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IGNITION AND FRONTIER SCIENCE ON THE NATIONAL IGNITION FACILITY

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ABSTRACT
The National Ignition Facility (NIF), the world's largest and most powerful laser system for inertial confinement fusion (ICF) and experiments studying high-energy-density (HED) science, is now operational at Lawrence Livermore National Laboratory (LLNL). The NIF construction Project was certified by the Department of Energy as complete on March 30, 2009. NIF, a 192-beam Nd-glass laser facility, will produce 1.8 MJ, 500 TW of light at the third-harmonic, ultraviolet light of 351 nm. On March 10, 2009, a total 192-beam energy of 1.1 MJ was demonstrated; this is approximately 30 times more energy than ever produced in an ICF laser system. The principal goal of NIF is to achieve ignition of a deuterium-tritium (DT) fuel capsule and provide access to HED physics regimes needed for experiments related to national security, fusion energy and for broader frontier scientific exploration.

NIF experiments in support of indirect drive ignition will begin in FY2009. These first experiments represent the next phase of the National Ignition Campaign (NIC). The NIC is a 1.7 billion dollar national effort to achieve fusion ignition and is coordinated through a detailed execution plan that includes the science, technology, and equipment. Equipments for required for ignition experiments include diagnostics, cryogenic target manipulator, and user optics. Participants in this effort include LLNL, General Atomics (GA), Los Alamos National Laboratory (LANL), Sandia National Laboratory (SNL), and the University of Rochester Laboratory for Energetics (LLE). The primary goal for NIC is to have all of the equipment operational and integrated into the facility and be ready to begin a credible ignition campaign in 2010. With NIF now operational, the long-sought goal of achieving self-sustained nuclear fusion and energy gain in the laboratory is much closer to realization.

Successful demonstration of ignition and net energy gain on NIF will be a major step towards demonstrating the feasibility of Inertial Fusion Energy (IFE) and will likely focus the world's attention on the possibility of an ICF energy option. NIF experiments to demonstrate ignition and gain will use central-hot-spot (CHS) ignition, where a spherical fuel capsule is simultaneously compressed and ignited. The scientific basis for CHS has been intensively developed [1] and has high probability of success. Achieving ignition with CHS will open the door for other advanced concepts, such as the use of high-yield pulses of visible wavelength rather than ultraviolet and Fast Ignition concepts [2, 3]. Moreover, NIF will have important scientific applications in such diverse fields as astrophysics, nuclear physics and materials science. The NIC will develop the full set of capabilities required to operate NIF as a major national and international user facility. A solicitation for NIF frontier science experiments to be conducted by the academic community is planned for summer 2009.

This paper summarizes the design, performance, and status of NIF, experimental plans for NIC, and will present a brief discussion of the unparalleled opportunities to explore frontier basic science that will be available on the NIF.

INTRODUCTION

NIF is the U.S. Department of Energy (DOE) and National Nuclear Security Administration (NNSA) national center to study inertial confinement Fusion (ICF) and the physics of extreme energy densities and pressures.* [4] NIF concentrates all the energy of its 192 extremely powerful laser beams onto a centimeter-scale fusion target, driving it to conditions under which it will ignite and burn, liberating more energy than is required to initiate the fusion reactions. NIF is designed to achieve target temperatures of 100 million K, radiation temperature over 3.5 million K, density of 1,000 g/cm^3 and 100 billion times atmospheric pressure. These conditions have never been created in a laboratory and exist naturally only in the interiors of the stars and during thermonuclear burn.

NIF will operate in the "indirect-drive" configuration (figure 1-a) where the fusion capsule [5], filled with a deuterium-tritium (DT) mixture, is mounted inside a cylindrical hohlraum. Laser beams enter the hohlraum through a hole in each end of the cylinder, are absorbed by the interior wall, and converted to x-ray energy. These x-rays bathe the capsule and ablate its outer layer. Conservation of momentum requires that the remaining material implode or compress. Compression of the DT fuel to extraordinarily high temperature, pressure, and density causes the central hot spot to ignite, and a burn wave propagates through the remaining fuel. NIF can also be configured in a "direct-drive" arrangement (figure 1-b) wherein the laser beams are directed onto the surface of the DT fuel capsule. Figure 1-c illustrates the fast ignition concept.

