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ACADEMIC PROGRAMS QUARTERLY

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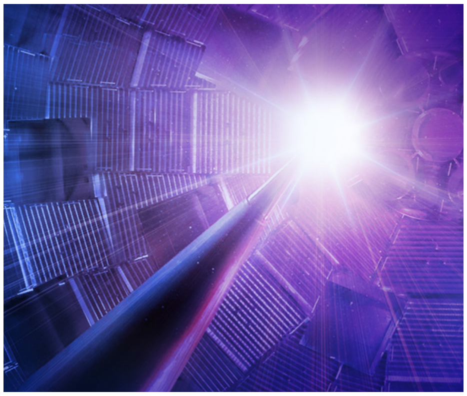
Welcome to the summer issue of the *Academic Programs Quarterly* (APQ). As many changes are underway in the federal government, we are pleased that the Academic Programs of the National Nuclear Security Administration (NNSA) continue to be supported and recognized for their contributions to maintaining U.S. preeminence in fields vital to national security.

This issue features groundbreaking work at the National Ignition Facility (NIF) at Lawrence Livermore National Laboratory where laboratory ignition was achieved in December 2022. The team at NIF has achieved repeatability and reproducibility of the ignition experiment and have gone on to achieve ignition a total of eight times as of April 2025. The bigger news is that the team has increased the energy yield with continued experiments and has reached the result of producing 8.6 MJ of energy from an energy input on target of 2.08 MJ. These results have far-reaching consequences for the future, allow for new orders of high energy density science to be probed at NIF, and pave a way to uncovering a future source of safe, abundant, reliable energy.



Inside the NIF Target Chamber at Lawrence Livermore National Laboratory. Read about NIF's ignition successes on pages 2-3.

We also feature recent work undertaken in collaboration with the ZNetUS effort. ZNetUS is a consortium of pulsed power facilities and pulsed power scientists in the United States supported by NNSA with a goal of providing more student access to pulsed power facilities for conducting student research. The work featured in this issue explores the effect of different liner materials in gas-puff, z-pinch experiments. Graduate student researchers from the University of California San Diego undertook experiments at the COBRA pulsed power facility at Cornell University. Much like laser facilities, pulsed power facilities have the potential for achieving high energy density conditions, and providing students with hands-on opportunities like the ones featured here pave the way for more future breakthroughs of monumental proportions.

The Presidential Early Career Award for Scientists and Engineers (PECASE) Panel at the 2025 SSAP Symposium on June 10-11, 2025 in Chicago, Illinois. Left to right: Stephanie Miller (NNSA, Academic Programs) with Amber Guckes (NNSS), Petros Tzeferacos (University of Rochester), and Amy Lovell (LANL). See pages 4-5 for Symposium highlights.

We bring you highlights from the 2025 Stewardship Science Academic Programs (SSAP) Symposium. Researchers attended from NNSA, the Department of Energy (DOE)/NNSA national laboratories, and academia. A graduate student poster session was held and the outstanding poster award recipients are listed on page 5.

A significant change to report for this quarter is that I am transitioning out of my role as the Director of the Technology and Partnerships Office and stepping into my new role as the Deputy Assistant Deputy Administrator of the Office of Warhead Assembly and Non-Nuclear Modernization (NA-193). The program is in good hands as the core team supporting the Academic Programs remains intact. I will miss being part of the Academic Programs, and I extend my utmost gratitude to all of you, to the exceptional Academic Programs' team, and to the greater enterprise for your dedication and support throughout the Nation in our universities, laboratories, plants, and sites. We do amazing science at NNSA, and we work hard to fuel the success of the next generation.

Until we meet again!

Jahleel A. Hudson

Jahleel A. Hudson
Director
Technology and Partnerships Office

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2025 CALENDAR

7/13-17	2025 Computational Science Graduate Fellowship (CSGF) Annual Program Review, Hilton Washington DC, The Wharf
7/27-30	ASME Fluids Engineering Division Summer Meeting, Philadelphia, PA
8/18-21	Monterey Data Conference, Monterey, CA

Academic Programs Quarterly (APQ) highlights the academic programs supported by the Department of Energy/National Nuclear Security Administration (DOE/NNSA). APQ is published quarterly by the Defense Programs Technology and Partnerships Office. Questions and comments regarding this publication should be directed to Terri Stone at terri.stone@nnsa.doe.gov. Learn about the NNSA Academic Programs at https://www.nnsa-ap.us.

