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Indirectly Driven Targets for Ignition

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Abstract. Both Los Alamos and Lawrence Livermore Laboratories have studied capsule and laser driven target designs for the National Ignition Facility. Our current hohlraum design is a 2.76mm radius, 9.5mm long gold cylinder with 1.39mm radius laser entrance holes covered by 1μm thick plastic foils. Laser beams strike the inside cylinder wall from two separate cones with a peak power less than 400 TW. The problem with a pressure pulse caused by wall plasma stagnating on axis has been overcome by filling the hohlraum with gas. Currently this is equi-molar hydrogen-helium gas at 0.83 mg/cc density. One capsule uses a 160μm plastic ablator doped with oxygen and bromine surrounding an 80μm thick DT ice layer with an inner radius of 0.87 mm. Los Alamos integrated calculations of the hohlraum and this capsule using 1.4 MJ of laser energy achieve yields of 4.9 MJ using LTE atomic physics, and 3.5 MJ with non-LTE. This confirms Livermore calculations of ignition. For radiation driven implosions, a beryllium ablator offers a viable alternative to plastic. It is strong enough to contain high DT pressures. Copper, soluble at required levels, is an excellent dopant to add opacity. A beryllium capsule with a 155 μm thick ablator doped with 0.9 atom % copper, and the same inner dimensions as the plastic capsule, placed in a similar hohlraum , yields 6.9 MJ with LTE. Although these calculations show the designs are sensitive, they add to our confidence that NIF can achieve ignition. Using our best integrated calculations which are not yet fully optimized, we confirm Livermore calculations of ignition with a plastic capsule, and have added an alternate capsule design with a beryllium ablator.

1. Introduction

The near-term goal of the U.S. Inertial Confinement Fusion (ICF) Program is to demonstrate ignition and moderate gain in a proposed next-generation laser, the National Ignition Facility (NIF). Of the many possible target designs, we have focussed our work on two different capsules, one using a plastic ablator, and the other a beryllium ablator, placed into a common hohlraum with a few variations. We have integrated the hohlraum and capsule calculations into a single two dimensional radiation hydrodynamics calculation, using the laser light input. We calculate the laser absorption, x-ray radiation, material motion, energy transport to the capsule, the capsule implosion, and fusion burn. This comprehensive and computationally intensive technique was developed over the last two years. Previously a hohlraum might be calculated alone, the angularly and temporally dependent radiation fluxes tabulated, and then linked to a second calculation of the capsule implosion.

These integrated calculations use our best numerical packages for hydrodynamics, radiation transport, atomic physics, and thermonuclear burn. They include effects such as the refraction, reflection and absorption of laser light passing through the spatially and temporally varying laser entrance hole and hohlraum plasma. They include the filling of the hohlraum with plasma, the motion of the laser absorption region, the time dependent emission of X-rays from the laser heated plasma, their absorption and reradiation, and final absorption onto the capsule, the spatial and temporal variation of the capsule ablation, its implosion, and thermonuclear burn. But our integrated calculations are incomplete. The calculation of colliding low density plasmas is lagrangian, and does not model plasma interpenetration. Particle-In-Cell simulations may help understand this phenomenon. Laser plasma instabilities such as Brillouin and Raman scattering are not modeled. Capsule mixing and yield degradation due to short scale length hydrodynamic instability growth must be modeled separately.

To date our integrated calculations of one plastic capsule and one beryllium capsule in NIF hohlraums have ignited. They have also shown us how to modify the laser target for better performance.

2. The Hohlraum

Our colleagues at Lawrence Livermore Laboratory designed the basic hohlraum, a 9.5 mm long by 2.76 mm radius gold cylinder, 40 μm thick, with 1.39 mm radius laser entrance holes. The NIF lasers were simulated by two cones of beams. We added a 10 μm thick plastic liner around the lip of the entrance hole to help keep it open. Our first integrated calculations used a 2.5μm thick polystyrene (CH) lining on the gold hohlraum walls with the expectation that it would slow the expansion of the gold wall into the hohlraum center. However we found that the plastic stagnated on axis and created a pressure pulse, whose added impulse caused the capsule axis to implode early, and the capsule to fail to ignite.

