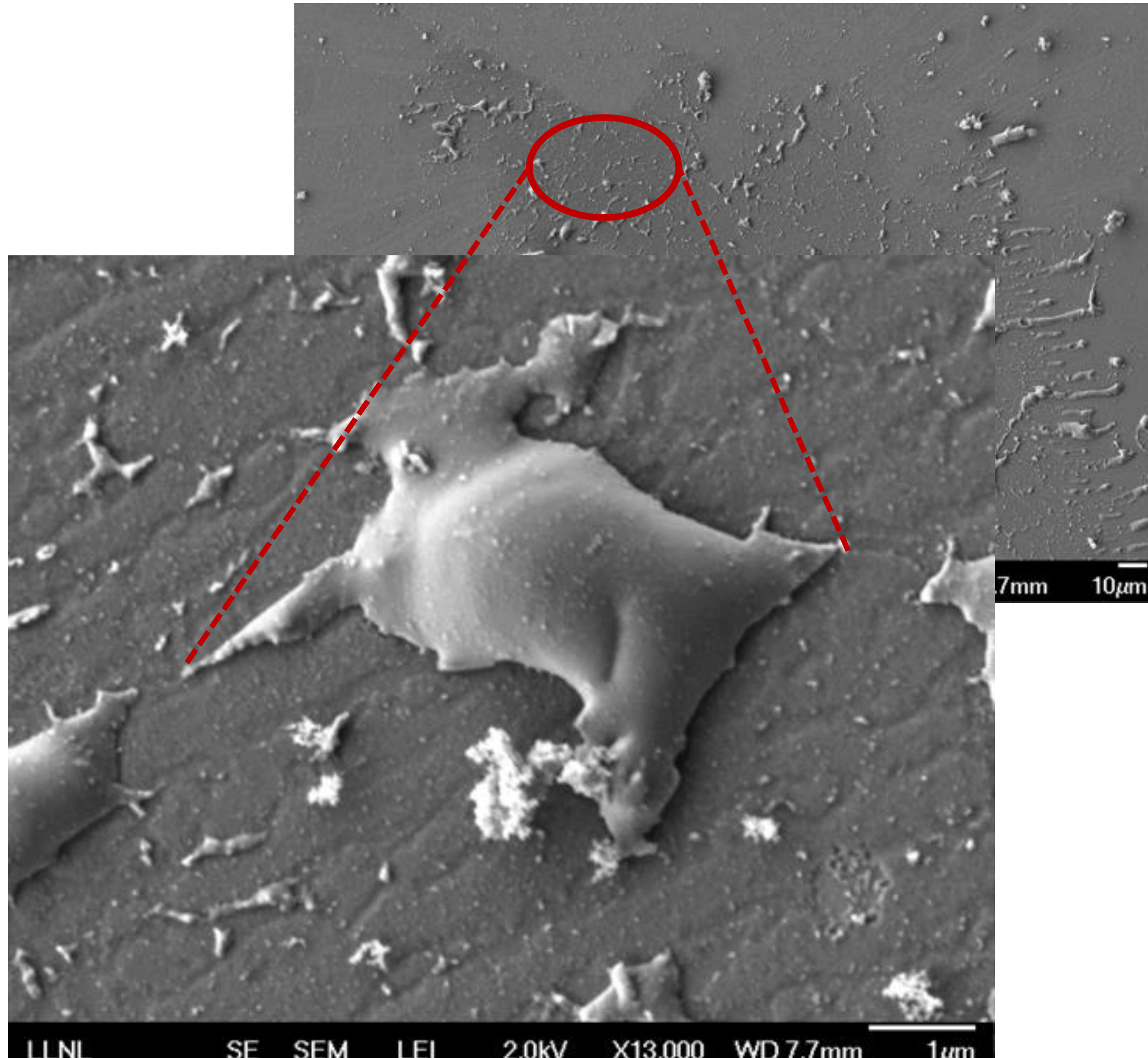




OK great, but what does this have to do with Stockpile Stewardship?

or – why I'm really "here" today…

National Nuclear Security Administration
DEFENSEPROGRAMS

OFFICE OF EXPERIMENTAL SCIENCES
OES
Science for an Enduring Stockpile

Birth of Science-Based Stockpile Stewardship

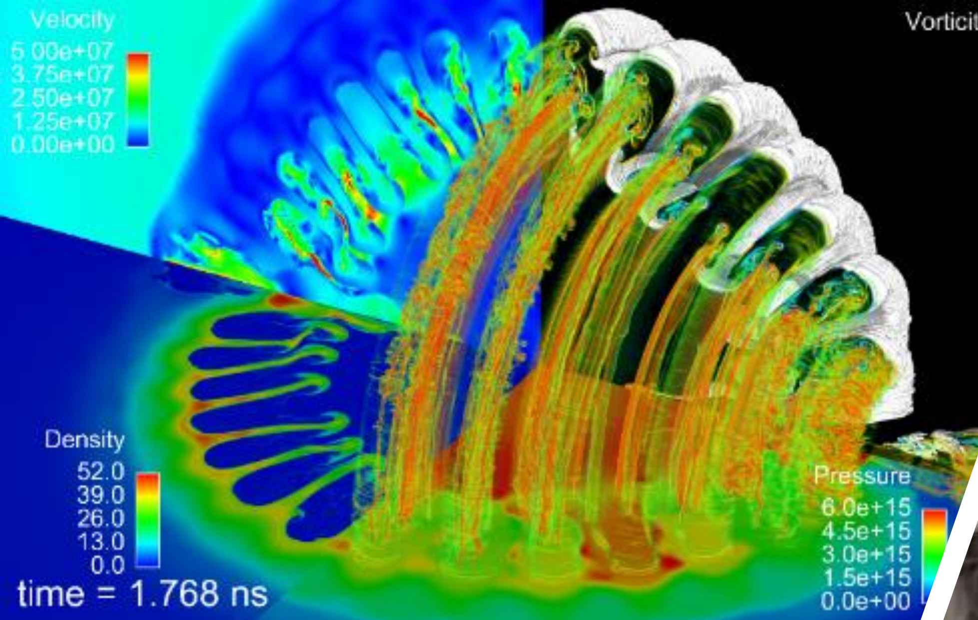
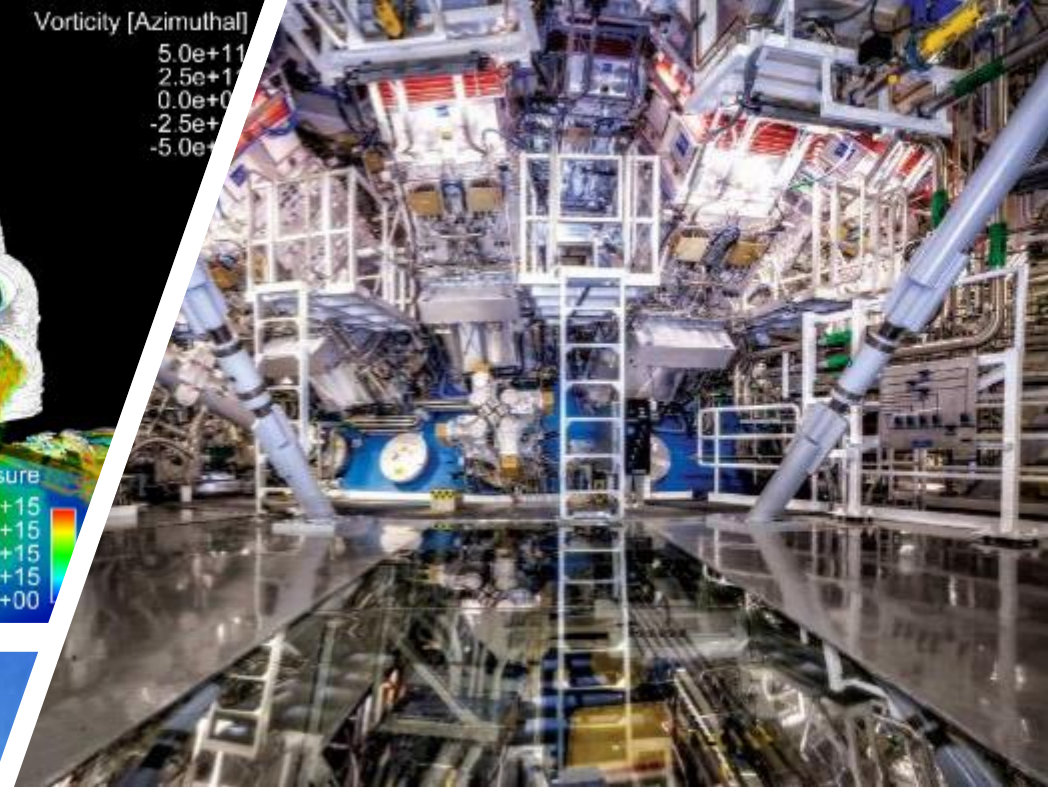
- **Oct 1991** Soviet Secretary General Mikhail Gorbachev declared moratorium on Soviet nuclear weapons tests
- **1992** President George H. W. Bush declared moratorium on U.S. nuclear weapons tests
- **1996 Comprehensive Test Ban Treaty** signed but not ratified
- **In the 1990s**, the Department of Energy created the science-based **Stockpile Stewardship Program** to maintain the safety, security, and reliability of the U.S. nuclear deterrent without full-scale testing

The Stockpile Stewardship Program (SSP)

- SSP is designed to increase our confidence in the assessment of the safety, security and reliability of the stockpile
  - Provides the technical basis to inform the President as to the state of the U.S. deterrent and whether there is a technical need to resume nuclear testing
- Over the past decade, U.S. policy has included:
  - No nuclear testing (since September 1992)
  - No new weapon development (no new weapons produced since 1991)
  - Limited production capability for re-manufacturing

What is Stockpile Stewardship?
(Think - High-End Sports Car)

2020 Alfa Romeo 6C photo – autoevolution.com

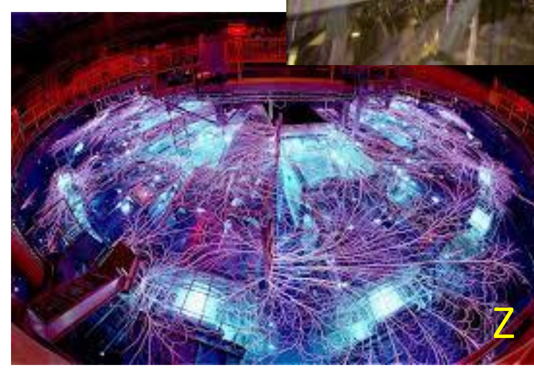

Velocity
5.00e+07
3.75e+07
2.50e+07
1.25e+07
0.00e+00
Vorticity [Azimuthal]
5.0e+11
2.5e+1
0.0e+0
-2.5e+
-5.0e+
Density
52.0
39.0
26.0
13.0
0.0
time = 1.768 ns
Pressure
6.0e+15
4.5e+15
3.0e+15
1.5e+15
0.0e+00


A major focus area for the NNSA is in understanding the properties of high energy density plasmas (HEDP)

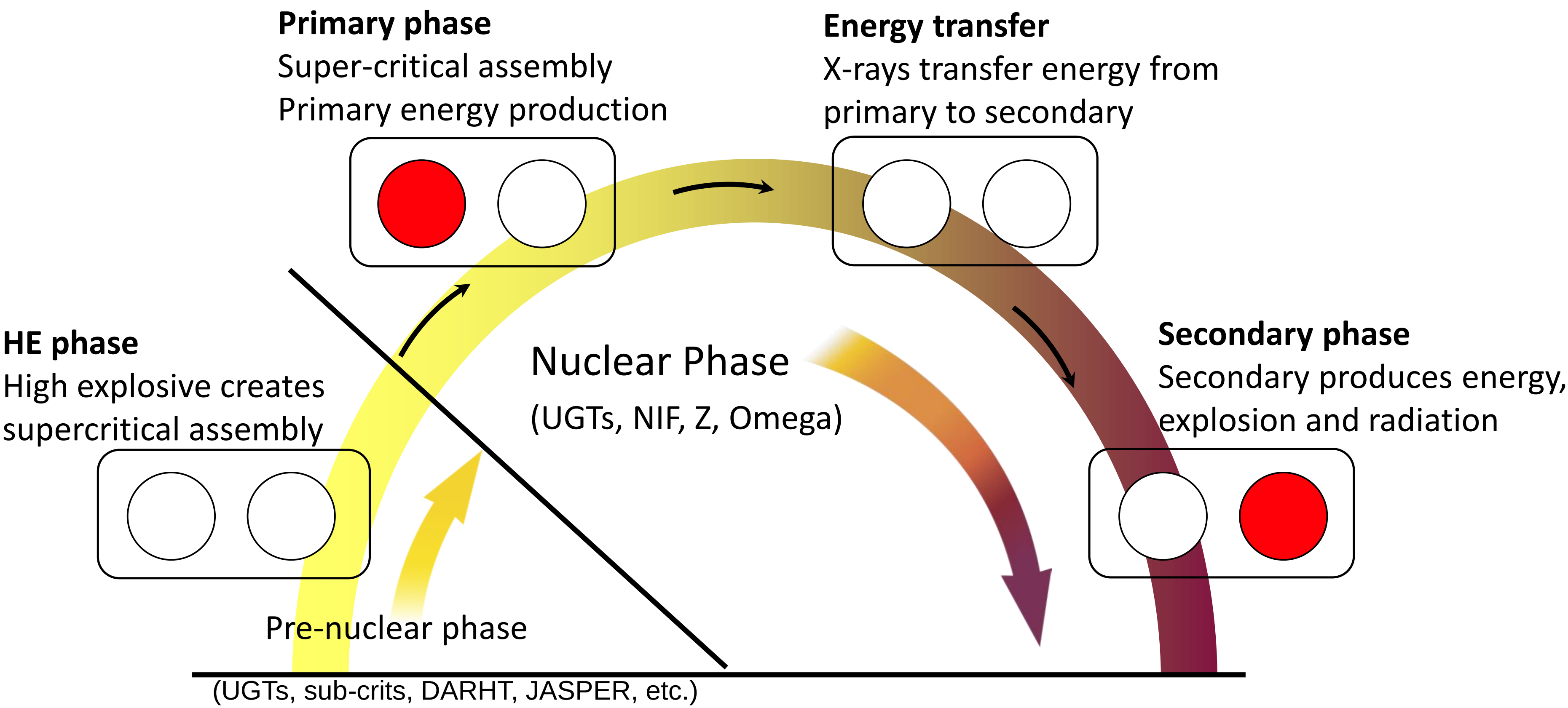
- High energy density (HED) plasmas are defined as media with energy density greater than 0.1 trillion J/cubic meter—more than 20x the pressure needed to make a diamond

- Achieving the extreme states of matter relevant to understanding nuclear weapons is made possible with HED facilities such as **Omega, Z, and NIF**

- **Why?**



Because - the majority of the yield of a nuclear weapon occurs in the HED state



To maintain deterrence the US must maintain preeminence in weapon Science, Technology, & Engineering

ST&E delivers validated physics modeling capabilities in support of stockpile missions:

- Improve and modernize assessment and certification of US stockpile
- Enable future life-extension options
- Anticipate and respond to technical surprises and technology advances
- Recruit, train, and retain world-class next-generation stewards

