Fender has hooked up with Advanced LIGO and Virgo, respectively the US- and European-led gravitational-wave detectors, to follow up on each other's observations. For example, says Fender, "if one object is spiraling into another, from the gravitational signal alone you can estimate the distance, assuming general relativity is right. Say LOFAR sees a flash, too. If the distances don't match, general relativity is wrong."

Besides astronomical research, LOFAR is serving as physical and software infrastructure for studies in agriculture and geophysics. The first agricultural project involved measuring temperature, humidity, and other parameters to help battle phytophthora, a fungal disease in potatoes. Among the geophysics projects in the works are seismic and infrasound studies to detect and characterize such events as earthquakes, nuclear detonations, volcanic eruptions, and sonic booms. Both sets of experiments involve attaching sensors to LOFAR's network. Delft University of Technology's Guy Drijkoningen, who heads the geophysics applications of LOFAR, says that for seismic and infrasound data, "the highly innovative aspect is the design and use of interferometry. It allows [us] to see sources in and above the Earth which have not been seen before."

Toni Feder

DOE looks again at inertial fusion as a potential clean-energy source

As ignition experiments get under way at the National Ignition Facility, an official says the Department of Energy should be preparing for a decision on whether laser-driven fusion energy can be harnessed.

Sometime during the next two years, physicists are expecting to achieve a long-sought milestone in fusion research: ignition and high energy gain. That breakthrough won't be happening at ITER, the international collaboration that is building a reactor in France, but at the National Ignition Facility (NIF) for nuclear weapons–related experiments that was completed two years ago at Lawrence Livermore National Laboratory (LLNL).

In the quest to develop nuclear fusion as a bountiful source of clean energy, the inertial confinement route, in which high-powered lasers implode tiny capsules of fuel to fuse heavy isotopes of hydrogen, has long been seen as the underdog. The magnetic confinement approach, in which powerful magnetic fields are used to bottle up plasmas of deuterium and tritium that are heated to more than 100 million K, has been pursued for decades by the US and other industrialized nations in the hope that it will become a practical and clean source of energy. Inertial confinement fusion (ICF) has been advanced primarily for its military applications, because it can simulate in the laboratory some of the processes that occur in the fusion stage of thermonuclear weapons.

But that landscape could be about to change as scientists begin to experiment in earnest toward their goal of achieving ignition and high gain at NIF. If they are successful, for the first time in more than 50 years of ICF research experimenters will get more energy from the fusion reaction than they put in to produce it. Already, scientists and engineers have begun to reexamine the possibility that ICF might offer a quicker path to fusion energy. At the request of Steven Koonin, DOE undersecretary for science, a National Research Council (NRC) committee is looking at inertial fusion energy (IFE) and will advise how soon and at what cost the required technologies could be developed. Chaired by Ronald Davidson, former director of Princeton Plasma Physics Laboratory, and Gerald Kulcinski, a professor at the University of Wisconsin–Madison, the committee has met twice since December, and is expected to provide its interim findings to DOE in the summer.

In an interview, Koonin says he wants the NRC analysis in hand if and when ignition is achieved, so that he'll be prepared for the inevitable questions. Quoting hockey great Wayne Gretsky, Koonin says DOE should be "skating to where the puck will be" on IFE. Using that rationale, Koonin last year recruited David Crandall, the chief scientist in DOE's National Nuclear Security Administration (NNSA), to a new post that would administer DOE's IFE R&D, should LLNL experiments be successful.

