Analyses of laser-plasma interactions in NIF ignition emulator designs

D. E. Hinkel, D. A. Callahan, N. B. Meezan, L. J. Suter,
C. H. Still, D. J. Strozzi, E. A. Williams, and A. B. Langdon
Lawrence Livermore National Laboratory, Livermore, CA, USA
hinkel1@llnl.gov

Abstract. The National Ignition Campaign is currently conducting energetics experiments at the National Ignition Facility (NIF). These experiments directly test all aspects of ignition hohlraum performance. An important aspect of good performance is understanding and mitigation of laser-plasma interactions, which enables laser coupling to the target. The hohlraum energetics target and pulse-shape are designed to produce an ignition-hohlraum-like plasma to test laser-plasma interactions. The pre-shot laser-plasma interaction predictions for the first energetics targets (one room temperature target, and one cryogenic target) are presented here. These findings correlate well with the experimental data, namely that the primary concern is stimulated Raman scatter of the inner beams deep in the target. Such scatter is mostly re-absorbed, but modifies the energy deposition profile and thus the symmetry. Stimulated Brillouin scatter is at low levels, both in pre-shot predictions and in the experiments.

1. Introduction
Currently, we are conducting an energetics campaign at the National Ignition Facility (NIF). This campaign is designed to directly test all aspects of ignition performance. The goals of this campaign are to demonstrate: (1) acceptable radiation drive, (2) acceptable backscatter levels, (3) acceptable hot-electron preheat, (4) implosion symmetry tuning, and (5) power flow accounting in the target. Laser-plasma interactions (LPI) directly impact all of these goals, and thus are a main concern.

There are two distinct types of laser-plasma interactions in ignition targets: single-beam LPI, and multiple-beam LPI. Single-beam LPI includes effects such as: (1) backscatter, where the incident laser light resonantly scatters off electron plasma waves (stimulated Raman scatter, or SRS) or ion acoustic waves (stimulated Brillouin scatter, or SBS); (2) filamentation, where intensity modulations create density depressions that can refract and intensify the light; (3) refractive intensification, where the laser light is intensified by beam refraction over the capsule; and (4) re-absorption of scattered light, which modifies the energy deposition profile. These single-beam LPI phenomena will be discussed in this paper. Multiple-beam LPI, such as power transfer from one beam to another via a mutually shared plasma wave also occurs in these targets. Such phenomena are the subject of a paper by P.A. Michel et al. [1] in these conference proceedings.

NIF emulator designs[2] are 78% of ignition scale, and use 500-600 kJ of laser energy. The first emulator target that was shot as part of this experimental campaign was the room temperature emulator. It is composed of a gold hohlraum wall lined on the interior with a 60% Au/ 40% B liner about 1 μm in thickness. This liner is used to suppress SBS in the wall plasma blow-off. The capsule
is filled with propane, and has a CH ablator. The target gas fill is neopentane. The laser entrance hole (LEH) is 64% of the target radius. For this target we predict (from beam propagation simulations with pF3D[3]) 0.5% SRS generated over the capsule at the end of peak power, which, after cross-beam amplification in the LEH would suggest a reflected power of 1-2%. We find negligible SBS on both inner and outer beam quads, and negligible SRS on the outer beam quads.

The second type of emulator shot at NIF was a cryogenic target. This target is of the same dimensions as the room temperature target, with the same wall composition. The capsule is filled with He, and has a CH ablator. The gas fill is H4He. For this target, we predict (from beam propagation simulations) ~3-4% SRS generated over the capsule, which, after cross-beam amplification in the LEH would suggest a reflected power of ~ 20-30%. We find negligible SBS on both inner and outer beam quads, and negligible SRS on the outer beam quads for this target as well. There is no evidence of filamentation in these beam propagation simulations. There is refractive intensification of the inner beam quads of the cryogenic target, which results in a larger reflectivity for the cryogenic target. Also in the cryogenic target, re-absorption of SRS as it propagates out of the target somewhat modifies the energy deposition profile.

The remainder of this paper details the analyses that led to these conclusions.

2. LPI assessment at the hydrodynamic scale

We first assess LPI by calculating the gain exponents for stimulated backscatter amplification. The code newlip[4], developed by E. A. Williams at Lawrence Livermore National Laboratory, calculates the kinetic, steady state convective gain exponent for SBS and SRS along rays in the radiation-hydrodynamics simulations performed of the emulator targets[2]. This provides a distribution of gains across a given beam, as in the transverse direction the beam is interacting with different materials with transverse as well as longitudinal variations. We formulate the cumulative sum of the gain distribution to find the fraction of power above gain (FOPAG). Here we compare FOPAGS of the room temperature and cryogenic emulators.

![Figure 1](image1.png)  
**Figure 1.** SBS FOPAGs for the 30° beams near the end of peak power. The blue curve is the room temperature target FOPAG, and the black is that of the cryogenic target. No ray sees a gain exponent above 9.

