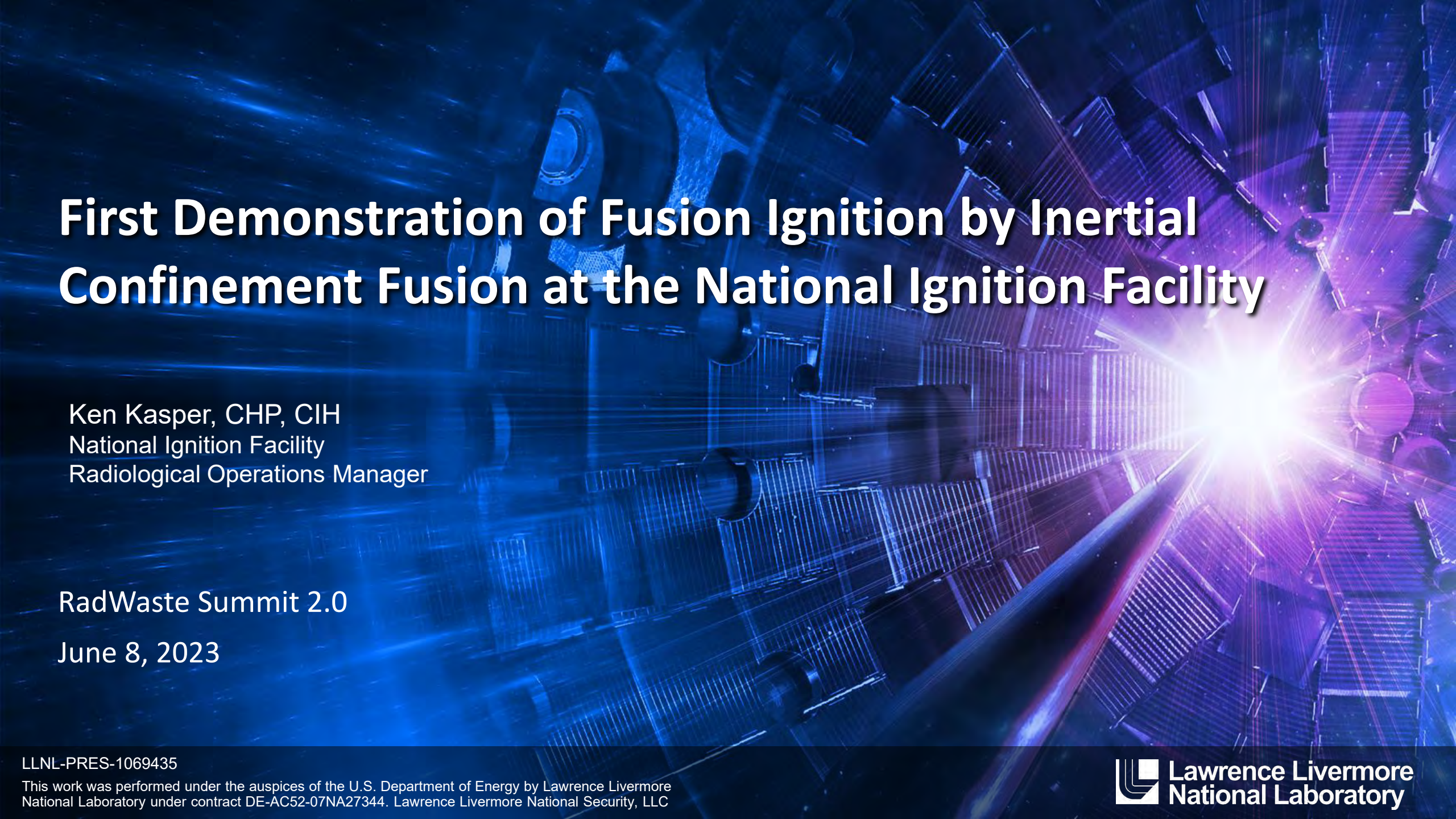

First Demonstration of Fusion Ignition by Inertial Confinement Fusion at the National Ignition Facility

Ken Kasper, CHP, CIH
National Ignition Facility
Radiological Operations Manager

RadWaste Summit 2.0

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LLNL-PRES-1069435

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Lawrence Livermore National Laboratory

Lawrence Livermore National Laboratory

- Established in 1952
- ~1.7M sq.ft.
- ~526 facilities
- Approximately 7,400 employees

NIF is the world's most energetic laser system enabling the study of high energy density conditions to support:

