DOI/NA-0141

National Nuclear Security Administration

Stewardship Science Today

Office of Defense Programs

VOLUME 5 | NUMBER 1 | MARCH 2023

Stewardship Science Today (SST) highlights the stewardship science and academic programs supported by the Department of Energy/National Nuclear Security Administration (DOE/NNSA). SST is published quarterly by the NNSA Office of Defense Programs. Questions and comments regarding this publication should be directed to Terri Stone via email at terri.stone@nnsa.doe.gov.

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CALENDAR

4/10-14/2023
Materials Research Society Spring Meeting & Exhibit, San Francisco, CA; 4/25-27 - Virtual portion of the meeting

4/26-28/2023
14th OMEGA Users Group (OLUG) Workshop, hybrid, University of Rochester

5/7-12/2023
14th International Particle Accelerator Conference (IPAC'23), Venice, Italy

5/15-19/2023
21st International Conference on Atomic Processes in Plasmas (APiP 2023), Vienna

5/21-25/2023
50th International Conference on Plasma Science (ICOPS), Santa Fe, NM

INSIDE

*Contractor Support

Welcome to the March 2023 issue of *Stewardship Science Today*. We've recently returned from the 2023 Stewardship Science Academic Programs Symposium that was held in-person for the first time in three years. Attendance was high, interactions between students and National Nuclear Security Administration (NNSA) leadership and laboratory staff were plentiful, and the talks and presented posters were excellent. Thank you to everyone who attended and to the exceptional staff members who worked so hard to bring us all back together again.

In the last issue, I touted the incredible scientific achievement that occurred on December 5, 2022 when fusion ignition was achieved at the National Ignition Facility at Lawrence Livermore National Laboratory (LLNL). This issue includes an article about this monumental event—one that was more than seven decades in the making, and that many believed unachievable. The success of the experiment is a testament to what vision, persistence, teamwork, dedication, and cutting-edge national resources can achieve. And I would stress that this was a national achievement. Although the experiment occurred at LLNL, scientists, engineers, and technicians from across the NNSA national laboratories and academic partners were members of the team who brought about this success. For example, as you will see highlighted in this issue, the modeling efforts of teams from Los Alamos National Laboratory and the Laboratory for Laser Energetics at the University of Rochester contributed to the experimental design for the ignition shot and will be vital as the program moves from the achievement of ignition to achieving reliable, high gain in the laboratory.

The Poster Session of the 2023 SSAP Symposium provided a forum for students to discuss their research and network. Read about the 2023 Outstanding Poster Awards on page 5.

These are exciting times in stewardship science. I will miss experiencing them with all of you in the up close and personal way I've been able to since joining the NNSA. If you attended the Symposium, you heard me announce that I will be moving on to a new role in the Office of the Administrator. It has been an honor to be a part of this community and regardless of my role, I will remain a champion for academic programs at NNSA!

Dr. Njema J. Frazier
Assistant Deputy Administrator (Acting)
Strategic Partnership Programs

NNSA Stewardship Science Academic Programs Symposium and Outstanding Poster Awards

The Department of Energy/National Nuclear Security Administration's (DOE/NNSA's) Stewardship Science Academic Programs (SSAP) Symposium was held in person for the first time in three years on February 14-15, 2023 in Santa Fe, New Mexico. The Symposium enjoyed a robust turnout with more than 420 in-person attendees and approximately 60 virtual attendees.

As in past years, the Symposium featured the cutting-edge research performed by grantees from the Stewardship Science Academic Alliances and High Energy Density Laboratory Plasmas programs. Special presentations were given by staff from NNSA's Academic Programs: Dr. Njema Frazier, Acting Assistant Deputy Administrator for the Office of Strategic Partnership Programs, gave the welcome address followed by program overviews by Betsy Snell, Program Manager for the Minority Serving Institutions Partnership Program and David Etim, Program Manager for the Predictive Science

(continued on page 3)

The National Ignition Facility Achieves Ignition

by O.A. Hurricane and Richard P.J. Town (Lawrence Livermore National Laboratory)

On December 5, 2022, fusion ignition was achieved in the laboratory at the National Ignition Facility (NIF) at Lawrence Livermore National Laboratory (LLNL). This incredible scientific achievement has a significant impact on the field of stockpile stewardship, enabling the US to continue to ensure a safe, reliable, and effective nuclear weapons stockpile without conducting underground testing, impacts modernization efforts for the aging stockpile, and is a major step forward for future energy production. This groundbreaking achievement was greater than seven decades in the making and relied on the persistent, dedicated research and experimental efforts of multiple teams and multiple generations of scientists, technicians, and engineers. Understanding the basics of the scientific problem and some pivotal events in the quest for ignition allows us to contextualize this achievement and speaks to the importance of the roles that continued intellectual curiosity, persistence, teamwork, and dedicated national resources play in monumental scientific advancement.