![Figure 2](image2.png)  
**Figure 2.** SRS FOPAGs for the 30° beams near the end of peak power. The red curve is the room temperature target FOPAG, and the black is that of the cryogenic target. Approximately 50% of the power is in gain exponents > 10.

Figure 1 is a plot of the SBS FOPAG along the 30° beams near the end of peak power. The blue curve is the FOPAG for the room temperature target, and the black curve is the FOPAG for the cryogenic target. The gains are quite similar in these targets. The slight difference at lower gains is
where the rays propagate through the gas fill, C_6H_{12} for the room temperature target and H_4He for the cryogenic target (more strongly damped). No ray has a gain exponent above 10.

Similarly, Figure 2 is a plot of the SRS FOPAG along the 30° beams near the end of peak power. The red curve is the FOPAG for the room temperature target, and the black curve is the FOPAG for the cryogenic target. The gains are approximately equal at this time. Approximately 50% of the power is in gains above 10.

Along the outer beams at the end of peak power, SBS occurs primarily in the wall blow-off, which is composed of Au_{6}B_{4} (B was added to suppress SBS). Here, no ray has a gain exponent above 8. For SRS, no ray has a gain exponent above 5. Thus our primary concern is SRS along the inner beams. To further analyze this, we perform beam propagation simulations with our massively parallel code, pF3D.

3. Beam propagation simulations

pF3D[3] is a laser beam propagation code that couples paraxial wave equations for the incident and reflected waves to a plasma fluid model. These simulations account for effects such as longitudinal and transverse gradients, laser speckle physics, refractive intensification, plasma self-smoothing, and spatial, temporal and polarization beam smoothing, to name a few. The incident light wave is depleted by an SBS coupling term, an SRS coupling term (depending on the reflected light wave and density fluctuation amplitudes), and a refraction term (that depends upon density fluctuations and the incident light wave amplitude). The reflected light waves are driven by the amplitude of their respective density fluctuations coupled to the incident wave. The acoustic and electron plasma wave density fluctuations satisfy respective wave equations driven by the ponderomotive force of the light waves. The background plasma is described by a standard, multi-material nonlinear fluid model that couples to the laser via ponderomotive pressure and inverse bremsstrahlung.

**Figure 3.** A plot of an azimuthal slice of the forward intensity pattern of a 30° quad at peak power for the cryogenic emulator. Laser speckles are evident at higher intensity (white). The propagation path is 6 mm long and the box is 2 mm in cross section. The beam enters the target 1/6 of the way through the box. It is channeled between the ablator and the wall plasma in the latter half of the box.

**Figure 4.** A plot of an azimuthal slice of the SRS intensity pattern of a 30° quad at peak power for the cryogenic emulator. SRS is generated near the end of the simulation box, up over the capsule. The longer wavelength SRS refracts differently than the incident light as it propagates out of the target. About 3-4% of the incident light propagates out of the front of the box as SRS light.
Figure 3 is a plot of an azimuthal slice of the forward intensity pattern of a 30° quad at peak power for the cryogenic emulator. As the beam enters the target (1/6 of the way through the box), it refracts off the LEH and propagates toward the wall. Halfway through the simulation box the beam begins to get channeled between the ablator plasma (dark plot of plot in top left half) and wall plasma (dark part of plot in top right half). There is evidence of refractive intensification for the cryogenic emulator, and this is what increases the reflectivity in the cryogenic emulator.

Figure 4 is a plot of an azimuthal slice of the SRS intensity pattern of a 30° quad at peak power for the cryogenic emulator. SRS is generated over the capsule in the gas fill plasma between the ablator and wall plasma. This longer wavelength light will undergo greater absorption (via inverse bremsstrahlung) as it propagates out of the target than the incident light underwent as it propagated inward (approximately 50% of the incident light is absorbed before it reaches the wall). It will also refract differently than the incident light, as evidenced in Figure 4. We find approximately 3-4% of the incident light is reflected out of the front of the simulation box as SRS light. This does not account for multiple beam effects near the LEH, which will further amplify the SRS reflectivity. We find negligible SBS in this simulation (<< 1%).

4. Summary
We have analyzed a variety of laser-plasma interactions for the first energetics experiments at NIF. These targets are below threshold for filamentation, and show low levels of SBS. This is in agreement with the experiments. We find SRS occurs on the inner beams, and is larger for the cryogenic emulator than for the room temperature emulator. This is also in agreement with the experiments. The SRS seed that is generated in these simulations (~ 0.5% for the room temperature target at peak power, and ~ 3-4% for the cryogenic target at peak power) will be further amplified at the LEH of the target by multiple beam effects, the subject of a paper by P. A. Michel et al. [1] in these conference proceedings.

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