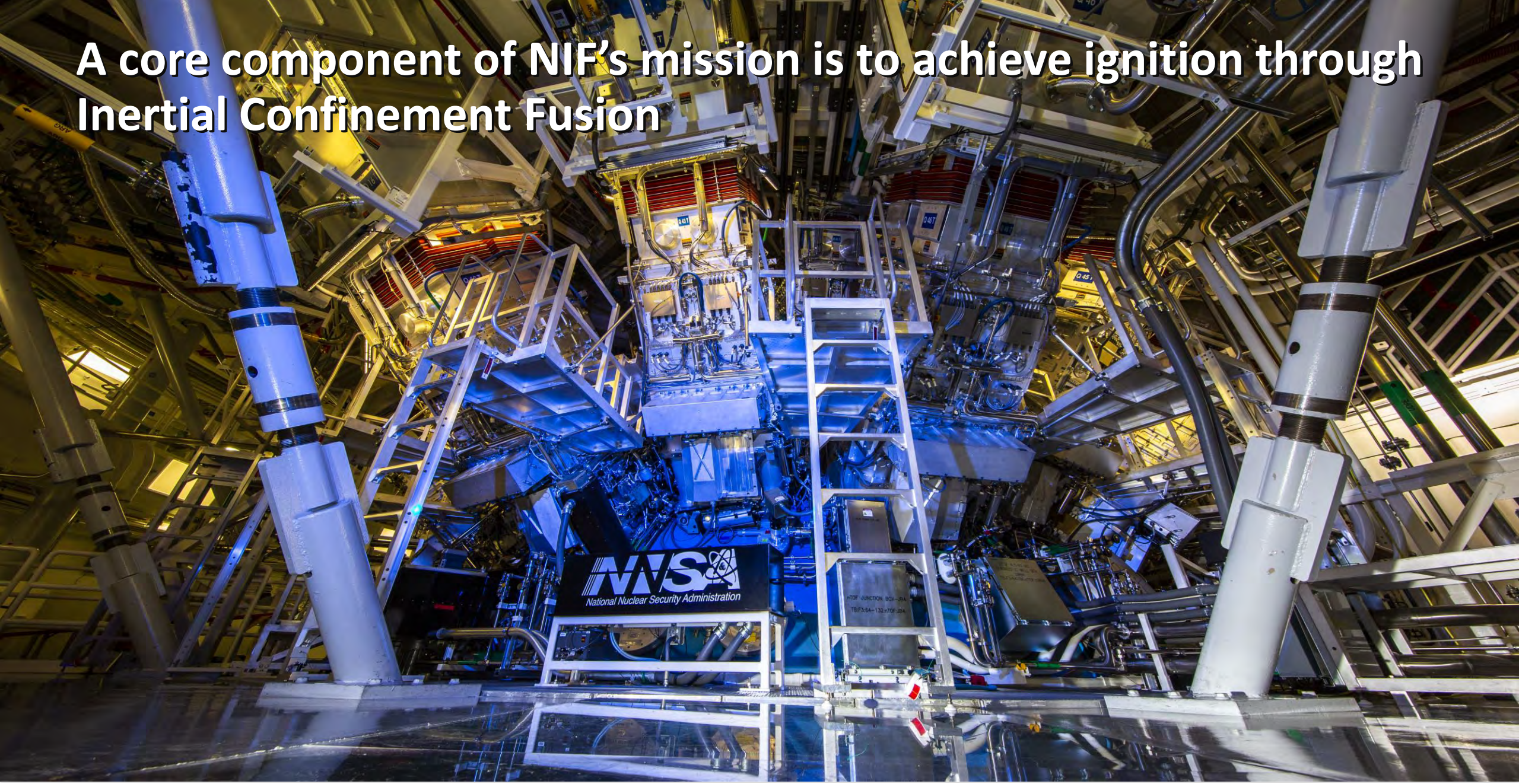
- Stockpile Stewardship
- Inertial Confinement Fusion
- Discovery Science

- 192 Beams, 1.9 MJ Energy, 500 TW Power
- Matter temperature >10^8 K
- Radiation temperature >3.5 x 10^6 K
- Densities >10^2 g/cm^3
- Pressures >10^{11} atm
- Number of Diagnostics >120

