# NATIONAL IGNITION FACILITY

## Supporting stockpile sustainment and modernization through a wide range of high-energy-density (HED) science experiments and capabilities, including fusion ignition

*Technicians work inside NIF's target chamber, where the decades-long quest to achieve fusion ignition and energy gain in a laboratory setting culminated with a NIF experiment performed on December 5, 2022.*

### IGNITION ACHIEVED

A historic inertial confinement fusion (ICF) experiment at the National Ignition Facility (NIF) on December 5, 2022, achieved ignition and energy gain, with 2.05 megajoules (MJ) of delivered laser energy producing 3.15 MJ of fusion energy. The NIF team bettered this result in a shot on July 30, 2023, that attained 3.88 MJ of energy with the same laser energy. Subsequent experiments in October 2023 achieved, respectively 2.4 MJ and 3.4 MJ. These remarkable results were made possible by the hard work of the ICF community over many decades and benefited from key advances gained over the last several years.

Achievement of ignition and energy gain is a major accomplishment of the Stockpile Stewardship Program and vital to meeting current and future needs for stockpile sustainment and modernization. Ignition and thermonuclear burn are complex processes that involve the physics of hot, dense plasmas, which are very challenging to model even on the fastest supercomputers. NIF fusion experiments will enable scientists to gain insights and gather data to better understand the underlying physics. The knowledge gained and improvements in the physics codes will help reduce uncertainties in and assessing weapon performance. Experiments that produce copious amounts of high-energy neutrons are also important to assuring the survivability of U.S. nuclear weapons and other military systems in threat nuclear environments (see p. 6).

### ICF TARGET DESIGN IMPROVEMENTS

ICF target designers use information gained from experiments to enhance multiphysics simulation codes that are applied to improve target performance. The arrival of the Sierra supercomputer in 2018 provided a major step in capability, enabling the first high-resolution spherical 3D simulations of ICF implosions with the HYDRA code. The simulations gave scientists a clearer understanding of what obstacles prevented ignition and predicted that a better target design and quality was needed to succeed. Designers used HYDRA to devise a more robust target for a higher energy laser pulse, changing the hohlraum's size and making the capsule thicker to increase the stability of the implosion. In parallel, the target fabrication team improved target production processes resulting in improved capsule quality. For the shot in December 2022, the design team estimated a slightly better than 50 percent chance of break-even fusion yield.

ICF target design is further benefiting from application of cognitive simulation (CogSim)—the combining of machine learning and artificial intelligence techniques with high-performance computing simulations and empirical data to dramatically improve predictive analysis. A promising technique, called transfer training of a deep neural network, trains the machine with simulations, and then "corrects" the model through additional training using experimental results. Transfer learning from additional experiment results leads to continual improvement of the tool.

*The new fused silica debris shield optic, shown here being inspected through the Advanced Mitigation Process to improve its laser damage resistance, was a critical factor in NIF's ability to deliver more than 2 megajoules of laser energy.*