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National Ignition Facility Builds on Ignition Success to Advance Stewardship Science

by Charlie Osolin (Lawrence Livermore National Laboratory)

Figure 1. Lawrence Livermore researchers Eric Stern (left) and Kelton Grange work on the fielding hardware commissioned for use in NIF weapons survivability experiments. The steel case protects against the destructive force from significant amounts of X-rays and debris generated by megajoule-class inertial confinement fusion experiments. Credit: Garry McLeod/LLNL.

A key test of any scientific accomplishment is repeatability—can a successful experiment be performed again with the same, or even better, results? In the case of Lawrence Livermore National Laboratory's (LLNL) historic demonstration of fusion ignition on the National Ignition Facility (NIF) in December 2022, that test has been met not once but many times.

Ignition—producing more energy from a fusion reaction than the energy required to drive the reaction—had been achieved on NIF a total of eight times as of April 7, 2025. On that date, NIF's 192 powerful lasers fired 2.08 megajoules (MJ) of ultraviolet energy into an eraser-sized target containing a tiny capsule filled with the hydrogen isotopes deuterium and tritium. The resulting fusion reaction produced approximately 8.6 MJ of energy, the highest energy yield achieved until then. The shot also set a record for energy yield vs. energy on target, or target gain, of 4.13.

Researchers have every expectation that the current trend toward higher energy yields and energy gain will continue well into the future, further demonstrating that NIF, the world's highest-energy laser system, can repeatedly conduct fusion experiments at multi-megajoule levels of energy output.

Repeating ignition gives scientists access to new regimes of high energy density science to probe the extreme conditions found at the center of nuclear explosions, strengthening NIF's primary mission: to support the National Nuclear Security Administration's science-based Stockpile Stewardship Program to help certify the safety, security, and effectiveness of the U.S. nuclear deterrent. It also has established the scientific basis for the pursuit of fusion as a potential future source of abundant, safe, and reliable energy.

"The physics understanding we gain from NIF on how materials behave at extreme pressures and temperatures, how radiation is transported in complex geometries, and how thermonuclear fusion ignition happens is crucial to ensuring that our nation's nuclear stockpile stays safe, secure, and reliable in the absence of underground testing," says Mark Herrmann, LLNL associate director for Weapon Physics and Design. "NIF is an essential tool in sustaining our deterrent."

Ignition shots also have 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 X-rays and neutrons that can be used to test the survivability of nuclear and nonnuclear weapon components and materials.

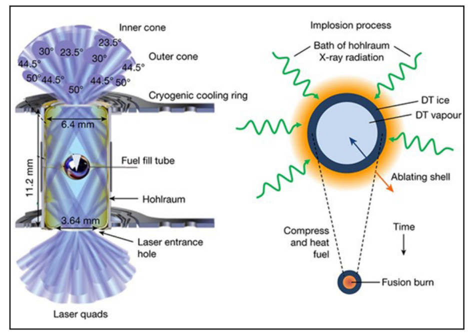

Figure 2. A typical NIF indirect-drive target configuration. On the left, laser beams (blue) enter a pencil-eraser-sized cylinder called a hohlraum through laser entrance holes at various angles. At right, in the center of the hohlraum, a target capsule, filled with a thin layer of cryogenic deuterium-tritium (DT) fuel and a volume of DT gas, is bathed in X-rays. The X-rays heat and blow off, or ablate, the outer surface of the capsule, causing a rocket-like implosion that compresses and heats the fuel in the capsule's central "hot spot" to the densities and temperatures required to fuse the atoms. The resulting fusion reactions create high-energy alpha particles (helium nuclei) that accelerate into and heat the cold fuel surrounding the hot spot, generating an explosive, self-sustaining fusion reaction that leads to ignition.

