The National Ignition Facility: An Overview

WHEN Secretary of Energy Hazel O'Leary visited LLNL last October 21, she brought a message long awaited by researchers here and throughout the international scientific community. The Secretary announced to an enthusiastic crowd of employees, community leaders, and industry representatives that she had approved "Key Decision 1" to build the National Ignition Facility (NIF) and that LLNL's expertise in laser fusion made it the preferred site for the approximately $1-billion facility.

An international research center comprising the world's most powerful laser, NIF will achieve ignition of fusion fuel and energy gain for the first time in a laboratory. When it begins operation in 2002 (see the box on p. 2), NIF will serve researchers from many different institutions and disciplines for both classified and unclassified projects.

As a DOE–Defense Programs facility, NIF will be a key component in the Department's science-based Stockpile Stewardship Program to ensure the safety and reliability of the nation's enduring stockpile of nuclear weapons. By yielding considerably more fusion energy than is put in by the laser (energy gain), it also will bring us a large step closer to an inertial fusion energy (IFE) power plant. NIF will also advance the knowledge of basic and applied research in high-energy-density science. Finally, the project to construct NIF and equip it with the most modern components will spawn technological innovation in several U.S. industries and enhance their international competitiveness.

If NIF is sited at LLNL, it will be the largest construction project and permanent facility in our history. Scientists worldwide will be performing research here, invigorating LLNL in many existing and new technical areas. Additionally, the project will benefit dozens of Bay Area and California construction and manufacturing companies, creating many new jobs.

NIF is comparable in size to a municipal sports stadium. (See the illustration on p. 9.) The heart of the facility is a neodymium laser system of 192 beams, with each beam optically independent for outstanding experimental design flexibility. Together, the laser beams will produce 1.8 million joules (approximately 500 trillion watts of power for four billionths of a second) of energy. In comparison, LLNL's Nova laser, currently the world's largest, produces 45,000 joules (approximately 15 trillion watts for three billionths of a second).

The beams will compress and heat to 100 million degrees 1- to 3-millimeter-diameter capsules containing deuterium-tritium fuel, thereby producing ignition (self-heating of the fusion fuel) followed by a propagating thermonuclear burn. The implosion process will produce fusion burns with significant energy gain, up to ten times the energy required to initiate the reaction. (See the box on p. 5.)

This sequence of events will produce the equivalent of a miniature star lasting for less than a billionth of a second, yet long enough for researchers to make accurate measurements of its temperature, pressure, and other properties. Indeed, we will "look" at fusion microexplosions with a spatial resolution of 10 micrometers (about one-tenth the size of a human hair) and freeze the action at a time resolution of 30 picoseconds (trillionths of a second).

Culminates 30 Years of Research

NIF will represent the scientific culmination of more than 30 years of inertial confinement fusion (ICF) research at LLNL and throughout the world. Calculations by Livermore physicists in the 1960s showed that a laser generating a megajoule of light in ten billionths of a second could ignite a fusion microexplosion in the laboratory. They reasoned that such microexplosions could be used to simulate the detonation of nuclear weapons and that such a fusion technology might one day generate electrical power.

Over the years, Livermore scientists built and operated a series of laser systems, each five to ten times more powerful than its predecessor. (See Figure 1.) Long Path, Livermore's first neodymium glass laser, was completed in 1970 and was our workhorse laser for five years. Our two-beam Janus laser, completed in 1974, demonstrated laser compression and thermonuclear burn of fusion fuel for the first time. In 1975, our one-beam Cyclops laser became operational and was used to perform target experiments and to test optical designs for the future Shiva laser. A year later, the two-beam Argus laser increased our understanding of laser–target interactions.