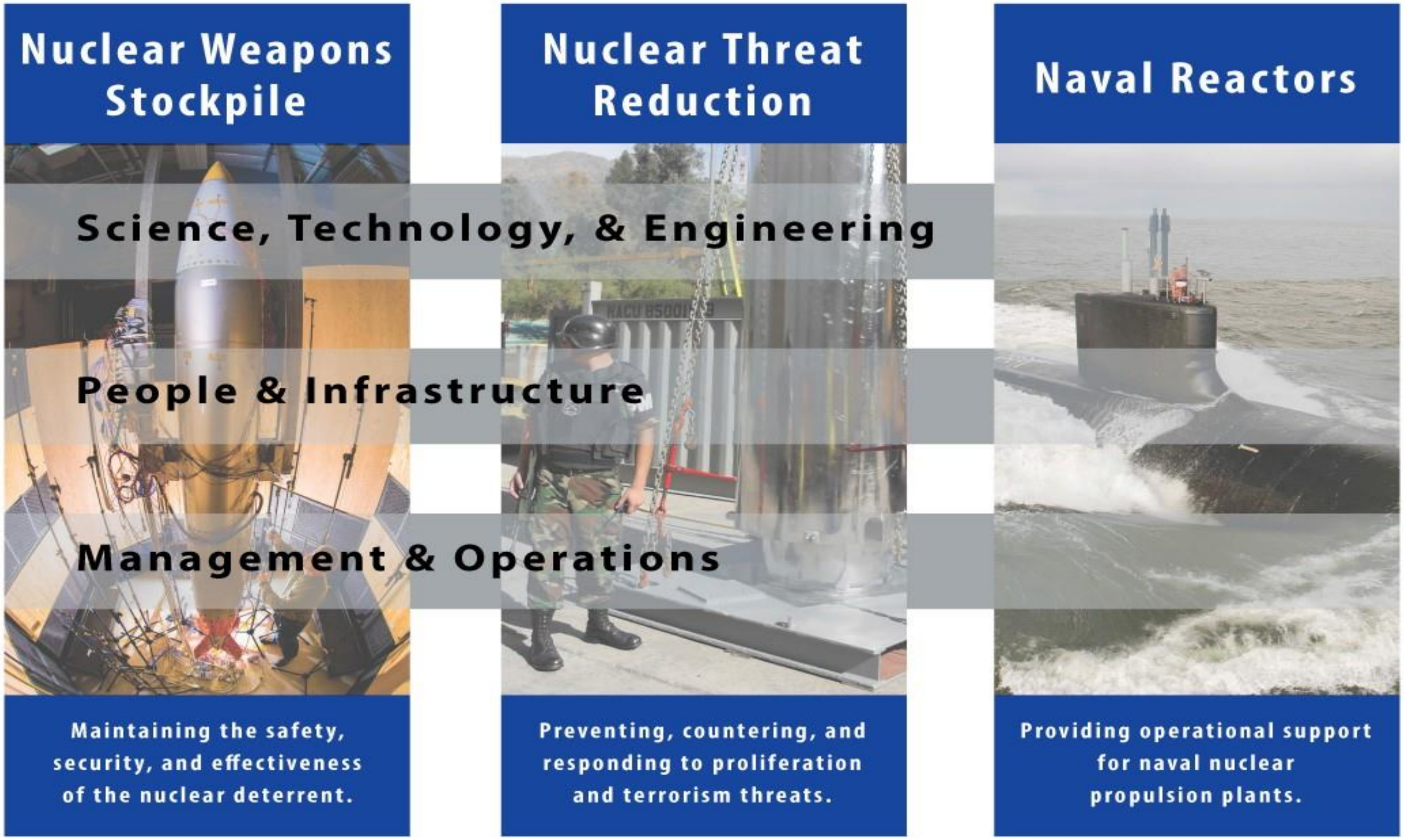
So how do you do that?

I'm with the Federal Government, I'm here to help.

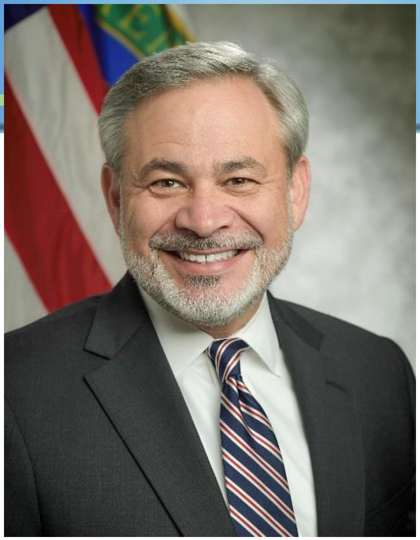
National Nuclear Security Administration DEFENSEPROGRAMS

OFFICE OF EXPERIMENTAL SCIENCES OES Science for an Enduring Stockpile

DOE/NNSA Mission Pillars and Cross-cutting Capabilities



DOE/NNSA Leadership



Secretary, DOE
Confirmed – December 2, 2019

Acting Under Secretary for Nuclear Security
& Acting Administrator, NNSA
Confirmed - May 23, 2019 (as Deputy)

National Nuclear Security Administration

Deputy Administrator for Defense Programs, NNSA
Confirmed – Sept. 18, 2018

Stockpile Research, Technology, and Engineering (SRT&E)

Certifying the Stockpile – Preparing for the Future

Advanced Manufacturing Development

Delivers modern technologies necessary to enhance secure manufacturing capabilities and to provide timely support to critical needs of the stockpile

Engineering

Delivers technology solutions that facilitate surety, surveillance, survivability, and testing throughout the weapon lifecycle

Assessment Science

Delivers weapons-relevant data, models, methods and capabilities that increase confidence in annual assessments and certification of refurbished weapons, explore future LEP options, and facilitate Significant Finding Investigations closure for Nuclear Explosives Package issues

Inertial Confinement Fusion

Delivers high energy density physics platforms to access extreme conditions essential to assessing weapons

Advanced Simulation and Computing

Delivers computer platforms and integrated codes with models and algorithms to facilitate assessment of weapon systems

Five Critical Elements of Science-Based Stewardship

Enable Stockpile Missions

Support for LEPs

Options for stockpile modernization

Scientific basis/certification/ qualification for new technologies and reused components

Resolution of key weapons performance issues

Test readiness

Quantify Weapons Phenomena

Thermonuclear Burn

Radiation Transport

Radiation Hydrodynamics

Material, Plasma, and Nuclear Properties

Outputs, Environments & Effects/ Nuclear Survivability

Provide Scientific Deterrence

Weapons Physics Peer-review

Exploration of extreme pressure/temp/density

Advanced R&D platforms

Multiple approaches to future multi-MJ yield

Advanced Technology R&D

Predictive physics models for design codes

Uncertainty Quantification

Build & Maintain Experimental Tools for the Complex

Facilities

Targets

Optics

Diagnostics

Ensure Stewardship Sustainability

Process Improvement

Facility Diversity

Recruitment, training, and retention of personnel

Strong Academic pipeline

Science Supporting Weapons Activities

Enduring Stockpile

- Advances scientific methods for nuclear weapons assessments
- Develops advanced capabilities to enable the resolution of significant finding investigations

Life Extension and Responsiveness

- Explores initial concepts to enable life-extension modifications to the stockpile
- Researches and develops new technologies for future stockpile needs

Knowledge Base and Infrastructure

- Preserves the U.S. core intellectual and technical competencies in nuclear weapons
- Recruits and trains new generation of scientists, engineers, and technicians

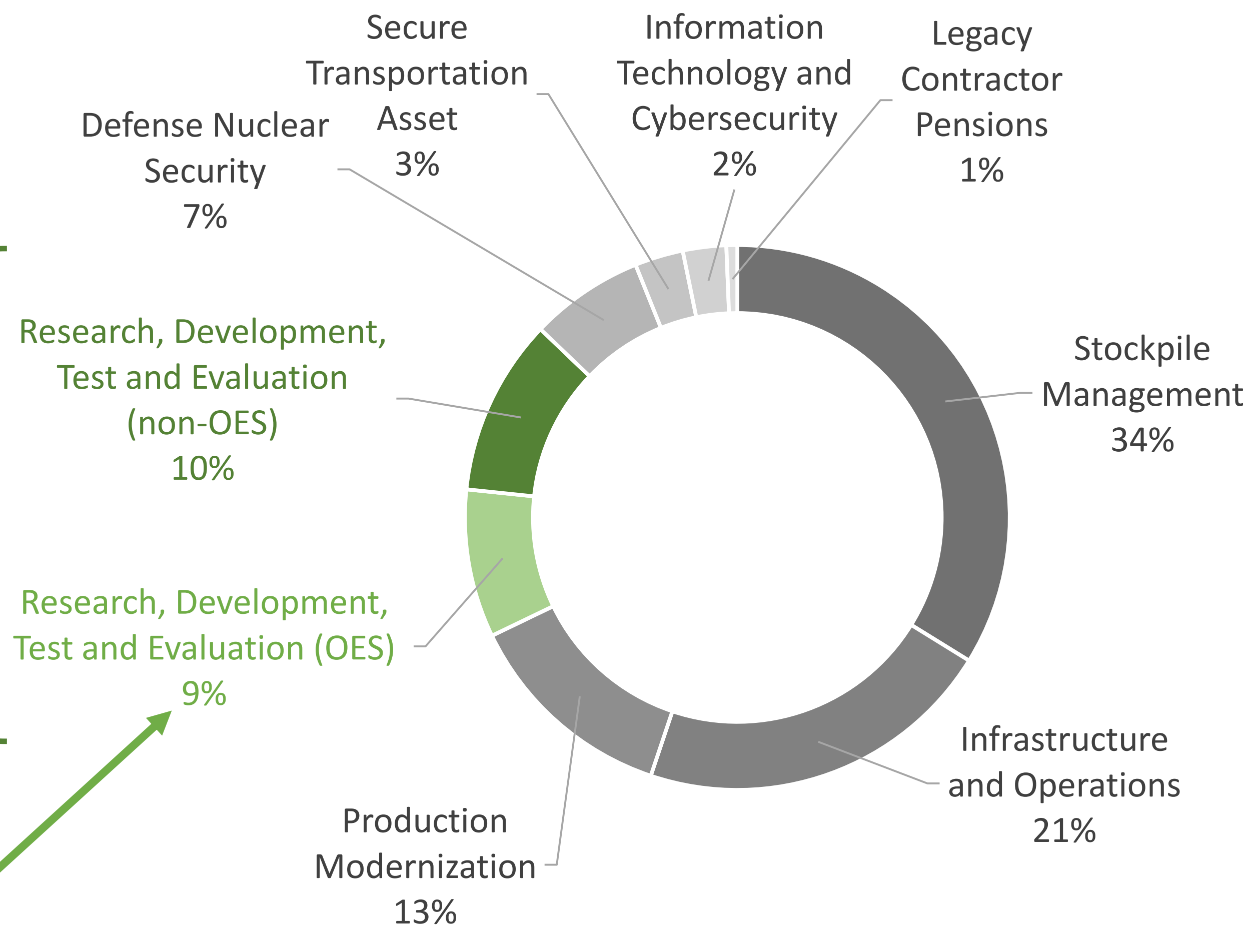
Broad National Security Mission

- Leverages resources to address emerging nuclear security threats
- Supports the assessment of foreign and adversary nuclear weapons for intelligence activities

Weapons Activities & SRT&E

Dr. Mark C. Anderson, SES
Assistant Deputy Administrator for Stockpile Research, Technology, and Engineering

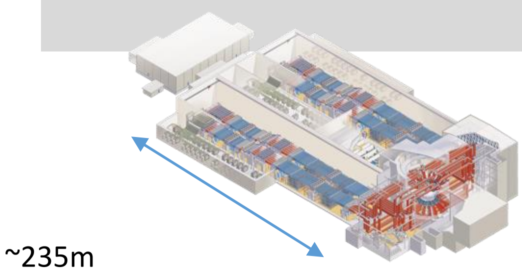
Dr. Njema J. Frazier, SES
Director, Office of Experimental Sciences



Three Major HEDP Facilities in the US

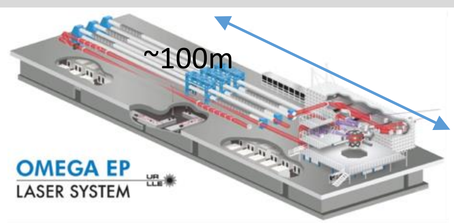
National Ignition Facility (NIF)

- Largest Laser on Earth
- Primary facility for Laser Indirect Drive fusion



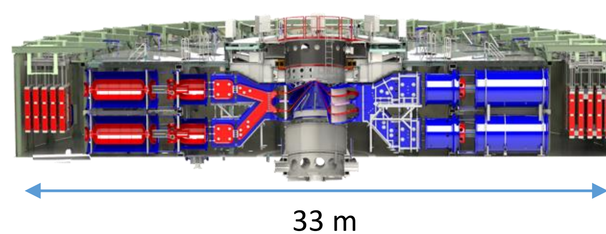
OMEGA Laser Facility

- High shot-rate academic laser facility
- Primary facility for Laser Direct Drive fusion



Z Facility

- Largest Pulsed Power Facility on Earth
- Primary facility for Magnetic Direct Drive fusion



Pulsed Power & HEDP within SRT&E

- Inertial Confinement Fusion (ICF)
  - A high fusion-yield capability is a long-standing goal, would reduce need for physics scaling of models
- Stockpile Applications
  - Instabilities, laser-plasma interactions, etc.
- Hostile nuclear environments
  - Survivability in all potentially encounterable environments
- Dynamic compression of materials
  - High pressure properties of many stockpile-relevant materials can be reached
- Advanced diagnostics
  - Enhancing the capabilities necessary to underwrite certification of the stockpile

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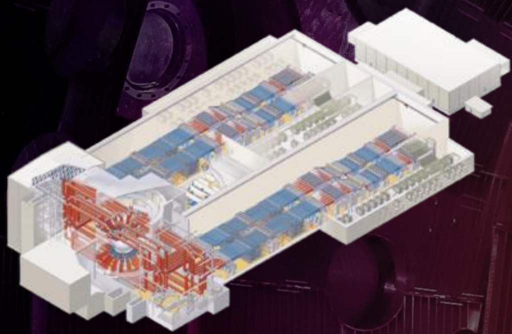
Fusion drives exciting fundamental science, and is an enabling tool for stockpile stewardship