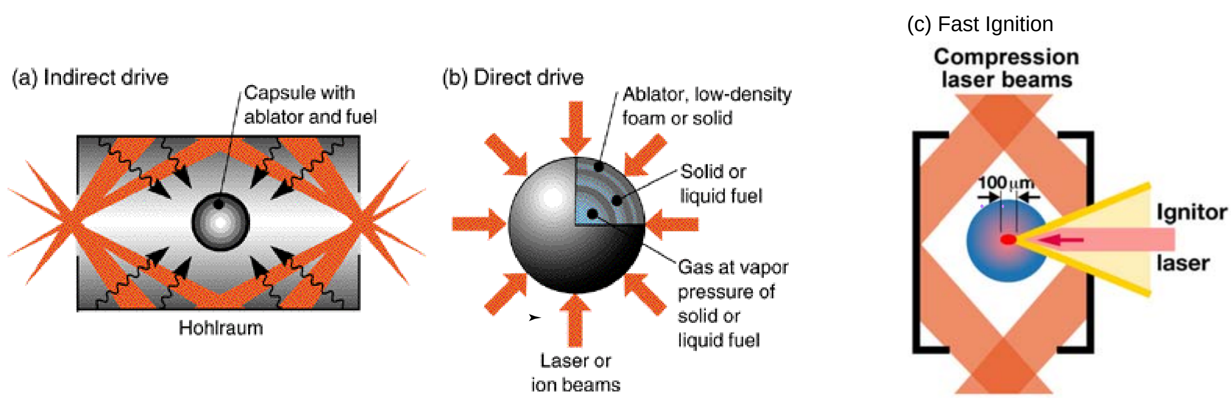

Figure 1. Illustration of ICF target concepts (a) indirect drive, (b) direct drive (c) fast ignition.

The mission to achieve thermonuclear ignition in the laboratory was identified in the early 1990s by DOE's Fusion Policy Advisory Committee and the National Academy of Sciences Inertial Fusion Review Group as the next important step in inertial fusion research. The experimental program to accomplish ignition [6] is detailed in the NIC Execution Plan [7], including all required science, technology, and experimental equipment. The central goal of the NIC Program is to perform credible ignition experimental campaigns on the NIF beginning in FY2010 and to transition NIF from project completion to routine facility operations in FY2012.

To prepare for the FY2010 ignition campaign, many activities are under way at NIF and other medium-scale facilities including OMEGA at LLE, Z at SNL, Trident at LANL and Jupiter at LLNL. Experiments at these facilities are being used to develop and demonstrate shock timing, laser ablation and the diagnostics techniques needed to achieve ignition. In addition, the NIC team is conducting a simulated campaign that is stepping through the processes of preparing and executing the NIC to refine requirements

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*NIF web site, http://www.llnl.gov/nif/

on targets, diagnostics, lasers, optics, data collection and analysis, and to optimize the NIC strategy and shot plans to balance risk and resources.

THE NATIONAL IGNITION FACILITY

The National Ignition Facility is designed to achieve ignition of a DT nuclear fusion target. NIF's 192 laser beam lines are housed in a building with a volume of about 350,000 m^3 (figure 2). Each laser beam line contains 36 to 38 large-scale precision optical elements, depending on beam line configuration (figure 3), and hundreds of smaller optical components. The combined total area of precision optical surfaces is 3600 m^2, and the total radiating aperture is 22 m^2. For purpose of comparison, the combined optical surface area of the two Keck Telescopes, the world's largest, is 152 m^2, approximately 4% of that of NIF. The NIF 10-meter-diameter high-vacuum target chamber (figure 4) contains entry ports for all the laser beams and over 100 ports for diagnostic instrumentation and target insertion. Sophisticated diagnostic instruments such as x-ray and neutron spectrometers, microscopes, and streak cameras, can be mounted around the equator and at the poles of the target chamber. About 35 different types of diagnostics are planned for NIC. For indirect-drive fusion studies, all 192 beams will be focused into a cylindrical hohlraum through two round entrance holes 2.5 mm in diameter. The conditions created in the hohlraum will provide the necessary environment to explore a wide range of high-energy-density physics experiments, including laboratory-scale thermonuclear ignition and burn. All of the 192 beam lines have been operated at the fundamental 1053-nm wavelength (1ω), delivering greater than 19 kJ per beam line.

The initial laser pulse is produced by a cw Yb-fiber master oscillator. The initial pulse passes through an array of fiber-optical components used to provide the required precise temporal shape and bandwidth, then is split 48 ways, sending pulses into the preamplifier modules. Pulses from each of the 48 preamplifier modules are further split and delivered into the 192 beam lines. Each beam line, illustrated in figure 2, operates as a four-pass amplifier, enabled by the LLNL invention of the large aperture plasma-electrode Pockels cell (PEPC) [8]. The PEPC functions as follows: A pulse is injected into each beam line near the focal plane of the transport spatial filter (TSF), from where it expands to the full square-aperture beam size of 37.2 × 37.2 cm, then passes through the spatial filter lens, which collimates the beam. The pulse passes through the power amplifier (PA), reflects from a mirror and a polarizer then passes through the cavity spatial filter (CSF) and main amplifier (MA). It reflects from a deformable mirror used to correct wavefront distortions and then makes a second pass through the MA and CSF. During the time required for the pulse to make this double pass, voltage is applied to the PEPC that rotates the polarization of the pulse by 90 degrees. It then passes through the polarizer, reflects from a second mirror, and makes another double pass through the PEPC, CSF and main amplifier. Before the pulse returns to the PEPC, its voltage is switched off, so the pulse reflects from the polarizer and mirror and makes a final pass through the PA and TSF and propagates on to the switchyard. There, beam transport mirrors direct the pulse through a final optics assembly (FOA), shown in figure 5, consisting of a 1ω vacuum window, focal-spot beam conditioning optics, two frequency conversions that change the wavelength to 351 nm, a focal lens, main debris shield that also serves as a diagnostic beam splitter and a thin, disposable debris shield used to protect the optics from debris produced by irradiation of the target.

