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N. B. Meezan, S. H. Glenzer, L. J. Suter

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# Target designs for energetics experiments on the National Ignition Facility

**N. B. Meezan, S. H. Glenzer, and L. J. Suter**

Lawrence Livermore National Laboratory, P.O. Box 808, Livermore, CA, U.S.A., 94551-0808

E-mail: `meezan1@llnl.gov`

**Abstract.** The goal of the first hohlraum energetics experiments on the National Ignition Facility (NIF) [G. H. Miller *et al* , Optical Eng. **43**, 2841 (2004)] is to select the hohlraum design for the first ignition experiments. Sub-scale hohlraums heated by 96 of the 192 laser beams on the NIF are used to emulate the laser-plasma interaction behavior of ignition hohlraums. These "plasma emulator" targets are 70% scale versions of the 1.05 MJ, 300 eV ignition hohlraum and have the same energy-density as the full-scale ignition designs. Radiation-hydrodynamics simulations show that the sub-scale target is a good emulator of plasma conditions inside the ignition hohlraum, reproducing density $n_e$ within 10% and temperature $T_e$ within 15% along a laser beam path. Linear backscatter gain analysis shows the backscatter risk to be comparable to that of the ignition target. A successful energetics campaign will allow the National Ignition Campaign to focus its efforts on optimizing ignition hohlraums with efficient laser coupling.

## 1. Introduction

The National Ignition Facility (NIF) [1] is designed to achieve fusion ignition using the inertial confinement fusion (ICF) scheme [2]. The design of an optimal ignition hohlraum is a compromise between capsule hydrodynamic robustness and laser-plasma instabilities (LPI)– especially stimulated Raman backscatter (SRS) and Brillouin backscatter (SBS). Reducing the hohlraum operating temperature decreases the LPI risk because both the peak laser power and the plasma ablation into the hohlraum are reduced; however, decreasing the ablation rate of the capsule increases the risk of hydrodynamic instability, requiring more laser energy to maintain capsule robustness.

The National Ignition Campaign has chosen hohlraum designs that span a wide range of backscatter risk, as described by Callahan *et al* in the preceding paper [3]. The primary goal of the first large-scale energetics campaign on the NIF, which will utilize 96 of NIF's 192 laser beams in the 30° and 50° cones, is to select the ignition hohlraum from the candidate designs. Three of these ignition designs drive a capsule with a beryllium ablator at peak radiation temperatures ($T_{RAD}$) of 300 eV, 285 eV, and 270 eV. The fourth design drives a capsule with a plastic (CH) ablator at 300 eV. The 300 eV beryllium design requires 1.05 MJ of laser energy, while the others require 1.3 MJ. The 96-beam energetics campaign will accomplish this goal by measuring the energetics performance of sub-scale hohlraum targets that emulate the plasma conditions and LPI risk of ignition hohlraums.

## 2. Campaign goals

An ignition hohlraum must satisfy three energetics requirements:
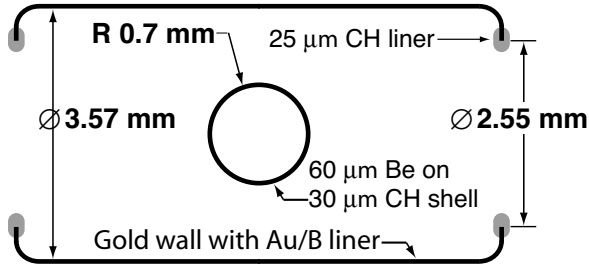
**Figure 1.** Schematic of the sub-scale target for 96-beam energetics experiments. The emulator has all of the features of the ignition target that are relevant to LPI: A Au/B-lined hohlraum wall, a cryogenic helium/hydrogen gas-fill, a CH-lined laser-entrance hole (LEH) with a polyimide window, and a surrogate capsule with a beryllium (or CH) ablator.

(i) Reaches the desired peak radiation temperature $T_{RAD}$

(ii) Low backscattered power on the inner (23.5° and 30°) and outer (44.5° and 50°) cones

(iii) Low levels of DT-fuel pre-heat due to hot-electron generation

Energetics performance is tested experimentally by measuring the net laser power delivered to the hohlraum and the x-ray flux leaving the laser entrance hole (LEH). The NIF's laser diagnostics measure the delivered laser power. Backscatter diagnostics measure the reflected SRS and SBS power on one 30° quad and one 50° quad. Previous experiments using one NIF quad showed that some of the backscattered power is not reflected back into the beam apertures, so the diagnostics also measure light scattered around the apertures [4]. The DANTE filtered x-ray diode array [5] measures the absolute radiation flux at an angle of 37.5° from the hohlraum axis. Hot electron generation is quantified by measuring the hard x-ray *bremsstrahlung* produced by hot electrons with the FFLEX multi-channel filter fluorescer [6].