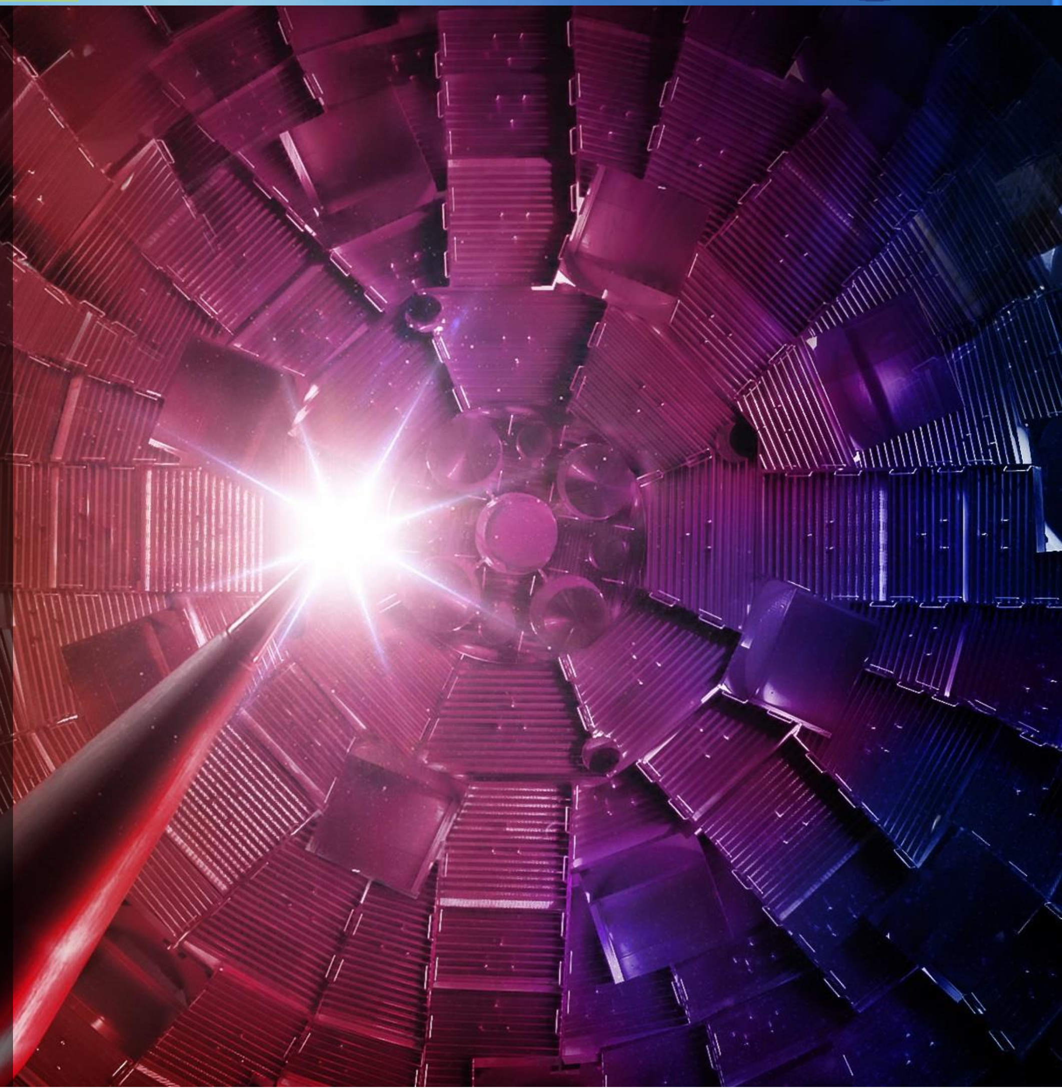
Yield	High Energy Density Science Applications
~0.01 MJ	• Interplay of thermonuclear fusion burn and mix • Nuclear physics data (reaction-in-flight, fission, and radiochemistry)
>0.1 MJ	• Transport of charged particles in plasmas • Threshold for fusion-fission physics
~few MJ	• Threshold for enabling 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

Excerpt from NNSA 2018 ICF Framework Document

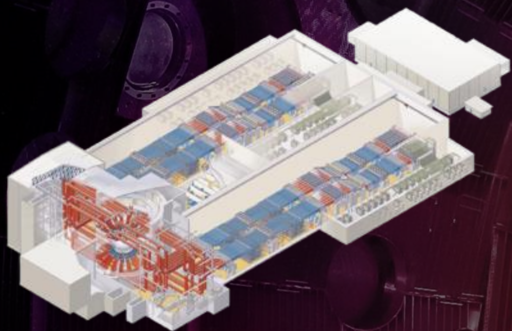
National Ignition Facility



- Began operations March, 2009
- Worlds most energetic laser facility
- 1.8 million joules in 192 beams
  (the energy of a car at highway speeds)
- 500 Trillion Watts of Power
  (1,000x the power used by the US at any instant)
- 400+ experiments/year for ignition, HED, national security, and basic science

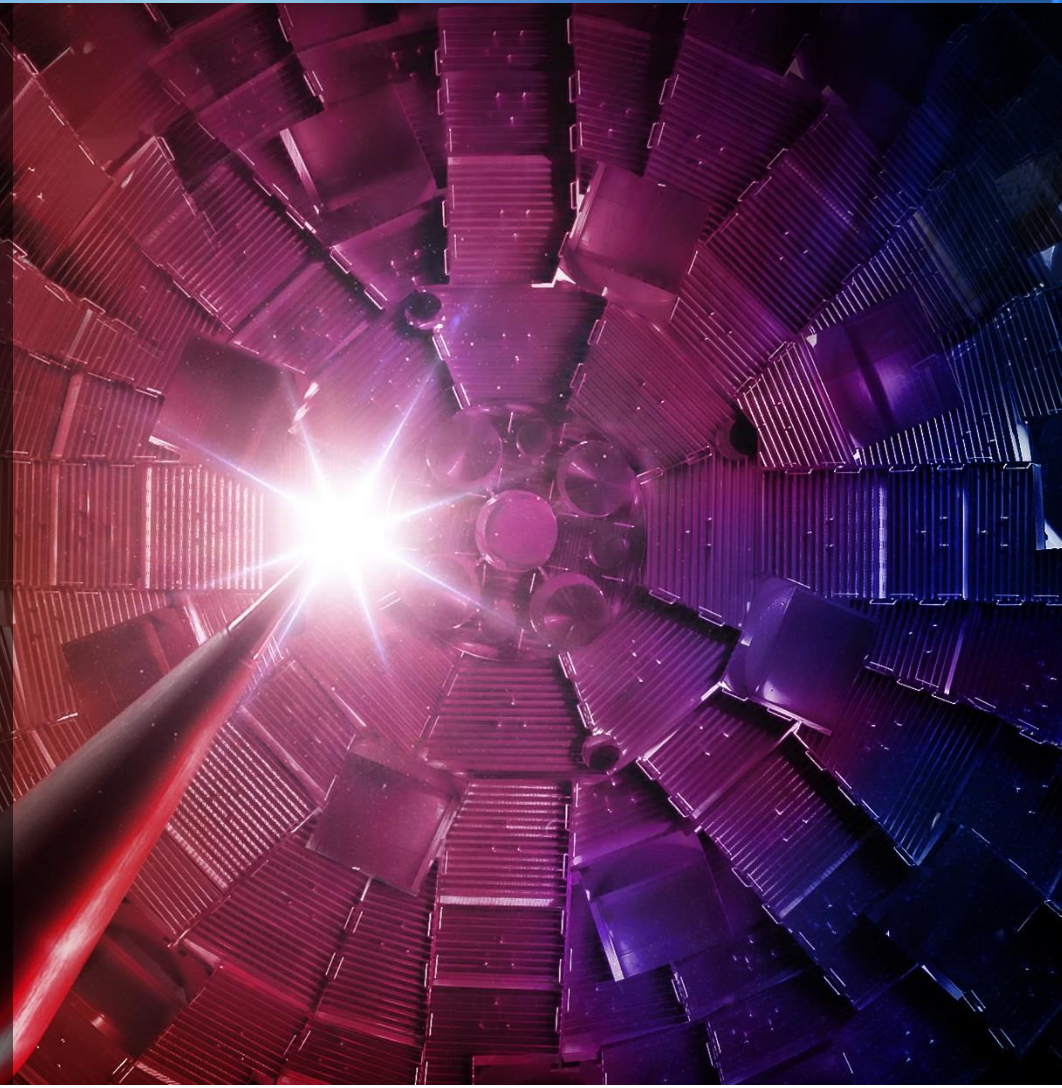


National Ignition Facility

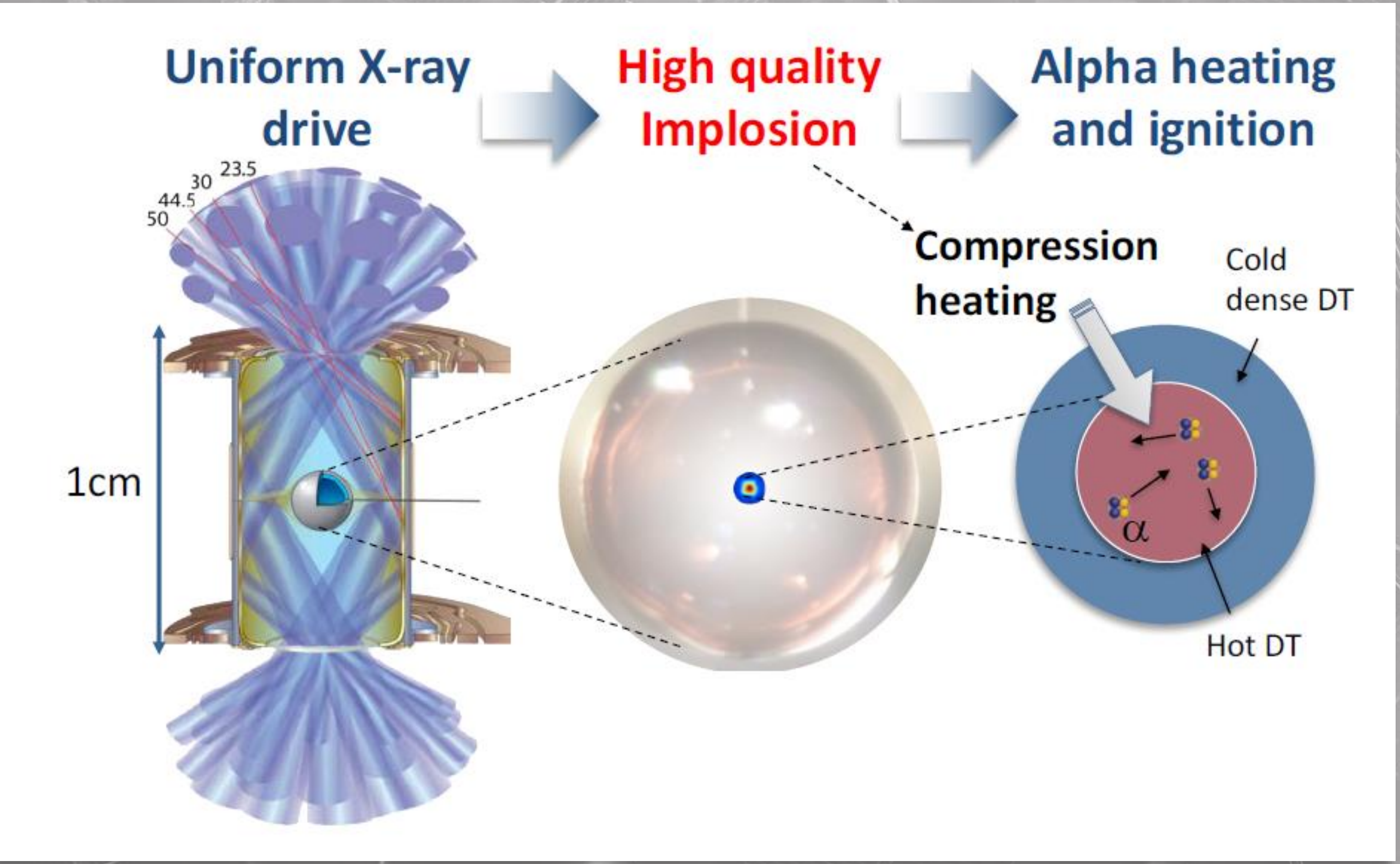


Key roles for NIF:

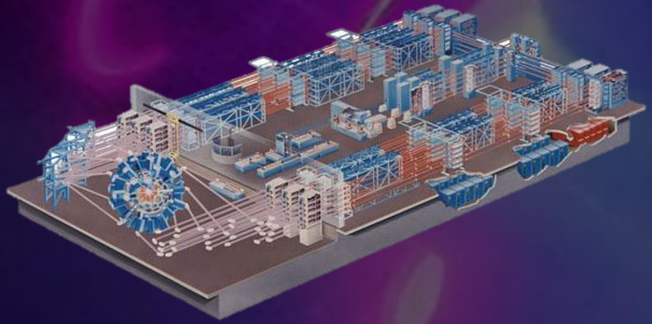
- Tests materials and design options for Life Extension Programs
- Measures Plutonium properties at pressures reached in nuclear weapons simulations
- Generates intense bursts of neutrons and x-rays for survivability testing
- Leads the indirect-drive fusion ignition approach
- Only facility sized and built to attempt ignition



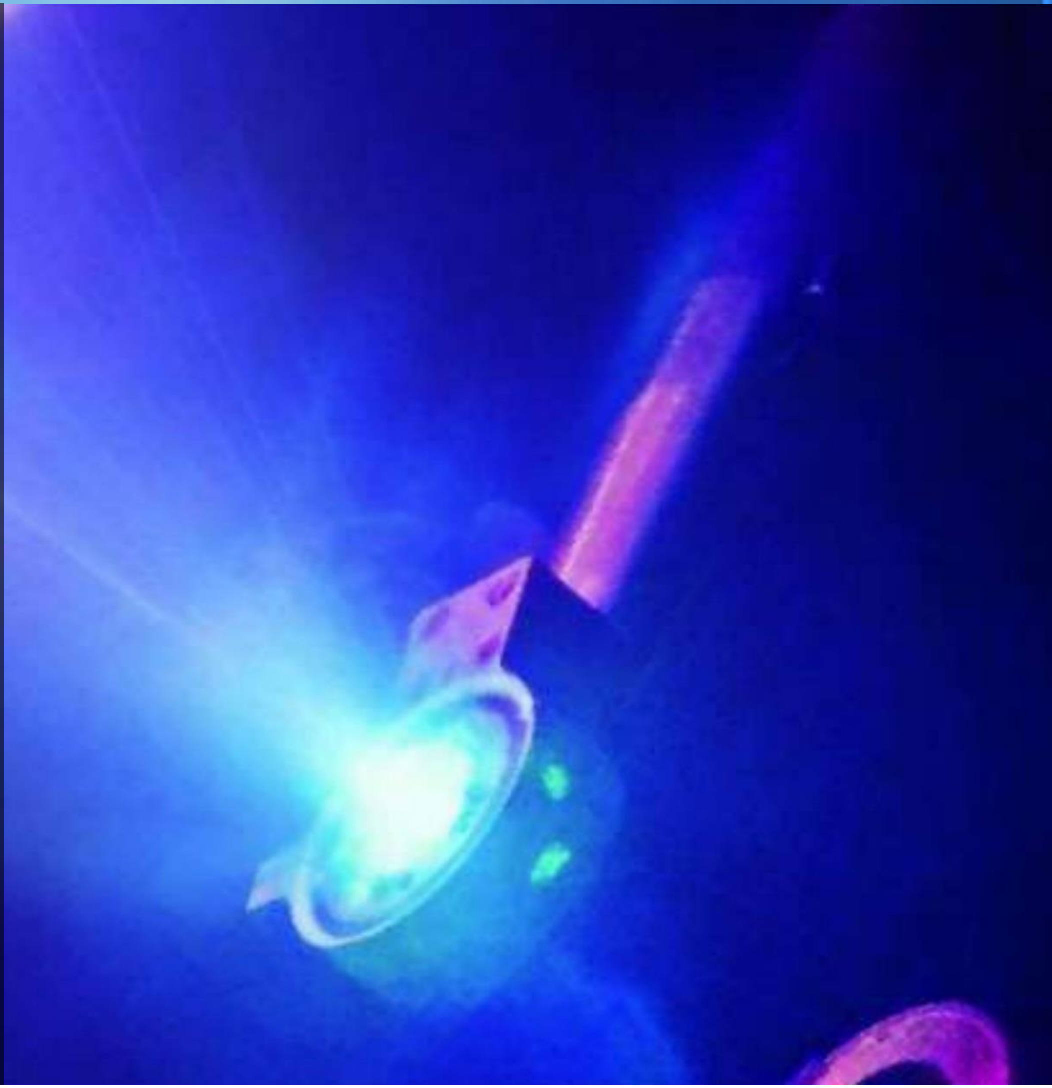
Inertial Fusion: Laser Indirect Drive



Omega Laser Facility



- Omega:
  - 60-beam, 30 kJ main laser
    (the energy of 30 million laser pointers over a second)
- Omega EP:
  - 4-beam, 40 kJ Joule short-pulse-capable laser
- Approximately 160 diagnostic systems
- Rapid shot rate ~ 2100 expts annually