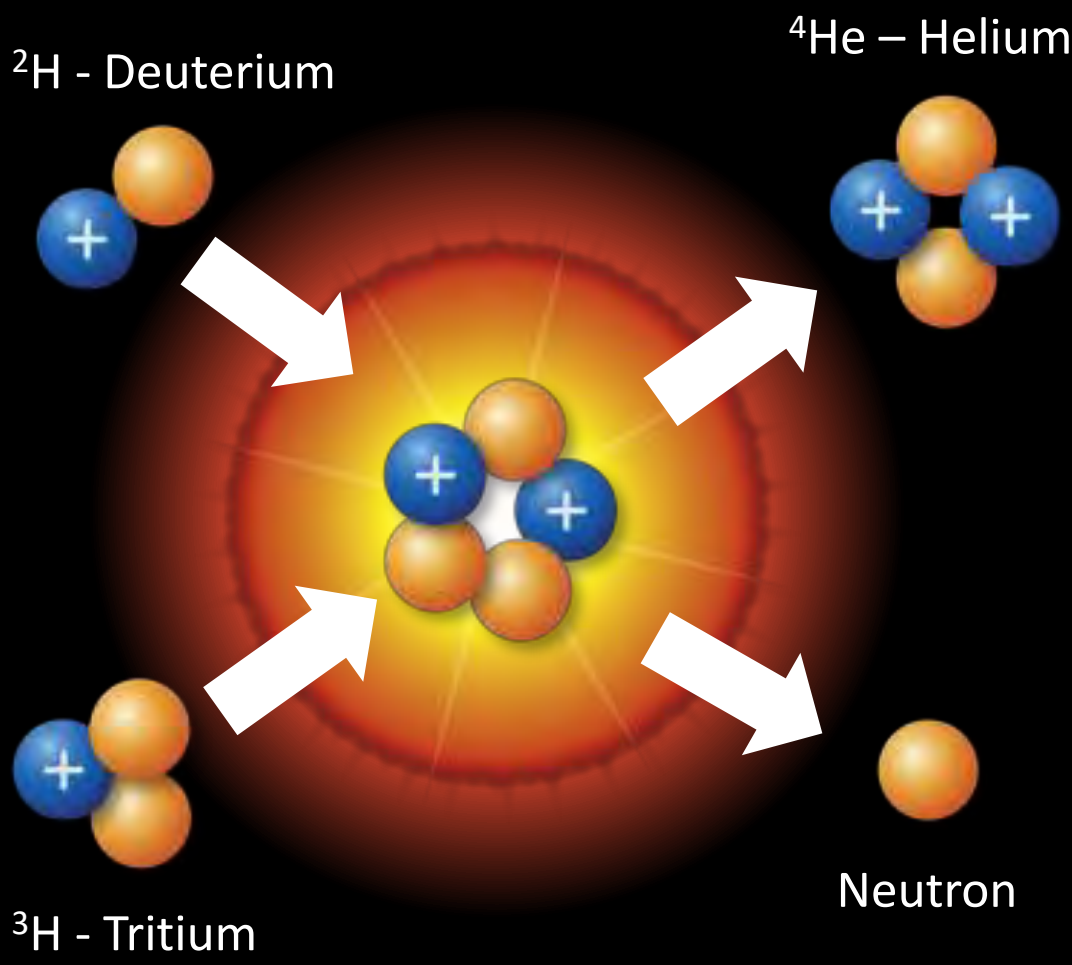
NIF is a core part of ensuring a safe and reliable deterrent without returning to underground nuclear testing

NIF provides a laboratory to test our understanding of diverse and extreme physical regimes — the same regimes experienced by stars and our nuclear deterrent, and required for fusion energy

A core component of NIF's mission is to achieve ignition through Inertial Confinement Fusion