During this time, laser development and ICF experiments proceeded rapidly at other facilities, including KMS Fusion, the Laboratory for Laser Energetics (LLE) at the University of Rochester, and the Naval Research

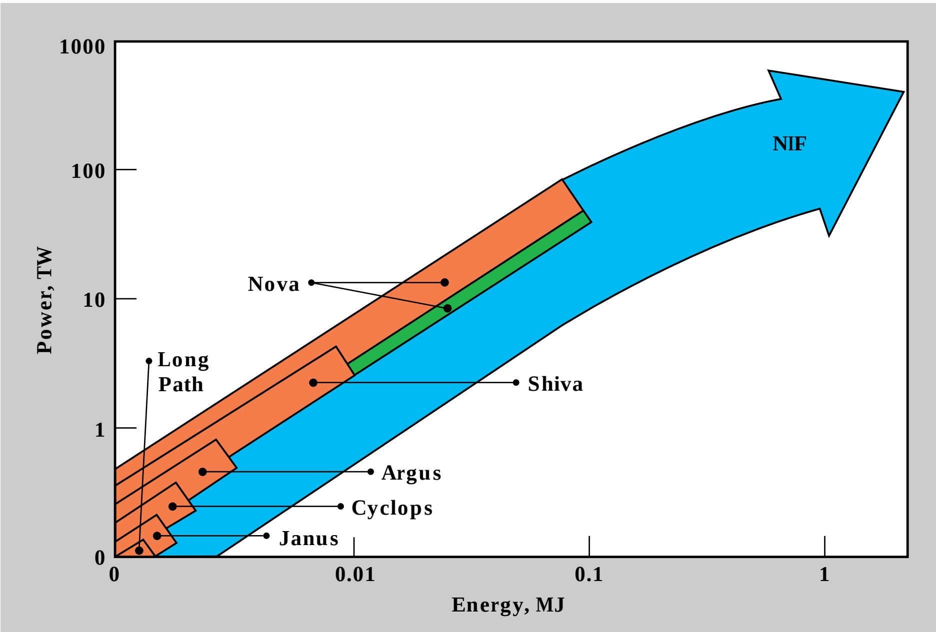


Figure 1. **The energy and power of neodymium glass lasers built for inertial confinement fusion (ICF) research at LLNL have increased dramatically over the past two decades.**

Planning for NIF

The Department of Energy's procedure for approving large projects such as NIF is based on "Key Decisions" (KDs) made by the Secretary of Energy. In January 1993, the Secretary approved KD 0, which affirmed the need for NIF and authorized a collaborative effort by the three DOE defense laboratories and the University of Rochester's Laboratory for Laser Energetics to produce a conceptual design report. This report was completed in April 1994.

KD 1 was signed by the Secretary in October 1994. This decision initiated preliminary design, safety analysis, cost and schedule validation, and a two-year Environmental Impact Statement, which will include public involvement. NIF has been identified as a low-hazard, non-nuclear facility based on the Preliminary Hazards Analysis Report.

In addition, the DOE has agreed to steps before KD 2 that will examine NIF's likely impact on nonproliferation and stockpile stewardship issues. KD 2, scheduled for late fiscal year (FY) 1996, includes detailed engineering design, further cost and schedule validation, and final safety analysis. KD 3, in late FY 1997, will authorize construction and major procurements. KD 4, in late FY 2002, will authorize facility operation and the first experiments.

Detailed planning for NIF has been led by five institutions that have long collaborated on laser fusion experiments: LLNL, Los Alamos National Laboratory, Sandia National Laboratory, the University of Rochester, and General Atomics. The cooperative spirit of the five institutions and their interactions with industry and the public were cited by Vic Reis, Assistant Secretary for Defense Programs, during a visit to LLNL last November.

Laboratory. Major programs in the Soviet Union, Japan, China, Germany, France, and the United Kingdom were established or expanded.

In 1977, the 20-beam Shiva laser was completed. The largest American ICF project at that time, it delivered more than 10 kilojoules of energy in less than a billionth of a second. Meanwhile LLE's 24-beam Omega system became operational in 1980. Novette, which came on line in 1983, was the first laser designed to generate green and ultraviolet light. It confirmed work done at several ICF centers, showing that plasma instabilities were suppressed by shorter wavelength light.

As a result of this work, Nova was redefined as a 10-beam system with frequency conversion rather than the 20-beam infrared system originally approved. Nova became operational in late 1985, the same time that the French Phebus laser, consisting of two Nova-style beamlines, was completed.