Our solution was to remove the plastic liner and add gas with a density of approximately 0.001 g/cc. Since the capsule must be maintained at approximately 18 K, the gas could be only hydrogen or helium, or a mixture of the two. Our most recent design uses 0.000833 g/cc of an equi-molar mix. This mixture was chosen to reduce Brillouin scattering based on theory and experiments presented in other papers at this conference. To contain the gas, 1 μm thick plastic windows were added over the entrance holes. With these changes stagnation pressures were reduced to the point where they no longer degraded the capsule implosion.

3. Plastic Capsule

In the center of this hohlraum we placed a 1.11 mm radius spherical capsule. In its center, out to 0.87 mm is DT gas at an equilibrium density of 0.0003 g/cc. From 0.87 mm to 0.95 mm is solid DT, 0.25 g/cc. From 0.95 mm to 1.11 mm is a doped plastic ablator of density 1.05 g/cc with an atomic composition of 0.475 C12, 0.475 H1, 0.05 O16, and 0.00025 Br. A 1D calculation of this capsule implosion with the radiation temperature drive of figure 1 gives a yield of 14 MJ.

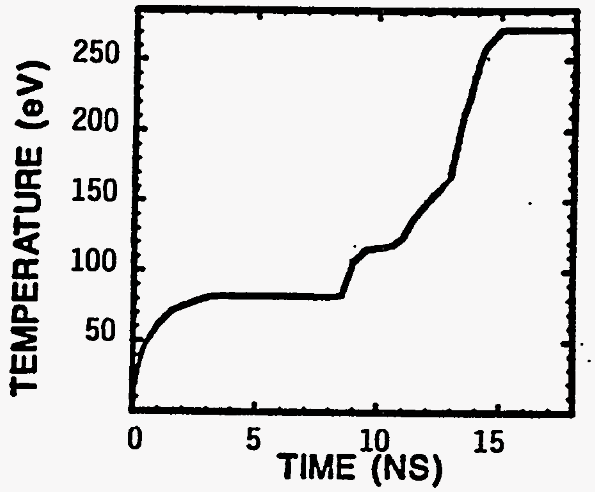

Figure 1. Temperature drive - plastic capsule

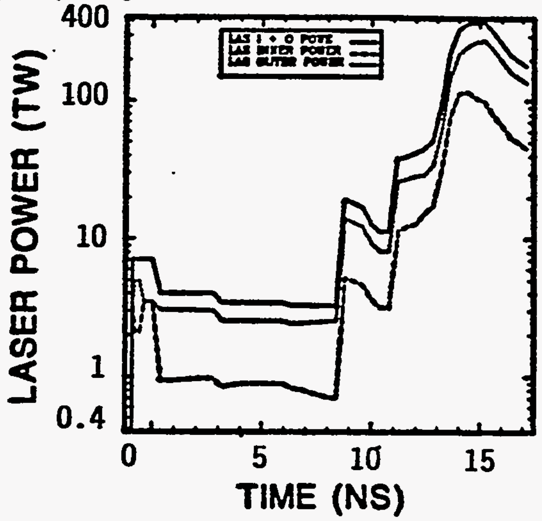

Figure 2. Laser power drive - plastic capsule

For the 2D integrated calculation the time dependent power in two laser beam cones and the spatial pointing of those beams had to be specified. Figure 2 shows a typical power history of the inner and outer beam cones, and the total. The total laser power was adjusted to drive a capsule implosion similar to the 1D calculation. Finally the time dependent split between the inner and outer cone powers was adjusted to minimize the time dependent P2 asymmetry in the radiation flux. The pointing of the cones was adjusted to minimize the time averaged P4 asymmetry. Our best calculation using an LTE assumption in the atomic physics calculations of the opacity and EOS gives 4.9 MJ yield with an input laser energy of 1.37 MJ.

Our non-LTE atomic physics package attempts to model the time dependent level populations, particularly in the laser irradiated plasma. This change causes less radiation emission from the laser deposition regions, and more plasma motion. The radiation source for the capsule moves, and therefore a new beam balance is needed. Our best non-LTE calculation to date produces a yield of 3.5 MJ with 1.32 MJ of laser energy. In no calculation is the full 1.8 MJ of expected laser energy used. We allow for unexpected losses of laser light and some expected loss from Brillouin scattering.