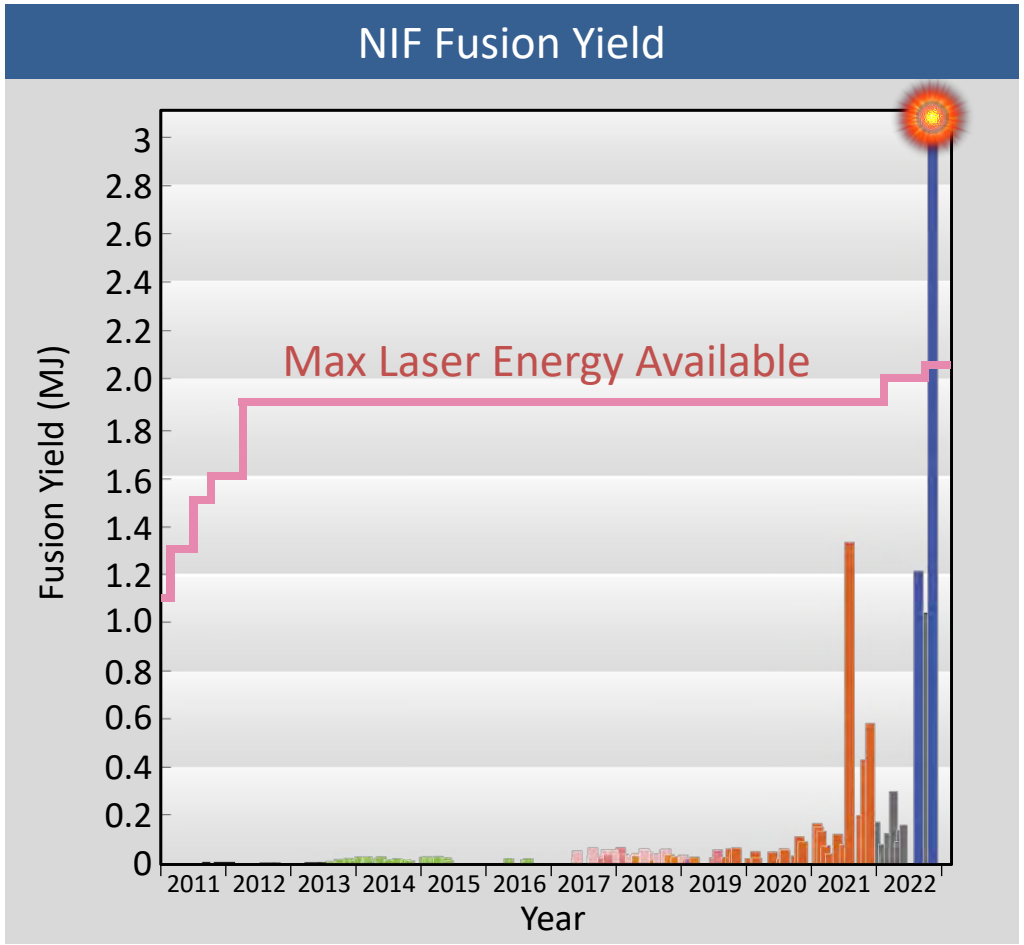


The sun and the stars are powered by fusion



192 laser beams are concentrated onto a mm^3 target

On December 5, 2022, NIF exceeded the threshold* for ignition, with 3.15 MJ of fusion output for 2.05 MJ laser delivered



- This shot used a new increased energy laser drive capability (2.05 MJ on target) and a slightly thicker shell, and resulted in a target gain of 1.5 and a capsule gain of ~12
- This shot follows a series of alpha dominated burning plasma experiments which achieved 100's kJ – 1.35 MJ [1,2,3] and built understanding in the ignition regime.
- Achieving such yields required a concerted long-term effort to improve our:
  - Target quality
  - Laser accuracy and increased energy delivery
  - Diagnostic capabilities
  - Physics Design
- Improved understanding has led to design refinements enabling 3 shots that have exceed a MJ since Fall 2022

Ignition enables a new era of applications for stockpile stewardship and the foundation for inertial fusion energy