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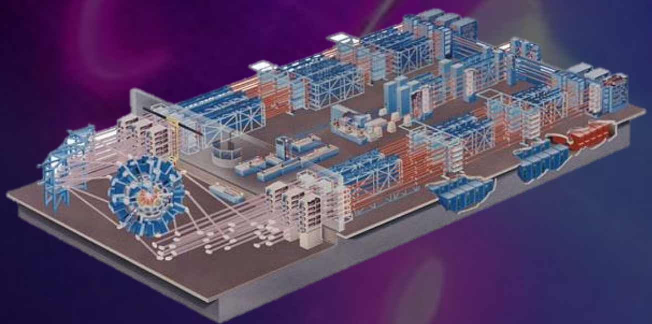
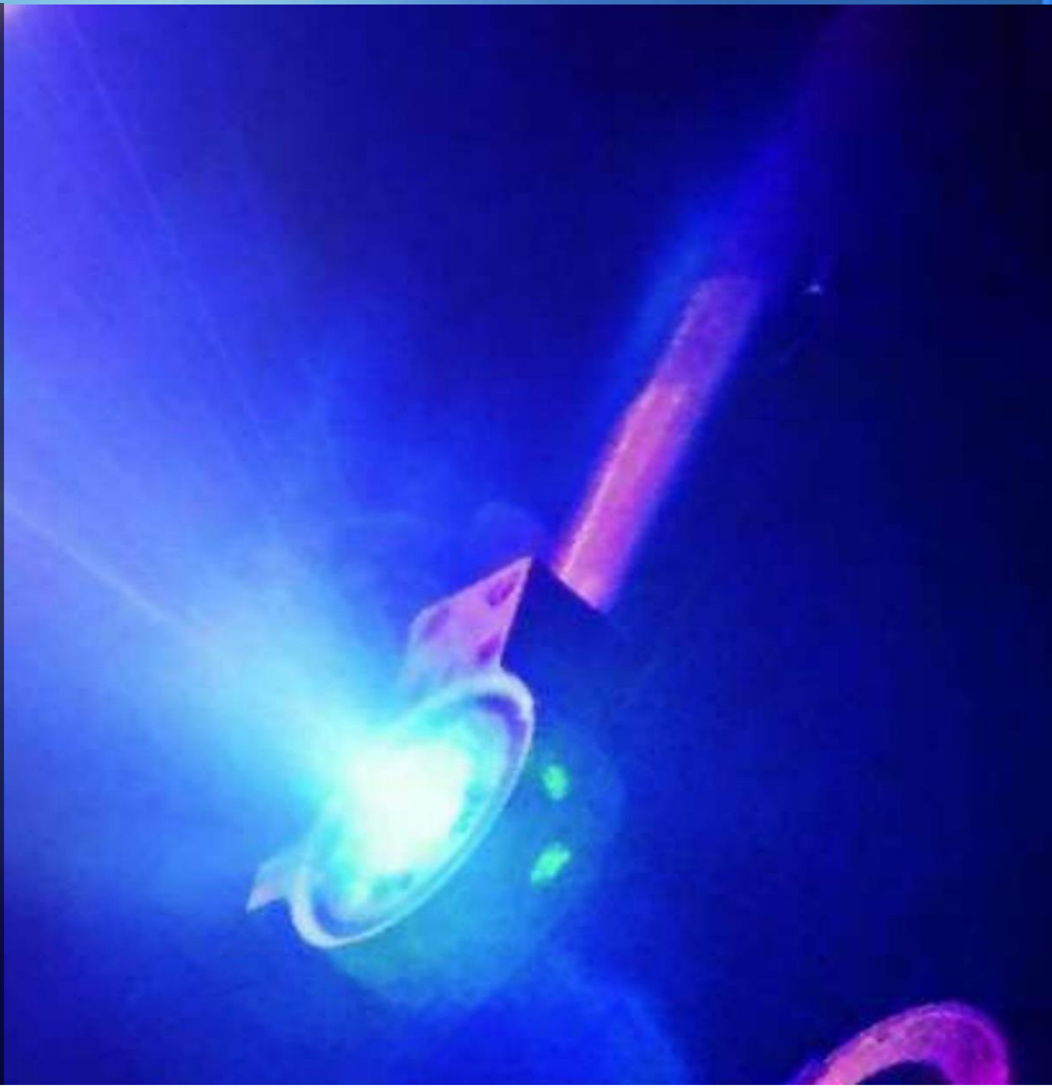
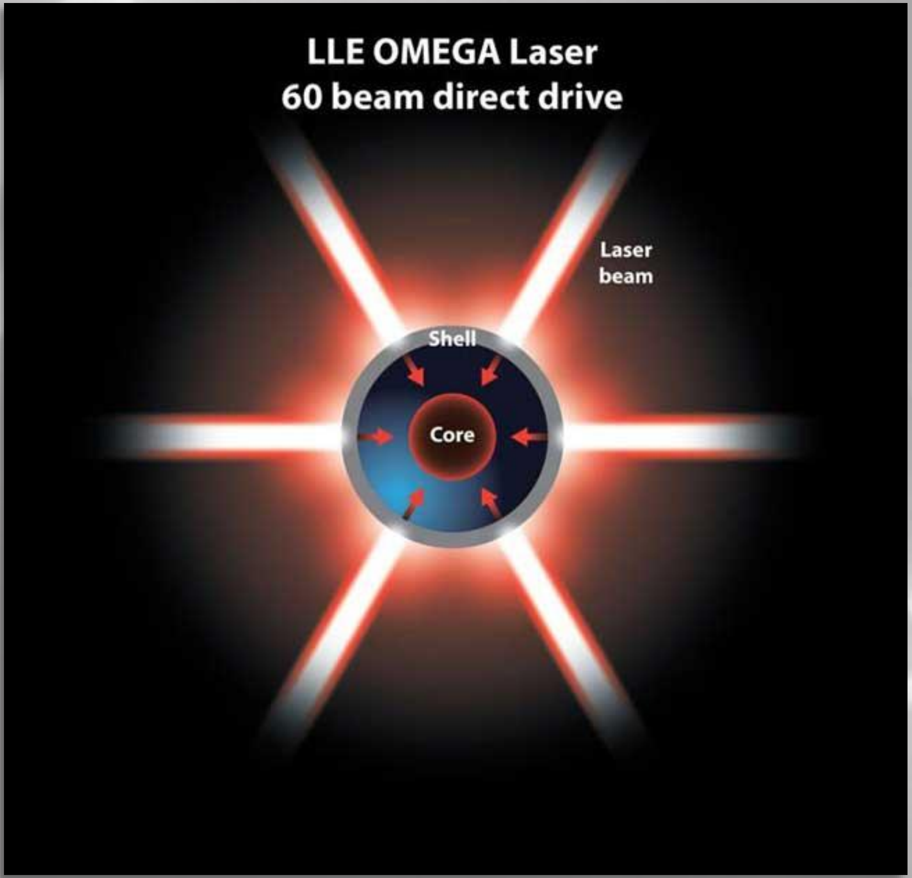


Key roles for Omega:

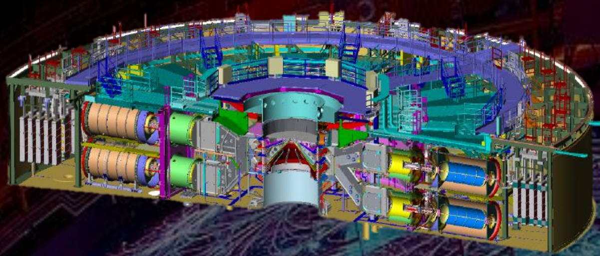
- Develops new methods and diagnostics for NIF
  - Phase diffraction methods (now applied to Pu on NIF and Z)
  - Short-pulse radiography
- Pioneers breakthroughs in laser technology
- Leads laser-direct-drive fusion ignition approach
- Trains future stockpile stewards:
  - 300+ Rochester PhDs to date
  - 400+ users from academic community
  - New HED degree program



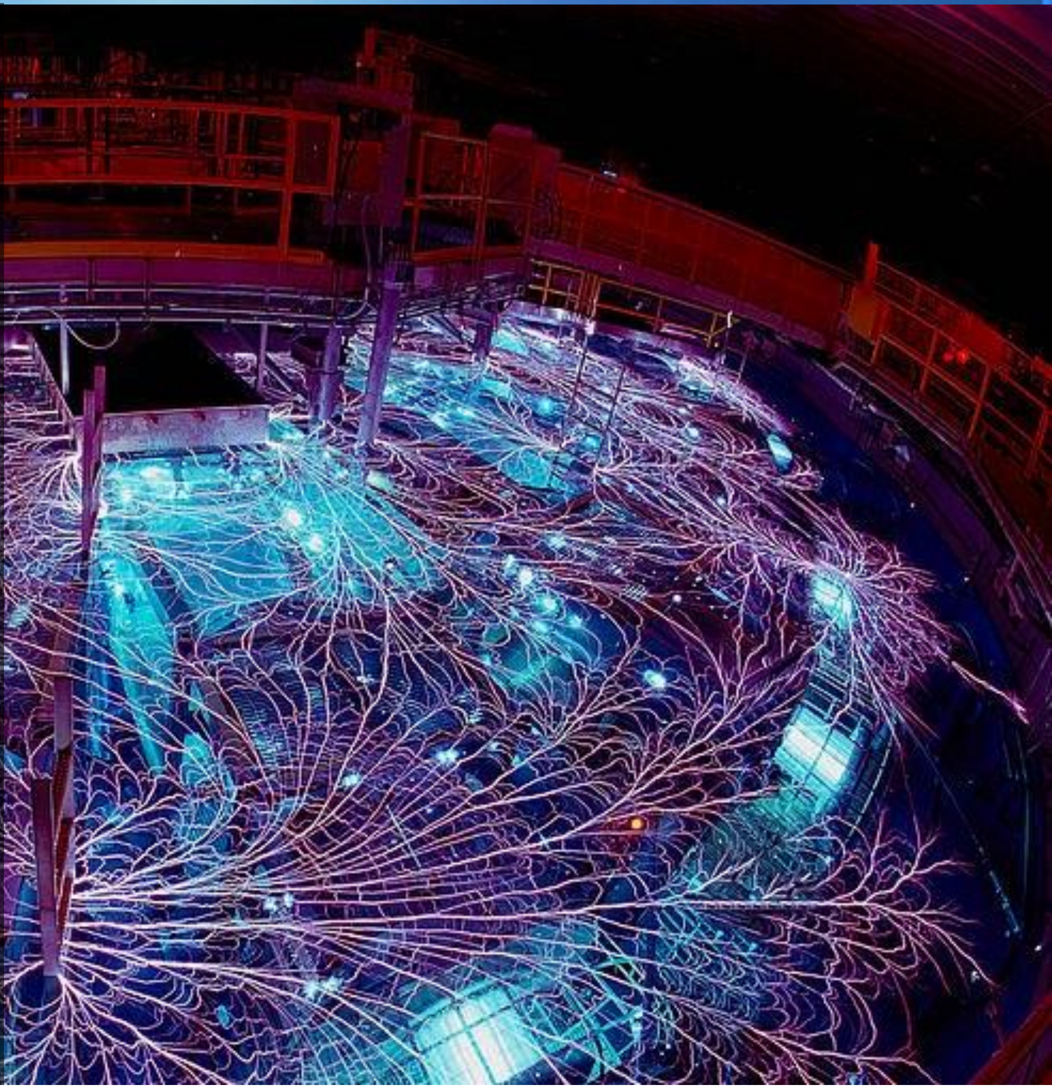
Inertial Fusion: Laser Direct Drive



Z Pulsed Power Facility



- Worlds most powerful laboratory radiation source
- 80-trillion-Watt electrical pulse (1,000x the power in a lightning bolt)
- Delivers power over 100 ns (20,000x faster than a lightning strike)
- Coupled with 2-kJ Z-Beamlet laser facility (provides x-ray backlighting and preheating)