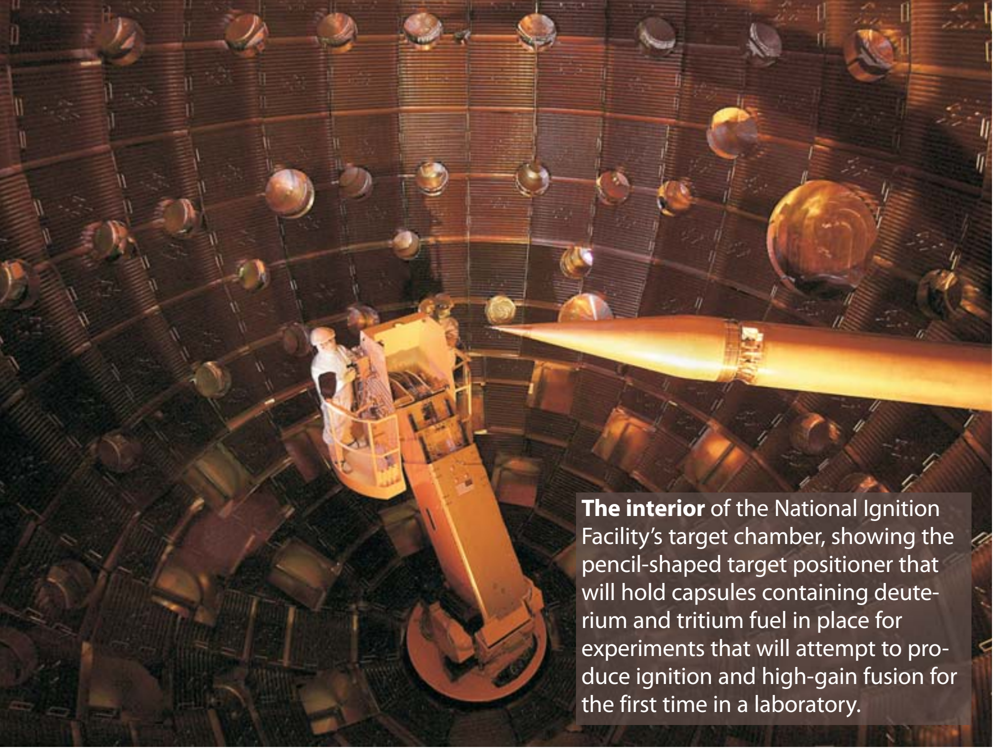
The importance of ignition

Even proponents agree that the success of the experiments known as the national ignition campaign is critical to IFE's future. "You have to be able to show that a driver can compress a pellet enough to get at least as much fusion energy out of it as you are putting in," says Stephen Dean, president of Fusion Power Associates, an industry group. It's hoped that NIF will get 10–20 times the amount of energy out as went in. To become economical, a power plant might need to achieve a gain of 50–100, Dean says.

Koonin is no stranger to ICF. He has kept a close eye on the DOE program for the past two decades, during most of which he was a professor and provost at Caltech. He is personally overseeing the ignition campaign, and has already visited LLNL twice to review the initial results. He has appointed a group of outside experts to provide their own takes on the experiments. Koonin has been a member of several external ICF review panels, including a 1992 committee that explored IFE's potential (see the article by William Hogan, Roger Bangerter, and Gerald Kulcinski in Physics Today, September 1992, page 42). At least four other assessments of IFE, not counting the current one, have taken place, from 1978 to 2007. Each of them identified ignition as the required next milestone.

Koonin is well acquainted with NIF, having chaired a 1997 NRC committee that recommended DOE proceed with construction of the facility. At the time, the department estimated NIF would cost \$1.1 billion and be completed in 2002. In reality, the device was completed in 2009 for \$3.5 billion. But Koonin stands by his assertion in a December memo to other top agency officials that "the speed and efficiency with which the NIF was built and brought on line, in spite of unforeseen difficulties encountered along the way, are remarkable."

The NIF ignition campaign will be critical to IFE, Koonin says. While a failure to attain ignition within a few years could be a death sentence for IFE, its success would hardly assure its feasibility. For starters, NIF's lasers aren't capable of firing rapidly enough to produce meaningful amounts of energy. The laser optics must be cooled between shots. In weapons-physics experiments, that's not an issue, because one shot a day is more than enough. But LLNL already has proposed a different solid-state laser for IFE, where NIF's flashlamps are replaced by diodes, and new



LAWRENCE LIVERMORE NATIONAL LABORATORY

The interior of the National Ignition Facility's target chamber, showing the pencil-shaped target positioner that will hold capsules containing deuterium and tritium fuel in place for experiments that will attempt to produce ignition and high-gain fusion for the first time in a laboratory.

optics would have channels through which coolant can pass. Named LIFE, for laser inertial fusion energy, the demonstration plant LLNL has proposed would draw upon experience gained from NIF, and utilize the base of suppliers that it had built up during NIF construction. But there are other alternatives to glass drivers, including pulsed power, krypton fluoride gas lasers, and heavy-ion accelerators, that could be better suited for IFE. Koonin says the NIF results will provide useful data for further development of the other candidate drivers.

Apart from the driver, DOE will also need to decide whether to take an indirect- or direct-drive approach for driver and target interaction. The NIF indirect drive approach mimics the fusion process in a nuclear weapon. A capsule of deuterium and tritium fuel is located inside a hollow cylinder known as a hohlraum. Beams from NIF's 192 lasers enter the holes at either end of the capsule and, striking the gold-coated interior, produce x rays. The radiation implodes the fuel, causing the isotopes to fuse. As its name implies, the direct-drive approach omits the hohlraum; the driver's energy is deposited directly onto the fuel. That direct approach has been pursued both at the US Naval Research Laboratory and at the University of Rochester's Laboratory (NRL) for Laser Energetics. Both have long been contractors to NNSA.

Dissenting voices

Not everyone is optimistic about NIF's ignition potential. One prominent skeptic is Stephen Bodner, a former director of the NRL's ICF program, who has consistently maintained that NIF will fall short of ignition. Among unresolved physics concerns that Bodner has raised are unwanted magnetic fields generated by hohlraums and other laser–plasma instabilities that could prevent ignition.

The Natural Resources Defense Council (NRDC) has fought NIF from the outset of the project and argues that any discussion of IFE is wildly premature. "Until DOE has a much firmer grasp of the fundamental science and technology requirements for ignition and control of a fusion reaction in the laboratory, and then from there can actually discern a plausible path to cost-effective energy gain, it is worse than useless to speculate" on the key challenges associated with a demonstration and commercial plant, NRDC's Christopher Paine told the NRC committee.