*National Academy of Sciences 1997 definition for ignition, target gain >1

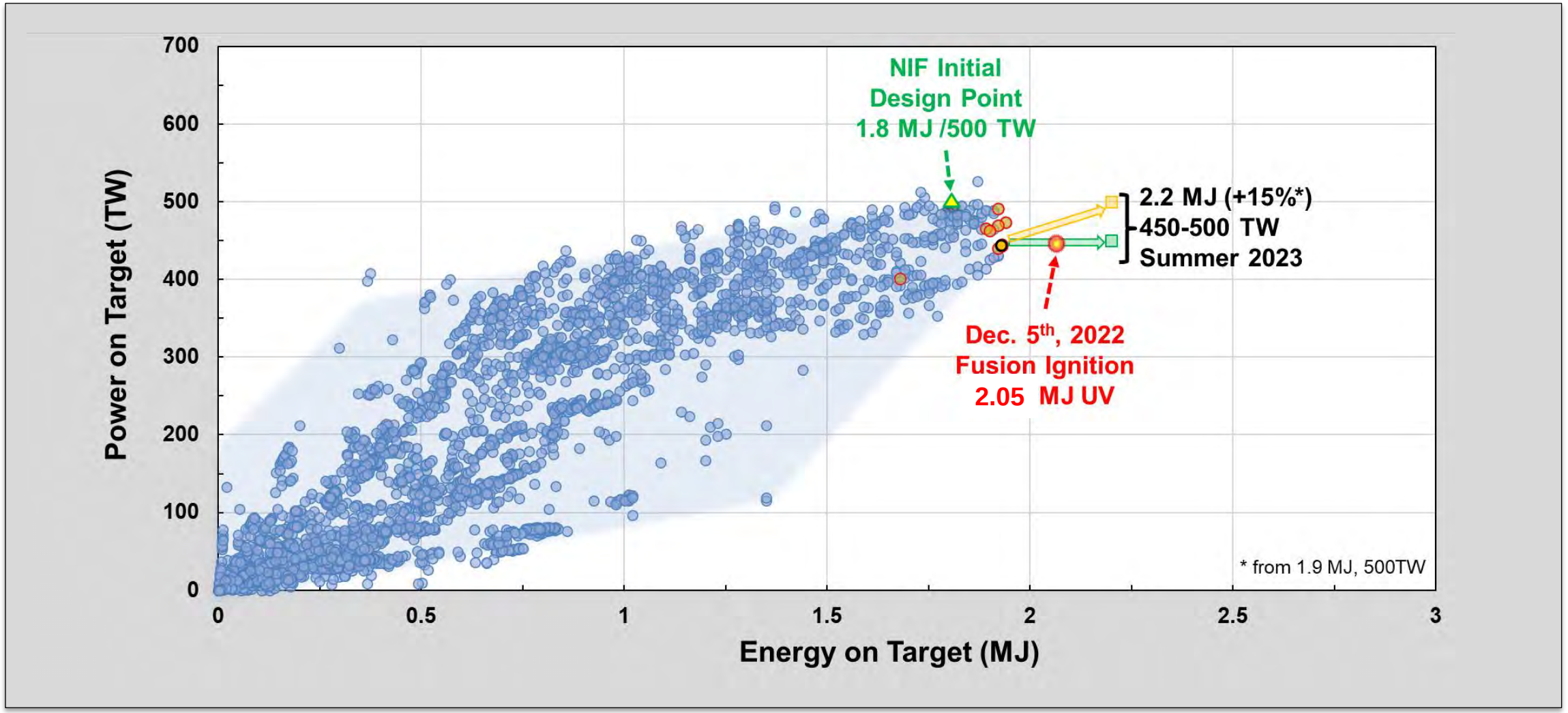
[1]H. Abu-Shawareb et al., PRL, 129, 075001 (2022)
[2]A. L. Kritcher et al., PRE, 106, 025201 (2022)
[3]A. B. Zylstra et al., PRE, 106, 025202 (2022)

Next Steps: exploit ignition for stewardship application with routine MJ-yield operations and ignition

NIF has not yet reached its full potential

Few MJ	Yield
2023 Routine MJ-yield operations and ignition	2023–2028 Long-term Sustainment Increase Energy and Power
2.2 MJ	Laser Energy

For the summer 2023, the NIF laser will deliver 8% more energy compared to Dec. 5th, providing more margins and allowing routine MJ yields

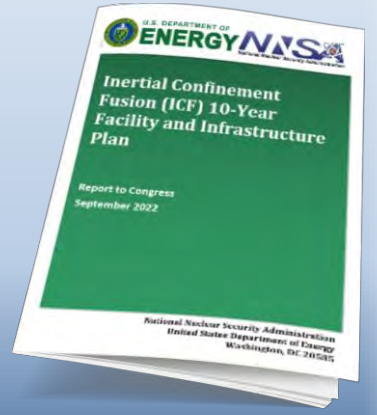


Di Nicola et al. *Nucl. Fusion, 59,* (2019)

