# NATIONAL IGNITION FACILITY

## Supporting stockpile stewardship through a wide range of experiments and with achievement of ignition; and operating as a national user facility for high-energy-density (HED) science

*The final optics before the laser light enters the target chamber are switched out regularly; however, the 192 integrated optics modules that house the final optics assemblies, which experience wear and tear, have not been serviced since they were installed. Their refurbishment is a key NIF sustainment activity.*

### NIF EXPERIMENTS AND RECORD-BREAKING RESULTS

The inertial confinement fusion (ICF) experiment at NIF on February 10, 2024, produced 5.2 megajoules (MJ) of energy. That record-breaking shot also resulted in the highest target gain, about 2.3 times more energy than laser beams delivered. A prior experiment on October 30, 2023, was the first ignition shot driven by 2.2 MJ of laser energy. This increase over NIF's original design requirement of 1.8 MJ is crucial since target performance is very sensitive to delivered laser energy. Higher energies provide more robustness and less variability in results, an important requirement for the use of fusion yield in the survivability testing now being conducted. Years of effort determining and minimizing the causes of damage to optics has enabled use of 2.2 MJ for ignition experiments. A key step was the installment in FY 2023 of fused silica debris shields, which greatly improved the method for protecting valuable optics from debris created by experiments.

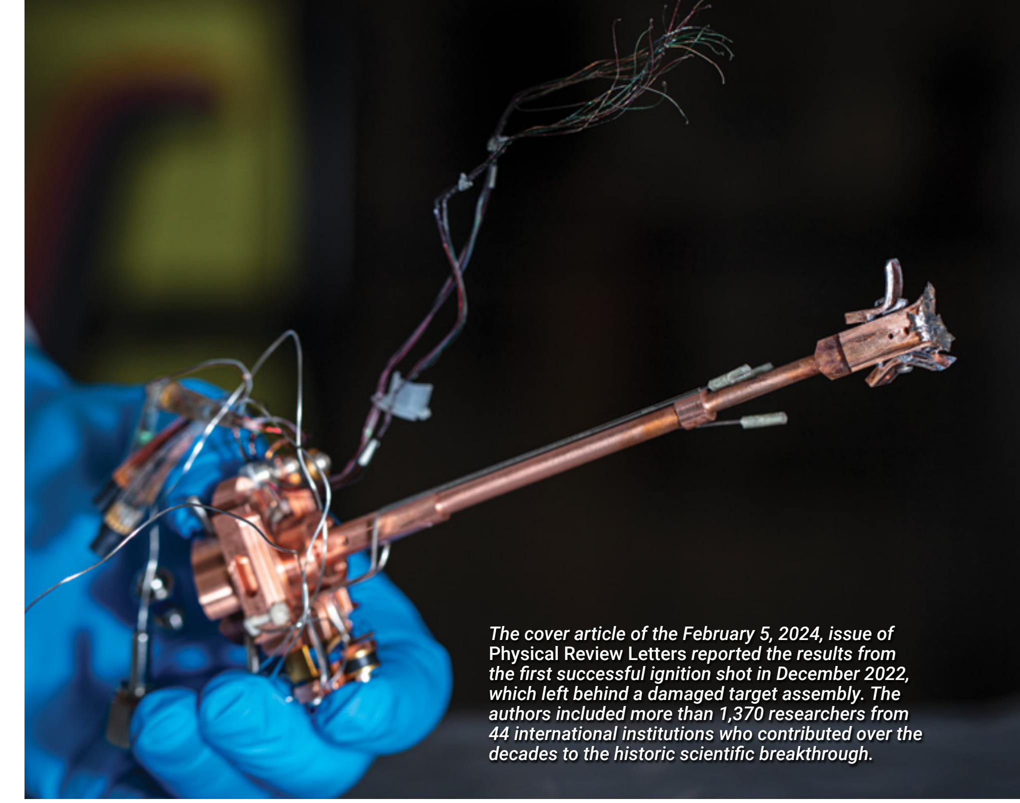
Improvements in target production are also important. LLNL, General Atomics (GA), and Diamond Materials GmbH of Freiburg, Germany, partner to produce batches of target capsules. GA researchers developed the 4Pi Integrated Metrology System to help identify the best capsules for use in the remainder of the multi-month production process and deliver only the very best targets. Near perfect roundness and surface smoothness are essential. The 4Pi system, which is used to characterize an average of 30 targets a week, can rapidly examine an ICF capsule's entire surface and internal alignment. In addition, Laboratory researchers are advancing the state-of-the-art in two-photon polymerization additive manufacturing to 3D print NIF target capsules. A future inertial fusion energy power plant would require about one million near-perfect capsules per day (see p.19).

Ignition shots have also provided unique opportunities to collect valuable data for assuring that the nation's nuclear weapons and other critical military systems would survive and function under hostile conditions in a nuclear conflict. Each shot creates an intense dose of neutrons that can be used to test components and materials. Other stockpile stewardship experiments examined properties of uranium and plutonium at extreme conditions. In addition, discovery science campaigns are examining the role of shocks and turbulent mixing in star formation, attempting to create solid metallic hydrogen at NIF, and studying the role of helium in the evolution of white dwarf stars as they cool.