Paine was referring to the charge DOE had given to the committee, which was also asked to consider the economics; Koonin emphasized that the cost of fusion power will need to become competitive with nuclear energy and natural gas generation. "Building an IFE plant at 20 cents per kilowatt with no prospect of coming down the learning curve isn't going to do us much good," Koonin said, when gas or nuclear energy costs 5 or 6 cents. And a fusion plant costing $8 billion won't fly when a utility could build a small modular nuclear plant for $1 billion (see PHYSICS TODAY, August 2010, page 25).

Harold Forsen, a retired senior vice president of Bechtel who has long been involved in fusion research, told the

NRC committee in December that a 10^6 improvement in NIF's repetition rate and a 10^5 increase in NIF's fusion energy per shot will be needed to make a fusion power plant economically viable.

Bureaucratic issues

A multitude of other engineering issues will remain for IFE should ignition be attained. Materials for lining the target chamber must be developed that can withstand both the constant bombardment of neutrons and the flying debris that will be generated as targets explode several times per second. In an IFE plant, the neutrons produced during fusion would breed the tritium needed to make new fuel from lithium that lines the inside wall of the target chamber.

Researchers will have to develop a system for extracting tritium from the reactor, and they will need a high-volume process for manufacturing fuel pellets. A scheme for repetitively and accurately positioning targets in the path of the driver's beam is also required. While Koonin doesn't see any showstoppers, he expects that target fabrication could prove to be the most daunting challenge. But Dean says that DOE contractor General Atomics has a conceptual design for fabricating targets at 16 cents a copy.

If NIF succeeds, a more immediate question will be where the IFE effort should be housed within DOE. Koonin thinks it should be with the Office of Science, but that organization has its hands full with magnetic fusion and ITER and has no funding to spare. Having NNSA run IFE is problematic, since energy is not part of NNSA's weapons-related mission. On the other hand, the weapons program did administer an IFE program for 10 years. Carried out by the NRL, the high-average-power lasers program worked toward developing an integrated IFE system based on a krypton fluoride direct-drive process. The program fell between the cracks in the congressional appropriations process two years ago and hasn't been revived.

If the NIF schedule holds, IFE will be about 10 years ahead of the timetable for ITER's ignition experiments. Assuming the successful development of the required materials and the meeting of fuel fabrication needs, a decision on an IFE demonstration plant could come in 10 years, Koonin says. But choosing between magnetic and inertial confinement is much further off, he feels. "We are engaged in an obvious next stage on the magnetic side," he says, referring to ITER. "We are at the very beginning of IFE."

David Kramer

Obama calls for increased spending for electric vehicles and solar energy

Advanced batteries, high-risk energy research, and development of clean electricity would benefit from the plan outlined in the State of the Union address. The president sends Vice President Biden and other top officials out to sell that plan.

Looking to maximize the adoption of cleaner energy sources and create new US jobs, President Obama is proposing a major increase in federal funding for renewable energy R&D, including creation of three new multidisciplinary research centers and a big increase for a three-year-old Department of Energy program that awards grants for long-shot research into potentially transformative energy sources. In a State of the Union speech that included a proposed five-year freeze on domestic discretionary spending, the president said the increases could be offset by ending subsidies now enjoyed by fossil-fuel producers.

In remarks a day after the State of the Union address, Energy Secretary Steven Chu predicted that batteries capable of powering an electric car up to 400 miles on one charge will be commercially available in as few as "half a dozen years." Currently available all-electric vehicles have a maximum range of 100 miles per charge, insufficient to overcome the "range anxiety" that deters many would-be buyers. That same day, Vice President Biden told workers at Ener1, an Indiana manufacturer of advanced batteries, that their factory owed its existence to a $118 million DOE grant funded through the American Recovery and Reinvestment Act.

Obama, in his 25 January address, said, "Two years ago, I said that we needed to reach a level of research and development we haven't seen since the height of the space race. We'll invest in biomedical research, information technology, and especially in clean-energy technology—an investment that will strengthen our security, protect our planet, and create countless new jobs for our people."

JOHN MARTIN FOR GENERAL MOTORS

The lithium-ion battery that powers the Chevrolet Volt (left) is based on technology that was developed at Argonne National Laboratory. In his State of the Union speech, President Obama called for major spending increases for R&D on advanced batteries and other technologies in support of his goal of having one million electric vehicles on US roads by 2015.

Although the details of his new clean-energy push didn't become public until the mid-February release of the fiscal year 2012 budget request (after PHYSICS TODAY went to press), pieces of it emerged as Biden, Chu, and other high-ranking administration officials fanned out in the days following Obama's speech to sell it to the public. The White House said it will ask Congress to increase current spending for clean-energy technology by one-third, to around $8 billion. Specific new items are to include establishment of three "energy innovation hubs"—interdisciplinary R&D centers housed at universities or federal labs that bring scientists and engineers together to tackle a particularly tough energy technology challenge. The Bell-lablets, as Chu sometimes refers to the hubs, are meant to address their topic from the basic research end of the R&D spectrum to the pre-commercial-development stage. Obama had sought to create eight hubs in FY 2010, but lawmakers provided money for only three. The president's request for FY 2011 included a fourth hub. But Congress has failed to approve any of the annual appropriations