Using the Nova and Omega lasers, as well as underground nuclear experiments in the Halite-Centurion Program, scientists have made important progress in understanding ICF. At the same time, the study of scaling glass lasers to systems much larger than Nova provided the technical guidelines for a future system to create target ignition and energy gain. (See Figure 2.) ICF takes its place among decades-long international efforts to reach fusion conditions in the laboratory. Unlike magnetic fusion designs, ICF strives to compress fusion fuel isentropically before raising its ion temperature to ignition levels.

Such an ignition facility was strongly recommended by the National Academy of Sciences and the DOE Fusion Policy Advisory Committee in their 1990 reports and by the DOE Inertial Confinement Fusion Advisory Committee and the JASON Review Committee in 1994. This facility, eventually called the National Ignition Facility, would use improved laser design and engineering as well as advanced optics, laser amplifiers, and frequency converters.

Two conceptual designs for NIF were prepared, one using 240 beams and the other employing 192. As Figure 3 indicates, the smaller and less expensive of these designs adequately meets target requirements, with a safety margin of about two for achieving ignition.

NIF Benefits

By demonstrating thermonuclear ignition and burn in the laboratory for the first time, NIF will play a critical role in the DOE's science-based Stockpile Stewardship Program. With the end of the Cold War, America's nuclear

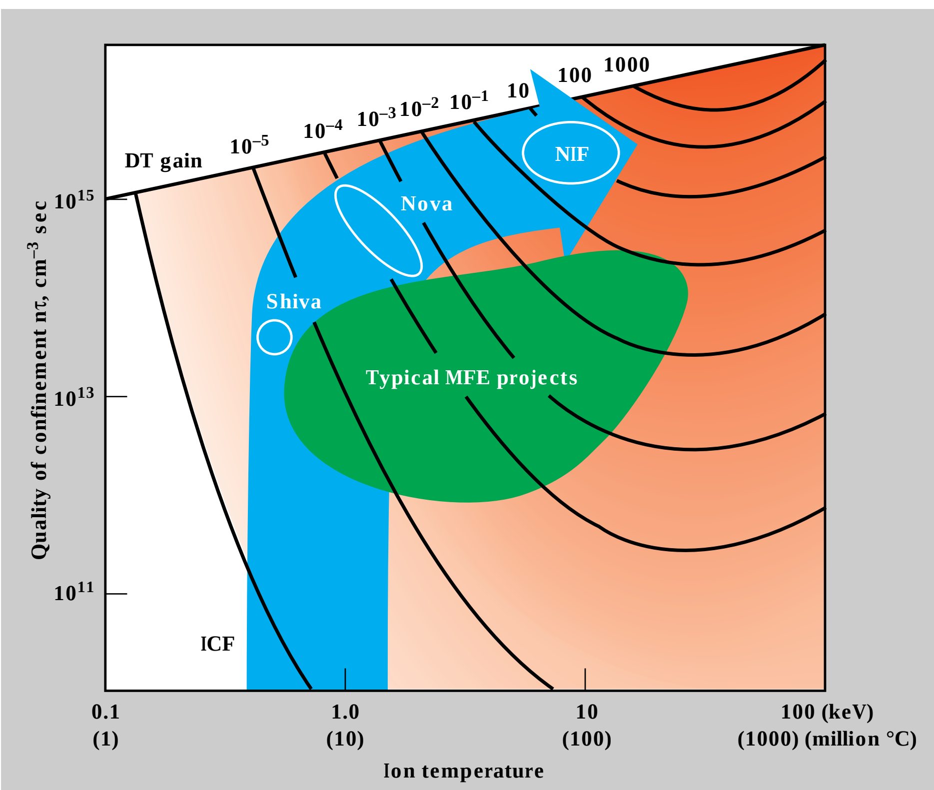


Figure 2. NIF will be the culmination of over two decades of research by the international ICF community into the use of glass laser systems to create controlled target ignition and energy gain in the laboratory. Unlike magnetic fusion energy (MFE) designs (e.g., the Princeton Large Taurus, Doublet II, the Tokamak Fusion Test Reactor, and the Joint European Taurus, which trap fuel in an intense magnetic force field to induce fusion), ICF strives to compress fusion fuel isentropically before raising its ion temperature to ignition levels.