### NIF REFURBISHMENT

In FY 2024, the NIF team continued work on a multi-year 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. NIF's Facility Maintenance and Refurbishment (FM&R) periods, which are scheduled three times per year, provide time for teams to perform tasks in normally inaccessible areas and refurbish parts of NIF that have been untouched since experiments began. During the April 2024 FM&R period, a NIF team removed and replaced one of the four 1,100-pound cryopumps that had earlier stopped working; had another failed, operations would have ceased. In addition, a five-year effort has begun 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 recycled regularly, but the modules themselves have experienced wear and tear over 20 years. In addition to sustaining NIF's outstanding performance, these activities refresh the knowledge base about system components and train the current workforce.





*The cover article of the February 5, 2024, issue of Physical Review Letters reported the results from the first successful ignition shot in December 2022, which left behind a damaged target assembly. The authors included more than 1,370 researchers from 44 international institutions who contributed over the decades to the historic scientific breakthrough.*

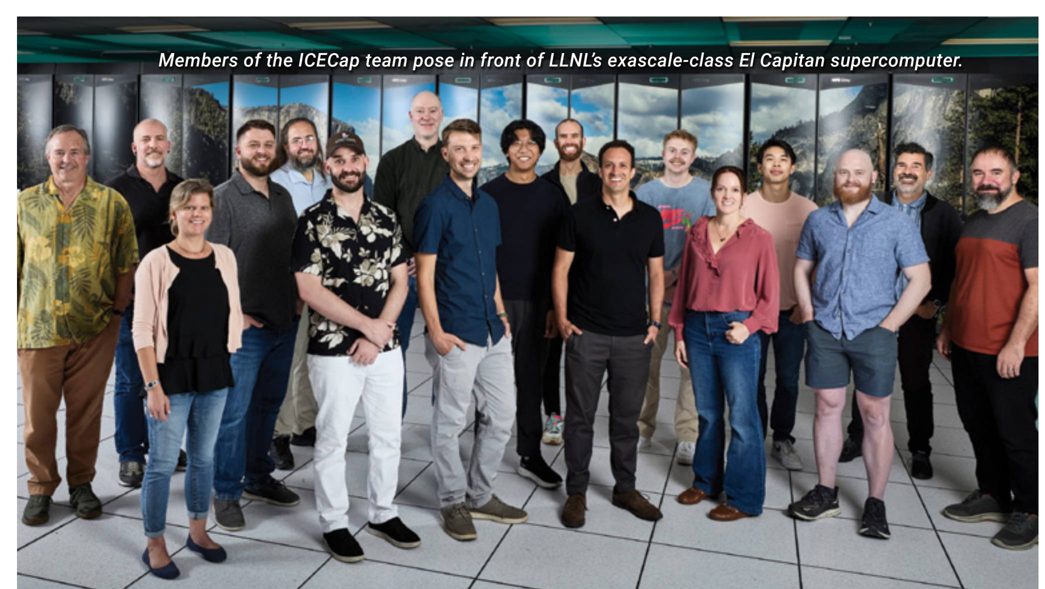
### ENHANCED YIELD CAPABILITY FOR NIF

DOE's approval in September 2024 of a Critical Decision 0 (CD-0) provided an important step for the Laboratory's Enhanced Yield Capability (EYC) project. CD-0 formally recognizes NNSA's mission need for increasing the feasible yield of NIF and enables the start of conceptual design. A proposed approach for the project entails installing additional laser glass in unused empty locations in NIF's power amplifiers, which will boost the laser's energy current high of 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 researchers to experimentally replicate 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.

### ICECAP FOR TARGET DESIGN INNOVATION

ICECap (Inertial Confinement on El Capitan) transforms LLNL's approach to ICF target design optimization. The project combines exascale computing with machine learning (ML) to advance scientific innovation and revolutionize digital design. ICECap focuses on discovering the next generation of robust, high-yield ICF designs, which are vital for NNSA's stockpile stewardship mission as well as future viable fusion power plants. The modular approach employed in the design of ICECap allows for flexibility and portability in addressing a wide range of challenging science and engineering problems. With a focus on data-driven approaches to digital design and computational modeling, the project could accelerate science, transform the way scientists conduct research, and drive advancements across various disciplines by offering new solutions to previously untenable problems.

In a paper published by *Physics of Plasmas*, the researchers describe a successful 1D test of the ICECap approach. Using only a few hundred simulations, the ML-based workflow optimized target design at 17 different parameters simultaneously, a feat previously thought unattainable in such a limited number of simulations. The results demonstrated the framework's ability to make design choices that align with physics intuition in an automated and efficient manner. El Capitan will provide the computational power to perform 2D and 3D simulations in concert with tools for running large-scale ML-based workflows that have been developed at Livermore and applied to ICF and drug design (see p. 18). The ICECap team has devised innovative mitigation strategies utilizing El Capitan's early-access hardware to address anticipated challenges in ensuring seamless operation while managing millions of large-scale simulations and massive data volumes.



*Members of the ICECap team pose in front of LLNL's exascale-class El Capitan supercomputer.*