Also, new for NIF is the introduction of the line-replaceable unit (LRU) design concept [9]. In this concept, developed at LLNL for the Atomic Vapor Isotope Separation Program, the laser is assembled using modular components that are easily removed for maintenance, thus allowing the laser to maintain nearly continuous operation. Other key developments essential to the success of NIF are: a continuous pour method for producing extremely low-defect laser glass [10], rapid growth of large, frequency conversion crystals of potassium dihydrogen phosphate (KDP) and deuterated KDP [11], and the LLNL-developed strategy for increasing damage resistance and economically managing optical damage. Complete description of these key developments is beyond the scope of this paper; details can be found in the cited references.

(a) (b) (c)

Figure 2 (a). NIF facility aerial photograph, (b) cut-away drawing, and (c) Laser Bay 2**.**

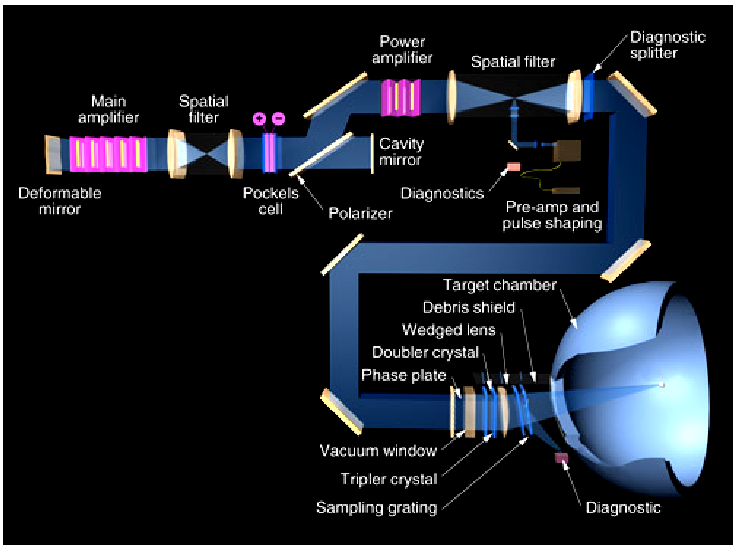


Figure 3. Schematic of one of NIF’s 192 beamlines.

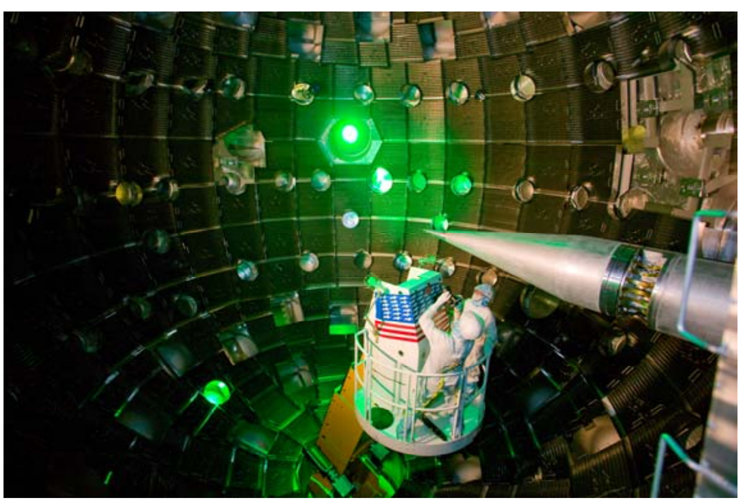


Figure 4. Inside the NIF target chamber, a 10-m-diameter sphere of 10-cm-thick aluminum coated with a 40-cm-thick neutron shielding concrete shell. The entire assembly weighs about one-half million kilograms. The target positioner is on the right.