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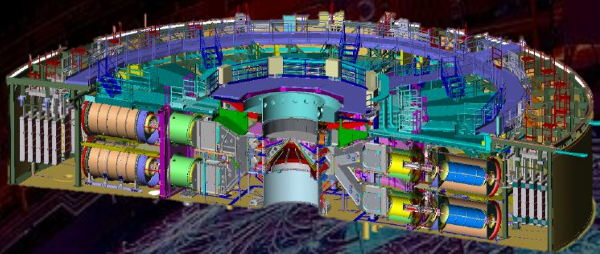
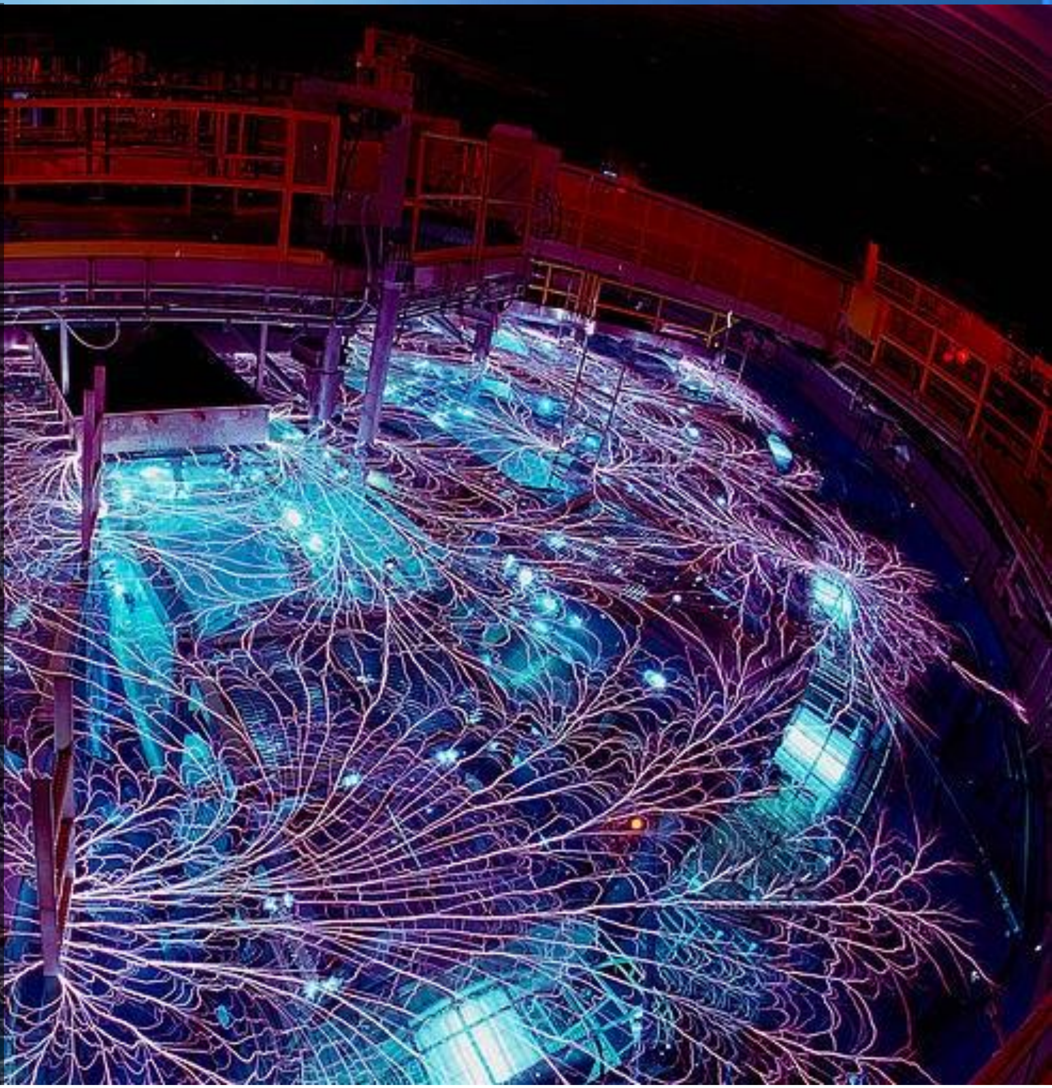
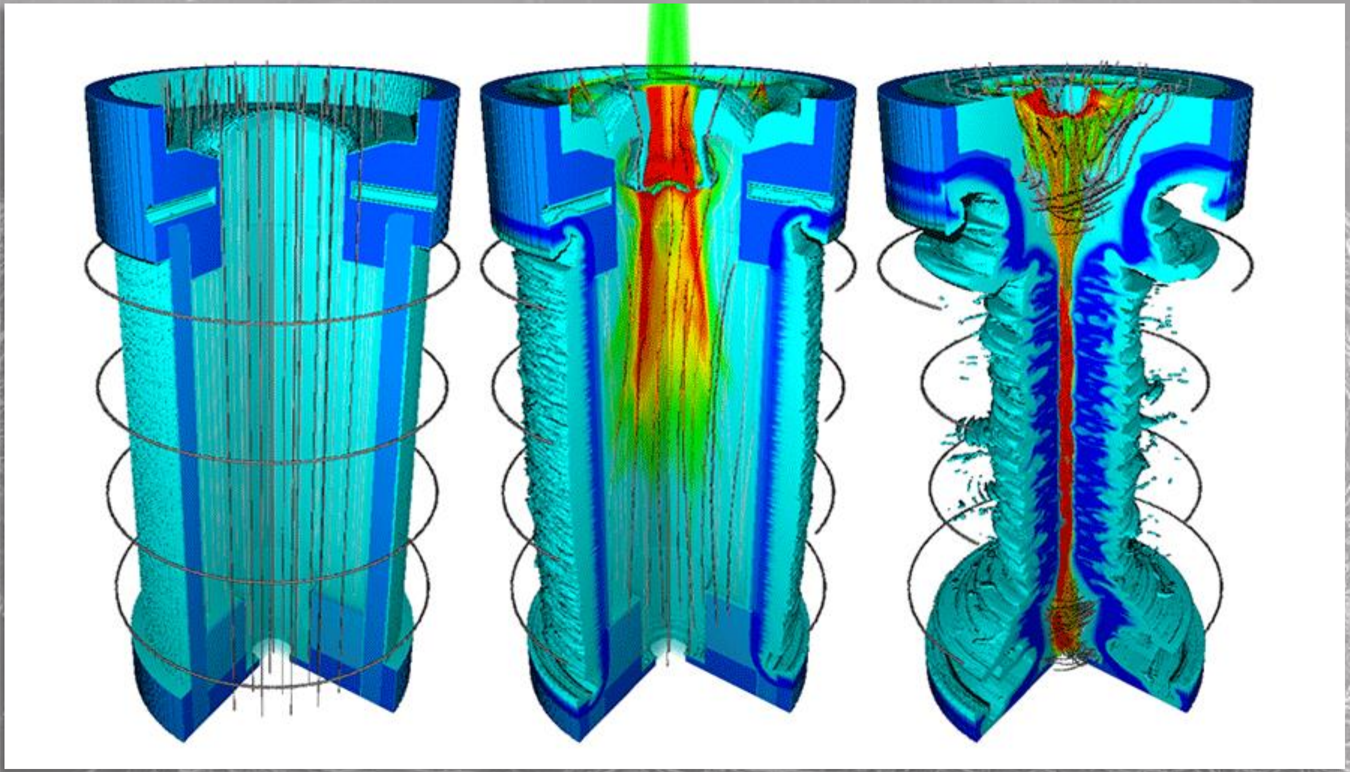


Key roles for Z:

- Tests Pu properties, aging, and manufacturing questions with representative sample sizes at relevant conditions using stockpile material
- Validates hostile-environment models by testing components with highest x-ray energies and rates available
- Leads magnetic-direct-drive fusion ignition approach

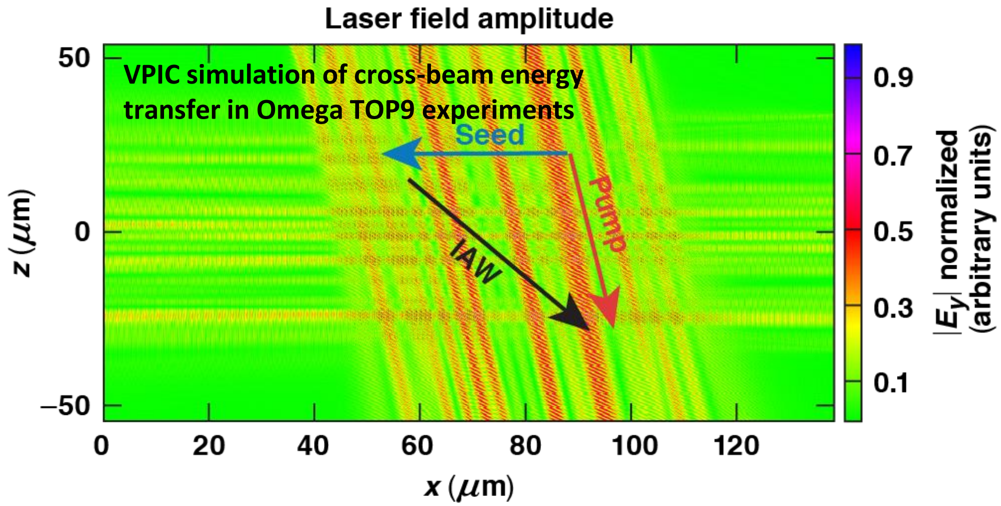


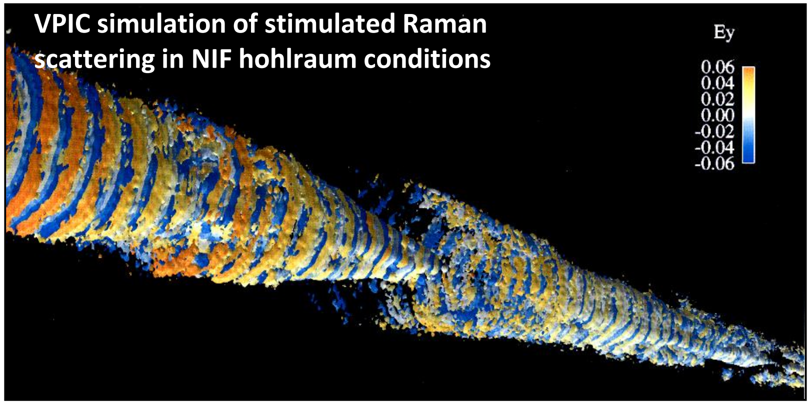
Inertial Fusion: Magnetic Direct Drive



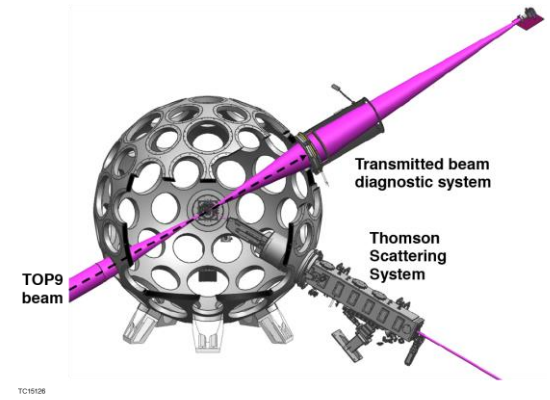
M. Gomez *et al.*, Phys. Rev. Lett. (2014)

ICF - Laser plasma instabilities (LPI) pose a challenge to efficient coupling of laser energy to ICF capsules





The LLE TOP9* (Tunable Omega Port 9) platform has been developed for focused studies of CBET in ICF relevant plasmas



Kinetic modeling on large-scale NNSA supercomputers (Trinity, Sierra) and novel LPI experiments & diagnostics are enabling LPI studies at unprecedented fidelity

*B.E. Kruschwitz et al. *Proc. SPIE* 10898, 108904 (2019)

Pulsed Power & HEDP within SRT&E

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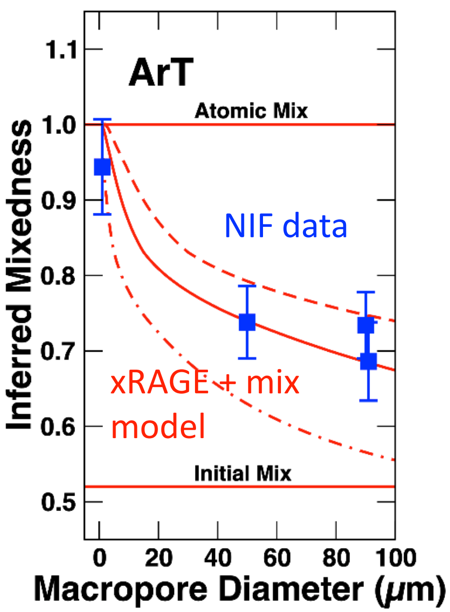
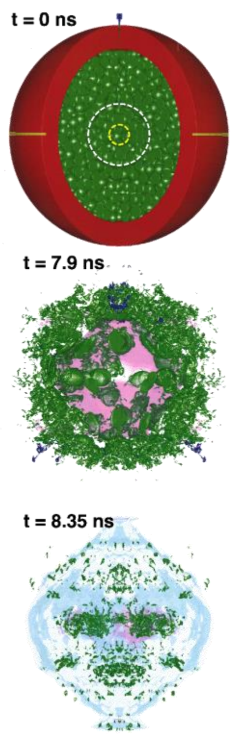
Stockpile - Understanding Mixing Dynamics and Thermonuclear Burn

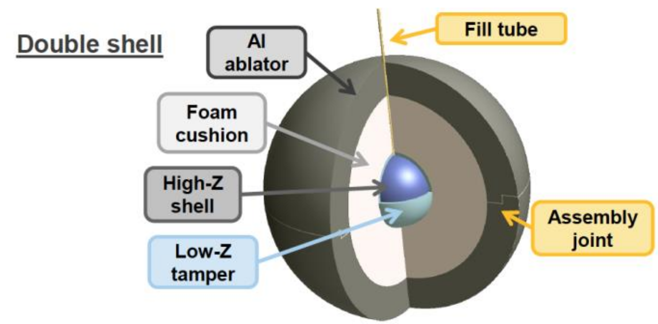
The MARBLE separated reactants platform probes the effects of *mix morphology* on thermonuclear burn

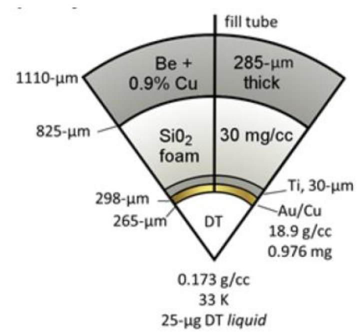


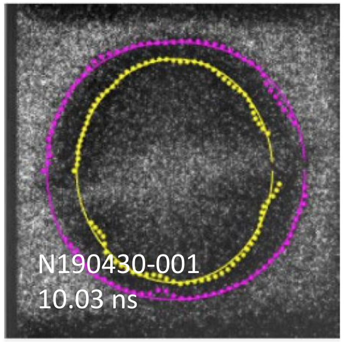
3D xRAGE simulation of MARBLE capsule implosion



Double shell ignition experiments study *volumetric thermonuclear burn* in a *radiation trapping environment*

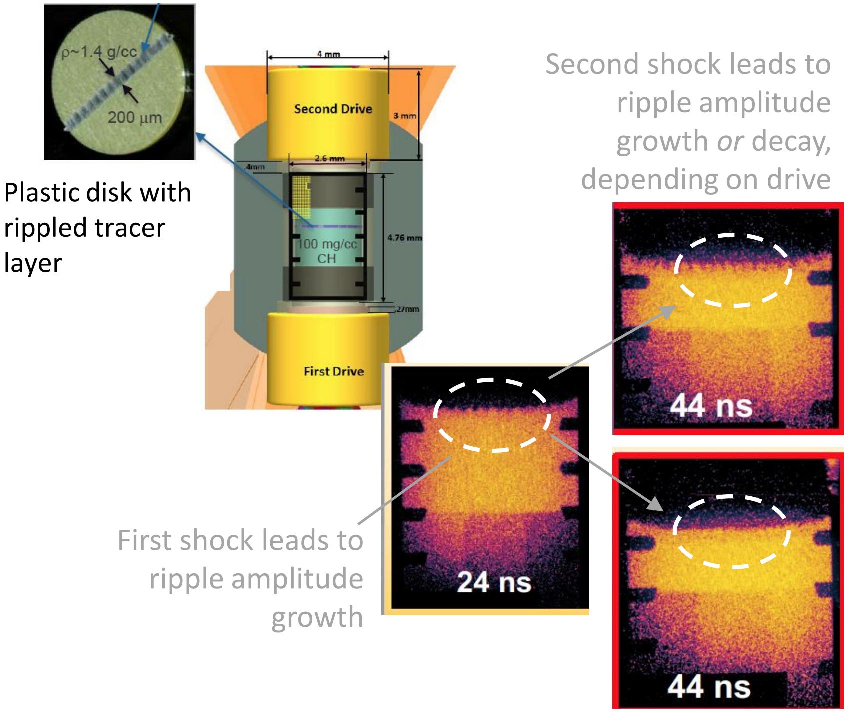




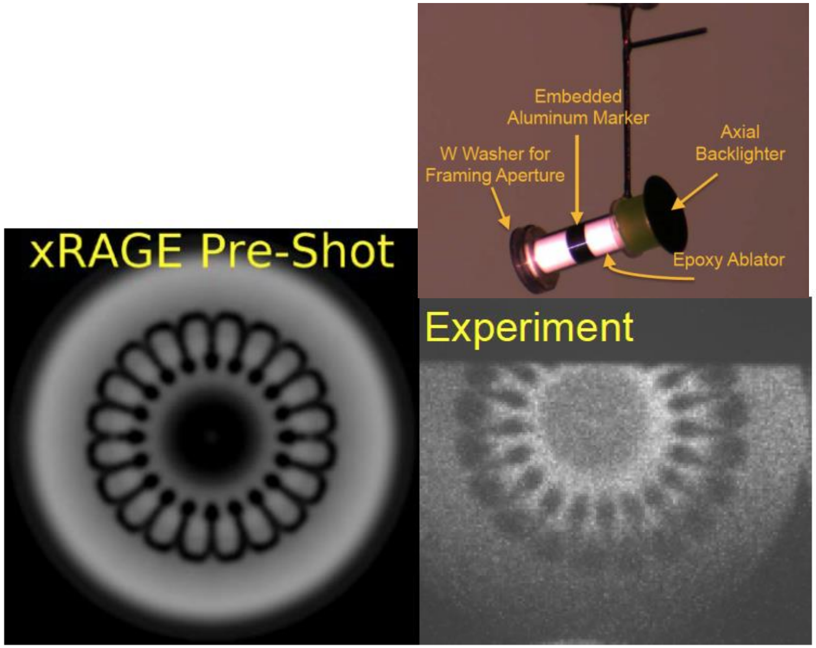


Stockpile - Understanding Growth of Instabilities and Mix

The M(ulti)-Shock platform allows us to study instability growth in *multiply shocked* media



