

# NATIONAL IGNITION FACILITY

Supporting stockpile modernization through a wide range of experiments and with achievement of ignition, and operating as a national user facility for high-energy-density science

*A target area operator services a Dante diagnostic, a broadband, time-resolved x-ray spectrometer that measures the hohlraum temperature. It is one of NIF's more than 100 advanced diagnostics designed, built, and honed with collaborators.*

## RECORD-BREAKING FUSION EXPERIMENTS

On April 7, 2025, NIF produced a record-breaking 8.6 megajoules (MJ) of energy in an inertial confinement fusion (ICF) experiment. The lasers delivered 2.08 MJ of energy to the target in a pulse with 456 terawatts of peak power. In addition to being the highest yield shot, the test achieved a record-setting target gain of 4.13. The previous record yield of 5.2 MJ was set in February 2024. The April experiment was a retest of an improved target design that achieved 5 MJ of energy and a target gain of 2.4. The notably better performance has been attributed to the combined effects of a higher quality target and improved laser delivery.

Ignition shots provide unique opportunities to collect valuable data to assure that the nation's nuclear weapons and other critical military systems would survive and function under hostile conditions in a nuclear conflict. The created intense dose of neutrons can be used to test components and materials. A milestone experiment performed by LLNL tested the survivability of weapons-

grade plutonium samples (see p. 9). A Los Alamos National Laboratory (LANL)-led team fielded an ignition experiment in June 2025 to explore a novel means for studying the effects of x-rays produced by the burning plasma on materials located outside the hohlraum. The team tested the Thinned Hohlraum Optimization for Radflow (THOR) window diagnostic system as a modification to the record-breaking LLNL target system design. Achieving 2.4 MJ, the test showed that THOR's x-ray windows worked and did not prevent ignition from occurring.

## NIF REFURBISHMENT

In FY 2025, the NIF team continued work on a multiyear Sustainment Plan to carry out urgently needed refurbishments, recapitalization, and improvements to assure mission delivery through the facility's design lifetime into the 2040s. Obsolete components are being replaced and some equipment hardening is needed to tolerate the more extreme radiation environment produced in high-energy-yield shots. Last year, a multiyear effort began to refurbish each of the 192 integrated optical modules (IOMs) that sit at the

edge of the target chamber. The crucial final optics inside the IOMs are exchanged regularly, but the modules themselves have experienced wear and tear over 20 years. A source of debris was identified that particularly affects the 32 upper inner beamlines. A fast-track refurbishment effort of the one-ton IOMs is underway and will be completed in FY 2026. As a precautionary step, the maximum NIF shot energy has been lowered from 2.2 MJ to 1.9 MJ and will be raised as progress on the refurbishment dictates.

## AI ASSISTED TRANSFORMATION

Innovative application of AI at NIF is assisting both target design and operational efficiency. In one project, an LLNL-led tri-laboratory team is applying semi-autonomous AI to accelerate the pace of ICF target designs. With a tool called the Multi-Agent Design Assistant (MADA), they are using a specially trained large language model to interpret natural language prompts from human designers, generate full physics simulation decks for MARBL (a next-generation 3D multiphysics code), and launch the files

to run on El Capitan or Tuolumne. In a recent demonstration, MADA successfully took a hand-drawn capsule diagram and a natural language request from a human designer, then produced a complete simulation deck and ran thousands of simulations to explore variations in ICF capsule geometry to generate a novel target design.

A NIF team is also working in partnership with Amazon Web Services to develop an AI-driven troubleshooting and reliability system. The AI integration project aims to enhance efficiency, improve responsiveness, and support NIF operations into the 2040s and beyond. The team recently completed the first phase of integrating generative AI capabilities into operations. Advanced semantic search capabilities are now deployed across NIF's comprehensive operational history, encompassing more than 98,000 archived problem logs spanning 22 years of operations. This extensive dataset includes detailed documentation of symptoms, causes, and corrective actions taken across all NIF systems. The project aims to establish a new standard for AI application in high-stakes scientific facilities and may influence operational approaches at other national laboratories.

## A MILESTONE NUCLEAR SURVIVABILITY TEST

In a pioneering nuclear survivability experiment conducted on October 1, 2025, weapons-grade plutonium samples were exposed to intense, pulsed thermonuclear neutron radiation at NIF, recreating in a safe and controlled laboratory setting some of the conditions associated with a nuclear encounter. The results provide essential data for assessing the resilience of strategic systems such as the W87-1 in



*The cryogenic-compatible x-ray, neutron, and blast snout safely houses material samples to be subjected to fusion ignition irradiation environments inside a solid double-containment enclosure during a NIF experiment.*

hostile threat environments and support ongoing efforts to modernize and ensure the reliability of the U.S. nuclear deterrent. The experiment produced a fusion yield of 3.6 MJ and an intense 14 megaelectron volt (MeV) neutron source for survivability studies—the kind of environment made possible by ignition-class shots. Researchers used gram-quantity pit core samples from a legacy W87-0 pit and a newly manufactured W87-1 pit produced at LANL, which were securely sealed within specialized hardware and safely subjected to a high-fluence 14 MeV neutron environment. Following the experiment, the samples were removed and analyzed under strict safety protocols.

A multiyear campaign at NIF has also led to the development of a capability to measure the temperature of materials—and in particular, plutonium—under extreme pressure. Material temperature has been a

missing gap of information in equation-of-state experiments at hundreds of gigapascal pressures crucial to weapons performance, ICF, and planetary science. The extended x-ray absorption fine structure (EXAFS) diagnostic capability is designed to fill that gap. EXAFS can determine a material's properties by knocking electrons out of their orbits around an atom's nucleus and observing their interaction with other atoms.

## ENHANCED YIELD CAPABILITY FOR NIF

DOE's approval in September 2024 of a Critical Decision 0 (CD-0) was an important first step for the Laboratory's Enhanced Yield Capability (EYC) project. In June 2025, the LLNL EYC project team completed a Conceptual Design Review that was well received by NNSA and an external review committee—moving EYC closer to a CD-1 decision in early FY 2026. The project entails installing additional laser glass in unused empty locations in NIF's power amplifiers, which will boost the laser's maximum energy from 2.2 MJ to 2.6 MJ. At that higher level, fusion yields greater than 30 MJ become possible. Optics upgrades and additional hardening of the facility to support higher yield are also needed. EYC will enable replication of a wider range of extreme conditions that exist during thermonuclear detonation and probe weapons physics phenomena in ways that have never been possible. Experiments will also inform decisions about next-generation high-yield ICF facilities.



*During a Facility Maintenance and Refurbishment period, workers remove an Integrated Optics Module for servicing, a key activity for NIF sustainment.*