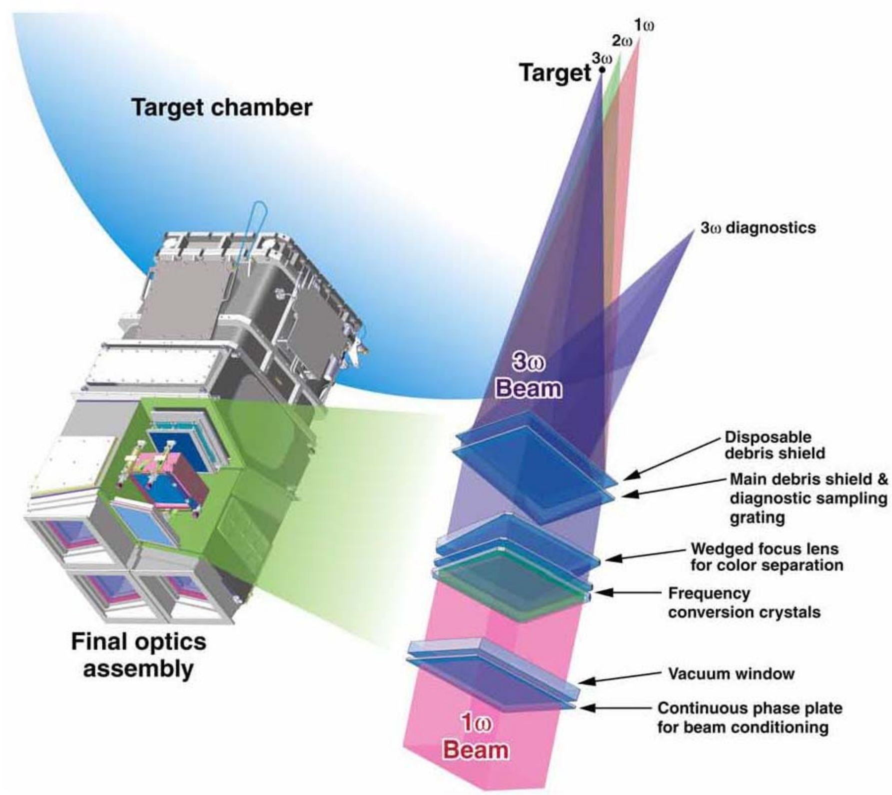


Figure 5. NIF final optics assembly containing a beam-conditioning phase plate, KDP frequency-conversion crystals, fused-silica focus lens and two fused-silica debris shields.

THE NATIONAL IGNITION CAMPAIGN

The National Ignition Campaign is a collaborative effort by LLNL, GA, LLE, LANL and SNL with two major goals: execution of DT ignition experiments starting in FY2010 with the goal of demonstrating > 1 MJ in fusion energy output, and demonstration of a reliable, repeatable ignition platform by the end of the NIC in Q4FY2012. Planning and schedules for the NIC are highly integrated, and both must be completed on schedule to support the NIC. The NIC FY06 thru FY12 budget is shown in Table 1 below.

Site	FY2006	FY2007	FY2008	FY2009	FY2010	FY2011	FY2012
GA Total	15,756	17,580	18,726	15,228	15,641	15,655	16,056
LANL Total	12,581	11,698	12,633	12,945	13,253	13,253	13,252
LLE Total	38,633	38,647	53,100	56,296	56,489	57,477	58,627
LLNL Total	93,586	100,415	157,922	228,179	305,293	292,747	292,748
SNL Total	1,065	1,130	1,179	1,210	1,239	1,239	1,240
Grand Total	161,621	169,470	243,560	313,858	391,915	380,371	381,923

Table 1. NIC funding profile (NIC Execution 17580Plan Revision 3.1)

Components of the NIC Plan

Components of the NIC plan include: target physics, systems engineering and operations as well as targets, and equipment such as target diagnostics, the cryogenic target positioner, and user optics required for the ignition experiment. The first effort to achieve ignition will be by indirect-drive ICF using target designs that have been calculated to ignite at energy of approximately 1 MJ for 3ω pulses. Key elements of the NIC plan are:

- Design, fabrication, and execution of ignition experiments
- Experiments on NIF and supporting NNSA experimental facilities prior to the FY2010 ignition experimental campaign that are needed to verify and validate the ignition design and mitigate risks
- Diagnostics, user optics, cryogenic target system, targets, personnel and environmental protection systems, NIF operations personnel, and operating inventory
- Equipment and technology needed to maintain a sustained effort on ignition beyond the initial experimental campaigns

Creating a NIF target requires the joint efforts of target designers, materials scientists, and engineers. Targets for the NIC experiments are being developed through a collaborative effort between scientists and engineers from LLNL, GA, LLE, and LANL. Designers establish specifications for the target, which typically are only a few millimeters in size. Their complicated shapes must be machined to meet precise requirements, including specifications for density, concentricity, and surface smoothness. Nanoscale materials developed for NIF experiments include high-density carbon, very low-density copper and gold foams, and graded-density foams.

The conditions that targets will encounter during experiments make their performance highly sensitive to imperfections in fabrication. Manufacturing requirements for all NIF targets, thus, are extremely rigid. Components must be machined to within an accuracy of 1 µm, with joints as small as 100 nm. In addition, the margin of error for target assembly is less than 8 µm. The current design for the ignition target is a copper-doped beryllium capsule with a smooth solid layer of DT on its inner surface. The radially tailored fusion capsule will be mounted at the center of a 9-mm-high by 5-mm-diameter cylindrical hohlraum made of a material with high atomic number, such as gold.

For NIF to achieve ignition, the beryllium capsule must have a precise spherical shape. The capsule's surfaces must be smooth to within 1 nm—an unprecedented requirement for surface roughness—and the thickness and opacity of the copper-doped layers must be carefully controlled. Making the capsule begins by depositing beryllium on a smooth, perfectly spherical plastic mandrel. As the mandrel is rotated, a 150-µm-thick layer of beryllium slowly builds up on its surface. After a capsule is polished, a laser is used to drill a 5-µm fill hole. An oxidation technique removes the mandrel through the drilled hole, and a 10-µm tube is attached to the capsule so it can be filled with DT gas.