Directly driven cylindrical implosions enable a detailed study of *late-time instability growth*



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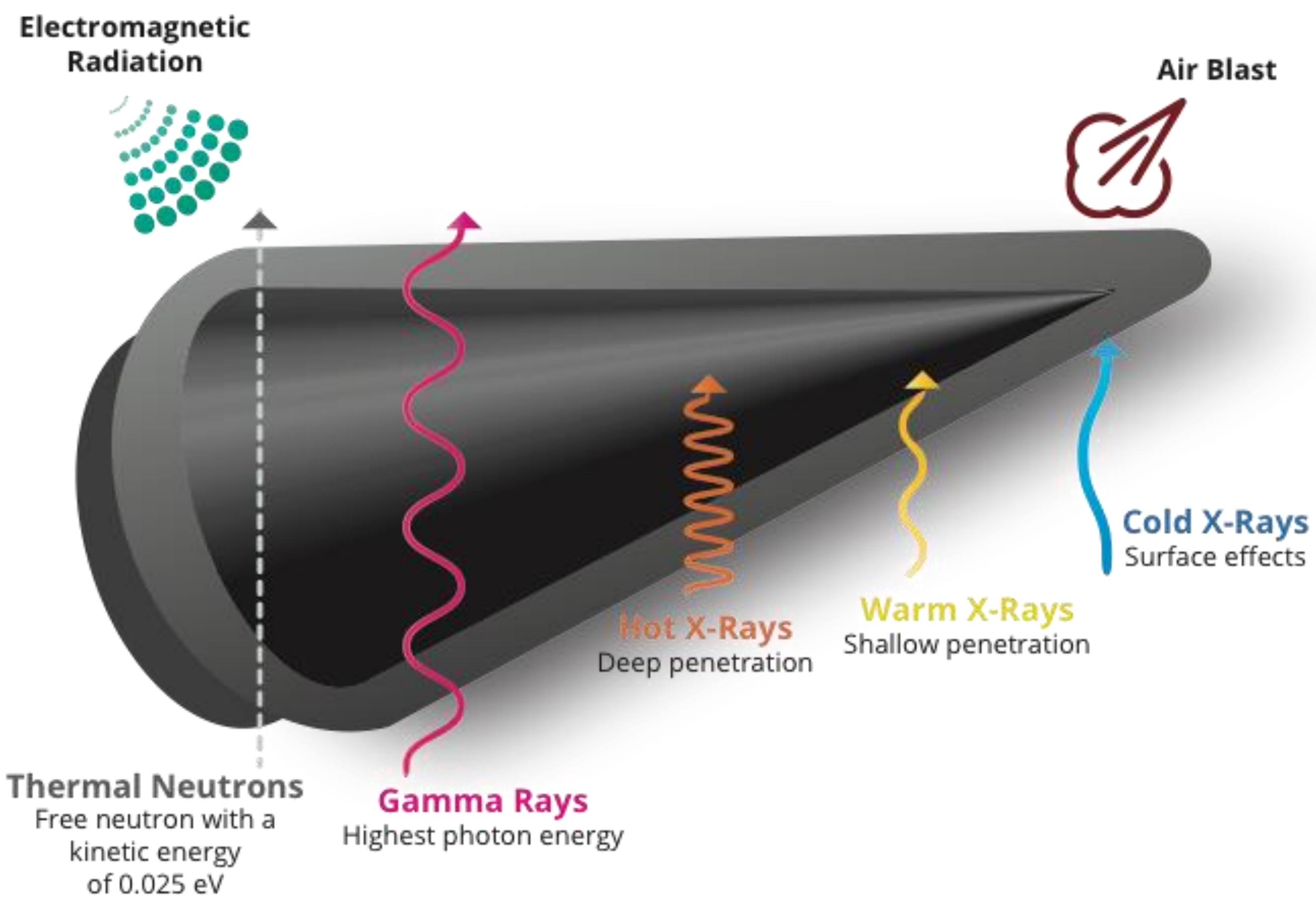
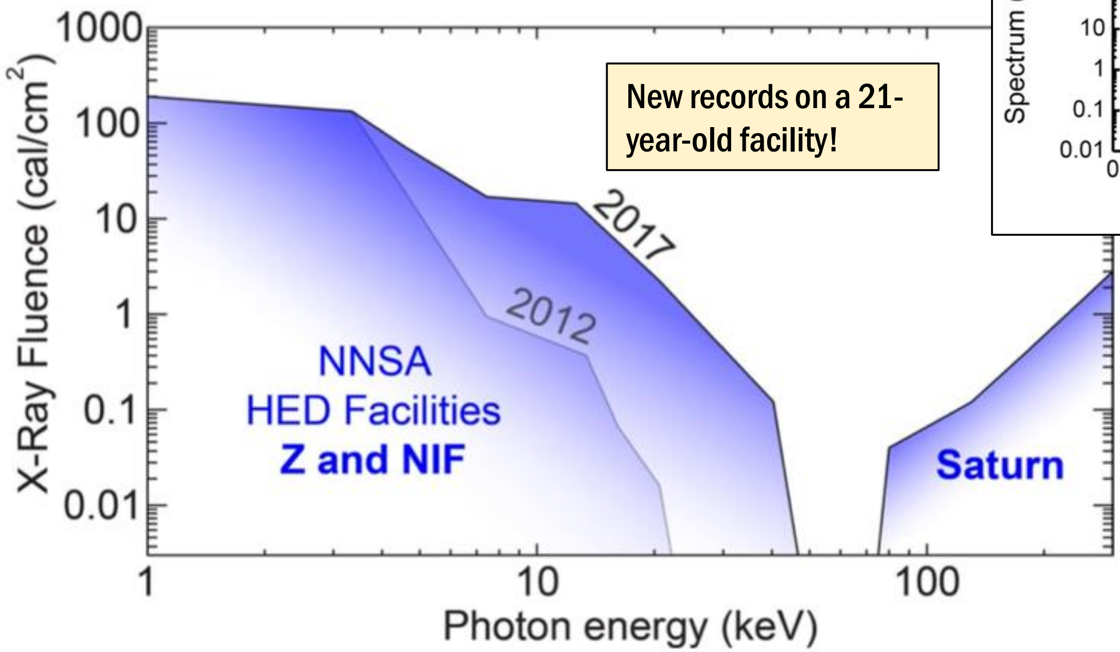
  - Survivability in all potentially encounterable environments
- Dynamic compression of materials
  - High pressure properties of many stockpile-relevant materials can be reached
- Advanced diagnostics
  - Enhancing the capabilities necessary to underwrite certification of the stockpile

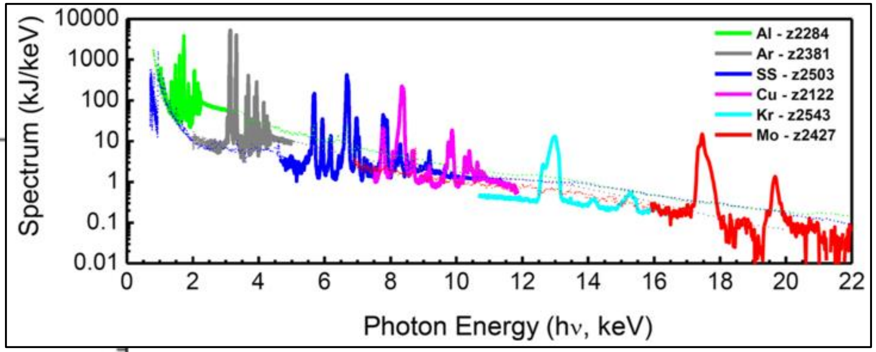
One mission focus is assessing the effects of hostile environments on nuclear weapons systems



Hostile - Record X-ray Yields Through Collaboration

Sandia and Lawrence Livermore National Laboratories are collaborating to produce record levels of >10 keV X-rays using a variety of Z-pinch sources*





Z and NIF are developing advanced x-ray sources that provide unprecedented >10 keV yields

* D.J. Ampleford *et al.*, Phys. Plasmas 21, 056708 (2014).

Pulsed Power & HEDP within SRT&E

- Inertial Confinement Fusion (ICF)
  - A high fusion-yield capability is a long-standing goal, would reduce need for physics scaling of models
- Stockpile Applications
  - Instabilities, laser-plasma interactions, etc.
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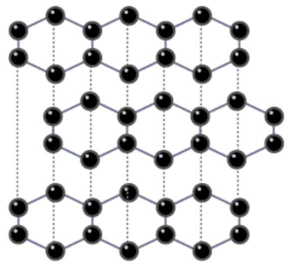
Need for accurate next-generation material property models

Phase of the material matters

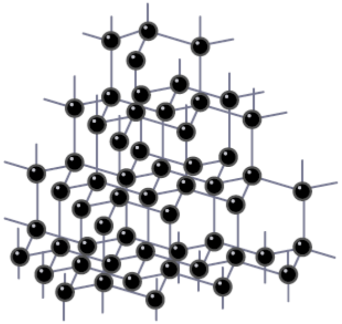
Graphite

Atomic Structure

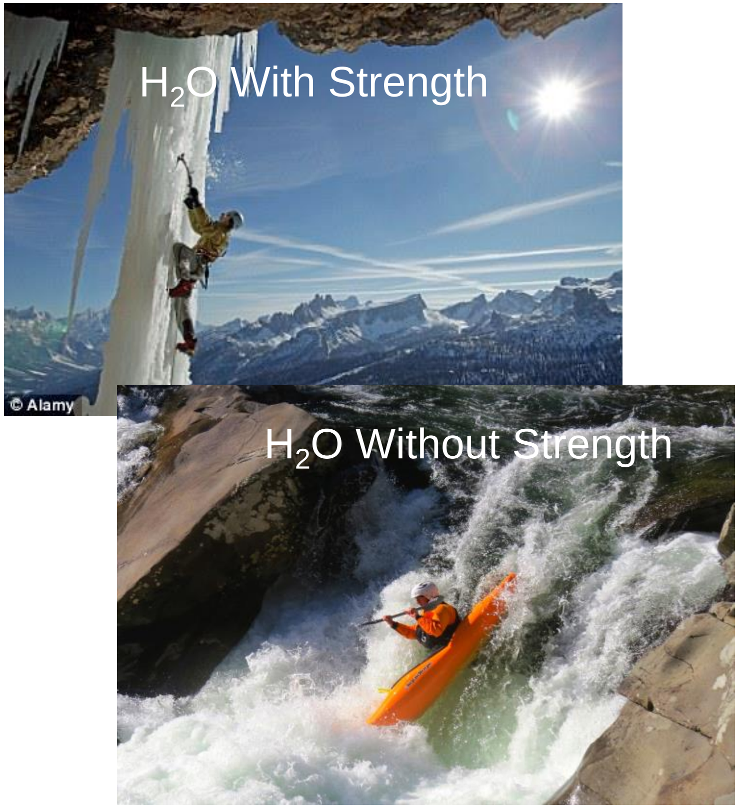


Diamond

Atomic Structure

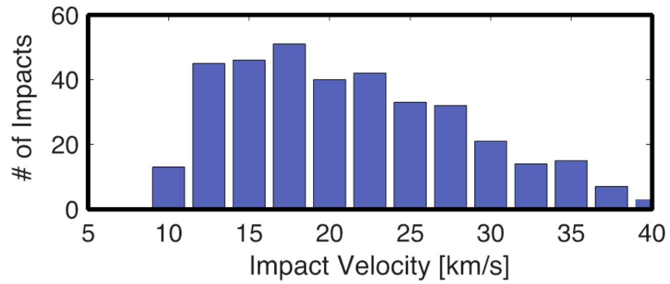


Strength of the material matters

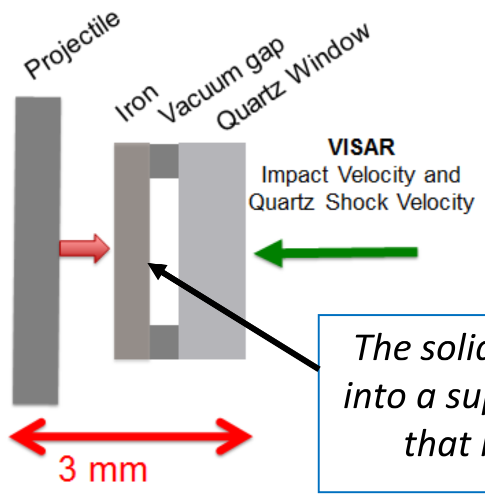


HED delivers validation data in regimes previously only accessed through theory and simulations

Materials – Vaporization of Iron

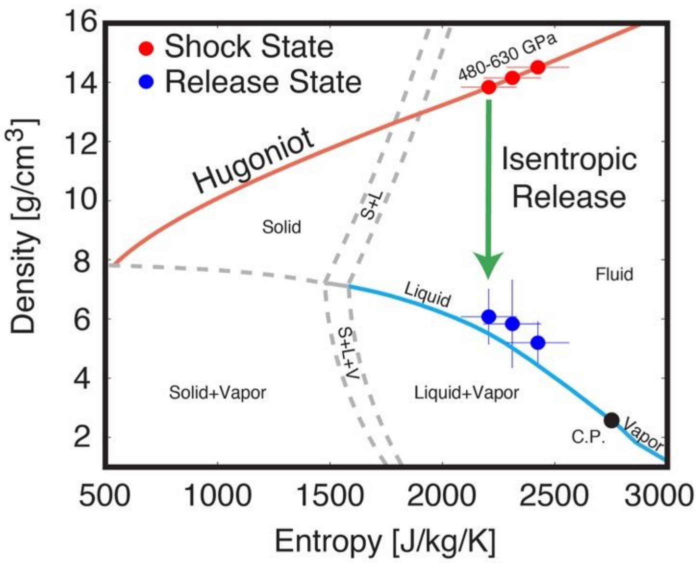


- On Z, can launch flyer plates up to 40 km/s
- It is possible to directly probe the full range of planetary impact conditions