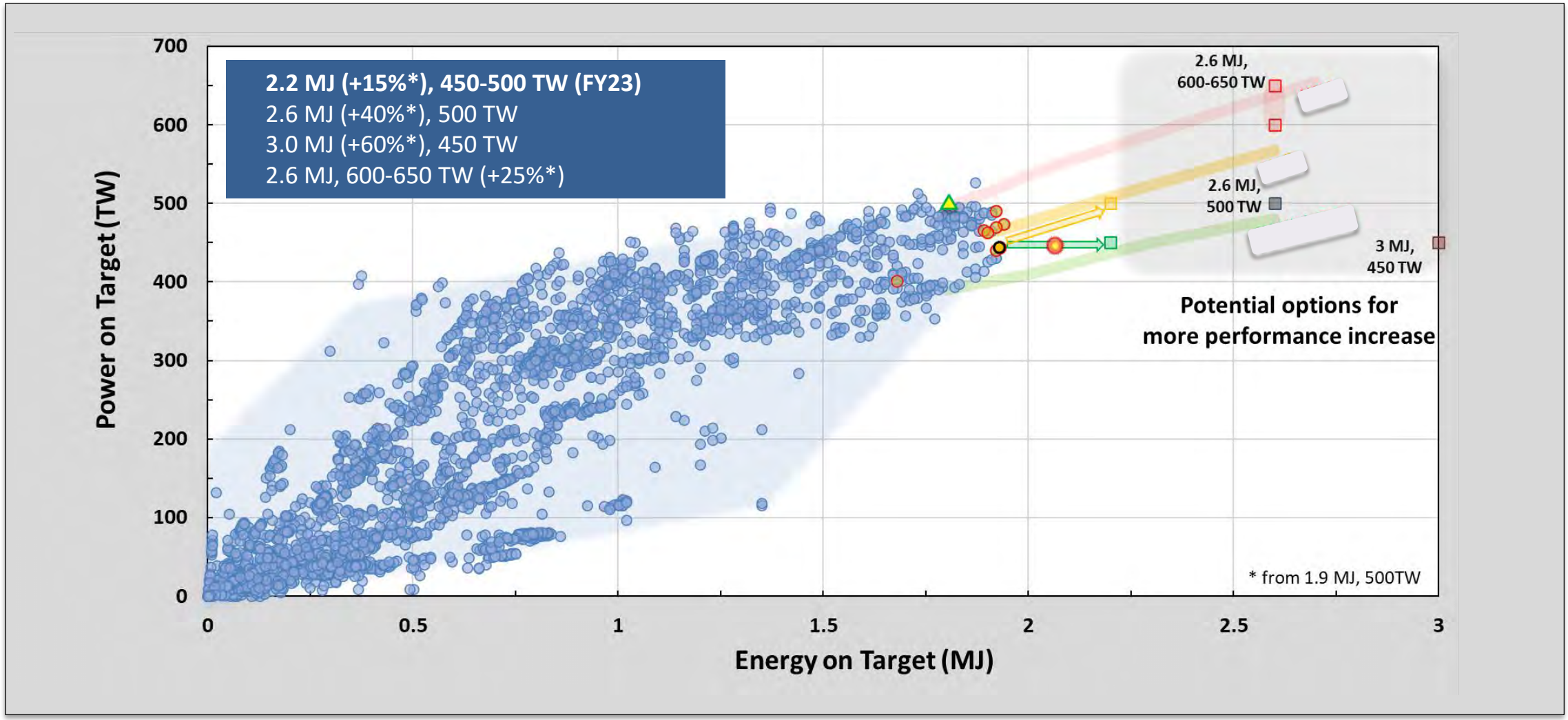
Next Steps: Perform long-term sustainment, increase energy and power

NIF has not yet reached its full potential

Few MJ	10s of MJ	100+ MJ??	Yield
2023	2023–2028	2030–2040	
Routine MJ-yield operations and ignition	Long-term Sustainment	Increase Energy and Power	Explore high-yield, high-gain regime
2.2 MJ	2.6-3 MJ		Laser Energy



The current NIF design, with modest modifications, can support much higher performance



Di Nicola et al. *Nucl. Fusion, 59,* (2019)

Next Steps: Explore high-yield, high-gain regime

NIF has not yet reached its full potential

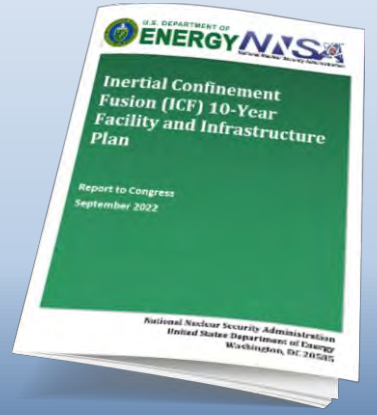
Few MJ → 10s of MJ → 100+ MJ?? (Yield)