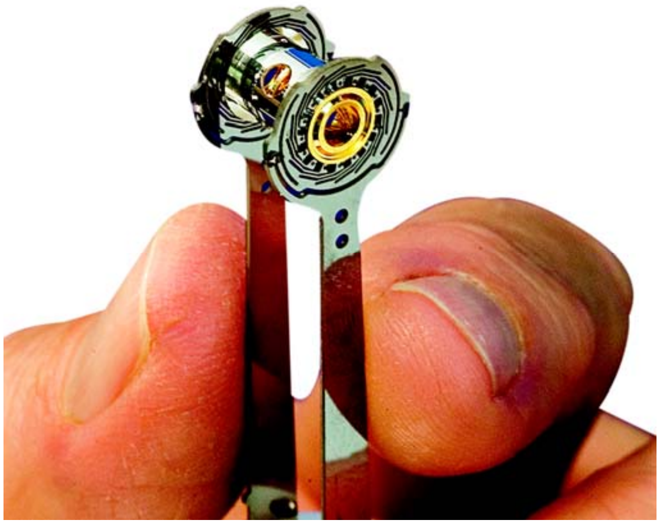
Researchers at LLNL, LANL and LLE have pioneered procedures [12] to form the frozen layer of DT fuel inside the fuel capsule at 1.5 degrees below the triple point of the DT mixture. Temperature can fluctuate no more than 1 mK—a demanding requirement for accuracy. Beta decay of the tritium helps smooth the layer by selectively heating thicker regions and evaporating hydrogen. NIF researchers found that the DT ice can be shaped by precisely controlling heat transfer within the hohlraum, including contributions from thermal convection of helium. Auxiliary heaters located on the hohlraum shape the temperature field within the target to produce a nearly spherical isotherm. To control the ice layer's surface roughness, the NIF team developed a seeding and cooling procedure that achieves a surface roughness of about 0.5 µm (rms) at the solid-gas interface. A thermo-mechanical assembly encasing the target (figure 7) is able to maintain its position to within 2 µm, while holding it at 18 to 20 K with fluctuations limited to only 1 mK. This system integrates the ICF target with a cryogenic layering and characterization station and a target positioner attached to NIF's target chamber. The system includes a positioning boom to center the target in the chamber. An ignition-target inserter cryostat attached to the positioner cools the target and the DT fuel to meet temperature and uniformity requirements. The layering and characterization station can image the DT fuel layer along three axes within a few minutes.

To measure the performance of the lasers, hohlraum and target capsule and to record the results of NIF experiments, the target chamber is surrounded by dozens of detectors, oscilloscopes, interferometers, streak cameras and other instruments designed to capture reaction history, dynamic temperature and opacity of the target over dynamic ranges far greater than the capabilities of previous systems. Diagnostic instruments must be precisely positioned and aligned to capture data from the mm-size fusion target, operated remotely, and be able to quickly transmit vast amounts of data to instruments kept at a safe distance from the target chamber's harsh radiation environment, which will include neutrons, x-rays, gamma rays and electromagnetic pulses.

In NIF, about 35 different diagnostics will be used to study target behavior with high accuracy and precision. Advanced ignition diagnostics planned for the NIC include:

- Velocity Interferometer (VISAR) diagnostic for shock timing. The intense X-rays produced by the laser beams rapidly heat the outer surface of the spherical target, driving shock waves toward the target center. VISAR uses sophisticated interferometric techniques to accurately measure the speed of these shock waves, with the information used to optimize design of the target
- The Dante soft x-ray power diagnostic to characterize the X-rays generated by the experiments
- A Cherenkov gamma-ray detector to measure the history of the hydrogen fuel's ignition and burn with 50-ps resolution
- A magnetic recoil spectrometer for neutron spectroscopy
- X-ray emission and backlit imaging system to image the target core as it ignites

(a) (b)



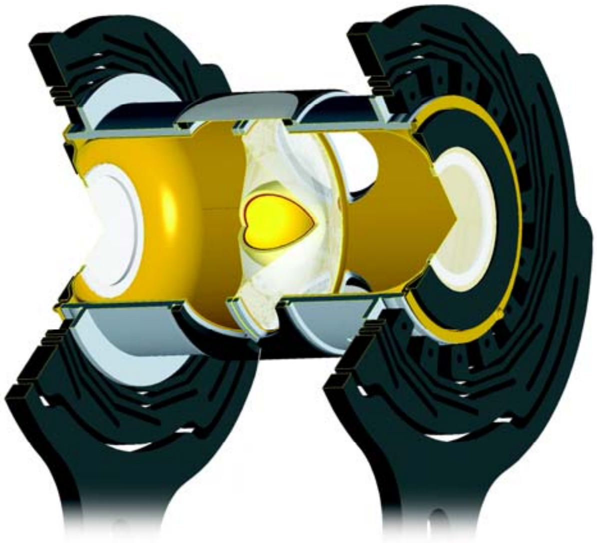


Figure 6. (a) NIF fusion target thermo-mechanical package, (b) cut-away drawing shows 2-mm fuel capsule supported at the hohlraum center.

NIC Experimental Plan

The NIC will consist of four series of deuterium-tritium ignition implosion experiments as shown in Figure 8. The first series will culminate with the first attempts at inertial fusion ignition in late FY2010. The subsequent three series will refine the target and laser parameters and investigate the physics of the ignition regime, with a goal of providing a reliable and repeatable ignition platform for use in stockpile stewardship experiments by the conclusion of NIC at the end of FY2012.