In 1997, just as ground was broken for NIF construction at LLNL, the National Academy of Sciences (NAS) proposed a definition for ignition as target gain (G_{target}) greater than one. This definition was accepted by the National Nuclear Security Administration (NNSA). Target gain is defined as the fusion yield output divided by the laser energy incident upon the target. The December 5 experiment at the NIF generated 3.15 MJ of fusion energy from 2.05 MJ of laser energy delivered to the target, achieving a target gain of ~ 1.5 and meeting the NAS definition of ignition for the first time ever in a laboratory setting.

The NIF predominantly uses the laser indirect drive approach to inertial confinement fusion (ICF). In this approach the NIF's 192 laser beams enter the hohlraum, a high-Z cavity, through two laser entrance holes and strike the inner surface. The beams are absorbed and heat the hohlraum wall generating x-rays that flood the cavity. Inside of the hohlraum cavity is a capsule. The capsule is a spherical shell of high density carbon filled with deuterium-tritium (DT) fuel suspended by a plastic membrane. Some of the x-rays inside of the hohlraum are absorbed by the capsule which heats up and expands outward. This drives the DT fuel inward to a high pressure and density state initiating fusion.

Whereas steady progress over past decades led to the ignition result on December 5, a key turning point came in late 2020. At this time, the JASON were completing their assessment report on the U.S. ICF program,[1] and burning plasmas were achieved in the laboratory at the NIF[2-4] following a strategy laid out years earlier.[5] When this occurred, Riccardo Betti, Professor and Chief Scientist at the Laboratory for Laser Energetics, noted[6] that now that a burning plasma had been created in the laboratory, the question of ignition became one of when, not if.

A burning plasma is one for which a fusion plasma's self-heating exceeds external sources of heating. This is a necessary but not sufficient condition for ignition. Ignition occurs when a fusion plasma's self-heating exceeds the sum of all the cooling mechanisms present in the plasma. This results in a thermodynamic instability that sustains and rapidly increases fusion output for some interval of time.

The central most element of physical interest in an ICF system is the fusion fuel. Fuel gain (G_{fuel}) is defined as the ratio of fusion energy produced over the net energy externally

