Under Secretary for Science
Washington, DC 20585

June 20, 2011

FROM: STEVE KOONIN
UNDER SECRETARY FOR SCIENCE

SUBJECT: Third Review of the National Ignition Campaign

I convened a third one-day review of the National Ignition Campaign (NIC) on June 2, 2011 at the Forrestal Building in Washington, DC. This review is meant to provide an independent technical perspective on NIC progress and plans. It followed the format of prior reviews held October 2010 and January 2011 in which I, and a continuing group of knowledgeable individual reviewers, participated in a set of interactive presentations by the NIC leadership team.

The laser, diagnostics, and target preparation have shown outstanding progress and performance with 65 system shots on targets in the five months since the previous review. Just over half of these shots successfully supported NNSA's Defense Program and university user interests. These activities demonstrate an increased operational shot rate and the ability to tune the laser for precise science experiments. Facility maintenance and reconfiguration during the month of April helped to prepare for higher-yield, ignition-directed experiments. Overall, the past half-year has been a productive period for all NIF technical interests, including the ignition campaign covered by this review.

Background

The goal of fusion ignition at the National Ignition Facility remains of overriding importance to the Department. While outcomes remain uncertain, experiments are now revealing some consistent trends within the tuning framework developed to optimize ignition performance.

The NIC frames its activities and measures its progress through a calculated Ignition Threshold Factor (ITF), dependent upon four factors: **shape**, **velocity**, **adiabat**, and **mix**. Goal values have been established for each of these factors, and ignition should occur when all four are met simultaneously. The result should be a "hot spot" at the center of the imploding capsule with temperature (~10 keV) and areal density (~0.3 g/cm^2) sufficient for deuterium-tritium fusion and energy deposition by the fast alpha particles.

To optimize among the hundreds of possible variations in laser pulse and target configuration that influence these factors, a systematic tuning framework has been developed and is being implemented[1].

In experiments as of the date of the review,

- Partial control of **shape** has been demonstrated, but not yet with sufficient consistency or uniformity;
- The **velocity** of the implosion continues to be about 10% lower than expected;
- The **adiabat** has been too high by about a factor of three; and
- Mix has only occasionally been observed to be an issue (it may become more important as progress on the other factors produces more compact implosions).

The net result of these initial, non-optimized experiments has been that the ITF has increased to about 2% of that expected to be required for ignition. This value of ITF was achieved on the fourth cryo-layered experiments and is about a factor of 15 higher than the ITF achieved on the first cryo-layered experiment. Significant advances in fielding cryogenic hohlraums and in producing cryogenic layers on the NIF facility played a central role in these improvements. Understanding is sufficient to clearly define the experimental program for the next several months. This work will focus on improvements to the adiabat and the implosion velocity, the factors in ITF that are the furthest from meeting the ignition requirements.

<u>Status</u>

The laser power is delivered to the hohlraum in a series of incremental steps so as to adiabatically compress the capsule. The complex interaction of the laser with the plasma it creates within the hohlraum modifies the timing and symmetry of the energy delivered to the capsule. This drive has been measured and modeled, but as yet without complete understanding or self-consistency. The initial step in laser power is particularly important and had previously been affected inconsistently by a “frost” of frozen air on the target’s laser entrance hole. This “frost” was the result of small levels of residual air in the target chamber. With successful elimination of the frost, the capsule now responds consistently to the initial step.
Each step increase in laser power (four steps are used) generates a shock in the capsule materials. Controlling the timing of these shocks so that they simultaneously converge a few microns inside the imploding inner surface of the DT ice at a specified time is one of the most delicate tasks required for ignition.

An experimental approach to measure the timing and velocities of the shocks in specialized capsules filled with liquid deuterium has been developed, in part through work at the Omega laser. Several NIF experiments with these surrogate targets have produced excellent shock data and demonstrated that changes in shock timing, up to 20%, should produce the desired shock convergence.

---

[1] J. Lindl, et al, “NIC Tuning Campaign: A Technical Methodology for Achieving Ignition on the NIF” LLNL 479931

At the time of the review, there had been only four experiments with layered targets containing tritium and a variable ratio of hydrogen and deuterium (THD). These experiments were hampered by formation of layers that did not meet the tight specifications of cryo-layered implosions. Layering protocols and the capsule fill gas hardware have been modified and layers that meet THD implosion specifications are now being produced reliably. Work on surrogate targets has positioned the team to begin a series of shock timing experiments and to evaluate the improvement in the performance of THD capsule implosions.[2] This will be an important set of experiments whose results will inform our confidence in progress toward ignition. In particular, we need to know if the low implosion velocity and low areal density (with associated high adiabat) persist even when the shocks are well timed.

In addition to shock tuning, there are plans to explore variations in laser power, hohlraum characteristics, and the capsule ablation layer. Implosion velocity (and hot spot temperature) should rise with greater laser energy and power, so that an increase from previous high of 1.3 MJ / 420 TW to 1.5MJ / 500TW should be beneficial. A slightly shorter and slightly larger diameter hohlraum is being considered as baseline change; this is thought to improve the drive energy and the implosion shape. In another baseline change, the germanium ablator surrounding the DT ice will be replaced by a layer of silicon, which should improve the coupling of the drive to the DT ice layer. The efficacy of these changes will be ascertained in experiments over the next few months.

Path forward

From the first of these reviews, there has been frequent and thoughtful discussion of the balance between empiricism and a need/desire for campaigns toward deeper physics insight. That tension continues to be productive, since both of these complementary modalities are being consideredby the team.

The assumption is that the current NIF baseline is close enough to be "tuned" empirically to ignition. The current strategy is then to make iterative target and laser variations, guided by modeling and results, improving understanding in the process. When ignition is achieved, the program expects to improve performance by better understanding the underlying processes. That improved performance will, in turn, enable applications to science, stewardship, and energy goals.

Because systematic experimental changes can now be pursued and diagnosed, the rate of progress toward ignition should become more apparent through the next set of planned experiments. If progress does not occur as planned, longer and more specialized campaigns for deeper physics understanding could well be required. As an example, the complex laser plasma interactions within the hohlraum show significant, unanticipated phenomena. If incremental laser and target adjustments do not produce the expected results, a detailed plasma physics campaign may be required to make more radical changes. Similar comments apply to increasing the DT

[2] Experiments with the adjusted shock timing in the week following the review with THD and DT capsules improved the areal density, as had been expected, but without increase in implosion velocity.

areal density achieved in the implosions. More generally, a tighter and deeper iteration between models and non-integrated experiments will be required. It is not too soon to begin thinking about contingency plans for such studies; if they are required, progress to first ignition will be slower.

The planned campaign for the next several months has considerable technical richness, promise and flexibility. Near-term experimental results exploiting the tremendous laser, target, and diagnostic capabilities that have been created will show us where we stand relative to ignition and will guide further efforts toward that goal. While I can't confidently predict when ignition might be achieved, I would not preclude it from happening within the next year or two. More broadly, I judge a path to ignition remains quite likely.