Department of Energy
Washington, DC 20585

July 19, 2012

MEMORANDUM FOR DON L. COOK
DEPUTY ADMINISTRATOR FOR DEFENSE PROGRAMS

FROM: DAVID H. CRANDALL
ADVISOR ON NATIONAL SECURITY AND INERTIAL FUSION

SUBJECT: External Review of the National Ignition Campaign

Under your direction we have continued the external reviews of the National Ignition Campaign (NIC) that were initiated in October 2010 by then Under Secretary Steve Koonin. The most recent review was held on May 31, 2012. As you recall we had planned that Dr. Koonin might lead that review as a special government employee, but in the end he had a conflict that precluded him from serving in that capacity. I conducted the review with a set of external individual reviewers, who had previously served Dr. Koonin. Each of those reviewers independently submitted a brief written report on the technical status of the NIC. In addition we asked each reviewer to provide an estimate of the probability of achieving ignition within the plan presented by the NIC team that continued to December 31, 2012.

I attach my summary of those individual reviews submitted.

Review of the National Ignition Campaign

July 16, 2012

On May 31 the NNSA convened a review of the progress in the National Ignition Campaign (NIC) on achieving ignition at the National Ignition Facility (NIF). The review team included ten selected external reviewers who provided individual written comments after the review and four principal Federal staff. This document is a summary by the Federal staff based on the individual inputs from the external reviewers. This is the 6th review in a series initiated in October 2010 by Dr. Steven E. Koonin, then Under Secretary for Science, including the review by Federal staff on January 31, 2012. External reviewers who previously advised Dr. Koonin have continued to serve for the current review.

Summary:

All observers note that the functionality of the laser; the quality of the diagnostics, optics and targets; and the operations by the NIC and NIF teams have all been outstanding. By comparison with the startup of other large science facilities, the commissioning and startup of experimental operation on NIF has demonstrated an "unprecedented level of quality and accomplishment" according to one reviewer. Experiments on capsule compression, with improved diagnostic detail and exquisite laser pulse shape and energy control, have provided important insights into the details of the ignition capsule compression.

The integrated conclusion based on this extensive period of experimentation, however, is that considerable hurdles must be overcome to reach ignition or the goal of observing unequivocal alpha heating. Indeed the reviewers note that given the unknowns with the present "semi-empirical" approach, the probability of ignition before the end of December is extremely low and even the goal of demonstrating unambiguous alpha heating is challenging.

NIC relies on a parameter called the experimental "ignition threshold factor" (ITFX) which is a function of the experimental target yield and the measured target areal density. The value of ITFX would be about 0.3 to 0.5 for a target that shows significant alpha-heating and it is defined

so that a target that achieves 1 Mega Joule of energy released as fusion neutrons has an ITFX of 1.0. Presently ITFX remains at 0.1 or 10% of the desired value for 1 Mega Joule yield. The best understanding of the community is that the slow progress on improving ITFX is due to issues of ablator/fuel mix, low implosion velocity and "low mode asymmetries."

One key issue that has been noted is that state-of-the-art ICF simulation codes have predicted that present designs would ignite or at least show substantial levels of alpha heating and the failure to make better progress towards ignition reveals a significant lack of fidelity in the computer simulations. The codes are critical tools that are required to find the route to fusion ignition, especially so given the limited number of experimental tests. Thus a key concern of the reviewers is that the gaps between observed performance and code predictions means that the codes are of limited utility in choosing the next set of experiments to perform. Overall, this is the most important issue to address. The recent efforts to concentrate on using capsule only simulations to identify areas needing improved understanding in specific physics models is a step in a useful direction.