2023

Routine MJ-yield operations and ignition

2023–2028

Long-term Sustainment



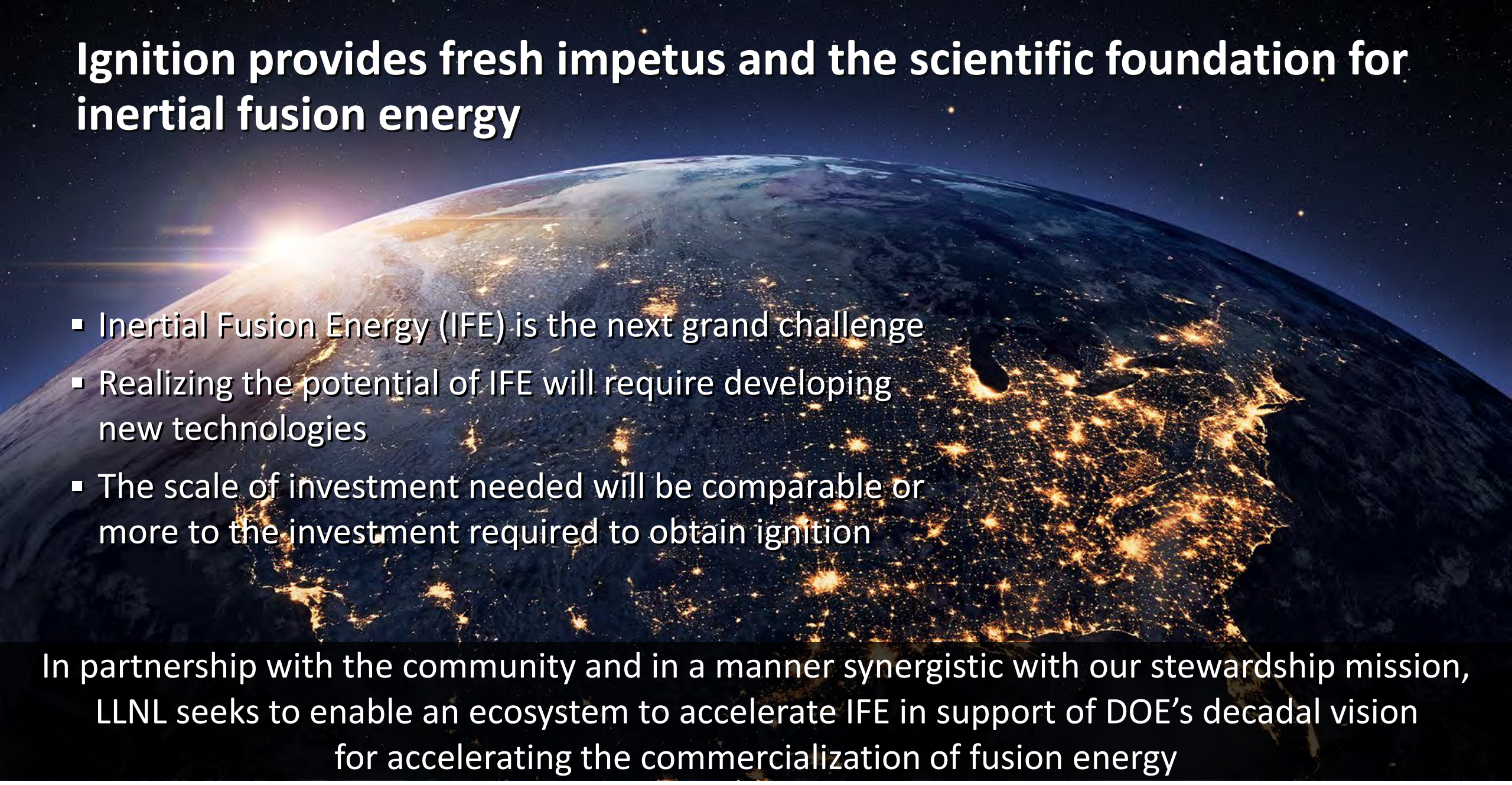
Increase Energy and Power

2030–2040

Explore high-yield, high-gain regime

2.2 MJ → 2.6-3 MJ → Laser Energy

Ignition provides fresh impetus and the scientific foundation for inertial fusion energy

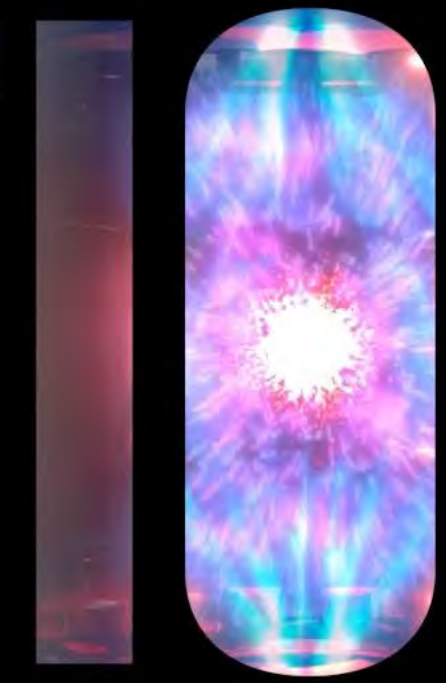


- Inertial Fusion Energy (IFE) is the next grand challenge
- Realizing the potential of IFE will require developing new technologies
- The scale of investment needed will be comparable or more to the investment required to obtain ignition

In partnership with the community and in a manner synergistic with our stewardship mission, LLNL seeks to enable an ecosystem to accelerate IFE in support of DOE's decadal vision for accelerating the commercialization of fusion energy

