

## Towards an integrated model of the NIC layered implosions

O. Jones<sup>1,a</sup>, D. Callahan<sup>1</sup>, C. Cerjan<sup>1</sup>, D. Clark<sup>1</sup>, M.J. Edwards<sup>1</sup>, S. Glenzer<sup>1</sup>, M. Marinak<sup>1</sup>, N. Meezan<sup>1</sup>, J. Milovich<sup>1</sup>, R. Olson<sup>2</sup>, M. Patel<sup>1</sup>, H. Robey<sup>1</sup>, S. Sepke<sup>1</sup>, B. Spears<sup>1</sup>, P. Springer<sup>1</sup>, S. Weber<sup>1</sup> and D. Wilson<sup>3</sup>

<sup>1</sup>*Lawrence Livermore National Laboratory, Livermore, CA, USA*

<sup>2</sup>*Sandia National Laboratory, Albuquerque, NM, USA*

<sup>3</sup>*Los Alamos National Laboratory, Los Alamos, NM, USA*

**Abstract.** A detailed simulation-based model of the June 2011 National Ignition Campaign (NIC) cryogenic DT experiments is presented. The model is based on integrated hohlraum-capsule simulations that utilize the best available models for the hohlraum wall, ablator, and DT equations of state and opacities. The calculated radiation drive was adjusted by changing the input laser power to match the experimentally measured shock speeds, shock merger times, peak implosion velocity, and bangtime. The crossbeam energy transfer model was tuned to match the measured time-dependent symmetry. Mid-mode mix was included by directly modeling the ablator and ice surface perturbations up to mode 60. Simulated experimental values were extracted from the simulation and compared against the experiment. The model adjustments brought much of the simulated data into closer agreement with the experiment, with the notable exception of the measured yields, which were 15–40% of the calculated yields.

### 1. INTRODUCTION

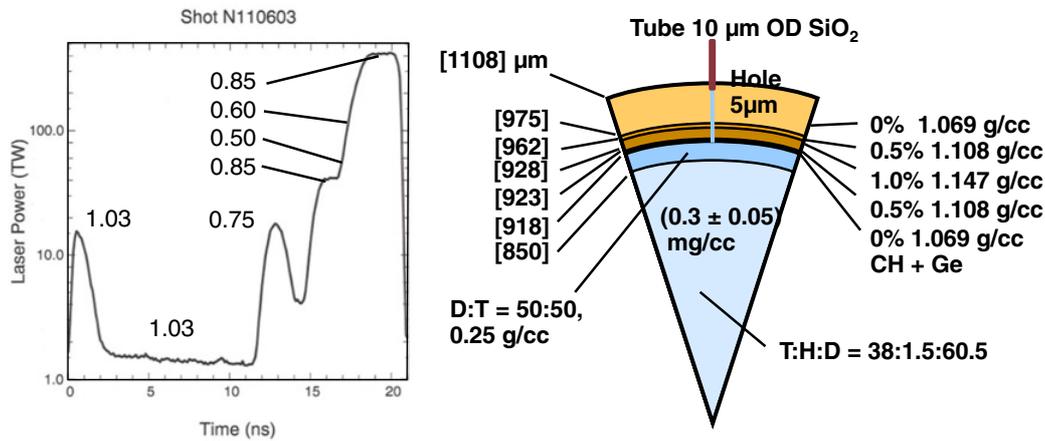
The present indirect drive NIC experiments use a laser-heated hohlraum that provides soft x-ray radiation drive to implode a spherical capsule containing a cryogenic DT fuel layer. The capsule needs to be imploded nearly symmetrically, with sufficient velocity, and with the fuel on a low adiabat in order to assemble a hotspot surrounded by cold, dense fuel that will ignite and burn [1]. The NIC strategy relies on a series of symmetry, shock timing, and ablator experiments to experimentally tune the implosion to the required velocity, symmetry, etc. [2–4].

We have modelled the DT implosions using the Hydra radiation hydrodynamics code [5]. The 2-D integrated (hohlraum + capsule) simulations described in this paper use the “high-flux model”—electron thermal conduction with a flux-limiter  $f = 0.15$  and the DCA non-LTE atomic physics model [6]. The hohlraum wall opacity is obtained from LTE tables (calculated offline using separate codes) for temperatures below 300 eV. Above 300 eV the inline DCA model computes the non-LTE emissivity and opacity. Tabular opacities and equation of state are used for the ablator and DT fuel. The input laser sources are adjusted to account for the backscattered energy and the crossbeam energy transfer that occurs in the hohlraum plasma [7, 8]. The Monte Carlo particle transport package was used to generate realistic neutron spectra for simulated neutron diagnostics.