Each of the four series of ignition implosion experiments will be conducted in four phases designed to tune the laser and cryogenic deuterium-tritium target to ignition conditions. In the first or "drive" phase, the empty hohlraum is tuned to produce the necessary radiation drive on the capsule as a function of time. In the "tuning" phase, a variety of non-cryogenic and cryogenic deuterium filled cryogenic capsules are used to adjust the hohlraum symmetry and shock timing so as so produce the compressed fuel central "hot spot" conditions required for ignition. The final tune consists of layered cryogenic implosions conducted with a 50%/49%/1% mix of tritium, hydrogen, and deuterium ("THD") respectively. The reduced yield from these targets allows the full diagnostic suite to be employed and the presence of the required temperature and fuel areal density to be verified. The final step is deuterium-tritium ignition implosions with expected gains of 10-20. The FY2010 deuterium-tritium ignition experiments will be conducted with E_{laser} ~ 1.5MJ. Laser energies of 1.8MJ should be available for subsequent experimental series.

NIC experiments on NIF will commence with hohlraum energetics experiments in the summer of FY2009. These first crucial experiments will measure backscattered laser energy from NIF hohlraums and directly address the issue of laser-plasma instabilities- a key area of risk identified by JASON and other review committees.

In preparation for execution of the ignition experimental series the NIC team has conducted a "simulated campaign" to exercise the experimental team and develop the ability of NIC scientists to quickly tune the ignition target to the correct conditions. The "Blue Team" specified and executed simulated experiments that exercise much of the NIF laser, target, and operational infrastructure, while the "Red Team" provided synthetic data that takes into account specified target fabrication errors, laser power imbalance, backscatter, and cross-beam energy transfer. Over a several month period the Blue Team demonstrated synthetic ignition by successfully adjusting laser and target parameters to compensate for detunings specified by the Red Team, and reduced from days to hours the time required to examine a data set and experimentally tune the laser and target to ignition conditions.

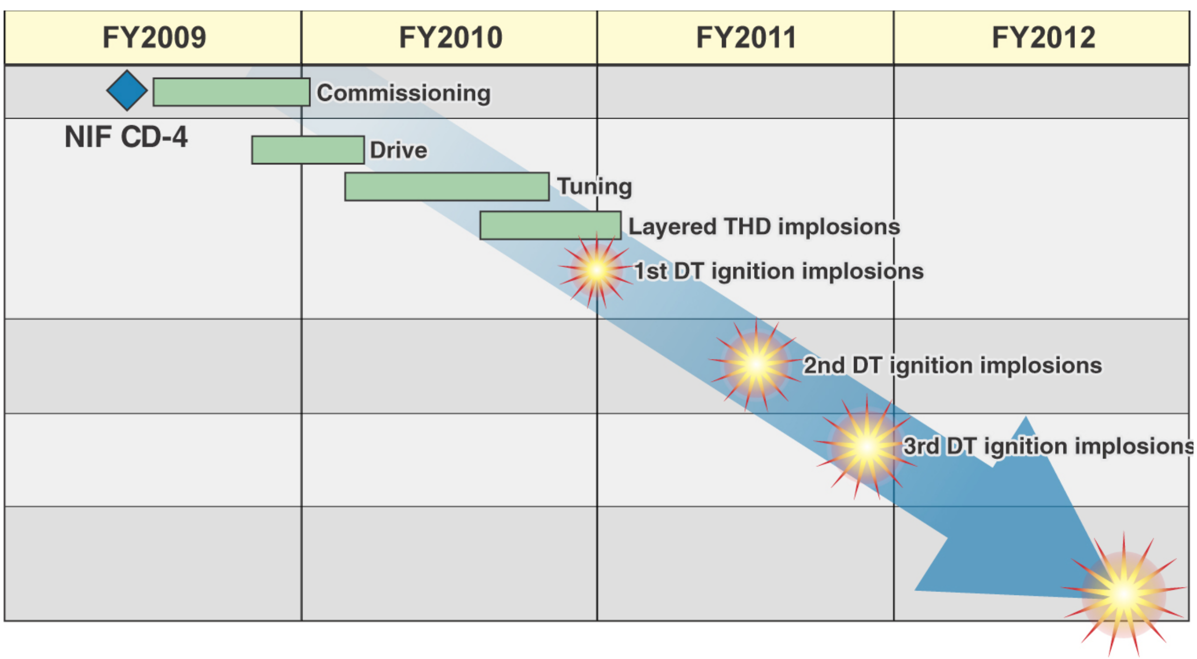


Figure 7. Schedule for NIF ignition experimental campaigns.

The NIC is managed as a project-like activity, with full earned-value implementation. The NIC Execution Plan (Revision 3.1) specifies the funding level planned as well as the scope and schedule for activities conducted by each NIC participant. The use of a project management approach is crucial for NIC success. The NIC team has approximately 1.5 years between completion of the NIC Project and execution of the ignition experiments. During this period the laser must be completely commissioned, over thirty sophisticated diagnostics fully installed, the complex cryogenic target system implemented, and the entire infrastructure for experimental execution brought on line. This is a massive and unprecedented technical and management challenge. No major ICF facility has gone from project completion to execution of highly sophisticated experiments in such a short time. Stability in the funding profile for NIC (Table 1) is crucial for success.