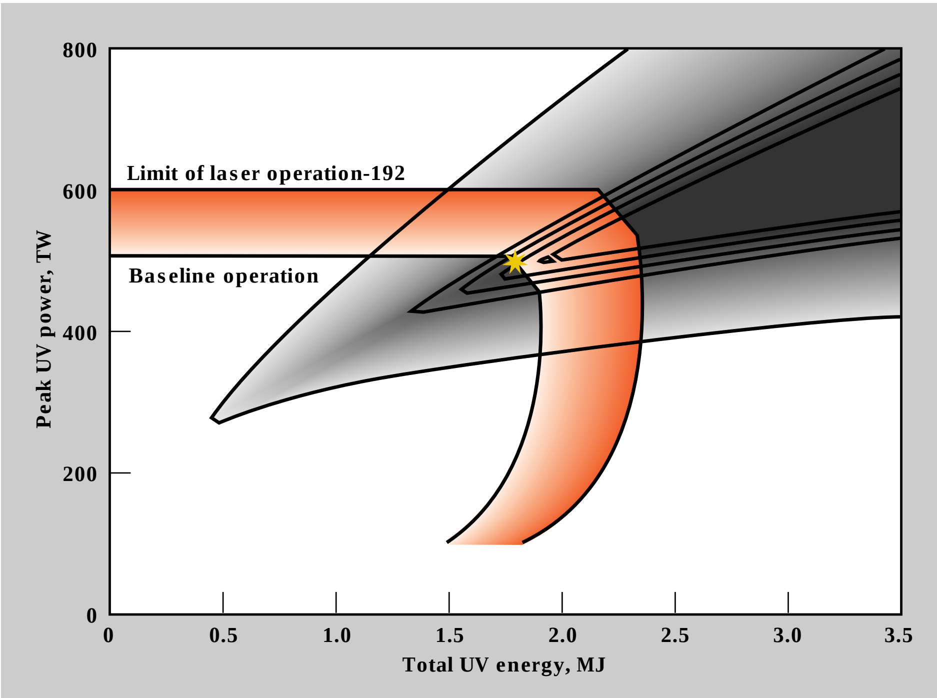


Figure 3. Two conceptual designs were prepared for NIF, one using 240 beams and the other employing 192. The smaller of these was chosen because it is more affordable than the 240-beam option. In addition, as the figure indicates, the 192-beam design will not only achieve the baseline operation requirement of 1.8 megajoules and 500 terawatts of power (the optimum point for target ignition indicated by the yellow star), but it can also operate at higher energy and power with increasing risk of damage to the system—up to a maximum acceptable risk or "redline" performance (2.2 megajoules and 600 terawatts). The shaded area indicates the increasing target margin above the minimum power and energy required to achieve ignition.

weapons stockpile is being significantly reduced. However, nuclear weapons will continue to exist for the foreseeable future. In the absence of underground testing, the reliability, safety, and effectiveness of the remaining stockpile can be assured only through advanced computational capabilities and aboveground experimental facilities. NIF is the only facility proposed for the program that addresses fusion and several other physical processes that involve high-energy density.

Data from NIF will complement data from hydrodynamic tests and will also be used to improve the physics in computer codes that are needed to certify the safety and reliability of our remaining stockpile. These more accurate codes will better simulate potential problems in the enduring stockpile as well as improve our interpretation of data from the archives of past underground tests.

