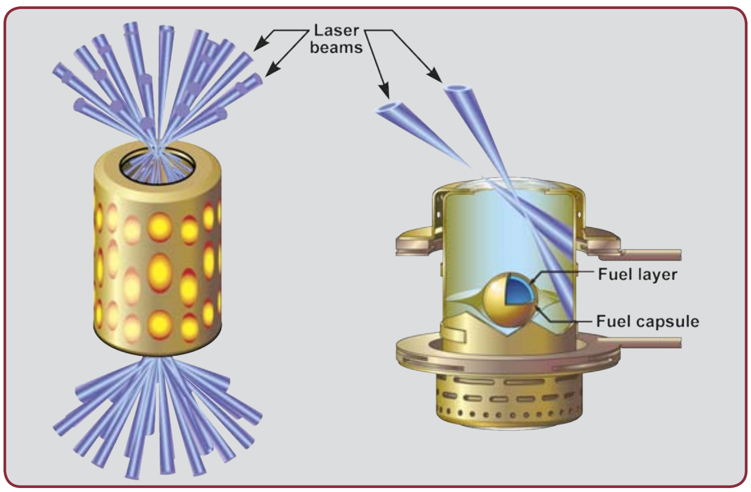
National Ignition Campaign

How to Make a Miniature Star

The idea for the National Ignition Facility (NIF) grew out of a decades-long effort to generate fusion burn and energy gain in the laboratory. Current nuclear power plants, which use the splitting of atoms (fission) to produce energy, have been pumping out electric power for more than 50 years. But achieving nuclear fusion burn and gain has not yet been demonstrated as viable for energy production. For fusion burn and gain to occur, a special fuel consisting of the hydrogen isotopes deuterium and tritium must first "ignite." A primary goal for NIF is to achieve fusion ignition, in which more energy is generated from the reaction than went into creating it. The National Ignition Campaign, a multi-institutional project, carried out the initial ignition experiments on NIF in 2010 and continues its research on ignition today.



The NIF Target

All of the energy from NIF's 192 beams is directed inside a gold cylinder called a hohlraum, which is about the size of a dime. A tiny capsule inside the hohlraum contains atoms of deuterium (hydrogen with one neutron) and tritium (hydrogen with two neutrons) that fuel the ignition process.

NIF was designed to produce extraordinarily high temperatures—tens of millions of degrees—and pressures many billion times greater than Earth's atmosphere. These conditions now exist only in the center of stars, planets, and nuclear weapons. In a star, strong gravitational pressure sustains the fusion of hydrogen atoms. The light and warmth that we enjoy from the sun, a star 93 million miles away, are reminders of how well the fusion process works and the immense energy it creates.

Replicating the extreme conditions that foster the fusion process has been one of the most demanding scientific challenges of the last half-century. Physicists have pursued a variety of approaches to achieve nuclear fusion in the laboratory and to harness this potential source of unlimited energy for future power plants.

How ICF Works

Since the late 1940's, researchers have used magnetic fields to confine hot, turbulent mixtures of ions and free electrons called plasmas so they can be heated to temperatures of 100 to 300 million kelvins (180 million to 540 million degrees Fahrenheit). Under those conditions, positively charged deuterium nuclei (containing one neutron and one proton) and tritium nuclei (two neutrons and one proton) can overcome the repulsive electrostatic force that keeps them apart and "fuse" into a new, heavier helium nucleus with two neutrons and two protons. The helium nucleus has a slightly smaller mass than the sum of the masses of the two hydrogen nuclei, and the difference in mass is released as kinetic energy according to Albert Einstein's famous formula $E=mc^2$. The energy is converted to heat as the helium nucleus, also called an alpha particle, and the free high-energy neutrons interact with the material around them.

