Team improves polar direct drive fusion neutron sources for use in laser experiments

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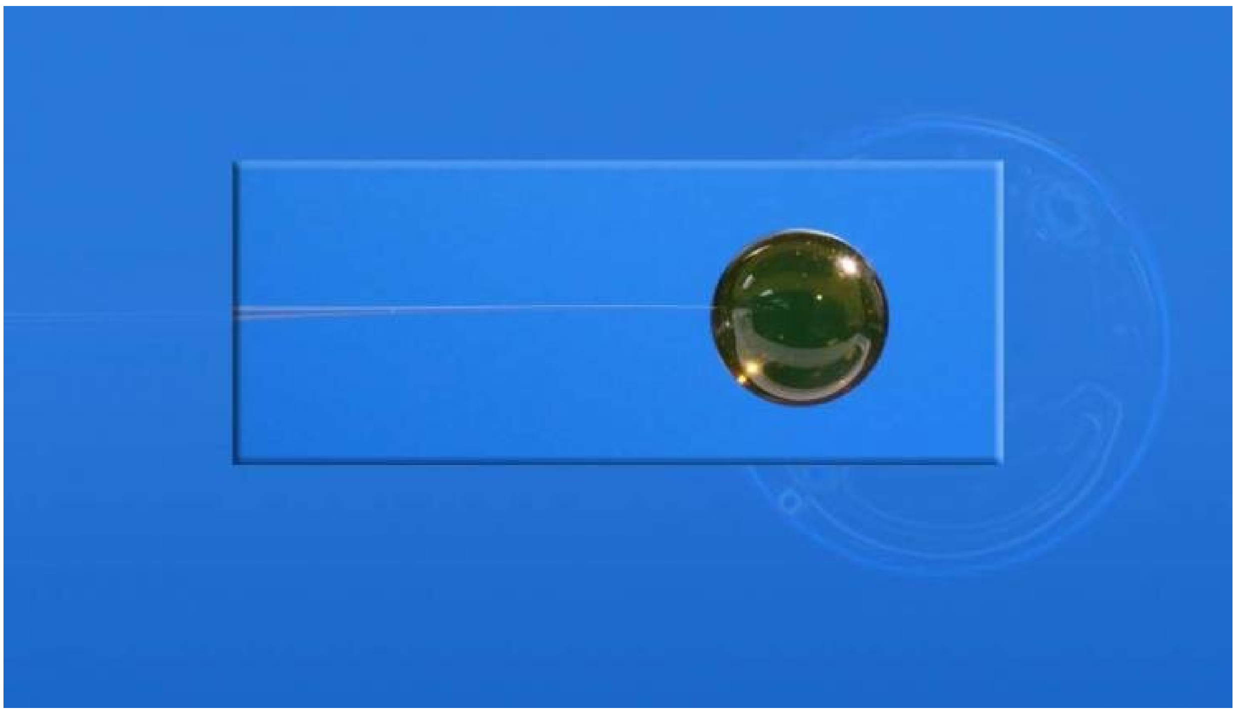

This is representative of the capsules used in the Orange and Cutie designs. Credit: Lane Carlsen/General Atomics.

Scientists from Lawrence Livermore National Laboratory (LLNL) and the Laboratory for Laser Energetics (LLE) are working to improve polar direct drive (PDD) neutron sources on the National Ignition Facility (NIF), the world's most energetic laser.

PDD neutron sources are capsules filled with deuterium-tritium (DT) gas at ambient temperature and shot with robust laser pulses that do not require stringent laser power contrast control or power accuracy. These sources are more time and resource efficient to field on NIF than conventional indirect drive sources that require high-quality cryogenic layers of DT ice. In addition, a lower generated target debris load allows neutron radiation effects experiments to position much closer to the target, creating a stronger neutron radiation field for testing.

The team substantially enhanced the total fusion output and laser-to-fusion energy conversion efficiency for PDD. The team also developed a PDD exploding pusher, or PDXP, platform that has enabled radiation effects testing of recoverable samples at record 14 MeV (Mega electron-volt) neutron fluence levels.