A Historic Breakthrough

NIF achieved ignition for the first time on December 5, 2022, after decades of effort by an international team of researchers from more than 40 international institutions. That experiment far surpassed the ignition threshold by producing 3.15 MJ of fusion energy output from 2.05 MJ of laser energy delivered to the target.

As subsequent experiments boosted the laser energy, modified the experimental design, and took advantage of improved targets, energy yield grew to a then-high of 5.2 MJ on February 12, 2024—more than double the input energy of 2.2 MJ.

NIF's ability to repeatedly produce more laser energy than its original design specification of 1.8 MJ is crucial, as target performance is highly sensitive to delivered laser energy. Higher energies provide more robustness and less variability in results, an important requirement

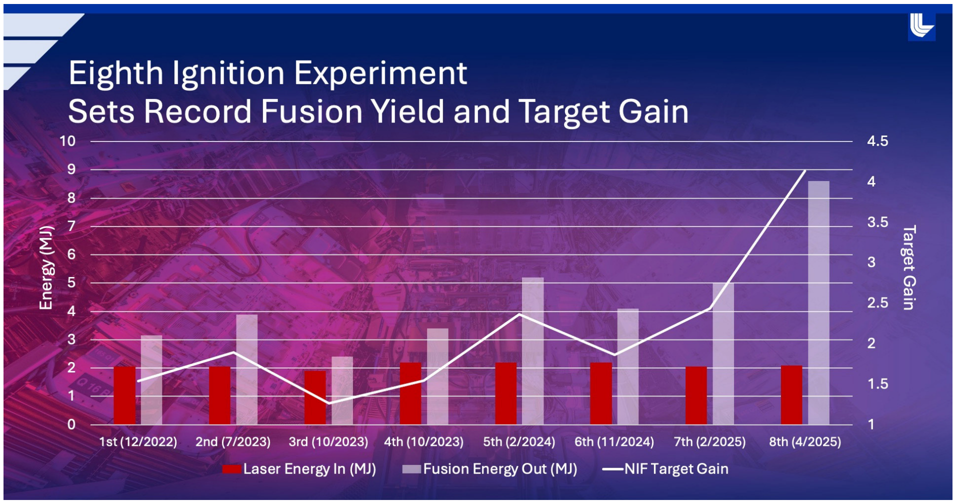

Figure 3. Chart showing the results of all the previous ignition experiments, including the latest April 7 experiment with a yield of 8.5 MJ.

for the use of fusion yield in weapons survivability testing.

Ignition experiments also provide data that help researchers evaluate the performance of new diagnostic instruments as well as the response of critical nuclear weapon components to extremes of pressure and temperature. Also, the ongoing series of shots helps researchers explore multiple avenues to improve the performance of NIF implosions, enabling development of new experimental platforms addressing outstanding stockpile stewardship questions.

This work was performed under the auspices of U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. DE-AC52-07NA27344. LLNL-MI-2005028.

The Effect of Gas Species and Density Profiling on Stability and Dynamics in Triple-nozzle, Gas-puff, Z Pinches

by Kimberly Inzunza, Oren Yang, and Robert Beattie-Rossberg (University of California, San Diego)

When an axial current from a pulsed-power generator is applied to a conductive cylindrical load, the material becomes a plasma, and a self-generated azimuthal magnetic field is produced. The resulting JxB force compresses the plasma radially until it stagnates on the z-axis. High energy densities and temperatures are produced at stagnation, making it promising for thermonuclear fusion and radiation effects applications.

The magneto Rayleigh-Taylor instability (MRTI) disrupts the uniformity of the plasma column, reducing energy confinement. Strategies to mitigate MRTI include density profiling, external magnetic fields, and radiation cooling. Previous HYDRA simulations [J. Narkis et al., Phys. Rev. E 105, 045205 (2022)] studied these effects, finding that high-Z liners improved compression—except when switching the inner liner from argon to krypton. Contrary to expectations based on atomic number, the simulation showed increased stability in argon outer liners compared to krypton. These simulations warranted further investigation experimentally.