While ignition experiments will be the primary focus of the ICF Campaign and NIC through FY2012, as shown in Fig. 8. NIF will execute other experiments in support of stockpile stewardship, national defense, and fundamental science. Weapons physics experiments conducted in this timeframe will reduce uncertainties in key areas and enabled improved predictive capability. Experiments conducted in collaboration with the Defense Threat Reduction Agency (DTRA) and the Missile Defense Agency (MDA) will validate NIF as a ultra-low debris soft x-ray (E < 15 keV) simulator. Nuclear survivability tests of specific components will also be conducted. Initial experiments in fundamental high energy density science in areas such as planetary interiors and supernova hydrodynamics will also be executed.

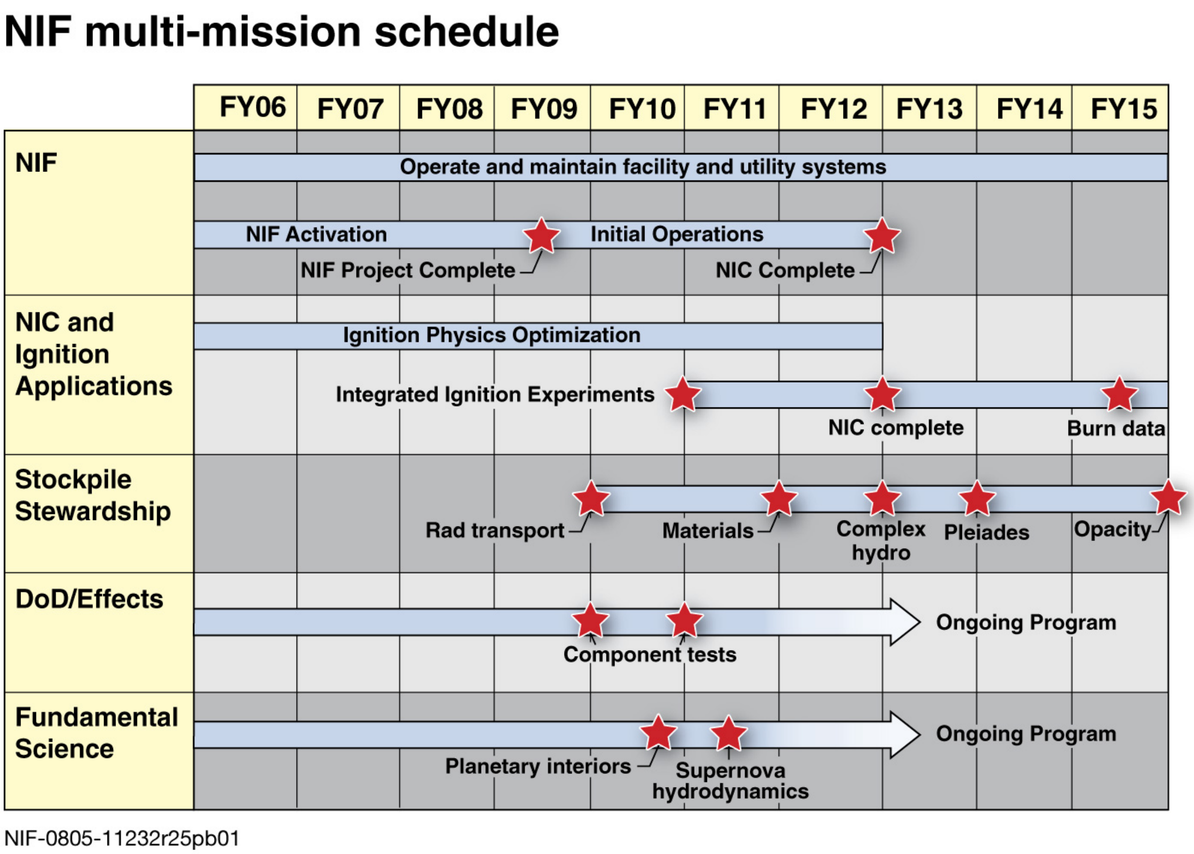


Figure 8. Integrated Timeline for the NIF Project and Planned Experimental Campaigns.

EXPLORING FRONTIER SCIENCE

NIF will also provide national and international researchers unparalleled opportunities to explore “frontier” basic science in astrophysics, planetary physics, hydrodynamics, nonlinear optical physics, and materials science. Up to 15% of NIF’s time and resources will be devoted to science experiments in these fields. With its 192 beams together generating up to 1.8 MJ of energy, NIF will provide the highest temperatures and densities that have ever been created in a laboratory, enabling scientists to study some of the most extreme conditions in the universe.

The coupling of high-intensity laser light to plasmas has been the subject of experimental investigations for many years. Past experiments have focused on measuring a broad range of phenomena [13], such as resonance and collisional absorption, filamentation, density profile and particle distribution modification, and the growth and saturation of various parametric instabilities. These phenomena depend on the properties of the laser and the composition of the plasma. NIF's large, uniform plasmas and laser-pulse shaping, coupled with diagnostics that will measure the plasma's electron and ion temperature, charge state, electron density, and flow velocity, make it an ideal site for studying these processes with new precision. Planned experiments include the evolution of plasma perturbations at the interface of two materials, stable and unstable high-Mach-number plasma flow, the transition to turbulence under extreme conditions, and multi-beam nonlinear optical processes in plasmas that can result in radiation fields propagating at new frequencies or in new directions.