"For over a year and a half after the initial experimental success, this design of PDD was the most efficient way in existence to convert laser energy input into fusion output," said Charles Yeamans, team lead and first author of a paper that appears in *Nuclear Fusion*. Co-authors include Elijah Kemp, Zach Walters, Heather Whitley and Brent Blue from LLNL, and Steve Craxton, Patrick McKenty, Emma Garcia and Yujia Yang from LLE.

"Shooting really big lasers at stuff can stimulate fusion reactions like what happens in the sun and other stars and terrestrially in the core of a nuclear detonation," Yeamans said. "We want to study how the intense radiation fields generated from fusion affect materials, electronics and engineered systems like satellites and airplanes. At NIF we are able to control and position our test objects close to that source."

Additionally, similar direct drive capsule platforms have many applications on the NIF. With different gas fills they can be used for studies of nuclear reactions of interest to astrophysics and as a source of protons for point backlighting. They also have been used to produce short pulses of high-brightness continuum X-rays for extended X-ray absorption fine structure (EXAFS) studies and for opacity measurements. Additionally, they have been used to make large compressed plasmas for studies of electron-ion energy transfer.

"Overall, a better NIF neutron source design allows us to conduct better radiation effects tests in greater numbers than if we were to rely solely on the mainstream NIF experiments," he said.

Yeamans said the work developed a valuable addition to the overall radiation effects experimental test capability for the Lab. "It also developed the modeling and simulation capability to understand and improve the neutron source design," he said. "With this work, we are better able to fulfill this responsibility now and in the future."

Team success

The work was conducted by a team of designers—scientists who run computer codes that do complicated physics calculations—and experimentalists—engineers who understand and operate the world's biggest laser, and who determine the best way to test in practice what works in the simulation.

Several of the team members work in both roles, and others specialize as either designer or experimentalist based on what the research team needs. Sixteen days of NIF experimental time spread over more than five years were included in the source development effort, with the three best-performing designs, each conducted during a shot day in 2019, selected for detailed discussion in the publication, said Yeamans.

Heather Whitley, associate program director for High Energy Density Science at LLNL, developed the initial design for a large diameter polar direct drive capsule with Craxton and Garcia from LLE and Warren Garbett from the U.K. Atomic Weapons Establishment.

"This platform is important because it provides high neutron fluences and enables the close positioning of samples near the source for survivability experiments," Whitley said. "The polar direct drive configuration also provides excellent diagnostic access for other high temperature plasma physics experiments."

Craxton from LLE helped lead the work of undergraduate students Garcia and Yang and said that the participation of the students has been important to this work. Each student was responsible for calculating the optimized laser beam pointing to achieve uniform implosion of a specific diameter of capsule. This optimization is complicated by the NIF beam entry angles being optimized to drive a cylindrical hohlraum target. McKenty worked closely with Craxton and the rest of the team to determine the ideal laser pulse shape.

"We went through a whole series of experiments over many years, first to produce neutrons to test NIF neutron diagnostics while NIF was being commissioned," Craxton said. "These experiments evolved to meet the needs of a wide variety of applications, with the largest targets producing the high yields required for the effects experiments."

Critical to the success of this effort was the fabrication and developing the proper testing protocols to obtain key data for prescribing safe fielding pressures of these large (2-5 millimeters in diameter), thin wall (approximately 10-30 micrometers) capsules, which are more susceptible to bursting. This was done by target fabrication team mainly at General Atomics (GA) in San Diego, working closely with LLNL's target fabrication team as well as the above mentioned physics team. Claudia Shuldberg and her team led the work at GA, while Bill Saied and Kelly Youngblood led the target fabrication engineering effort at

LLNL.

More information: C.B. Yeamans et al. High yield polar direct drive fusion neutron sources at the National Ignition Facility, *Nuclear Fusion* (2021). DOI: 10.1088/1741-4326/abe4e6

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