Experimental Achievements:

The Federal Managers Review on January 31, 2012 identified a number of experimental improvements that are providing greater range of laser parameters, greater shot rate and higher precision measurements. Additional improvements since then include:

- Streaked backlit radiography giving continuous image of capsule implosion and some measure on capsule thickness during compression,
- Higher laser energy and power (1.86MJ with 411TW peak power demonstrated before the review and 522 TW shortly after the review),
- Improved neutron diagnostics suggesting low mode asymmetry,
- Extended options on layering of the CH ablator with Si, Ge, and Cu in varying amounts and locations,
- Ability to polish capsules to greater smoothness than previous point-design specifications and to make smaller fill tubes for putting fuel inside the capsule.

Reviewers noted and appreciated the high quality measurements on shock timing, capsule implosions, and neutron intensity as providing excellent data.

Physics Issues:

That the National Ignition Campaign has not achieved its goals of alpha heating and ignition are attributable not to any systematic issue with the NIF facility or its operations, but rather to the fact that ignition targets (hohlraum plus capsule) do not perform in the manner that the codes and models had predicted. The coupling of the laser through the radiation inside the hohlraum to the capsule is less efficient than expected and the physical ablation process is somewhat different than expected resulting in a lower implosion velocity than is predicted to be required for ignition. The measured mix of ablator material into the DT fuel is consistent with a "mix cliff" limiting neutron yields. These issues are discussed at further length, but the general conclusion is that better understanding through detailed measurements and model adjustments informed by rigorous uncertainty quantification are needed both to understand how to better approach the ignition problem and to benefit the stockpile stewardship program.

Areal Density: Applying high precision laser control and extended ablator fabrication allowed an advance in fuel compression with higher stagnation pressure and measured areal density reaching 85% of ignition requirement. This is a major accomplishment in an area of concern where such an advance was not assured. Although there has been substantial improvement, stagnation pressures are still one half to one third of those required for ignition.

Radiation drive and ablation: Reviewers have noted the lack of ability to predict with any reasonable accuracy the radiation drive to the capsule inside the hohlraum. Of significant concern was the need for an ad hoc time dependent flux multiplier (up to 60%) that was required to match capsule performance (shock timing and convergence motion) with inferred drive. Just prior to the review, an improved equation of state (EOS) for the ablator was shown to reduce this correction to about 20% and reduced the time dependence of this correction. Nevertheless, this remains a substantial anomaly that should be further investigated and corrected. The laser deposition in the hohlraum is a complex topic dependent on laser plasma interactions that are not adequately modeled. Drive has been managed in particular ways (e.g. cross-beam transfer) that have been presumed to be sufficiently effective. Presently the radiation drive is measured from emission through the laser entrance hole that closes somewhat during the shot. Improved measurements on laser entrance hole closure have been applied and reduce the inferred radiation flux (hole closure less than presumed). Hole closure and other aspects of radiation drive are time dependent during the shot. The uncertainty in drive deserves careful analysis. Direct measurements of the radiation incident on the capsule are expected to be made through experiments scheduled for the near future.

Mix: The deleterious onset of mix is occurring at less stressing performance conditions than predicted and appears to be a significant factor limiting yields. Because of the precise measurements of implosion trajectories and mass remaining, systematic behavior of neutron yield with compression dynamics could be observed. At conditions where mix of ablation material into capsule fuel was inferred to be the highest based upon new total bremsstrahlung emission measurements, the neutron yield was lowest. A clear "mix cliff" causing reduced neutron yield occurred at implosion velocity greater than 300 km/s (370 km/s is the goal). The cliff occurs where inferred amount of ablator material mixed into the fuel core is greater than 300 ng. For the conditions attained, this mix cliff occurs when the ablator mass remaining is less than 0.40 mg or 13% of the original mass. The ignition design assumed that these capsules could be driven to only 0.28 mg of ablator mass remaining, and thus to higher implosion velocity, before mix would be an issue. In addition, precision placement of tracer elements (Ge and Cu) in the ablator, and measurement of the emission of the tracer when it enters the hot plasma of compressed fuel, allowed inference of the mix source. The growth of hydrodynamic instabilities in the outer surface of the ablator is inferred to be the likely source of mix. According to some reviewers these observations call into question whether or not the energy of NIF is sufficient to indirectly compress a large enough capsule to avoid the mix limit and reach ignition. However, thicker capsules can be driven with achievable laser energy/power (2MJ and 500TW) and that will be done in the coming months. In addition smoother capsules, that can now be made, could result in reduced mix. High precision measurements and improved models are needed to lead to better understanding and predictability of the limits that mix imposes.