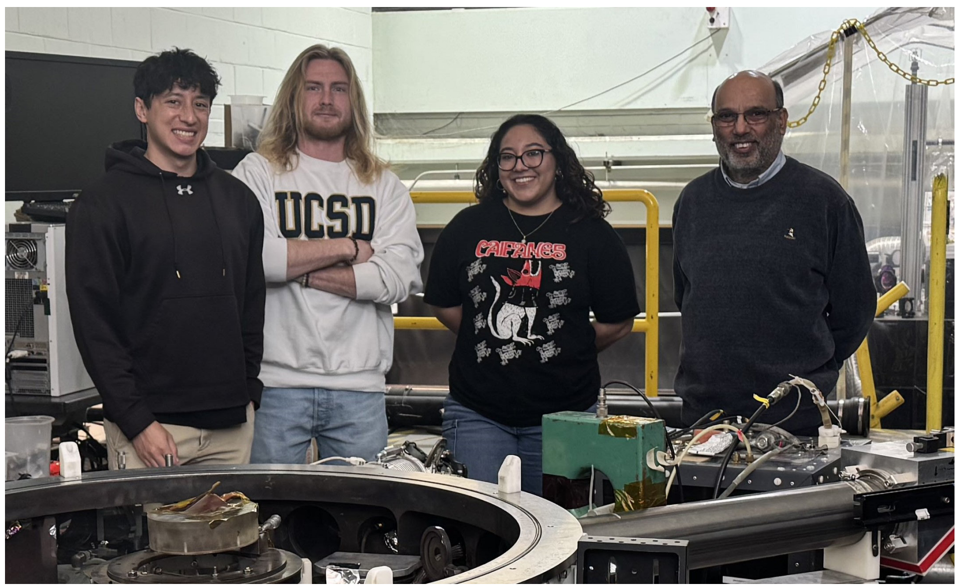

Figure 1. The UCSD research team on COBRA (from L-R): Oren Yang, Robert Beattie-Rossberg, Kimberly Inzunza, and Farhat Beg.

Led by graduate student Kimberly Inzunza, University of California, San Diego (UCSD) researchers (Figure 1) explored the effects of different gas species' liners (neon, argon, and krypton) on a xenon-doped hydrogen target in a triple gas-puff Z pinch configuration on the COBRA driver (~0.9 MA, 220 ns) to study pinch stability.

These experiments were made possible thanks to ZNetUS, a National Nuclear Security Administration (NNSA)-funded program that supported testing modeling predictions on Cornell's COBRA generator—one of the few 1 MA facilities in the United States with extensive diagnostics. "The COBRA facility is unique with myriads of diagnostics to explore exciting Z-pinch physics. It plays a pivotal role in training young scientists," Professor Farhat Beg remarked. The facility features a triple gas-puff injector, allowing precise tailoring of different gas species in the liner while using a doped gas as a target. This study used a hydrogen-doped target containing 1.4% xenon to extract information on target heating. The plasma dynamics were characterized by two extreme ultraviolet (XUV) framing cameras, four filtered soft X-ray photodiodes, a single frame Mach-Zehnder interferometer, a Thomson scattering

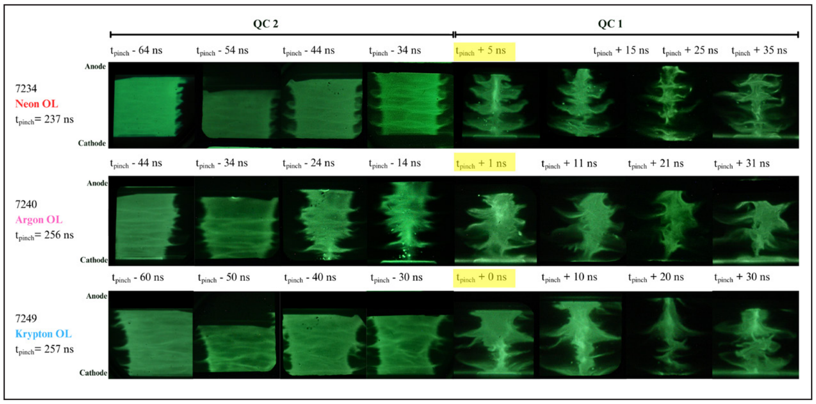

Figure 2. XUV images taken by two microchannel plate (MCP) cameras, each with four frames spaced 10 ns apart. Yellow boxes indicate the closest frame to stagnation, defined as the peak signal from the X-ray PIN diode with an aluminum 10 μm filter. Negative time values correspond to pre-pinch conditions, whereas positive values indicate post-pinch dynamics. The stagnation of the neon OL plasma column occurs approximately 15 ns before the peak current. Argon OL and krypton OL exhibit zippering near the nozzle and stagnate 30–40 ns after the peak current.

