Under Secretary for Science
Washington, DC 20585

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FROM: STEVEN KOONIN
UNDER SECRETARY FOR SCIENCE

SUBJECT: Initial Review of the National Ignition Campaign

On January 24, 2011, I spent a full and vigorous day, accompanied by a group of knowledgeable individuals, in a second review of the National Ignition Campaign's progress toward ignition. This memo follows on from the initial review I undertook on October 18-19, 2010, which was described in a memo dated December 8, 2010. Ignition on NIF remains a goal of overriding importance for the DOE and of considerable interest to diverse parties.

This second review was limited to one day so that not all of the issues were discussed as completely as they might have been. However, the NIC team's open communication of results and flexibility in experimental program were encouraging and responsive to my first report.

Despite intensive effort, progress toward ignition during this quarter was not as rapid as I had hoped. During this period some operational issues and some discrepancies between measurements and predictions have slowed progress in ways that do not surprise experienced observers. Nevertheless there were 83 system level shots (39 with targets) between the 2 reviews and the lasers performed remarkably with control and consistency. Progress on specific challenges is encouraging enough that progress toward ignition should accelerate in the near future.

Three operational issues ("dust"," frost", and" layering") restricted the number and kinds of experiments that were accomplished during this quarter.

- Microscopic **dust**, adhering to target surfaces during assembly, had previously been observed; it can compromise some measurements. Increased attention and observation over the past quarter appears to have reduced the amount of dust that could cause problems; improved microscopic metrology to better characterize such dust is expected to be operational in the near future.

- **Frost** (thin coatings of condensation) on laser entrance windows of cryogenic targets appears to have been an issue for a number of shots, despite a reasonable vacuum in the NIF chamber. Some frost mitigation procedures adopted may have had consequences for the observations, as I discuss below. If exposure of a cryogenic target to the chamber atmosphere is short enough or special dual-pane "storm" windows are used, the frost issue may be eliminated. A single experiment with new dual-pane windows on the night before our review, and some since that time, suggested that the issue can be eliminated.
- **Layering** of deuterium-tritium ice on the inside of target capsules to obtain microscopically smooth surface is one of the greatest operational challenges for NIC. Present capsules use a tritium-hydrogen fill with a small admixture of deuterium (72, 22, and 6 percent of T, H, and

D, respectively in the achieved layer); ice layering within these THD targets is thought to be similar to that in deuterium-tritium ignition capsules. The single THD experiment this quarter, shot a few days prior to our review had applied a minor process change to give a smooth-layered target. These THD shots are the most challenging and the most relevant to ignition shots in the future; more of them are needed.

Overall, the limited experience to date suggests that the dust, frost and layering issues may have been addressed. If so, they will not impede more rapid progress in the near future.

During the past quarter there was also significant improvement in diagnostics and measurement precision, for example fuel areal density from ±50% to ±20% and shape parameters from ±10% to ±5%. The value of these improvements will be viewed and discussed in context of what is needed to obtain progress to ignition.

The requirements for ignition are aggregated in an Ignition Threshold Factor (ITF) that quantifies the probability of ignition in terms of four physical implosion measures that must be controlled - the implosion velocity of the surface compression, the general shape of the imploded target (sausage, pancake, 4-sided…), the implosion-induced mix of ablator material into the deuterium-tritium fuel, and the adiabat (determining the compressibility of the fuel). Measurement of these four quantities is challenging, and is sometimes best done in surrogate, rather than THD, targets; the adiabat is inferred indirectly.

I have accepted that the ITF and the measured control of the 4 sub-factors is an appropriate scientific framework for understanding advance toward ignition. The most complex of the four ITF factors is the adiabat, to be controlled by laser pulse shape. Four changes in laser power during the pulse should drive 4 shocks into the capsule. These must be timed to arrive at the center simultaneously to achieve the required hot-spot temperature. A number of "keyhole" targets were shot this quarter to measure shock timing to 2%; results did not agree adequately with predictions. "Frost" and hot electrons may have been issues here. "Keyhole" target measurements allowed shock timing to be adjusted in several integrated experiments, where the adiabat still appears too high, relative to that required for ignition. Additional physics insight and measurements without frost are needed to help address this issue. The fidelity of Keyhole target surrogacy for shock timing in more integrated targets also remains to be explored.

The shape parameter is being controlled by variation of holhraum conditions through the laser drive. A number of surrogate measurements have been used to seek a "round" imploded shape. In spite of those adjustments, the final shape of the single new THD shot was considerably "pancaked." Additional shape adjustments, including shortening of the hohlraum, are planned and should be pursued in the next quarter. (Subsequent reports regarding two additional THD shots showed improved ability to tune.)

The velocity of the imploding shell is now measured to ±5% and soon may be improved to about ±2%. The measured velocities are consistently lower than expected by a little more than the current measurement precision. Simple physics suggests that the shell mass remaining would then be slightly larger than predicted. However, measurements show that it is consistently *lower*. These small but systematic discrepancies will be managed and may be understood in the near future.

Mix measurements are not new to the ICF program. It has long been understood that the growth of hydrodynamic instabilities in the ablator will mix ablator material into the fuel and that such mix needs to be controlled to reach ignition. Radiation from a layer of germanium in the ablator gives a useful signal of mix. NIF experiments show hot spots of germanium radiation within the compressed material that are still being interpreted. Adjustments to ablator mass, laser foot pulse, germanium layering, and experiments with deliberate bumps in the ablator can all be pursued to better understand and control mix, but detailed analyses of existing observations are needed to guide the future experimental choices.

In brief, I perceive a talented team who are just beginning the exciting work of understanding and exploiting the tools that have recently become available. The laser and target diagnostics are working extremely well and the challenging target fabrication is progressing. The degree of experiment control that has been achieved is an outstanding accomplishment and is fundamental to ignition success. However, having targets with the desired attributes available on schedule has been limiting. Measurements are adequate to show some discrepancies from predicted performance suggesting that there is physics yet to be understood. In this context, it remains important to conduct pre- and post-shot simulations and to use several independent codes for each. Repetition of selected experiments will help assure control and reproducibility sufficient for meaningful comparison to simulations. Appropriately, experiments are becoming the measure of truth rather than code-to-code comparison.