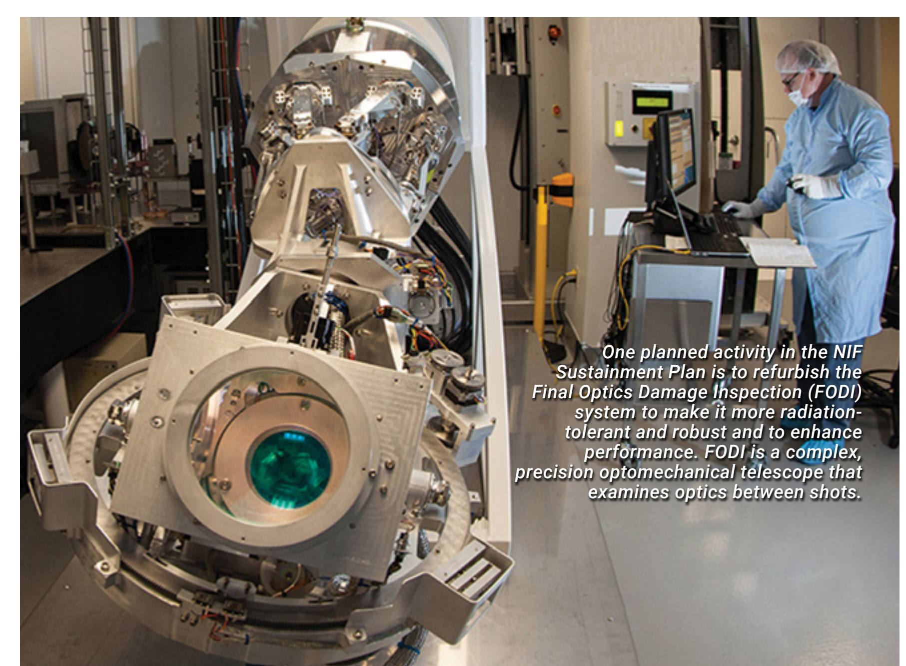
### IMPROVED LASER PERFORMANCE

To achieve ignition, NIF's laser system needed to deliver higher energy with precise control of the energy balance across all 192 laser beams. Precision starts in the master oscillator room, which generates low-energy laser pulses that are greatly amplified. They are precisely shaped in time and frequency-broadened to help smooth the intensity of the laser beams. In 2022, the NIF team completed a three-year modernization project that upgraded the 20-year-old system to enhance its capabilities and meet more stringent performance requirements to achieve ignition.

Precisely controlled higher laser energy succeeded in achieving ignition of the improved target. Advances in optics engineering enabled ignition shots at greater than 2 MJ of laser energy. The principal challenge was better protecting precious laser optics from debris created by the experiment. NIF was designed and built with two debris shields to protect the final optics: a disposable shield and the grating debris shield (GDS). In 2021, installation began of a third layer of protection—the fused silica debris shield (FSDS)—between the two shields to protect the valuable GDS from debris from the disposable shield. The FSDS has reduced the number of damage sites on the GDS by 98 percent. This reduction and efficient processes for inspecting and repairing FSDSs has enabled NIF ignition shots at 2.05 MJ—and in early FY 2024, the first experiment at 2.2 MJ, which yielded 3.4 MJ of fusion energy.

### SCIENCE EXPERIMENTS AT NIF

In FY 2023, the broad range of capabilities users have for studying HED science at NIF expanded with the introduction of a new experimental platform called the colliding planar shocks (CPS) platform. It promises to deliver precise measurements of the characteristics of warm dense matter (WDM), a state of matter exhibiting properties of both solids and plasmas. The CPS platform uses NIF laser beams to create two counter-propagating shock waves that produce uniform plasma conditions when they collide in the center of a cylindrical sample. Both x-ray scattering and radiographic data are obtained, enabling determination of density, temperature, and ionization state. Studying WDM, which makes up the cores of giant planets and brown dwarf stars, helps scientists gain a better understanding of the nature and evolution of the universe. The topic also sheds light on issues relevant to nuclear weapons science and ICF implosions.



*One planned activity in the NIF Sustainment Plan is to refurbish the Final Optics Damage Inspection (FODI) system to make it more radiation-tolerant and robust and to enhance performance. FODI is a complex, precision optomechanical telescope that examines optics between shots.*

### NIF REFURBISHMENT

In FY 2023, the NIF team began work on a multiyear Sustainment Plan to carry out urgently needed refurbishments and recapitalizations to assure mission delivery through the facility's design lifetime to 2040. Since experiments began in 2009, NIF has been exceptionally productive and reliable, with fewer than 30 days of unplanned down time in more than 2,400 days of shot operations. Maintenance has been an ongoing priority, but the facility has reached the age that a major effort is neccesary to address aging systems and reduce a backlog of deferred maintenance. The team identified 30 key refurbishment and recapitalization activities. The most urgent is elimination of debris in the amplifier and final optics systems that is threatening to lower NIF performance. In addition, obsolete components will be replaced and some equipment hardening is needed to tolerate the more extreme radiation environment produced in high-energy-yield shots. Completion of the NIF Sustainment Plan over the next several years will ensure the facility can continue to operate at high performance levels through the 2030s. The refurbishment will position NIF for future successes and is foundational to an upgrade being planned to push NIF's performance beyond the current baseline and enable higher yields for national security applications.