We have found that when we apply the model described above to the shock timing [3] and convergent ablation [4] experiments, it overestimates the shock speeds and shell velocity, and as a result predicts x-ray bangtimes  $\sim 300$ – $700$  ps earlier than measured. Thus the simulations have a higher implosion

---

<sup>a</sup>e-mail: [jones96@lln1.gov](mailto:jones96@lln1.gov)



**Figure 1.** (a) 1.3 MJ, 420 TW input laser pulse showing multipliers that were applied to fit shock timing and shell velocity data, (b) the Rev5 CH-Ge ignition point design capsule.

velocity and a different fuel adiabat than the experiment, so the 1-D performance is quite different. This 1-D discrepancy makes it difficult to use these calculations to sensibly assess the 3-D degradation occurring in the experiment.

## 2. ADJUSTED MODEL FOR JUNE 2011 LAYERED EXPERIMENTS

In this study we adjusted the input laser power to the simulations to approximately match the shock timing and shell velocity for a series of experiments from April to June, 2011. These experiments were driven by a ~20 ns, 1.3 MJ shaped laser pulse with a peak power of 420 TW that was used to heat a gold 5.44 mm (diam) by 10 mm long hohlraum with a 57% laser entrance hole. The capsules consisted of an ablator made of Ge-doped CH surrounding a cryogenic DT layer, whose specifications are shown in Figure 1b. Three shock-timing experiments (N110517, N110519, N110521) were done to measure the shock velocities, merger times, and merger depths, and to adjust the laser pulse to get the desired ignition design values. The tuned pulse was then used in a convergent ablator experiment (N110625) in which the radius versus time of the converging shell was measured using time-dependent radiography. We simulated all these experiments with our standard Hydra model and then adjusted the input laser power to best fit the data. The resulting laser power multipliers are shown in Figure 1a. The values of the power multipliers for the first three pickets do depend on our choice of LTE/NLTE transition temperature of 300 eV, but the peak power multiplier is independent of that choice.

We then applied the model to four cryogenic DT implosions that all used the same Ge-doped ablator, the same 544 hohlraum, and variants of the same laser pulse. These simulations had ideal “clean” ablator and DT surfaces (no surface roughness). Shot N110603 used the 1.3 MJ laser pulse shown in Fig. 1 and had a THD (tritium-hydrogen-deuterium) fuel layer with 65% T, 15% H, and 20% D. Shot N110608 was the same, but with a 50/50 DT mixture. Shot N110620 was similar to N110608, but the peak power was extended by 240 ps (1.4 MJ laser energy) in order to keep the full drive on the capsule longer and minimize shell decompression prior to stagnation. N110615 was another 1.3 MJ DT shot, but with the rise time of the 4<sup>th</sup> pulse shortened so that the peak power is absorbed at larger capsule radius. Although the 0.85 peak power multiplier was selected to match the convergent ablator experiment having the same pulse as N110603, the fact that the bangtimes still approximately match for the N110615 and N110620 experiments is evidence that the 0.85 peak multiplier is a decent approximation for those as

**Table 1.** Comparison of measured and simulated capsule performance metrics for June DT implosions.

	N110603		N110608		N110615		N110620	
	expt	sim	expt	sim	expt	sim	expt	sim
Yield	6.5e13	3.4e14	1.93e14	3.9e15	4.3e14	1.8e15	4.1e14	8.0e15
Ti (keV)	2.9	2.79	3.32	3.47	3.4	3.26	4.43	3.94
DSR	4.7%	4.87%	4.5%	5.79%	3.6%	4.67%	4.5%	6.3%
X-ray BT (ns)	22.27	22.34	22.57	22.62	22.28	22.29	22.23	22.38
$\gamma$ BT (ns)	22.33	22.39	22.58	22.69	22.29	22.30	22.31	22.44
X-ray BW (ps)	114	139	152	136	104	140	122	133
$\gamma$ BW (ps)	220	136	215	108	220	114	175	94
a0 ( $\mu$ m)	33.4	29.5	35.6	26.8	35.1	28.2	21.7	24.6
a2/a0	-0.59	-0.67	-0.22	-0.27	-0.52	-0.58	-0.09	-0.06

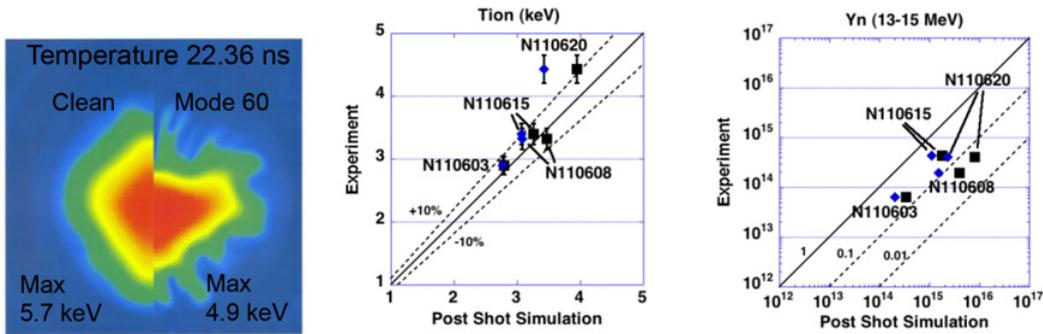
well. We found that by setting the crossbeam model to saturate at  $\delta n/n$  of  $4 \times 10^{-4}$ , we could match the time-dependent symmetry of all four shots, which varied significantly from shot to shot.