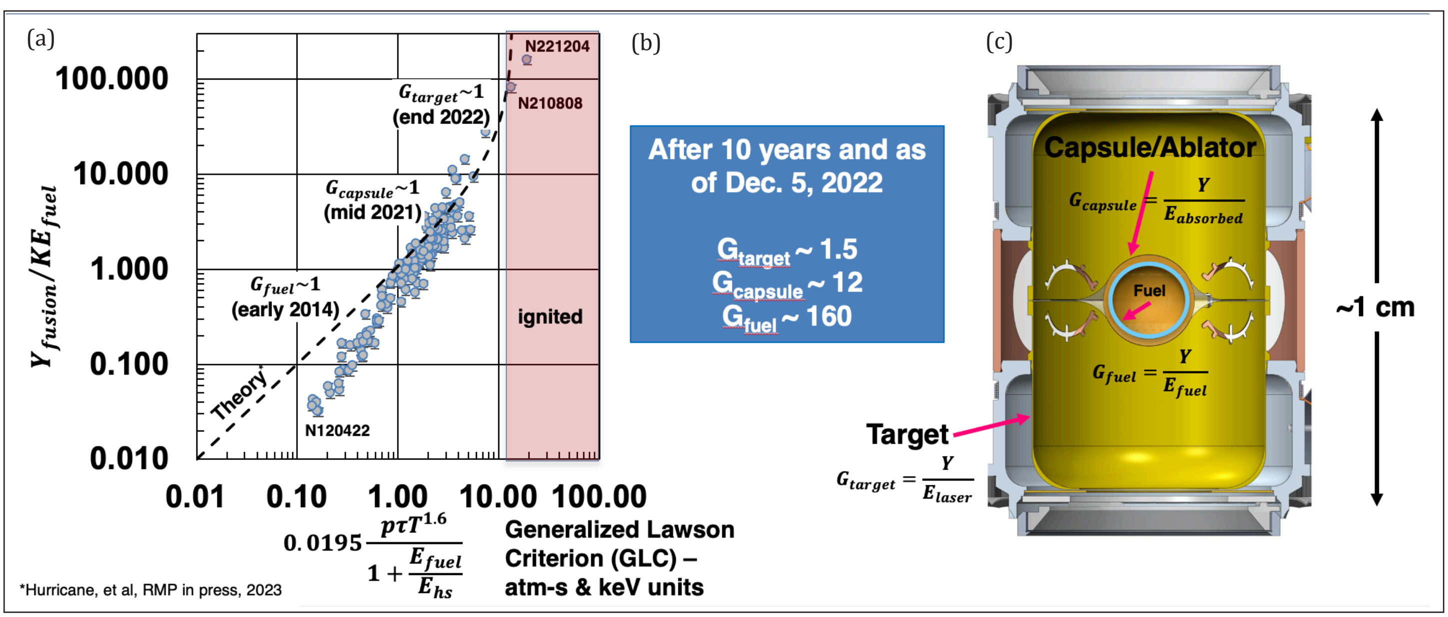

Figure 1. (a) A log-log-scale plot of fusion yield over DT fuel kinetic energy (approximately G_{fuel}) vs. a form of a generalized Lawson Criterion (GLC) formula. The data are the calculated values for NIF DT experiments starting with the National Ignition Campaign (NIC), which ended in FY 2012 to December 2022. As can be seen in the plot, when sufficiently high GLC is obtained, G_{fuel} becomes very large—this threshold behavior denotes ignition by Lawson's Criterion. The approximate dates of passing key gain metrics are noted. (b) The present record levels of gain are noted in the blue box. (c) A typical indirect-drive target geometry is shown with the definitions of fuel, capsule, and target gain shown pictorially. *Figure taken from O. A. Hurricane, LLNL-PRES-844193.*

This incredible scientific achievement has a significant impact on the field of stockpile stewardship, enabling the United States to continue to ensure a safe, reliable, and effective nuclear weapons stockpile without conducting underground testing, impacts modernization efforts for the aging stockpile, and is a major step forward for future energy production.

delivered into the fusion fuel. The generalized Lawson Criterion (GLC) for ignition[7,8] is related most directly to G_{fuel}, where G_{fuel} becomes very large when the Lawson Criterion is exceeded (see Figure 1). Capsule gain (G_{cap}) is defined as the ratio of fusion energy produced over the net energy absorbed by the capsule holding the fusion fuel. In August 2021, the first ICF implosion to obtain G_{cap}> 1 was achieved,[9] and this achievement was coincident with exceeding various formulations of Lawson's Criterion. Note that none of these gain definitions account for the energy expended by the facility which typically is orders of magnitude greater than the energy delivered to an ICF target. Thus, G_{fuel}>1, G_{cap}>1, nor G_{target}>1 do not necessarily imply net energy production. This is an important distinction, as the achievement of laboratory ignition as defined by the NAS does not imply the achievement of net energy production.

Since August 2021, the team at the NIF executed several experiments to better understand the repeatability of the G_{cap} > 1 design. They found two principal degradation mechanisms: 1) an imbalance between the laser beams or thickness variations in the capsule structure could cause the fuel to implode irregularly resulting in the fuel assembling asymmetrically; and 2) microscopic imperfections on and within the capsule structure when amplified by hydrodynamic instabilities could inject capsule material into the fuel causing it to cool. While using thicker capsules driven with more energy had been in the planning and development stages for years, these observations supported the idea that thicker capsules driven with more energy (in this case by 8% for both) should be more robust. These changes led to the successful experiment on December 5 that, for the first time ever in a laboratory setting, achieved target gain and ignition by the NAS definition.

The achievement of laboratory ignition now provides a unique capability for testing weapon components and subsystems in a pulsed thermonuclear neutron environment at the NIF, and this capability was performed on the December 5 experiment. This is a significant step forward for stockpile stewardship science and will allow for additional advancements for the NNSA mission. The achievement also has garnered much interest from the public for the possibility of producing fusion energy in the future. Although the achievement of laboratory ignition is a groundbreaking step for that purpose, achieving a target gain greater than one does not equate to achieving net energy production. More intellectual curiosity, dedication, teamwork, and national resources will need to be applied over more decades to reach that goal. This is an exciting time to be involved in this groundbreaking field of research.

References

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[8]R. Betti et al., Phys. Plasmas 17 (2010).

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SSAP Symposium and Outstanding Poster Awards *(continued from page 1)*

Academic Alliance Program. Other special presentations included Chandra Curry, SLAC National Accelerator Lab, discussing LaserNetUS, Keith LeChien, a NNSA contractor, discussing ZNetUS, Olivier Vacus of Commissariat à l'Energie Atomique et aux énergies alternatives Military Applications Division (CEA/DAM), "Opportunities for Postdocs in France," and Rebecca Lafave, LANL, "Protecting Scientific Research and U.S. Technologies." Also of note were presentations by NNSA laboratory and site staff focused on opportunities available at their locations. This was followed by a meet and greet at which attendees could meet with staff from the labs/sites, Krell Institute (who manage our fellowship programs), LaserNetUS, ZNetUS, Omega Users Facility, and the Dynamic Compression Sector.