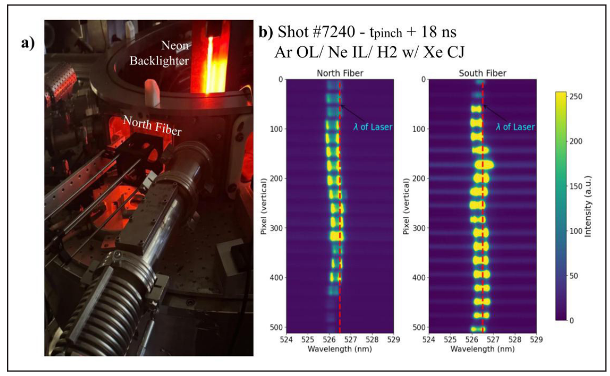

Figure 3. (a) Wavelength calibration of the North collection fiber bundle for Thomson scattering, using a neon backlighter. The Thomson scattering laser (λ = 526.5 nm) propagated 12 mm above the cathode plane, aligned along the axis of the gas puff valve. The diagnostic setup employed two fiber bundles, each containing twenty 100 μm fibers, enabling simultaneous light collection at two orthogonal angles relative to the laser wave vector. (b) Raw spectral data from the North and South fibers for Shot #7240 with an argon OL. In the absence of an axial magnetic field, rotation of the plasma column is observed. Periodic intensity variations in both fibers may indicate density modulations caused by magneto-Rayleigh-Taylor or kink instabilities.

system timed to the stagnation point, a time-integrated mica crystal X-ray spectrometer, and a time-integrated pinhole camera.

Experiments involved varying the outer liner (OL) gas species from neon to krypton. The data shows that the neon/neon doped target is the most stable configuration compared to the argon/neon doped target and the krypton/neon doped target configurations contrary to simulation predictions. Figure 2 shows pinch dynamics for the three cases discussed above. The target shows enhanced stable behavior for neon OL.

Funding from ZNetUS has played a vital role in training graduate students to investigate the underlying physics of gas puff Z-pinches and gaining hands-on experience with essential diagnostic techniques like Thomson scattering (Figure 3). This data will enable measurement of temperature, density, and rotation of the pinch. Kimberly Inzunza reflects, "Thomson scattering is an essential diagnostic in plasma physics. Having a chance to learn it in real time, I've gained a greater appreciation for its complexity. Everyone at Cornell was super helpful, and I particularly want to mention excellent support by Dr. Sander Lavine and Dalton Lund for making our experiment successful!"

2025 Stewardship Science Academic Programs Symposium

The 2025 Stewardship Science Academic Programs (SSAP) Symposium was held June 10-11, 2025, at the Chicago Marriott O'Hare in Chicago, Illinois. The Symposium highlights accomplishments from awards in the Stewardship Science Academic Alliances and High Energy Density Laboratory Plasmas programs. A highlight of the Symposium was the keynote address "Scientific Innovation for National Security" by Dr. Kim Budil, Laboratory Director, Lawrence Livermore National Laboratory. It was another exciting SSAP Symposium with opportunities to learn about the National Nuclear Security Administration (NNSA) and the NNSA Labs, Plants, and Sites, and partners, as well as make professional contacts from fields vital to our national security.

(a) Dr. Kim Budil's Keynote Address, (b) Poster Session and Reception, (c) Networking Lunch with NNSA Labs, and (d) Meet and Greet with NNSA Labs/Sites, Krell Institute, and User Facilities.

