Lasnex simulations of NIF vacuum hohlraum commissioning experiments

R. E. Olson¹, L. J. Suter², J. L. Kline³, D. A. Callahan², M. D. Rosen², K. Widmann², E. A. Williams², D. E. Hinkel², N. B. Meezan³, G. A. Rochau¹, A. L. Warrick³, S. H. Langer³, C. Thomas², S. N. Dixit², E. L. Dewald², M. B. Schneider², J. D. Moody², P. Michel², R. J. Wallace², O. L. Landen², J. Edwards³, B. J. MacGowan², S. H. Glenzer²

¹Sandia National Laboratories, Albuquerque, New Mexico 87181
²Lawrence Livermore National Laboratory, Livermore, California 94550
³Los Alamos National Laboratory, Los Alamos, New Mexico 87545

e-mail: reolson@sandia.gov

Abstract. Lasnex calculations and x-ray flux measurements are presented for a series of NIF vacuum hohlraum experiments that were among the first targets shot on NIF as part of the facility commissioning. An important result is that the hohlraum x-ray fluxes are significantly higher than predicted by pre-shot Lasnex calculations employing the baseline “configuration managed” physics packages used in the NIF ignition target calculations. A possible explanation for the high-flux vacuum hohlraum result has been explored via post-shot calculations in which non-baseline emissivity and heat conduction models are used.

1. Introduction
Among the first targets shot at NIF during the facility commissioning were empty, or “vacuum” gold hohlraums. Although these cylindrical targets were relatively simple, the on-target laser energies were up to 20x the maximum energy used in previous hohlraum experiments at Nova and Omega, and the targets had approximately 5x the surface area and more than 10x the volume of previous vacuum hohlraums heated to comparable radiation temperatures. An important goal of the experimental series was to validate the Lasnex code and associated physics packages at the increased size and energy regimes now available for hohlraum experiments at the NIF. An additional goal was to qualify the NIF Dante soft x-ray spectrometer [1].

Two types of vacuum hohlraums were used. “Scale 0.7” hohlraums were 6.40 mm long, 3.55 mm in diameter, with 2.65 mm diameter laser entrance holes (LEH), and “scale 0.9” hohlraums were 8.44 mm long and 4.55 mm in diameter with 2.95 mm diameter LEH. The hohlraum walls were 25 micron thick Au. Depending on the experiment, the hohlraums were heated with either half the NIF beams (actually 88 or 96 beams) or all the NIF beams (actually 184 or 192 beams). In all experiments, the laser pulse shape was nominally 2 ns square, and the laser power was approximately equally divided between the two LEH’s. The peak on-target laser intensities ranged from 1.2 x 10¹⁴ to 2.8 x 10¹⁴ w/cm². The laser energies, peak intensities, and peak radiation temperatures for each experiment are indicated in Fig. 1.
The x-ray flux measurements were made with the NIF Dante [1] looking into the lower LEH at an angle of 37.4 degrees relative to the hohlraum axis. Other diagnostics used in these experiments included a Static X-ray Imager (SXI) [2], hard x-ray spectrometer (FFLEX) [3], Near Backscatter Imager (NBI) [4], and Full Aperture Backscatter (FABS) [4]. Further details concerning the experimental setup and measurements of the NIF vacuum hohlraum series are provided in Ref. 5.

The Lasnex calculations were done in 2D, with the laser beams approximated as cones entering the LEH at angles of 30 and 50 degrees for the 88 or 96 beam experiments and at 23.5, 30, 44.5, and 50 degrees (relative to the hohlraum axis) for the 184 and 192 beam experiments. In all calculations and experiments, the outer cone energy was a factor of 2 larger than the inner cone energy. The Lasnex output was post-processed to provide the simulated time- and spectral-resolved flux that would be seen by Dante at the angle of 37.4 degrees relative to the hohlraum axis.