The Keynote address "An Exciting Time for a Career at a NNSA Lab" was delivered by Dr. Ellen Cerreta, Associate Laboratory Director, Physical Sciences, Los Alamos National Laboratory (LANL). This was followed by a graduate student poster session with over 130 posters. Read about the 2023 SSAP Outstanding Poster awards on page 5.

We hope to see you next year!

Modeling Three-Dimensional Features in Cylindrical Implosion Experiments

by J.P. Sauppe[1], Y.C. Lu[2], P. Tzeferacos[2], S. Palaniyappan[1], K.A. Flippo[1], and L. Kot[1]

[1]Los Alamos National Laboratory
[2]Flash Center for Computational Science, University of Rochester

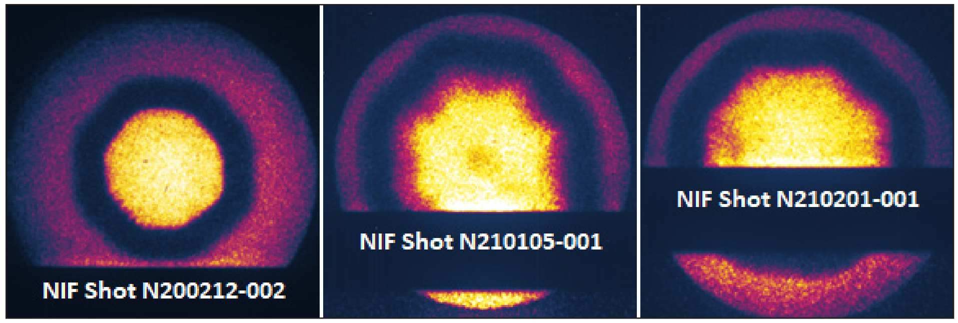

Figure 1. Experimental radiographs from cylindrical implosions performed at the National Ignition Facility showing a clear m=8 octagonal asymmetry on initially cylindrically symmetric targets.

Los Alamos National Laboratory's (LANL's) Inertial Confinement Fusion and Verification & Validation Programs, in collaboration with the Flash Center for Computational Science at the University of Rochester, are using the FLASH code to improve the understanding of three-dimensional (3D) features in cylindrical implosion experiments.

The Nation is supporting inertial confinement fusion (ICF) to assist in the stewardship of the nuclear stockpile in the absence of nuclear testing. In an ICF implosion, a spherical capsule containing deuterium-tritium fuel is compressed using lasers, heating the fuel to thermonuclear conditions and releasing energy from fusion reactions. The energy released depends critically upon many factors in the implosion, and potentially it could be larger than what was used to drive the system initially. Whereas there have been very recent and exciting successes in ICF experiments at the National Ignition Facility (NIF), including the achievement of laboratory ignition on December 5, 2022, there still are many unknowns on the path to high gain.

Hydrodynamic instabilities are one of the key factors limiting performance in these implosions. These instabilities are seeded by small-scale defects and engineering features, and they are magnified as the system converges to compress the fuel. They are especially damaging for traditional ICF targets which operate at large convergence ratios – the initial radius of the target divided by the final radius of the compressed fuel is typically a factor of 30 to 35. Probing systems, especially spherical ones, at these conditions is quite challenging, and experimental data to validate our models in these regimes currently is lacking.

In an effort to fill this gap, LANL scientists are fielding cylindrical targets to enable high-precision measurements of hydrodynamic instability growth in the high energy density regime relevant to ICF. These annular plastic targets are driven directly with lasers around the midsection, imploding the central portion of the cylinder that contains a thin layer embedded on the inner surface of the plastic tube. This thin layer is opaque to X-rays, allowing for direct measurements of instability growth at the layer by viewing down the cylinder axis, orthogonal to the direction of convergence.