Academic Programs Highlights

Laser-based Ignition of Rocket Engines: Fast Surrogate Models

PI: Professor Gianluca Iaccarino; Co-authors: Dr. Tony Zahtila, Dr. Davy Brouzet, Dr. Murray C. Cutforth, Adj. Prof. Diego Rossinelli (Stanford University)

Many challenges arise when designing a reliable laser-induced ignition system for rocket engines. Predictive simulations are complex and time-consuming because of the dynamics of fuel and oxidizer turbulent mixing, thermodynamics and hydrodynamics of laser energy deposition, and the modeling of high-speed flame growth. All this is conflated with the large design space corresponding to the laser operating conditions and the target location.

Ensembles of simulations are adopted to analyze the system, to characterize the uncertainties, and to predict the probability of ignition success. With the paradigm-shifting opportunities offered by machine learning, our focus has turned to developing fast deployable surrogate models. In our ongoing investigations, we deploy convolutional autoencoders to spatially compress field variables and neural ordinary differential equations to learn trajectories in the autoencoder latent space. Put together, this framework is introduced as the dynamic autoencoder (DnAE). After training, this approach only requires the input physical parameters and an initial condition (in the latent space) to generate a full spatial/temporal-sequence prediction (Figure 1). This process is fast, taking about a second of wall-clock time on a laptop, compared to hundreds of hours on GPUs for a full simulation. This is a pivotal development towards digital twins, and can combine both computations and experiments for training, thus enabling scientific discovery in unified data stream frameworks.

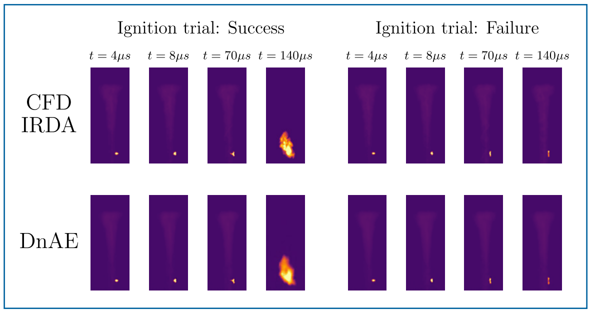

Figure 1. Top: Time-series visualization of infrared imaging; ray-traced paths of the temperature field inside the rocket combustor. Bottom: Prediction through DnAE surrogate model.

This work was performed under the auspices of U.S. Department of Energy/National Nuclear Security Administration's Predictive Science Academic Alliance Program.

2025 Stewardship Science Academic Programs Outstanding Poster Award Recipients

Several excellent research posters were presented at the 2025 SSAP Symposium Poster Session. Seven of the 115 graduate student posters received the 2025 Stewardship Science Academic Programs Symposium Outstanding Poster Award. We extend our thanks to the esteemed judges and congratulations to the recipients that follow.

Lucas Babati
University of Michigan
Mean Force Kinetic Theory of Warm Dense Matter

Sumner Gubisch
The George Washington University
Manipulating the Seebeck Coefficient by Engineering Point Defects through Laser Processing

Hannah M. Hansen
University of Iowa
X-ray Absorption Spectroscopy Investigations of Actinide-(boro) hydride Bonding

Chloe Jones
University of Notre Dame
Modeling Neutron Interactions in HECTOR Using GEANT4

Matthew Kafker
University of Washington
Time-Dependent Density Functional Theory Description of 238U(n,f), 240,242Pu(n,f) and 237Np(n,f) Reactions

Victor Perez-Ramirez
Stanford University
Optical Properties of Plasma Diffraction Gratings for High-Power Lasers

Thomas Varnish
Massachusetts Institute of Technology
Two-Fluid Effects in Pulsed-Power-Driven Reconnection

Academic Programs Coordinator and Federal Program Manager for SSAA and HEDLP Stephanie Miller (right) with six of the 2025 Stewardship Science Academic Programs Symposium Outstanding Poster Award recipients. (L-R): Gubisch, Jones, Hansen, Varnish, Babati, and Perez-Ramirez.

ZNetUS Call for Proposals

The goal of the NNSA-funded ZNetUS User Facility Program is to fund research collaborations executed at ZNetUS's six user facilities. Proposals received will be reviewed monthly for technical merit until September 30, 2025. Please visit the ZNetUS website (https://znetus.org) for details.