The solid iron sample turns into a supercritical iron fluid that hits the window

Iron Shock and Release Data

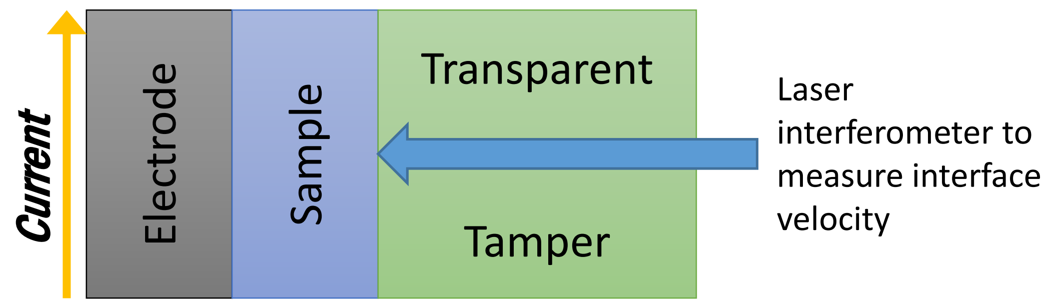


Partners: Harvard, UC Davis, LLNL

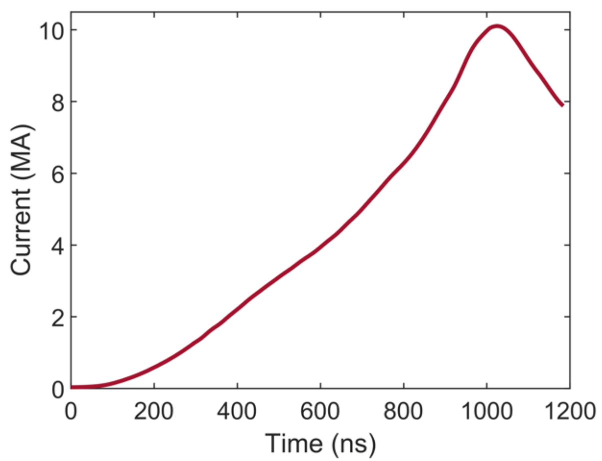
Materials – Tri-Lab Study of Tantalum Strength

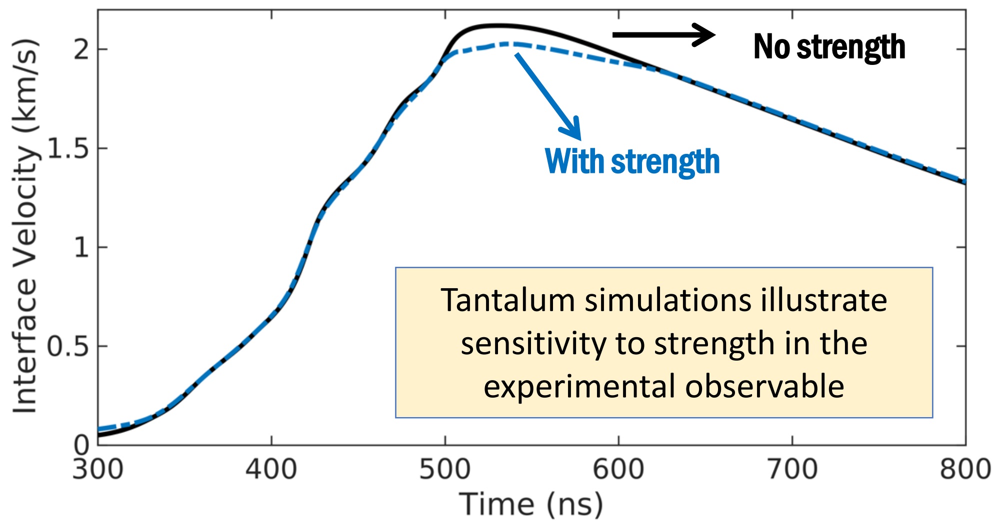
How does data from Z compare to gas gun or NIF data?

How much does the time scale or sample size affect the result?



Current pulse is shaped to result in ramp (shockless) loading of the sample





Partners: LANL, LLNL, SNL

Pulsed Power & HEDP within SRT&E

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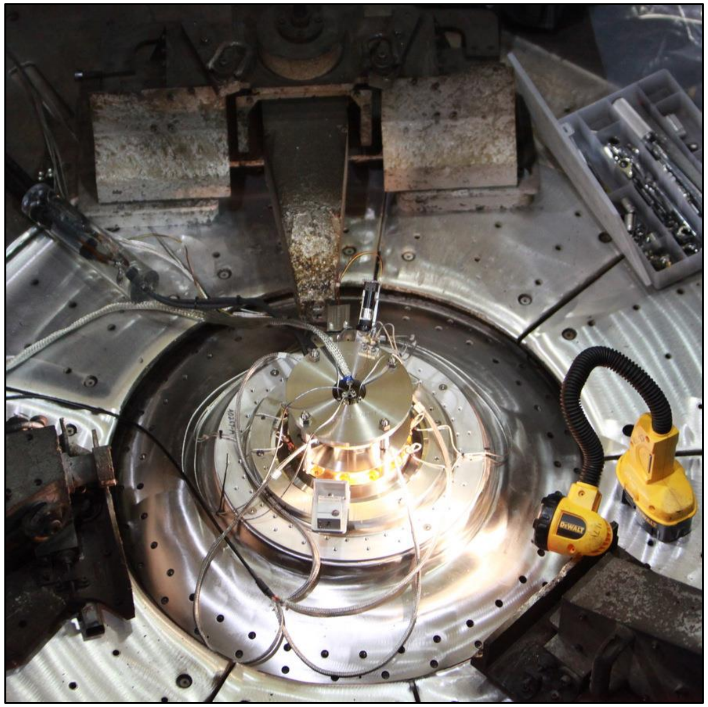
A Usual Day in the Target Chamber

Before

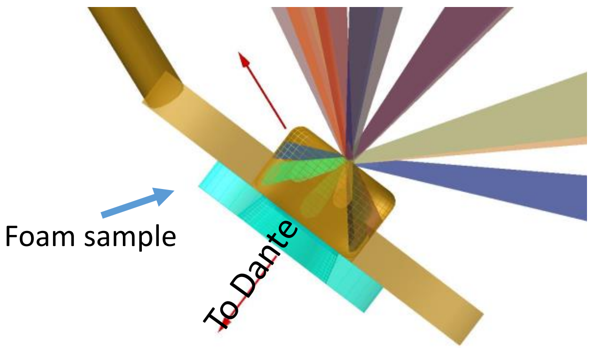


After

- Debris impacts laser optics and diagnostics
- Clean up and reload limits Z to 1 shot/day
- Diagnostic housings on Z are 2.5 cm thick tungsten
- Other facilities have their own harsh environments

Diagnostics/Platform Development for Plasma and Material Properties

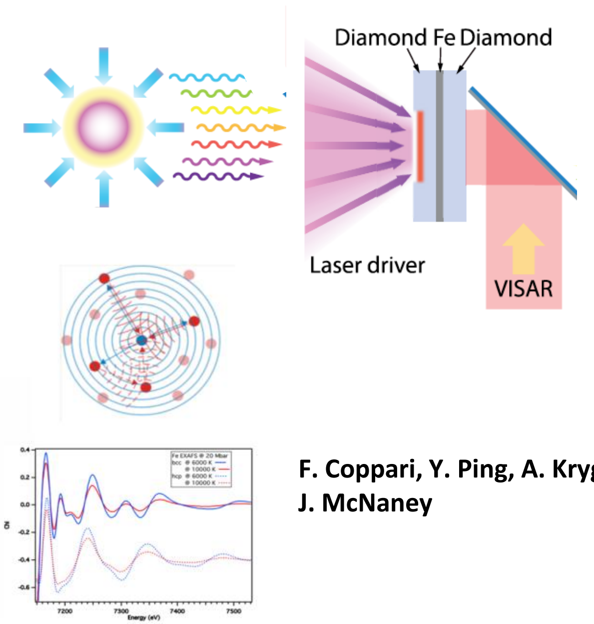
Foam/Porous EOS



Jon Eggert, Dayne Fratanduono, H.S. Park, Rick Kraus

EOS and properties of porous, foam, additive manufactured materials

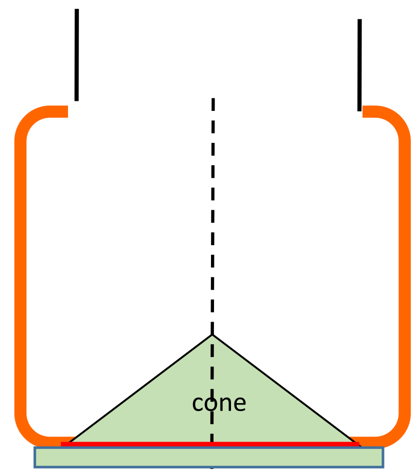
EXAFS



F. Coppari, Y. Ping, A. Krygier, J. McNaney

Develop EXAFS platform to infer bulk material temperatures

High Pressure Plasma EOS



Amy Jenei, Michelle Gregor, Damien Swift

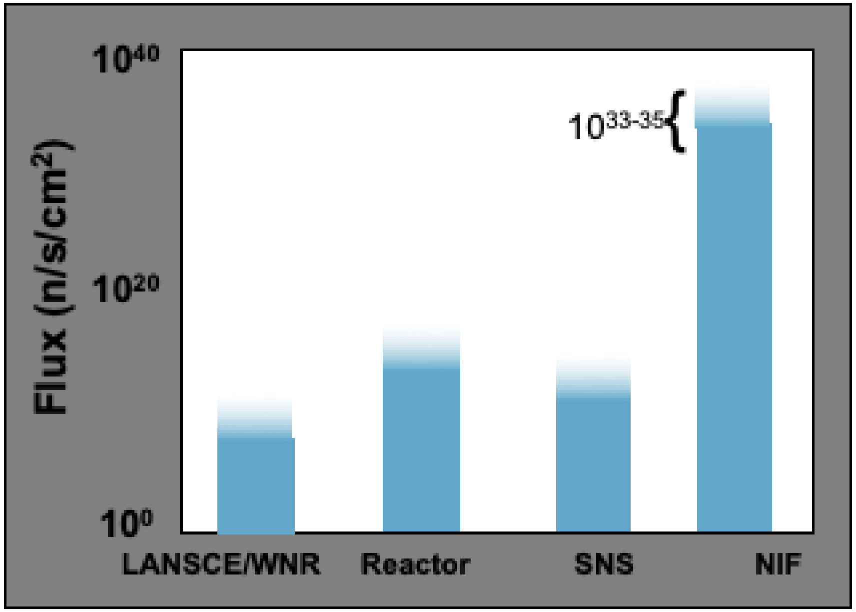
Develop an EOS platform to reach 100's of Mbar in a planar physics package

OK great, but what does this have to do with me?

or – jobs!

Research Background, Nuclear + Pulsed Power - NIF Radiochemistry (2008)

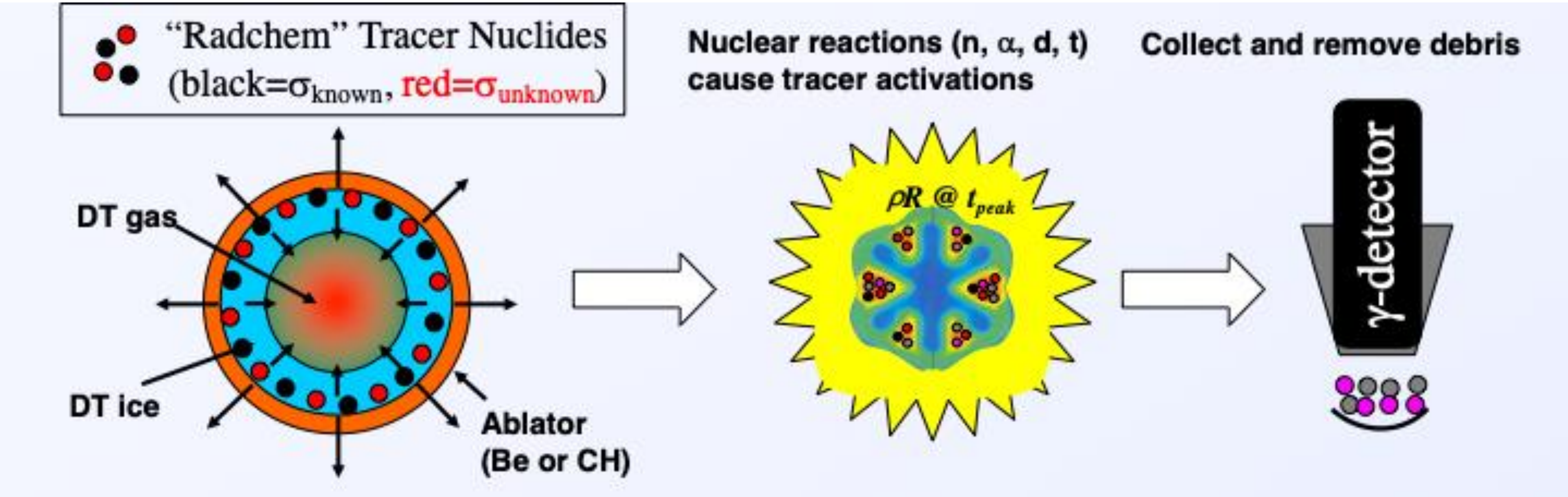
- Device performance was determined through tracer activations
- The majority of cross sections required to interpret tracer data are unknown
  - Theoretical cross sections have estimated uncertainties up to 50%
- Cross section measurements are required for validating codes and reducing uncertainties on performance
- Interpretation of radiochemical data has the largest uncertainties



The number of target atoms required for a measurement is inversely proportional to flux

NIF neutron flux will enable us to directly measure relevant cross sections for the first time

Research Background, Nuclear + Pulsed Power, con't.
- NIF Radiochemistry (2008)



- Radiochemical tracers added to a NIF capsule will undergo nuclear reactions with charged particles and neutrons.
- 50 kJ is sufficient for first-order reactions; ignition (>1 MJ) is required for multiple-order reactions
- Cross sections can be determined to 8% (most conservative estimate) assuming collection efficiency of $10^{-4} – 10^{-3}$

Future Stockpile Stewards

Confidence in stewards and capabilities grounded by experimental reality

Recruit, train, retain the next-gen stewards

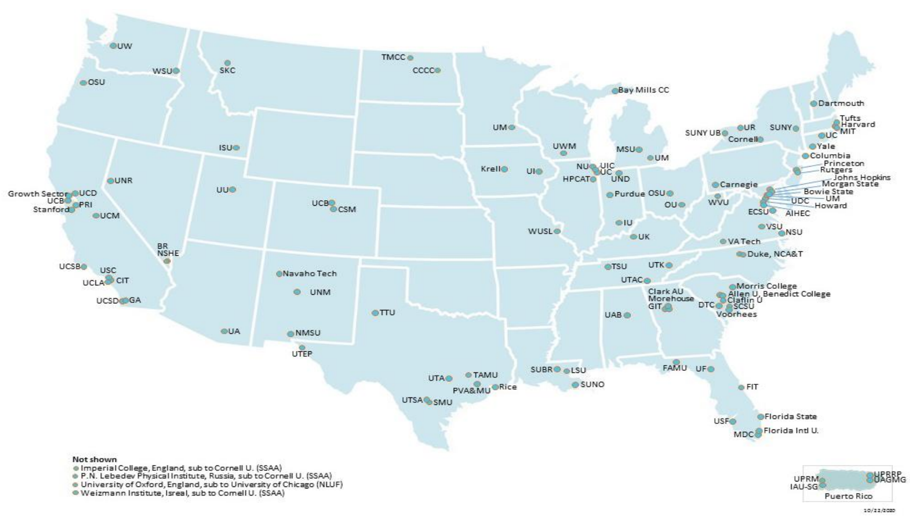
1945 | 1992 | Present | 2032

In the absence of further UGTs, HED and other experimental platforms are essential in recruiting, training, and retaining the next-generation stockpile stewards