In the 1970's, scientists began experimenting with powerful laser beams to compress and heat the hydrogen isotopes to the point of fusion, a technique called inertial confinement fusion, or ICF. In the "direct drive" approach to ICF, powerful beams of laser light are focused on a small spherical pellet containing micrograms of deuterium and tritium. The rapid heating caused by the laser "driver" makes the outer layer of the target explode. In keeping with Isaac Newton's Third Law ("for every action there is an equal and opposite reaction"), the remaining portion of the target is driven inwards in a rocket-like implosion, causing

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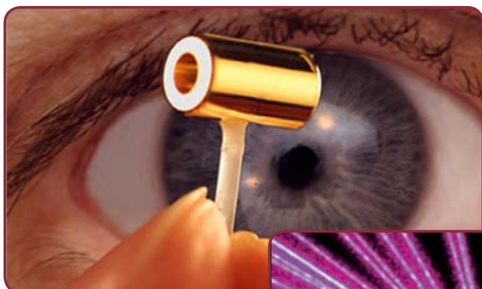
compression of the fuel inside the capsule and the formation of a shock wave, which further heats the fuel in the very center and results in a self-sustaining burn known as ignition.

The fusion burn propagates outward through the cooler, outer regions of the capsule much more rapidly than the capsule can expand. Instead of magnetic fields, the plasma is confined by the inertia of its own mass—thus the term inertial confinement fusion.

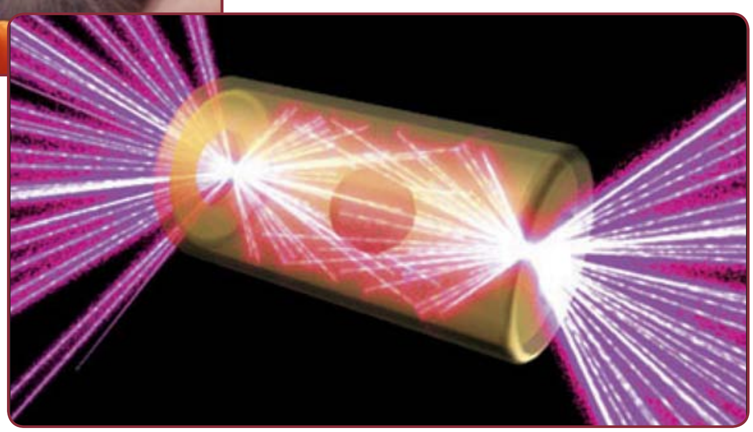
In the “indirect drive” method, the approach currently used at NIF, the lasers heat the inner walls of a gold cavity called a hohlraum containing the fuel pellet, creating a superhot plasma that radiates a uniform “bath” of soft X-rays. The X-rays rapidly heat the outer surface of the pellet, causing a high-speed ablation, or “blowoff,” of the surface material and imploding the pellet in the same way as if it had been hit with the lasers directly. Symmetrically compressing the pellet with radiation forms a central “hot spot” where fusion processes set in—the plasma ignites and the compressed fuel burns before it can disassemble.

NIF aims to be the first laser in which the energy released from the fusion fuel will exceed the laser energy used to produce the fusion reaction. Unlocking the stored energy of atomic nuclei will produce 10 to 100 times the amount of energy required to initiate the self-sustaining fusion burn. Creating ICF and energy gain in the NIF target chamber will be a significant step toward making fusion energy viable in commercial power plants. LLNL scientists also are exploring other approaches to developing ICF as a commercially viable energy source.

Because modern thermonuclear weapons use the fusion reaction to generate their immense energy, scientists will use NIF ignition experiments to examine the conditions associated with the inner workings of nuclear weapons. Ignition experiments can also be used to help scientists better understand the hot, dense interiors of large planets, stars, and other astrophysical phenomena.



A NIF Hohlraum
This tiny gold cylinder is a hohlraum designed for use during ignition experiments.



The fusion process

The fusion ignition process, from the heating of the interior of the hohlraum capsule to ignition at 100,000,000°C and fusion burn. Because there is only a tiny amount of fuel in the fuel capsule, the ignition and burn process is very brief.