## 3. Target design

The design goal for the 96-beam energetics targets is to produce ignition hohlraum-like plasma conditions. It is critical that the experiment address LPI in the correct physical regimes–the laser beams must sample the same materials as in an ignition hohlraum at similar electron density $n_e$, electron temperature $T_e$, and ion temperature $T_i$. To accomplish this, we directly scale down the target from the ignition hohlraum geometry by a factor $s$. Length scales as $L_{96} = sL_{192}$, so area scales as $s^2$, and mass (or volume) scales as $s^3$. To preserve energy density, we scale the laser pulse time by $s$ and the total power by $s^2$, $P(t)_{96} = s^2 P(st)_{192}$.

We choose a "plasma emulator" hohlraum that is 70% scale ($s = 0.7$) of the 300 eV, 1.05 MJ ignition design with a beryllium capsule (Fig. 1). The emulator has all of the features of the ignition target that are relevant to LPI, including a thin ($\approx 0.2\mu$m) liner of 80 % gold and 20 % boron co-sputtered onto the hohlraum inner wall. Boron ions in the blowoff plasma strongly Landau damp SBS. The LEH is not scaled, i.e., $R_{LEH,96} = R_{LEH,192}$, because the full-size ($s = 1$) ignition phase plates are used. We deliver the directly scaled power to the hohlraum with half of NIF's 192 beams, so the maximum power *per beam* is just below the ignition value: $P_{beam,96} = 2 \times (0.7)^2 P_{beam,192} = 0.98 P_{beam,192}$. We use one target to emulate all three ignition designs with beryllium ablators–only the laser pulse is changed. Note that direct scaling preserves the peak intensity of each beam for all the emulator hohlraums. Figure 2 shows the pulse-shapes for the beryllium capsule emulator designs. We can think of each laser pulse as a 2-part experiment: the first three bumps (the "foot") form the plasma, while the fourth (peak) bump is the interaction pulse. In this context, Fig. 2 shows clearly why backscatter risk decreases rapidly as $T_{RAD}$ is reduced: The plasma-forming pulse is reduced in duration and the interaction pulse is reduced in intensity.

In order to achieve ignition-like plasma conditions, the capsule ablator must eject the correct mass into the hohlraum before the interaction pulse begins. This requires matching the radiation drive in the foot to the ignition drive. Due to the time-dependence of the hohlraum wall albedo
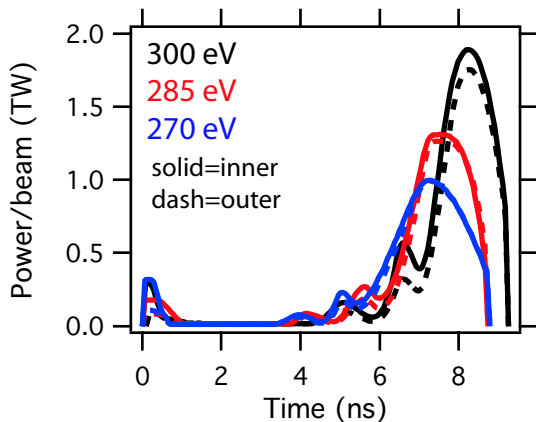
**Figure 2.** Laser pulses for plasma emulators of ignition designs with beryllium capsules.
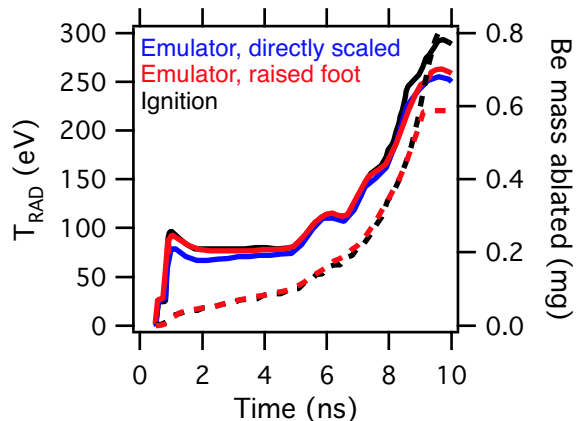


**Figure 3.** Radiation drive $T_{RAD}$ seen by the capsule and mass ablated by the capsule (dash) in HYDRA simulations of the 300 eV beryllium design and its sub-scale emulator.

(see [2] §4) and to some target features that are not scaled (e.g., the thickness of the window), the emulator foot-pulse must be increased to 20-40% above the directly-scaled power $P_{96} = s^2 P_{192}$. Figure 3 shows the $T_{RAD}$ seen by the capsule in 2-D radiation hydrodynamics simulations with the code HYDRA [7]. The emulator with a directly-scaled pulse never reaches the ignition drive in the foot. When the foot-pulse is increased, the drive matches the ignition drive. Note that the emulator is not expected to reach the ignition peak $T_{RAD}$. The mass ablated by the beryllium capsule is also shown in Fig. 3. The emulator target with a raised foot-pulse matches the (scaled) ablated mass of the ignition target up to the time of peak laser power. The x-axis (time) is scaled by $s = 0.7$ for the ignition design curves in Fig. 3.

