The National Ignition Facility: An International User Facility for High Energy Density Science

Christopher J. Keane and the NIF Team

Lawrence Livermore National Laboratory
7000 East Avenue, Livermore, CA 94550 USA

ABSTRACT The 192-beam National Ignition Facility (NIF) laser, completed in 2009, is operating 24/7 at Lawrence Livermore National Laboratory in Livermore, CA, USA. NIF is a high energy density science experimental facility, open to US and international users, with unprecedented capabilities to examine the behavior of matter at extreme conditions. NIF has conducted 192-beam experiments with energies and peak powers as high as 1.6 megajoules and 420 terawatts, respectively. The National Ignition Campaign (NIC), an international collaboration, has made significant scientific advances towards demonstration of inertial confinement fusion (ICF) ignition on NIF. The NIC team has demonstrated the highest fuel areal density product ($\rho r \sim 1.1$ gm/cm^2) ever achieved in ICF laboratory experiments, as well as a record neutron yield (5.7×10^{14} neutrons) from a laser-driven deuterium-tritium implosion. Initial fundamental science experiments at NIF have achieved 50-Mbar pressures in carbon, similar to conditions found in the centers of large planets, and also demonstrated the first production in ICF implosions of neutrons in the energy range (1-2 MeV) of interest for nucleosynthesis studies. With experiments ongoing in a variety of areas, a successful call for proposals in fundamental science executed in 2009-2010, and user infrastructure in place, NIF is establishing itself as a major international scientific user facility.

1. Overview of the National Ignition Facility

The National Ignition Facility (NIF), the world's most energetic laser system, is operational at Lawrence Livermore National Laboratory (LLNL) and conducting experiments in inertial confinement fusion (ICF) ignition and other scientific areas.[1,2] NIF is operational 24/7 and executed 286 system shots in the most recent fiscal year (October 2010-September 2011). The combination of laser, target, and diagnostic capabilities available at NIF make it an unprecedented user facility for advancement of ICF and other areas of high energy density (HED) science. With NIF available and other high energy density facilities in Japan,[3] France,[4] the UK,[5] and elsewhere under construction or complete, the world is entering a new era of discovery in HED science.

Fig.1. National Ignition Facility

The NIF laser consists of 192 individual laser beams grouped into four 48-beam "clusters," each composed of six 8-beam "bundles." NIF has demonstrated a total of 1.6 megajoules of ultraviolet (or 3ω) light on target in a 20-nanosecond pulse for a total power of nearly 420 terawatts. The laser will soon be capable of delivering 1.8 megajoules and 500 terawatts in the ultraviolet. This level of performance, fifty times more energetic than any previous laser system, has been demonstrated on a single bundle. The NIF laser also has precision and reproducibility unprecedented for a large ICF facility. This capability, coupled with precision targets and a high reliability diagnostics suite, allows NIF to conduct sophisticated experiments using a relatively small amount of shots.

Approximately 50 optical, x-ray, gamma, neutron and charged particle diagnostics are available at NIF, with additional advanced diagnostics planned. These diagnostics are either fixed or inserted into the target chamber via Diagnostic Insertion Manipulators or "DIMS." The DIM mount is used at a variety of facilities worldwide and facilitates broad collaboration in NIF diagnostics. A number of these diagnostics have been developed to handle conditions associated with high fusion yield; NIF is now qualified for use of tritium and to conduct fusion ignition experiments with single-shot yields up to 45 MJ. The NIF diagnostic team includes individuals from the academic, industrial, and national laboratories in the US as well as international collaborations.

2. The National Ignition Campaign (NIC) and Progress Towards Ignition

A central goal of NIF is the demonstration of inertial confinement fusion (ICF) ignition. Ignition is obtained via the compression and heating of mm-scale capsules filled with deuterium and tritium (DT) to temperatures and densities of approximately 10^8 degrees K and 1000 gm/cm^3, respectively. Ignition capsules include both a frozen and gaseous DT region and are held at cryogenic temperatures (18-19°K). The ignition program is executed by an international collaboration, the National Ignition Campaign (NIC), and consists of an experimental, computational, and theoretical effort aimed at tuning the laser and target parameters to those required for ignition.

NIC has made strong progress in the past year.[6,7] The target fabrication, diagnostic, and other techniques necessary to field and diagnose cryogenic ignition targets have been demonstrated, and the various experimental techniques used to tune the laser and target parameters have been validated. Cryogenic implosion experiments with 50/50 mixes of deuterium and tritium have been conducted at laser energies up to 1.6 megajoules and peak laser powers of 420 terawatts. These experiments have demonstrated the highest fuel areal density product ($\rho r \sim 1.1$ gm/cm^2) ever achieved in ICF laboratory experiments, as well as a record neutron yield (5.7×10^{14} neutrons) from a laser-driven deuterium-tritium implosion. The NIC team has also demonstrated an experimental ignition threshold factor (ITFX) approaching 0.1– a factor of over 50 increase in the past year. (Note ITFX = 1 implies a 50% probability of achieving ignition in a given ignition implosion experiment.)

3. Fundamental Science at NIF

The diagnostic and other capabilities implemented by the NIC team have also facilitated experiments in fundamental HED science. NIF's ability to access extreme conditions of matter will open new research frontiers and address compelling scientific questions in materials science, condensed matter physics, astrophysics, nuclear physics, and other areas.[2] As an example, in the past year scientists from the University of California (Berkeley), Princeton University, LLNL, and elsewhere conducted four experiments that compressed diamond to peak pressures exceeding 50 MBars—conditions never previously encountered in the laboratory and similar to those found in planetary interiors. Scientists are also developing techniques to perform nucleosynthesis experiments at NIF; in particular, NIF implosions are being developed as a source of relatively low energy neutrons (E~ 1-2 MeV) to look at the physics of the S-process. Initial experiments in supernova hydrodynamics have also been conducted. Experiments in a variety of other scientific areas have been approved for NIF.

4. NIF As a User Facility

NIF has also made progress towards operation as a user facility for fundamental HED science. In addition to the laser, diagnostic, and other facility capabilities described above, other infrastructure required by users is in place. LLNL has implemented a "HED Campus" to support visiting researchers. A successful call for proposals for fundamental science at NIF was executed in 2009-2010, and a NIF User Group is being formed.

5. Summary

NIF is a premier international experimental capability for research in ICF and other areas of HED science. The NIC team has made strong progress towards the goal of ICF ignition and established diagnostic, target fabrication, and other capabilities needed to advance the subject of HED science generally at NIF. Initial fundamental science experiments in materials science and astrophysics have further demonstrated NIF's scientific potential. The coming decade should truly represent a "golden age" for high energy density science as NIF and other user facilities worldwide enable the study of matter at extreme conditions never previously accessible.

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