### 3. COMPARISON OF MODEL TO EXPERIMENTS

Table 1 compares the measured capsule performance metrics with those extracted from clean 2D simulations of the four experiments. The yield is the number of neutrons with energies from 13–15 MeV. The ion temperature is derived from the width of the neutron spectrum. The down-scattered ratio (DSR) is defined as the ratio of the neutrons from 10–12 MeV to the neutrons from 12–15 MeV. The a0 and a2 Legendre moments of the 17% (of peak intensity) contour of the equatorial x-ray image are also tabulated.

The a2/a0 shape of peak simulated x-ray image matches the measured, while the image size is generally 10–30% larger than simulated, except for N110620. The x-ray bangtime (BT), gamma ( $\gamma$ ) BT, and x-ray burnwidth (BW) are close. However, the gamma burnwidth measured by the Gamma Reaction History diagnostic is 75–100 ps longer than simulated. The yield over simulated (YOS) varies from 5–25%, but we note that the two experiments that were highly out of round (N110603 and N110615) have the highest YOS, probably because the low mode asymmetry, which we are capturing in our simulation, was a significant contributor to the yield degradation in those cases.

We then increased angular resolution of our calculations from 72 to 512 zones per 180 degrees of polar angle in order to include realistic surface roughness on the ablator and ice surfaces. We chose to include modes up to 60 since that is calculated to have the most growth at the hotspot boundary [9]. We then applied the NIF specification roughness to all the surfaces and interfaces and reran the calculations. Figure 2a shows the temperature of the hotspot near bangtime for the clean and mode 60 calculations of N110620. Significant perturbation amplitudes are seen at the hotspot perimeter, which cool the hotspot compared to the clean calculation. Figure 2b and 2c show the burn-weighted ion temperature and yield for all the simulations compared to experiment. The simulated ion temperature is within 10% of the data for all experiments except N110620. The YOS now ranges from 15–40%, but remains low for the rounder implosions. Thus, a key conclusion is that our best mid-mode simulation that roughly matches the 1D implosion parameters and drive asymmetry cannot explain the low measured yields.



**Figure 2.** (a) Comparison of calculated electron temperature for N110620 near bangtime for clean (left) and mode = 60 (right), (b) ion temperature vs. experiment for clean (square) and mode = 60 (diamond), (c) yield vs. experiment for clean (square) and mode = 60 (diamond).

**Table 2.** Hotspot parameters from the experiment fit model [10] are compared to integrated calculations of increasing complexity for the N110620 experiment.

	N110620 fit	1D sim	2D Clean	2D Mode 60
Hotspot mass ( $\mu\text{g}$ )	2.8	18.2	19.7	20.1
Hotspot density (g/cc)	26	173	181	144
Hotspot pressure (Gbar)	80	488	377	219

To obtain further insight into the low experimental yields, we compared simulation results for N110620 to a static hotspot model fit to the experiment data. This model uses the neutron and x-ray diagnostic measurements to find a spatial density and temperature profile within the hotspot that is a best fit to the data [10]. The comparison is shown in Table 2. In the hotspot model fit, the low experimental yield implies very low hotspot mass, density, and pressure relative to the calculations. We see that as more realism is added to the simulations, the hotspot pressure falls closer to the experimental fit, but even with our best mode 60 calculation the pressure is still  $\sim 3$  times the fit value. This implies that actual hotspot is much less dense than calculated or that some 3D effect not captured in our calculations is resulting in very little of the available DT fuel participating in the burn, even though the burn-weighted ion temperature is close to what is measured.

## References

- [1] J. D. Lindl, *Inertial confinement fusion* (Springer, New York, NY, USA, 1998)
- [2] O. L. Landen, M. J. Edwards, S. W. Haan, et al., *Phys. Plasmas* **18**, 051002 (2011)
- [3] H. F. Robey, T. R. Boehly, R. E. Olson, et al., *Phys. Plasmas* **17**, 012703 (2010)
- [4] D. G. Hicks, B. K. Spears, D. G. Braun, et al., *Phys. Plasmas* **17**, 102703 (2010)
- [5] M. M. Marinak, G. D. Kerbel, N. A. Gentile, et al., *Phys. Plasmas* **8**, 2275 (2001)
- [6] M. D. Rosen, H. A. Scott, D. E. Hinkel, et al., *High Energy Density Phys.* **7**, 180 (2011)
- [7] R. P. J. Town, M. D. Rosen, P. A. Michel, et al., *Phys. Plasmas* **18**, 056302 (2011)
- [8] P. Michel, S. H. Glenzer, L. Divol, et al., *Phys. Plasmas* **17**, 056305 (2010)
- [9] S. W. Haan, J. D. Lindl, D. A. Callahan, et al., *Phys. Plasmas* **18**, 051001 (2011)
- [10] P. Springer, et al., these proceedings