2. X-ray Flux Measurements and Pre-Shot Lasnex Simulations

The NIF Dante [1] consists of an array of 18 K- and L-edge filtered photo-cathodes (“XRDs”) with some channels also employing grazing-incidence mirrors. As described in Ref. 6, the NIF Dante filters, mirrors, and XRDs are calibrated with a random flux error of 5-18% (depending on the energy channel), with a total flux uncertainty of about 7%. A new data unfold code is being developed and tested as a part of the NIF Dante qualification effort. It is anticipated that, within the next few months the new code will be incorporated into the NIF Shot Analysis and Data Visualization (SADV) website. In the meantime, however, an existing “desktop” Dante unfold routine has been employed here as a data analysis tool. The “desktop” code has been used routinely by Sandia National Laboratory in the analysis of Omega hohlraum data (eg, Ref. 7). It is based upon the iterative “test-spectrum” method described in Ref 8, and its Omega Dante results have been cross-compared with similar unfold codes that exist at other laboratories. Inputs into the unfold code include raw digitizer “scope” files, collimator and solid angle measurements, cable compensation measurements, attenuator and signal divider calibrations, and response functions (which have been derived from the filter, mirror, and XRD calibrations [6]). The total flux vs. time unfolds shown in Figs 2-6 were done using a version of the Sandia desktop code that was modified for use with NIF Dante data files. As such, the work is somewhat preliminary. At the time of this conference, the NIF Dante is new, the NIF Dante SADV analysis routine is not yet qualified, and all aspects of the measurements and analysis are still being closely scrutinized.

The NIF ignition campaign includes a number of different types of experiments (eg., hohlraum energetics, shock timing, symmetry, convergent ablation). During the planning phases of the ignition campaign, a “configuration managed” Lasnex setup was established to ensure that the different program elements would all be using physics assumptions that are consistent with the baseline ignition target design calculations [9]. For the vacuum hohlraum experiments, the pre-shot Lasnex simulations were done using the “configuration managed” Lasnex setup. The pre-shot Lasnex Dante flux predictions are shown as the dashed curves labeled “Lasnex (CM)” in Figs. 2-6. As can be seen in the figures, the peak measured Dante fluxes are ~20-50% higher than the pre-shot predictions.

3. Post-Shot Lasnex Simulations

Although the Dante x-ray flux measurements are much higher than predicted by CM-Lasnex calculations, the results were not entirely unexpected. It has been known for some time that detailed configuration NLTE emissivity models that produce more radiation per unit volume than the default Lasnex average atom NLTE model will increase the efficiency of the hohlraum [10]. Furthermore, it is expected that the increase in hohlraum x-ray conversion efficiency will become more pronounced at larger scale sizes due to the larger volume-to-surface ratio [11]. It has also been known that the default Lasnex electron flux limiter of 0.05 can lead to an underestimate of the heat conduction losses from the Au coronal plasma, and that a flux limiter of 0.15 produces a better match to experimental data in Au sphere x-ray conversion efficiency measurements at Omega [12]. The plasma emissivity in CM-Lasnex is calculated using the average-atom XSN package [13]. Historically, XSN has been used
in integrated computational simulations because it is fast enough for in-line use. However, its accuracy is severely limited. Upon obtaining the results shown in Fig. 2-6, a series of post-shot Lasnex calculations were run using recently-developed methods [14] for constructing atomic models.

**Fig. 1** NIF vacuum hohlraum shot summary.

**Fig. 2** Scale 0.7, 150 kJ, peak $T_r \approx 235$ eV.

**Fig. 3** Scale 0.7, 233 kJ, peak $T_r \approx 265$ eV.

**Fig. 4** Scale 0.7, 308 kJ, peak $T_r \approx 290$ eV.

**Fig. 5** Scale 0.7, 635 kJ, peak $T_r \approx 345$ eV.

**Fig. 6** Scale 0.9, 591 kJ, peak $T_r \approx 310$ eV.
that are compact and fast enough for routine use in integrated simulations while providing accuracy comparable to far more detailed models. In addition, the electron heat conduction model was altered to use an electron flux limiter of 0.15. These Lasnex “high flux” calculations are shown as the solid blue curves labeled “Lasnex (HF)” in Figs 2-6. As can be seen in the figures, it is possible to explain the seemingly high Dante x-ray flux measurements across the entire range of the 240-340 eV peak Tr vacuum hohlraum experiments with the new “high flux” Lasnex model.

4. Conclusions
The x-ray fluxes measured in the first vacuum hohlraum experiments at NIF are significantly higher than predicted by pre-shot Lasnex calculations employing the default “configuration managed” physics models. It has been demonstrated via post-shot Lasnex calculations that there is a reasonable explanation for the high flux measurements involving the emissivity and heat conduction in the hot coronal plasma. Due to the significant increase in scale size, it seems possible that the hohlraum x-ray conversion efficiency at NIF is higher than in previous hohlraum experiments done at the Omega and Nova scales, and that the high x-ray fluxes indicated by Dante are feasible.

At this point in time, the NIF Dante diagnostic and the associated unfold code are new, and all aspects of the measurements and interpretations are being closely scrutinized. A new SADV Dante data unfold code is in the process of being qualified. NIF experiments are currently being planned to corroborate the high flux measurements with other diagnostic measurements. These include capsule bang time, shock timing, and ablation rate, as well as dedicated measurements of Au x-ray conversion efficiency.

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