NIF will also help to maintain the skills of the nation's small cadre of nuclear weapons scientists and to attract new scientists to help manage

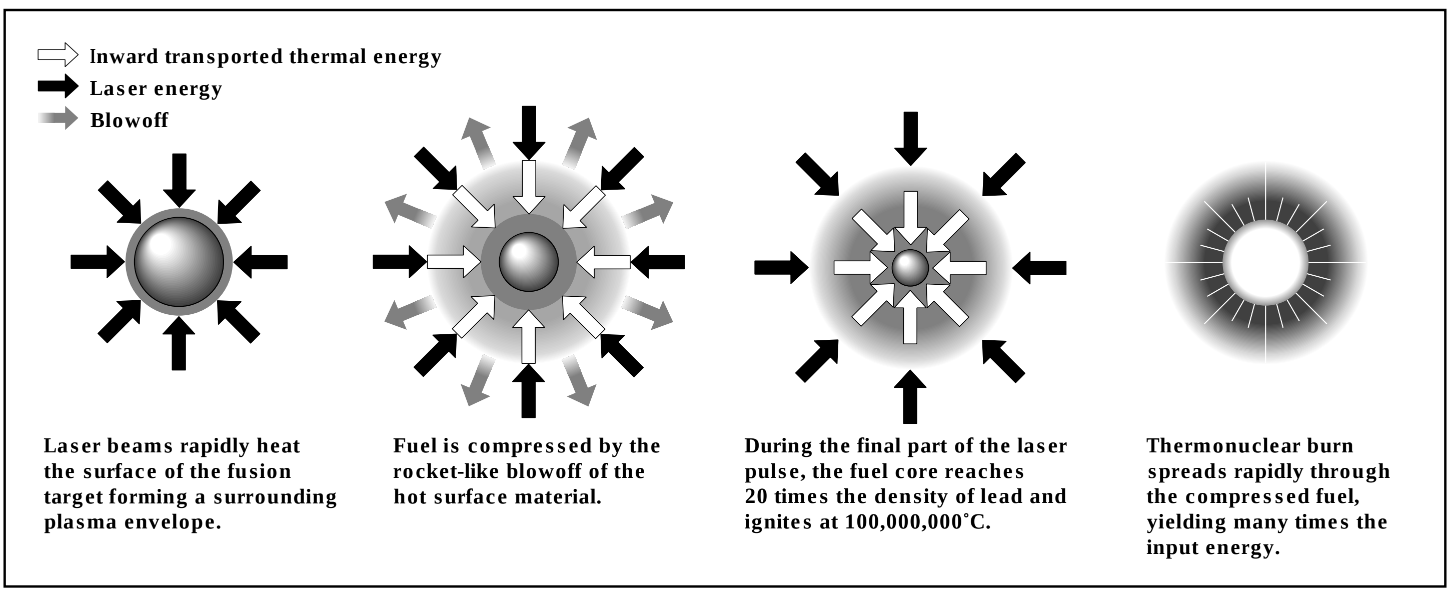


Figure 4. The steps of an inertial confinement fusion reaction, which produces up to ten times the energy used to initiate ignition. Under laboratory conditions, the sequence produces energy gain equivalent to the power of a miniature star lasting for less than a billionth of a second.

the Stockpile Stewardship Program, support U.S. nuclear nonproliferation goals, aid in the safe dismantlement of nuclear weapons, and respond to nuclear weapon crises.

Another major goal of NIF is to help establish the scientific basis for environmentally friendly electrical power generated by IFE. The *National Energy Policy Act of 1992* calls for DOE to support both IFE and magnetic fusion energy approaches to achieving fusion energy as a practical power source.

As envisioned, IFE power plants will use high-repetition-rate laser or ion drivers (about 10 pulses per second). The heat from the continual fusion reactions will be absorbed by coolants surrounding the fuel pellets and converted to electricity. NIF will provide crucial data on the design requirements of these drivers and on other critical components. Such data will also be used to help design an Engineering Test Facility that is planned for early next century as the next step toward a functioning IFE power plant.

NIF will also provide new capabilities for the high-energy-density physics community. Because fusion targets will experience temperatures and pressures similar to those found in stars, data from NIF experiments will attract scientists working in such areas as astrophysics, space science, plasma physics, hydrodynamics, atomic and radiative physics, material science, nonlinear optics, x-ray sources, and computational physics. These fields have been the subject of more than 1000 scientific papers published by ICF researchers since 1985.