The conditions that will be produced by NIF when it achieves ignition are extraordinarily well matched to the conditions that exist in stars in different phases of their evolution. Temperatures up 100 million K, densities of 1,000 grams per cubic centimeter, are clearly in the stellar range, and the neutron density at ignition, possibly as high as 10^{26} cm^{-3}, with fluxes up to 10^{33} neutrons cm^{-2} sec^{-1}, exceeds that of stellar nucleosynthesis [14].

Supernovae mark the death of massive stars by mechanisms not fully understood. The explosions are characterized by strong shocks and turbulent hydrodynamics. The NIF will replicate shock-induced nonlinear hydrodynamic instabilities in scaled laboratory experiments, although with spatial and temporal scales 10–20 orders of magnitude smaller than those of their astrophysical counterparts. NIF will allow researchers to conduct the first detailed three-dimensional experiments of strong-shock-induced Rayleigh–Taylor instability. Laboratory experiments will help researchers better understand the mechanisms occurring in remnants and to verify the accuracy of computational models developed to interpret supernovae behavior.

The stellar nucleosynthesis that produces heavy elements has been studied for several decades. While its properties are well established by the nuclear physics of the nuclei synthesized in it, where it occurs in the universe is not yet known. Leading candidate sites are core-collapse supernovae and colliding neutron stars. NIF will be able to shed light on this question by providing an environment in which some of the reactions that affect the process can be studied. In addition, the very high neutron flux generated by ignition may even be able to create some of the neutron-rich nuclides that will help scientists better understand the properties of those nuclei as they are synthesized.

Black holes are one of the most exotic objects in the universe. Understanding the dynamics of matter as it spirals inward toward a black hole is an enormous scientific challenge. Much of our understanding of black holes arises from observations of X-rays emitted by matter that is pulled into the deep gravitational wells of black holes. The extreme temperatures of these plasmas produce nuclei in very highly ionized states, with spectra quite different from atoms or slightly ionized ions. NIF will create photoionized plasmas to test models and improve interpretations of x-ray data recorded by space-based observatories of accreting black holes and neutron stars and will provide essential information about temperatures and densities in such extreme environments.

Many of the key questions in planetary physics are related to fundamental questions in extremely dense condensed matter physics. In just the last few years, astronomers have discovered more than 300 new planets outside our Solar System, including gas giants more than 15 times the mass of Jupiter and possible

Earth-like planets more than 150 times Earth's mass. All of the "extra-solar" planets discovered to date are giant or super-giant planets with interior conditions reaching pressures and temperatures as high as a gigabar and 10,000 K. Materials are known to undergo fundamental changes in their physical and chemical bonding properties at a fraction of such pressures, so there is considerable interest among scientists in experimentally observing materials at deep-planet conditions to better understand the makeup and geophysical evolution of these astronomical objects. Experimental data on the equation of state and other properties of hydrogen and helium are needed to test models of the interiors of Jupiter and Saturn and to better understand interior structures of the giant ice planets Uranus and Neptune. By providing new experimental capabilities for studying high-pressure, moderate-temperature states of condensed matter, NIF will enable scientists to access the deep core states of large planets and answer some of the most fundamental questions in condensed matter physics.

NIF will execute a solicitation open to academic researchers in summer 2009. This solicitation will support development of the scientific opportunities described above and develop NIF as a user facility. Potential NIF users will be encouraged to develop experiments leveraging the various experimental capabilities dcveloped to date for NIC and the weapon science program. An example of this leveraging is NIF planetary sciences program (R. Jeanloz (UC Berkeley) et al.). By making modest changes to the laser pulse applied to an ignition hohlraum, the UC Berkeley team will generate a ramp pressure pulse capable of compressing iron to "super-earth" conditions (P~ 20 Mbar). This will be the first in a series of NIF experiments designed to look at condense matter issues relevant to planetary interiors.

CONCLUSION

After many years of R&D, most of the pieces needed for ignition are in place: the NIF laser and the equipment needed for ignition, including high-quality targets and an ignition point design target. Initial ignition experiments will only scratch the surface of NIF's potential, including high yields with 2ω light and greatly expanded opportunities for the uses of ignition by decoupling compression and ignition using innovative Fast Ignition concepts.

All prior large laser facilities were designed and built with the latest technologies, and scientists then determined what research the facility could accomplish. In contrast, NIF was designed specifically to meet the needs of three missions: support stockpile stewardship for a safe and reliable nuclear stockpile, advance ICF as a clean source of energy, and to make significant strides in HED physics. These three missions share the need to expose materials to extraordinarily high pressures, temperatures, and densities—as much as 100 billion atmospheres pressure, 100 million degrees Centigrade temperature, and 1,000 g/cm^3 density. These conditions occur during thermonuclear burn, in supernovae, and in the fusion reactions that power our Sun and other stars and that may one day provide an inexhaustible power supply on Earth. Because of the similarities of these phenomena, the results of some NIF experiments will be applicable to all three missions.

We cannot venture inside stars, planets, or black holes, nor can we traverse billions of light years across the universe to examine a supernova explosion. However, with NIF, we can re-create in the laboratory the same physical processes that astronomers can only glimpse through a telescope. Our goal with the National Ignition Campaign is to demonstrate ignition and burn and launch a new era of high-energy-density science and energy research.

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