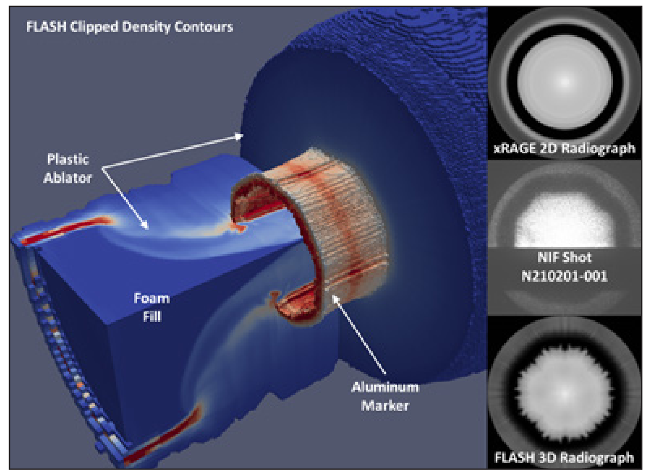

Figure 2. Left: Clipped rendering of 3D FLASH computation of a cylindrical implosion showing density contours and the aluminum marker, which provides radiographic contrast, in the central region of the cylinder. Upper right: Synthetic axial radiograph from 2D xRAGE computation. Center right: Experimental radiograph from NIF shot N210201-001 showing an m=8 asymmetry on the aluminum marker. Lower right: Synthetic radiograph from 3D FLASH computation which also shows the m=8 asymmetry.

By designing the laser drive to be nearly axially-invariant over a finite extent, it was hypothesized that the system should behave in a quasi-2D manner, and initial experiments at the Omega Laser Facility, which were well modeled with 2D simulations with LANL's xRAGE code, supported this belief. However, recent experiments using larger cylinders fielded at the NIF showed a significant asymmetry that was not predicted in this 2D modeling paradigm, as can be seen in the experimental radiographs shown Figure 1. Consequently, LANL scientists are collaborating with the Flash Center at the University of Rochester to use the FLASH 3D radiation-hydrodynamics code to better understand the origins of this drive asymmetry.

FLASH computations reproduce the octagonal pattern observed in experiments, which arises from differential absorption of the 45- and 50-degree NIF beams used to drive the target (Figure 2). The FLASH simulations also revealed a north/south asymmetry in the laser drive: the octagonal pattern appears with one phase at the north pole of the cylinder and a slightly offset phase at the south pole end. Critically, this phase difference is washed out in experimental radiographs viewing down the cylinder axis. This work demonstrates the importance of continued development of the 3D laser raytracing in xRAGE, the limitations on validating physics models based on NIF experiments with '2D symmetry,' and provides a validation evaluation of potential errors in interpretation when using 2D calculations if inadvertent 3D effects occur in the experiments.

2023 Stewardship Science Academic Programs Symposium Outstanding Poster Awards

Eight of the 130 graduate student posters featured during the Poster Session this year were selected to receive the 2023 Stewardship Science Academic Programs Symposium Outstanding Poster Award. We extend our thanks to all who participated in the judging and send kudos and congratulations to the winners!

Tanouir Aloui
Duke University
Ion Energy Distribution from Laser Ionization

Wesley Higgins
Texas A&M University
Investigating the Strain Rate Dependence of Hardness of Cu/Mo Nanolaminate Films Using Conventional and High Strain Rate Nanoindentation Methods

Ian Ocampo
Princeton University
Melting and Liquid Phase Response of Silia Shock Compressed to 154 GPa

Allison Pease
Michigan State University
Fe-Nitride Spin Transition Under Nonhydrostatic Compression and Impacts on the Strength of Fe-Nitrides

Michael Pokornik
University of California, San Diego
Investigating Laboratory Astrophysics Experiments with Collective Thomson Scattering Analysis

Afreen Syeda
University of Rochester
Viscosity Measurements in CH at Extreme Conditions

Eli Temanson
Florida State University
RESONEUT and the Study of the 10B(d,n)11C Reaction in Inverse Kinematics

Innocent Tsorxe
North Carolina State University
Measurements of Short-Lived Fission Product Yields from Photon-Induced Fission of Special Nuclear Materials

National Ignition Facility & Jupiter Laser Facility User Groups Meeting

The National Ignition Facility (NIF) & Jupiter Laser Facility (JLF) User Groups Meeting took place in Livermore, California from February 21-23, 2023. The meeting was held in person for the first time since 2020 at the Garré Winery near to Lawrence Livermore National Laboratory (shown below). Nearly 200 registered attendees gathered to hear presentations on big questions in high energy density (HED) science, current NIF Discovery Science experimental campaigns, recent JLF results, the status of capability development and refurbishment at both the NIF and the JLF, updates on the Nation's basic research needs for inertial fusion energy, and the National Academies of Science recommendations for the future of HED science in the United States. Nearly 80 posters were presented by students and post-docs. Forty graduate students received travel support from NNSA Defense Programs (DP). The organizers of the meeting gratefully acknowledge the work of the NIF User Group Executive Committee for putting together the technical program and thank the NNSA DP, DOE Office of Fusion Energy, and several corporate sponsors who helped make the meeting a success.