As the world's largest optical instrument, NIF will spur key U.S. high-technology industries, such as optics, lasers, materials, high-speed instrumentation, semiconductors, and precision manufacturing. U.S. industry has long been a major participant in the rapid progress of ICF research. Today DOE ICF scientists are involved in 24 cooperative research and development agreements (CRADAs) totaling over $160 million in the fields of microelectronics, microphotonics, advanced manufacturing, biotechnology, precision optics, environmental sensors, and information storage.

ICF scientists have also won 26 R&D 100 Awards for outstanding technological developments with commercial application. Most recently, LLNL and Moscow State University received a 1994 R&D 100 award for growing potassium dihydrogen phosphate (KDP) crystals much more rapidly, an achievement with significant promise for NIF.

Much further development in manufacturing technologies over the next three years is needed to meet the cost goals for NIF. For example, the size of NIF optics, such as KDP crystals, is up to two times larger than those used in Nova. In addition, the required damage threshold of these optics is two to three times higher than that of Nova's optics. We are planning a program to

Inertial Confinement Fusion

Thermonuclear fusion is the energy source for our sun and the stars and for nuclear weapons. In a fusion reaction, nuclei of light elements, such as deuterium and tritium (isotopes of hydrogen), combine at extreme temperatures and pressures to form a heavier element, in this case helium. The energy released in a fusion reaction is about one million times greater than that released from a typical chemical reaction.

There are essentially three methods for confining fusion fuel reactions: gravitational confinement, as inside stars, and magnetic and inertial confinement, which can be achieved in the laboratory. Both magnetic fusion and inertial confinement fusion (ICF) research are supported by DOE.

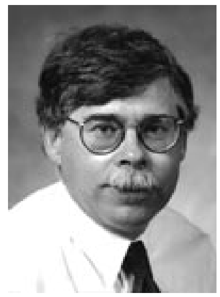
In ICF, energetic driver beams (laser, x-ray, or charged particle) heat the outer surface of a fusion capsule containing deuterium and tritium (D-T) fuel (see Figure 4). As the surface explosively evaporates, the reaction pressure compresses the fuel to the density and temperature required for D-T fusion reactions to occur. The energy released further heats the compressed fuel, and fusion burn propagates outward through the cooler, outer regions of the capsule much more rapidly than the "inertially confined" capsule can expand. The resulting fusion reactions yield much more energy than was absorbed from the driver beams.

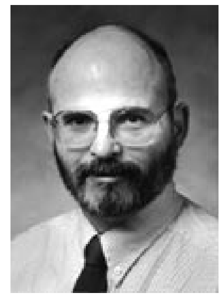
There are two basic approaches to ICF. In the first, called direct drive, laser beams impinge directly on the outer surface of the fusion target. In the second approach, called indirect drive, beams heat the surface of a metal case (hohlraum), causing emission of x rays that strike the fusion target capsule and drive the implosion. (See the box and figure on p. 38, which provide additional information about direct- and indirect-drive targets.)

help our suppliers substantially reduce their costs to manufacture high-quality, state-of-the-art NIF components, an achievement that will help them compete better in the international market.

When the first experiments are carried out on the NIF in 2002, they will begin a new era of advanced research with a laser system so powerful it was only dreamed about several decades ago. By achieving ignition and energy gain for the first time in the laboratory, NIF will maintain U.S. world leadership in ICF research and will directly benefit many different research communities. If sited at LLNL, it will considerably strengthen this laboratory and make it an even greater center of scientific research.

In this special issue of *Energy and Technology Review* dedicated to NIF, we describe in separate articles the importance of NIF to weapons physics and the science-based Stockpile Stewardship in which NIF will play an indispensable role; NIF's potential contributions to energy research; and NIF's likely impact on advancing science and technology. We also describe more fully the NIF facility by taking a tour of it from a laser beam's point of view, and finally, we review the environmental, safety, and health considerations relevant to NIF.





For further information contact Jeffrey Paisner (510) 422-6211 or Kenneth Manes (510) 423-6207.