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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 15-45% 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

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energy transfer that occurs in the hohlraum plasma [7,8]. The Monte Carlo charged 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 ~300-700 ps earlier than measured. Thus the simulations have a higher implosion velocity and a different fuel adaibat 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 544 μm (diam) by 1000 μm 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 1a. 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 1b.

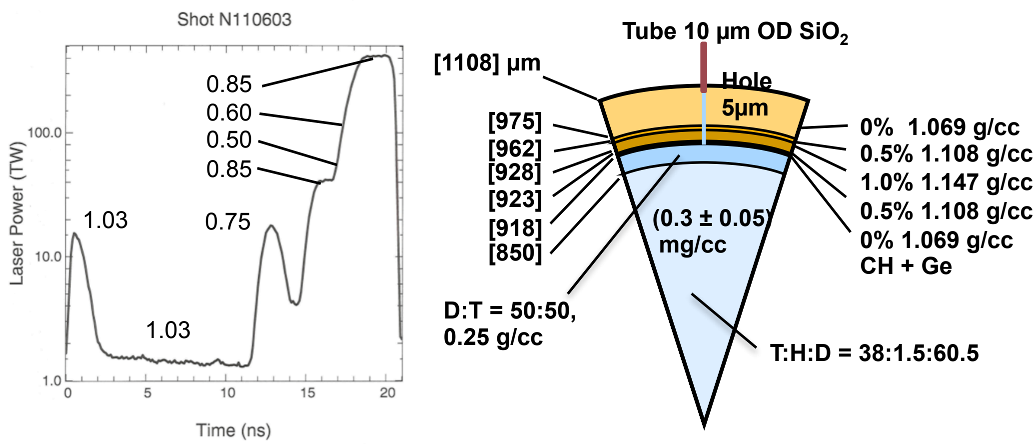

Fig. 1. (a) 1.3 MJ, 420 TW input laser pulse showing multipliers that were applied to fit shock timing and shell velocity data, (b) the Rev5 CH-Ge ignition point design capsule.

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 had a THD (tritium-hydrogen-deuterium) fuel layer with 6% D fraction. 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 230 ps, increasing the laser energy from 1.3 to 1.4 MJ. N110615 was another 1.3 MJ DT shot, but with the rise time of the 4th pulse shortened. We found that by setting the crossbeam model to saturate at $\delta n/n$ of 4e-4, we could match the time-dependent symmetry of all four shots, which varied significantly from shot to shot.

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

	N110603 expt	N110603 sim	N110608 expt	N110608 sim	N110615 expt	N110615 sim	N110620 expt	N110620 sim
Yield	6.5e13	3.35e14	1.93e14	3.9e15	4.3e14	9.0e14	4.1e14	8.0e15
Ti (keV)	2.9	3.09	3.32	3.47	3.4	3.26	4.43	3.94
DSR	4.7%	4.72%	4.5%	5.79%	3.6%	4.67%	4.5%	6.3%
XBT (ns)	22.27	22.34	22.57	22.62	22.28	22.29	22.23	22.38
GBT (ns)	22.33	22.37	22.58	22.69	22.29	22.30	22.31	22.44
XBW (ps)	114	134	152	147	104	140	122	131
GBW (ps)	220	126	215	147	220	140	175	102
a0 (μm)	33.4	29.1	35.6	26.8	35.1	28.2	21.7	24.6
a2/a0	-0.59	-0.55	-0.22	-0.27	-0.52	-0.58	-0.09	-0.06

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 (XBT) and burnwidth (XBW) are close. However, the gamma burnwidth (GBW) measured by the Gamma Reaction History diagnostic is 75-100 ps longer than simulated. The yield over simulated (YOS) varies from 5-45%, but we note that the two experiments that were highly out of round (6/3 and 6/15) 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 mot growth at the hotspot boundary. 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 calculation of N110620. Significant perturbation amplitudes are seen at the hotspot perimeter, which cool the hotspot compared to the clean calculations. 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 15-45%, 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.

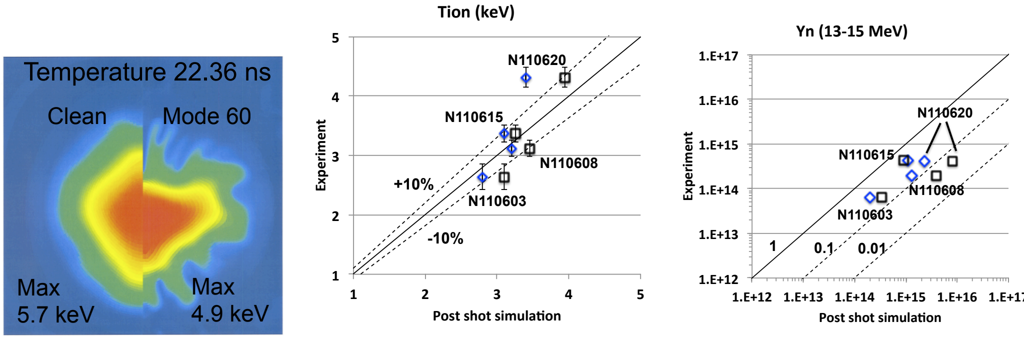

Fig. 2. (a) Comparison of calculated electron temperature for N110620 near bangtime for clean (left) and mode=60 (right), (b) ion temperature vs. experiment for clean (square) and mode=60 (diamond), (c) yield vs. experiment for clean (square) and mode=60 (diamond).

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 [9]. The comparison is shown in Table 2. The low experimental yield results in very low hotspot mass, density, and pressure for the model fit 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 ~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.

Table 2. Hotspot parameters from the experiment fit model [9] are compared to integrated calculations of increasing complexity for the N110620 experiment.

	N110620 fit	1D sim	2D Clean	2D Mode 60
HS Mass (μg)	2.8	18.2	19.7	20.1
HS density (g/cc)	26	173	181	144
HS Press (Gbar)	80	488	377	219

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