Asymmetry: Additional neutron detectors at varying geometrical locations have now indicated asymmetries in down-scattered neutron fluxes, which suggest the existence of "low mode" or long wave asymmetries in the distribution of the compressed cryogenic fuel. An increase in areal density at the poles of the target is inferred. Such compressed target asymmetry could be deleterious to neutron yield and could be caused by a variety of factors. Further improvements in neutron detection and mitigation attempts will be applied in the coming months. As an example of possible mitigation, the fill tube for passing fuel through the ablator is only 10 micrometer diameter but can introduce asymmetry; tubes of only 5 micrometers have now been demonstrated and can be applied.

Future Plans and Directions

The NIC team presented an experimental plan looking forward six months not just to the balance of FY 2012 and the end of the national ignition campaign (NIC), but to the end of CY 2012. The general approach taken for ignition is to increase ablator thicknesses while increasing laser power in the hope that this will mitigate mix effects and provide evidence of alpha heating at least, if not ignition. While the NIC team would also pursue further experiments on hot spot formation and low mode asymmetries as well as some more focused and less integrated experiments, particularly to study mix, the general sense of the reviewers was that the proposed program would continue the present semi-empirical approach to achieving ignition, without adequately resolving the gaps between codes and experiments. Given the time available in this campaign and the high quality of experimental operations, this approach can produce useful results that may provide some advance in fusion parameters and will give useful data to test models.

The reviewers generally supported this plan as presented for the balance of calendar year 2012, but there was also a uniform view that if alpha-heating and further substantial progress towards ignition is not demonstrated during this period, that the ignition program should be redirected towards a broader and more balanced research program to investigate and resolve physics issues and improve models to provide a more predictive capability in pursuit of its multiple national missions.

As noted, several factors contributed to the limited parameter advance. The coupling of the laser through the radiation inside the hohlraum to the capsule is less efficient than expected and the physical ablation process is somewhat different than expected resulting in compression velocity lower than needed. Also the mix of ablator material into the DT fuel has clearly applied a "mix cliff" limiting neutron yields at increasing velocity. These factors are not appropriately simulated in the implosion models but can be further investigated and perhaps partially mitigated. Better understanding through detailed measurements and model adjustments with rigorous uncertainty quantification is needed. Given the inadequacy of the models, the limits on parameters achieved and the limited time, the integrated estimate of the reviewers is that ignition within the calendar year 2012 is "highly unlikely".

The plan of experiments extending to the end of December 2012 is viewed by the reviewers as appropriate. The plan calls for thicker ablator in the capsules and higher laser energy and power (2 MJ and 500 TW) to drive these capsules, along with improvements in specific diagnostics to provide greater insight into compression behavior. While no reviewer thought ignition likely before December 31, 2012, some thought the intermediate goal of measurable alpha heating (increasing the neutron yield) might be achieved within that time and several expressed optimism about achieving ignition at NIF within a few years.

Reviewers for the May 31, 2012 external review of the National Ignition Campaign

Ricardo Betti, Rochester

Radha Bahukutumbi, Rochester

Paul Drake, Michigan

Warren Garbett, Atomic Weapons Establishment, UK

Don Haynes, LANL

Arthur Kerman, MIT

Ray Leeper, SNL

Dan Meiron, Cal Tech

Warren Mori, UCLA

John Nuckolls, LLNL (no written report)

Feds: David Crandall, Jeff Quintenz, Kirk Levedahl, Sam Brinker (LSO)