NATIONAL

IGNITION



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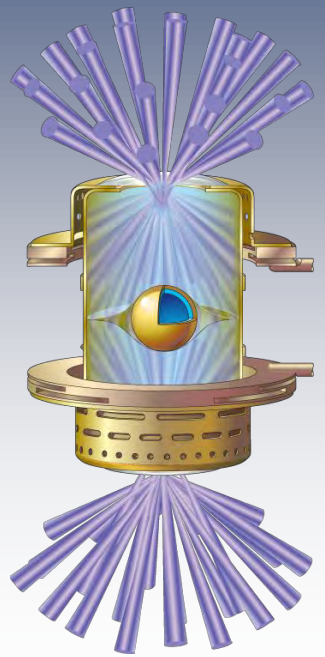
STAR TREK
INTO DARKNESS
05.17.13

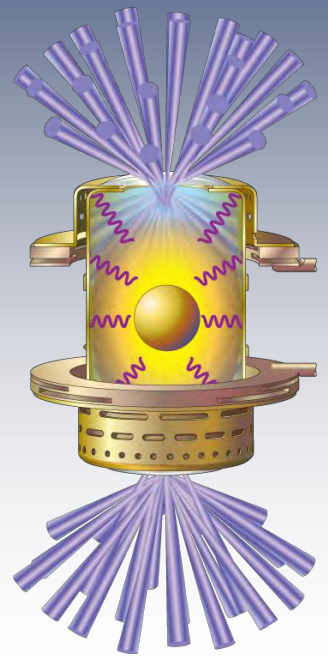
In building NIF, many challenges were addressed, relying on decades of advances on optical material, pulsed power, laser physics and architectures, target fabrication, and diagnostics

The NIF uses a laser driven hohlraum to compress a fuel capsule to achieve the conditions for ignition

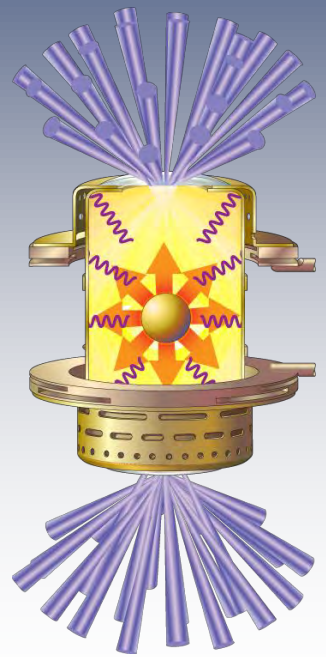
Each of the 192 laser beams are focused onto the inner wall of the hohlraum



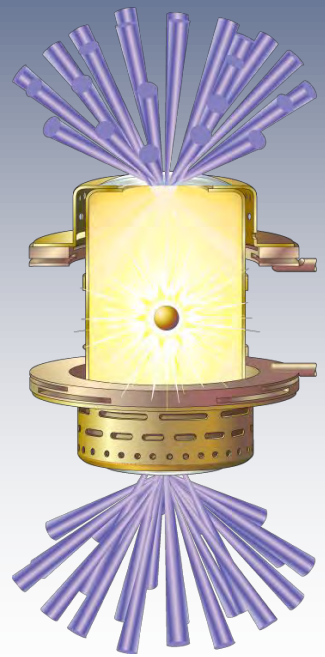
Laser beams rapidly heat the inside surface of the hohlraum creating x-rays



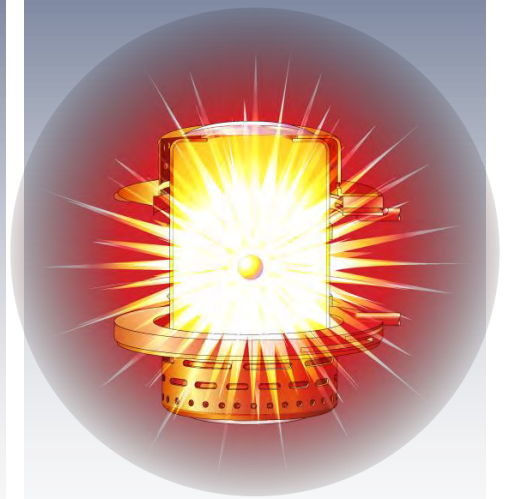
The x-rays blow off the fuel capsule wall, accelerating the fuel inward to ~500 km/s



The fuel core reaches 100 times the density of lead and ignites at 100,000,000°C



Fusion burn spreads rapidly through the compressed fuel, yielding many times the input energy



Achieving ignition in the laboratory is a Scientific Grand Challenge nearly 60 years in the making

J. Lindl, *PoP*, 1995; S. Haan, *et al*., *PoP,* 2011
J. Nuckolls et al., *Nature*, 1972