Academic Programs of NA-11

Program Goals

- **Workforce Pipeline:** providing a diverse, skilled, technical future stockpile stewards
- **External Expertise:** assuring quality through external review, critique, challenge
- **Creative Input**: leveraging expertise in areas thinking outside the mission



- Stewardship Science Academic Alliance **(SSAA)**
- Minority Serving Institution Partnership Program **(MSIPP)**; *including: Tribal Education Partnership Program **(TEPP)***
- Joint Program in High Energy Density Laboratory Plasmas **(JPHEDLP)**
- Computational Science Graduate Fellowships **(CSGF)**
- Predictive Science Academic Alliance Program **(PSAAP)**

Opportunities for HEDLP in NNSA Academic Programs

JPHEDLP

- FY21 FOA expected **Dec 2020**
- Annual Joint NNSA and DOE Office of Science issued solicitation

SSAA

- FY23 Centers- FOA expected **late 2021**

NEW

NNSA-NSF MOU in HED Science

- Computational Science Graduate Fellowship, DEADLINE **1/13/2021**
  - https://www.krellinst.org/csgf/
- Laboratory Residency Graduate Fellowship, DEADLINE **3/17/2021**
  - https://www.krellinst.org/lrgf/
- Stewardship Science Graduate Fellowship, DEADLINE **1/16/2021**
  - https://www.krellinst.org/ssgf/
- NNSA Graduate Fellowship Program, DEADLINE **October 2021**
  - https://www.pnnl.gov/projects/ngfp

Cool. Anything else?

But wait! There's more.

HED/ICF Related Studies in 2020

ICF 2020	JASON	NAS
• The efficacy of reaching ignition on the NIF and achieve credible physics scaling to multi-megajoule fusion yields for each of the three major ICF ignition approaches	• Independent Review of the ICF Program (S.R. 116-102/H.R. 116-83/P.L. 116-94)	• Assessment of High Energy Density Physics (P.L. 116-92)
• Requirement: NNSA	• Requirement: SEWD/HEWD	• Requirement: SASC/HASC

HED/ICF Related Studies in 2020, con't.

Near-Peer Capabilities

- Plan to Meet or Exceed Near Peer Technology Development in Lasers and Pulsed Power (P.L. 116-94)
- Requirement: SEWD

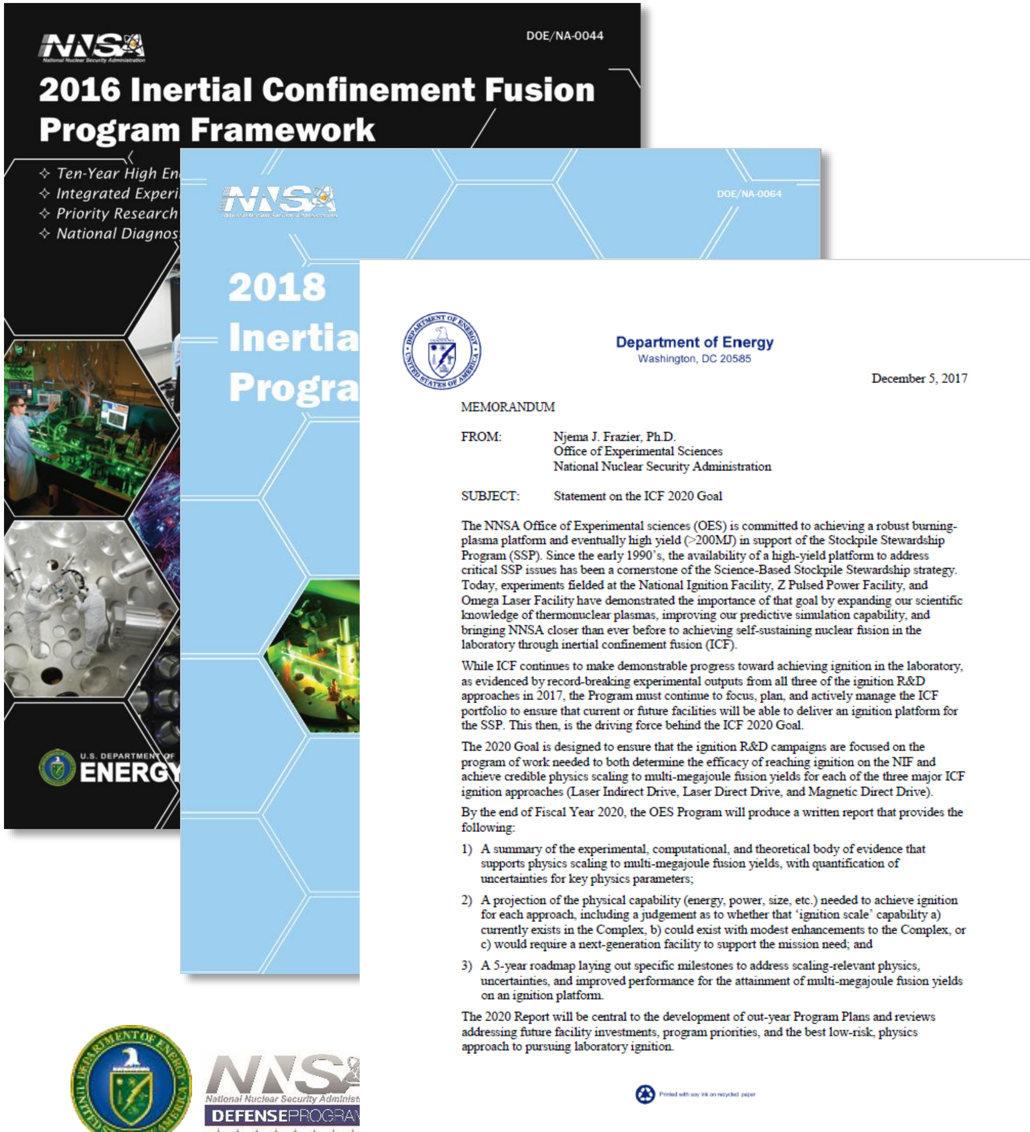
JPHEDLP

- Joint Program in High Energy Density Laboratory Plasmas (P.L. 116-94)
- Requirement: HEWD/SEWD

OTHERS

- Research in Plutonium Science and Metallurgy at the NNSA (S.R. 116-48)
- Major science questions facing the Stockpile Stewardship Program over the next 20 years (H.R. 116-120)
- Requirement: SASC & HASC, resp.

ICF 2020 Goal



Department of Energy
Washington, DC 20585

December 5, 2017

MEMORANDUM

FROM: Njema J. Frazier, Ph.D.
Office of Experimental Sciences
National Nuclear Security Administration

SUBJECT: Statement on the ICF 2020 Goal

The NNSA Office of Experimental sciences (OES) is committed to achieving a robust burning-plasma platform and eventually high yield (>200MJ) in support of the Stockpile Stewardship Program (SSP). Since the early 1990's, the availability of a high-yield platform to address critical SSP issues has been a cornerstone of the Science-Based Stockpile Stewardship strategy. Today, experiments fielded at the National Ignition Facility, Z Pulsed Power Facility, and Omega Laser Facility have demonstrated the importance of that goal by expanding our scientific knowledge of thermonuclear plasmas, improving our predictive simulation capability, and bringing NNSA closer than ever before to achieving self-sustaining nuclear fusion in the laboratory through inertial confinement fusion (ICF).

While ICF continues to make demonstrable progress toward achieving ignition in the laboratory, as evidenced by record-breaking experimental outputs from all three of the ignition R&D approaches in 2017, the Program must continue to focus, plan, and actively manage the ICF portfolio to ensure that current or future facilities will be able to deliver an ignition platform for the SSP. This then, is the driving force behind the ICF 2020 Goal.

The 2020 Goal is designed to ensure that the ignition R&D campaigns are focused on the program of work needed to both determine the efficacy of reaching ignition on the NIF and achieve credible physics scaling to multi-megajoule fusion yields for each of the three major ICF ignition approaches (Laser Indirect Drive, Laser Direct Drive, and Magnetic Direct Drive).

By the end of Fiscal Year 2020, the OES Program will produce a written report that provides the following:

1) A summary of the experimental, computational, and theoretical body of evidence that supports physics scaling to multi-megajoule fusion yields, with quantification of uncertainties for key physics parameters;
2) A projection of the physical capability (energy, power, size, etc.) needed to achieve ignition for each approach, including a judgement as to whether that 'ignition scale' capability a) currently exists in the Complex, b) could exist with modest enhancements to the Complex, or c) would require a next-generation facility to support the mission need; and
3) A 5-year roadmap laying out specific milestones to address scaling-relevant physics, uncertainties, and improved performance for the attainment of multi-megajoule fusion yields on an ignition platform.

The 2020 Report will be central to the development of out-year Program Plans and reviews addressing future facility investments, program priorities, and the best low-risk, physics approach to pursuing laboratory ignition.

Printed with soy ink on recycled paper

The 2020 Goal is designed to ensure that the ignition R&D campaigns are focused on the program of work needed to both determine the <u>efficacy of reaching ignition on the NIF</u> and achieve <u>credible physics scaling to multi-megajoule fusion</u> yields for each of the <u>three major ICF ignition approaches</u>

ICF 2020 Goal – Red Team

Detailed annual reviews of the program's plans for, and progress towards, the ICF 2020 goal.

Assess how new understanding has been incorporated into the plans for each approach

Opportunity for each of the three ignition approaches to adjust and improve their scaling arguments and to obtain feedback on the efficacy and completeness of their approach.

A new Charter is established each year that explicitly lays out the review criteria for that year's Red Team activities.

Each member of the Red Team provides their own independent evaluation report based on the review criteria for that year.

Comments from the Red Team are communicated back to the ICF program leads, action officers, and members of the ICF Executive Committee.

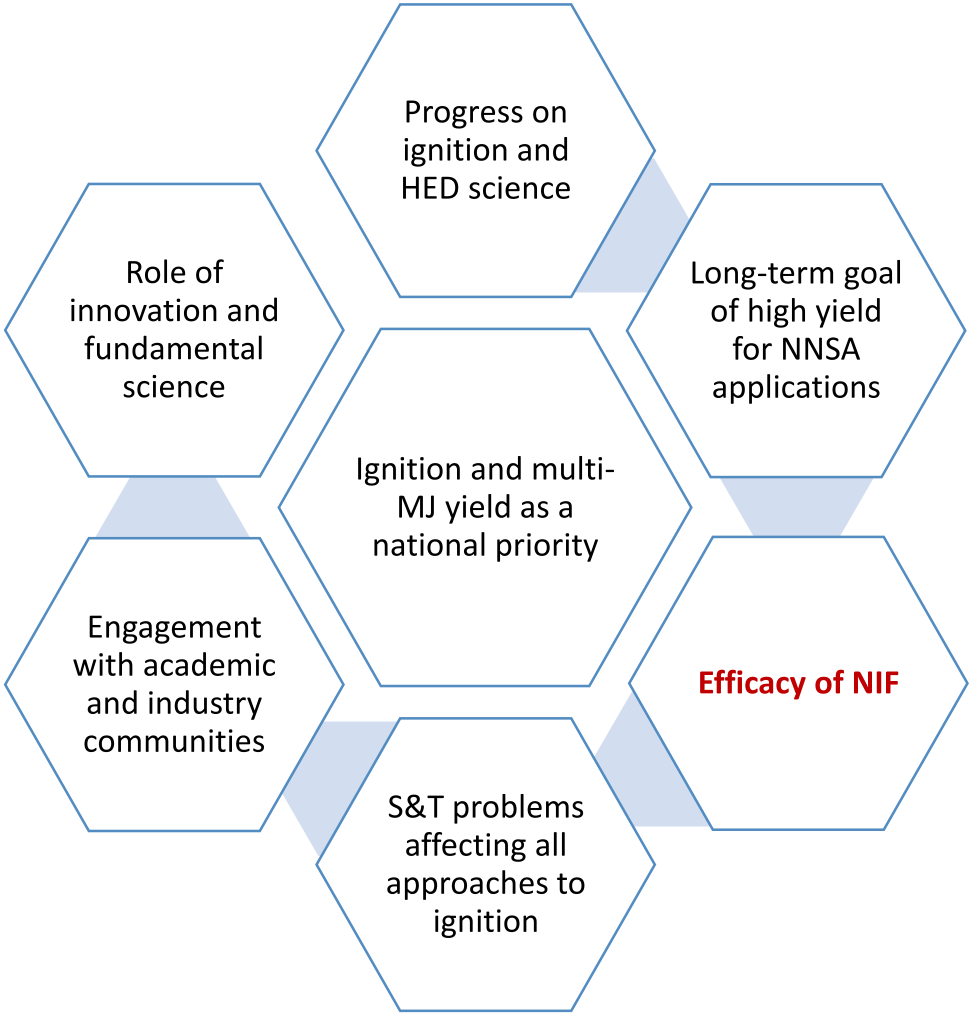
ICF 2020 Goal – Preliminary Statements (Nov 2020)

NIF is unlikely to achieve ignition as currently configured

- Remaining absorbed energy deficit

NIF continues to be our best platform to investigate ignition physics

- Continued progress in performance and understanding
- Open questions in compression, energy coupling, target engineering
- Laser, diagnostic, and target technology development



Office of Experimental Sciences | Office of Research, Development, Test, and Evaluation
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Ignition Science in the 2020s: Virtual Fall Workshop Series

- Review, refine and improve key scientific questions, technical goals, and research plans of the *national* US ICF effort for the next 5 years
- Identify opportunities for academic and industry collaborations to improve understanding and reduce scaling uncertainties towards ignition and multi-MJ fusion yield
- Working groups aligned with the major technical questions around performance and future scaling of ICF technologies *across approaches to ignition*
- Report from each working group identifying key questions, hypotheses, approaches, and research needs
- National laboratory staff, academia, industry
- Working group meetings ongoing
- February 2021: Summary report to NNSA

Working Groups
LPI
Hohlraum Physics
Current Delivery
Compression
Hot Spot Mix
Ignition Theory
Materials
Advanced analysis and simulation

Large HED facilities are as close as we can get to "holding the Sun" on Earth

- We precisely and reproducibly make macroscopic quantities (μL – mL) of high energy density, hot-dense matter which allows accurate study
- These conditions are invaluable for national security science and fundamental science
- When we make measurements on HED matter, ***quite often*** the measurements disagree with scientific predictions or expectations before the experiments → experiments are needed to validate our models
- We may someday be able to "create a star" in the laboratory, which would radically increase the HED conditions accessible

Questions