## 4. Target performance

The first requirement for an emulator target is that it produces ignition hohlraum-like plasma conditions in the laser beam paths. Figure 4 shows the ray-averaged electron density $n_e/n_c$ and electron temperature $T_e$ extracted from HYDRA's laser ray-trace package at 8.8 ns, just after the peak of the laser pulse. Note that the x-axis (distance) is scaled by $s = 0.7$ for the ignition target. We see that the emulator design with a directly-scaled pulse and the emulator with and ignition-like foot drive bracket the $n_e/n_c$ of the ignition design. This demonstrates that the electron density inside the hohlraum can be tuned by adjusting the foot-pulse. The electron temperatures $T_e$ for the emulators are 10-15 % below the ignition value.

We use linear gain analysis to compare the quantitative backscatter risk of the emulator and ignition targets. The gain exponents for SRS and SBS are proportional to laser intensity and to plasma length. Intensity is preserved, so an emulator with plasma conditions identical to the ignition hohlraum should have a lower gain exponent $G_{96} = sG_{192}$. Figure 5 shows the maximum SRS and SBS backscatter gains $G_{max}(t)$. While $s = 0.7$ for this design, the emulator SRS gain fluctuates between $G_{96} \approx 0.5G_{192}$ and $G_{96} \approx 1.1G_{192}$. On average, $G_{96} \approx 0.75G_{192}$ for SRS, but for SBS, $G_{96} \approx G_{192}$.

In order to reach ignition-relevant gains and to find the limits for acceptable backscatter, we use $s = 0.7$ phase plates on the diagnosed 30° and 50° quads. These interaction phase plates produce elliptical laser spots 49% smaller in area than the ignition phase plates, allowing the emulator experiments to access intensities $I_{96} \leq 2I_{192}$. By varying the foot-pulse level and the peak interaction intensity for a given emulator target, we can span the uncertainty in emulator
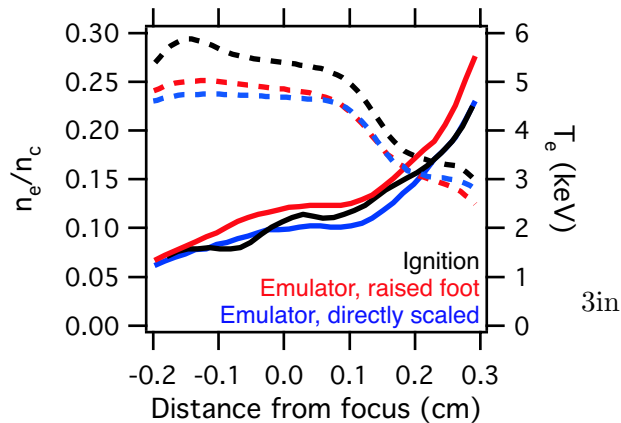
**Figure 4.** Ray-averaged electron density $n_e/n_c$ and temperature $T_e$ (dash) along a 30° quad from HYDRA simulations of the 300 eV beryllium design and its sub-scale emulators.
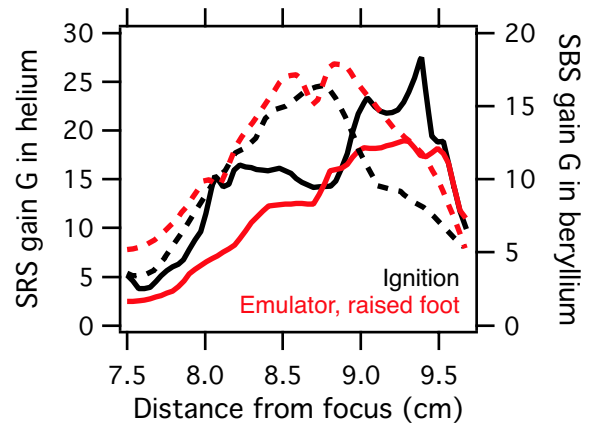
**Figure 5.** Peak SRS and SBS (dash) intensity gain exponents $G(t)$ for a 30° quad from HYDRA simulations of the 300 eV beryllium design and its sub-scale emulator.

quality and confidently find an energetically robust ignition hohlraum design.

## 5. Conclusions

The first large-scale energetics experiments on NIF directly test the energetics performance of the candidate ignition hohlraums. Sub-scale emulator targets driven by 96 NIF beams provide ignition-like plasma conditions to address backscatter risk in the correct physical regimes. With a single target, adjustments to the laser pulse can be used tune the emulator plasma conditions and the quantitative backscatter risk. These experiments provide an opportunity to put hohlraum energetics issues to rest and move forward with optimizing the performance of ignition hohlraums.

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