FUSION

What's next for the inertial confinement fusion effort?

A team of experts reviewed the National Ignition Campaign at its conclusion to assess the impediments to achieving ignition in the National Ignition Facility.

Despite the enthusiasm and confidence of earlier years, the National Ignition Campaign (NIC), which ended on September 30, 2012, was unable to achieve the ignition of fusion fuel using the laser-driven National Ignition Facility (NIF) at Lawrence Livermore National Laboratory. The Department of Energy recently issued a report by a team of experts who reviewed the NIC's work as the campaign ended. The report assesses the impediments to ignition in the NIF (which achieved about one-tenth of ignition conditions), the likelihood of the NIC's indirect-drive approach eventually achieving ignition (it was concluded that there are too many uncertainties to predict this either way), and what research should be carried out to advance the understanding of the requirements for ignition.

The panel followed on a process established by the DOE's former undersecretary for science, Steven E. Koonin, who in October 2010 began what became a series of quarterly reviews of the NIC, which has been the centerpiece of the inertial confinement fusion (ICF) effort in the United States. The 13-member group, chaired by Dan Meiron, of the California Institute of Technology, included representatives from the University of Rochester, the University of Michigan, the Massachusetts Institute of Technology, the University of California at Los Angeles, Sandia National Laboratories, the Thomas Jefferson National Accelerator Laboratory, Los Alamos National Laboratory, the United Kingdom's Atomic Weapons Establishment, and Livermore itself.

The NIC did not just miss a time deadline. Months before the end of September, it had become apparent that shots by NIF's neodymium-glass lasers, with its energy converted to X-rays (hence the term "indirect drive"), were not making the expected progress in heating and compressing the deuterium-tritium fuel. The computer models predicted effects and behavior that did not appear in real-world experiments, strongly indicating that what was taking place within a targeted fuel capsule and its surrounding *hohlraum* was not fully understood.

In November, the DOE's National Nuclear Security Administration—which is in charge of the NIF because of the facility's main role in the stewardship of the nation's nuclear weapons stockpile—responded to a congressional directive by stating that the ICF program will be redirected to further research at the NIF, the University of Rochester's Omega laser, and Sandia's heavy ion–driven Z Machine. If it is decided later that this research has made meaningful progress, a new ignition effort could be started in fiscal year 2015 (*NN,* Jan. 2013, p. 75).

The reviewers' report credited the NIC with a number of achievements, including the development of diagnostics and experimental platforms that provided new insights into fuel capsule performance. It also noted that in the course of many NIF shots, each of the four measures of target performance (adiabat, shape, velocity, and mix) was met, or nearly met, although all four would have to be met at the same time for ignition to occur.

As for what was preventing ignition, the reviewers said that beyond the known issues with laser-plasma interaction scattering and dispersing laser energy, there have been further reductions in X-ray drive, with the cause still to be determined. Also, laser energy transport effects may have produced nonuniform ablation pressure to implode the capsules. Recent radiography results have shown large perturbations in the spherical symmetry of the dense fuel. The conversion of kinetic energy from the drive to thermal energy at fuel hot spots was no more than one-third as great as had been expected, and low-mode shell asymmetries were seen as contributing factors.

"Mix," a set of phenomena related to instabilities at the interfaces at the surfaces of the inner and outer ablator and the inner shell of cryo-frozen deuterium-tritium, has been known to cause radiative losses, cooling the hot spot in the fuel and quenching potential ignition. Fuel capsule design had been developed on the basis of physics modeling that indicated that mix could be minimized, but results from the latest NIC experiments showed much greater mix than expected, perhaps calling into question the physics modeling or the representation of target imperfections. This shows one aspect of the larger concern with modeling and simulation. According to the report, "The main issue here is that some of the models describing the key phenomena . . . are incomplete relative to the physical regimes encountered in a NIF shot."

Listed as priority directions for research are the following:

- The use of NIF for the investigation of laser-plasma interaction.
- An investigation of achievable X-ray drive, especially its time dependence and angular distribution as it impinges on the ablator.
- Shape experiments, with radiography to assess implosion asymmetries.
- Experiments with low levels of capsule convergence, in part to reestablish the predictive capability of simulation codes.
- A variety of mix experiments, with the results used to validate modeling of the growth of three-dimensional perturbations.
- Further development of diagnostics, such as the Advanced Radiographic Capability laser.

During the years when the NIC was making substantial progress, it was clear that Livermore officials expected success with ignition and sought to move onward from there. In November 2010, at the American Nuclear Society's 19th Topical Meeting on the Technology of Fusion Energy, an initiative called Laser Inertial Fusion Energy (LIFE) was unveiled through a plenary session shared with a status report on NIF work and numerous papers at other sessions on detailed aspects of the project (*NN,* Jan. 2011, p. 73). LIFE was intended to lead to a demonstration reactor starting up in the 2020s, and a commercial reactor in the 2030s.

At a time when the world's main magnetic confinement fusion (MCF) project, the International Thermonuclear Experimental Reactor, was facing its first serious round of technical concerns, design changes, cost hikes, and schedule delays, LIFE's proponents were proposing to make ICF an energy-producing technology before MCF could become one. This seemed to signal a resumption of the ICF-MCF rivalry of the 1980s, which had ended with MCF the apparent winner. Since November 2010, however, not much more has been said about LIFE, and the postponement of any discussion of a new ICF ignition effort until FY 2015 or later makes LIFE's ambitious schedule untenable.

The reviewers' report, *Final Review of the National Ignition Campaign,* dated December 27, 2012, was made available online in February by the FIRE Place, a Princeton Plasma Physics Laboratory Web site. It can be downloaded from the following address: <http://fire.pppl.gov/NIF_NIC_rev6_Koonin_2012.pdf>. NN