Throughout this iteration process the capsule imploded asymmetrically, but produced some yield. Table 1 shows the yield and asymmetry of the capsule as the power balance, beam pointing, and total energy were changed. It shows that repointing the beams can reduce asymmetry, and with increased laser energy, can increase the yield. The yield degradation seems due to the asymmetry causing the hot spot temperature to rise later in the implosion. Adequate fuel ρr is always achieved. Adding extra laser energy compensates by producing a higher implosion velocity, and an earlier rise in the hot spot temperature.

Table 1. The effects of asymmetry, energy, and pointing on yield

Yield (MJ)	Asymmetry (Pole/Equator)	Laser Energy (MJ)	Outer Beam Pointing (μm)
0.013	7	1.12	0
0.060	6	1.12	0
0.20	5	1.12	+250
0.47	3	1.12	+250
1.3	6	1.37	+250
4.9	3.5	1.37	+250

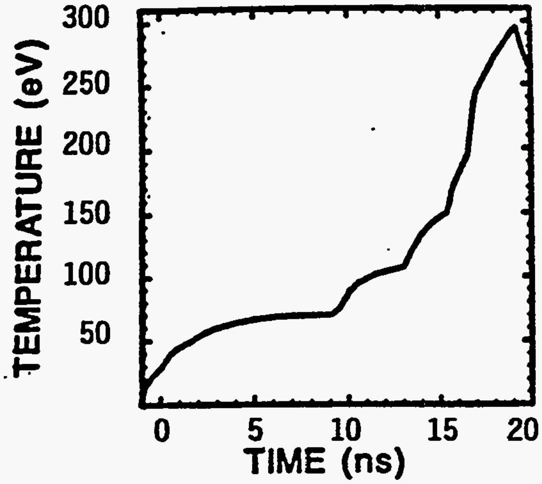

Figure 3. Temperature drive - beryllium capsule

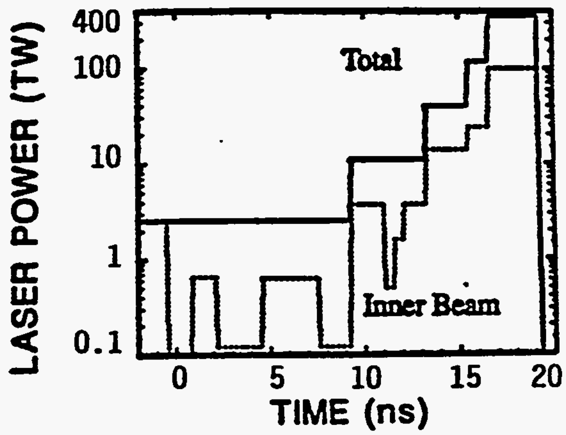

Figure 4. Laser power - beryllium capsule

4. Beryllium Capsule

Beryllium capsules are viable alternatives to plastic. Pure beryllium is a better ablator. It absorbs more hohlraum energy, and it produces a higher pressure than plastic at the same temperature. The technology of beryllium capsule fabrication is well developed – surface finishes of 20 nm have been demonstrated by lapping. It is strong enough to contain high DT pressures. Copper is an excellent dopant to add opacity and is soluble up to required levels. The fraction of dopant can be chosen to provide adequate opacity at the final drive temperature.

Our beryllium capsule is similar to the plastic but with an outer radius of 1.105 mm. The atomic composition of the ablator is 0.991 beryllium and 0.009 copper. A one dimensional calculation of this capsule with the radiation temperature drive of figure 3 gives a yield of 14 MJ. It can also be driven with five flat steps in the radiation pulse between 70 and 300 eV to give a yield of 8.8 MJ. As with the plastic capsule, the timing of the steps is critical.

Figure 4 shows the time history of the laser beam power driving the two dimensional integrated calculations. The highest yield achieved to date is 6.9 MJ in an LTE calculation. We used the same beam pointing as in the plastic capsule calculation, but different power history and balance.

In summary, using our best integrated calculations we confirm Livermore calculations of ignition with a plastic capsule, and have added an alternate capsule design with a beryllium ablator. The problem with a pressure pulse caused by stagnation on axis has been overcome by filling the hohlraum with gas. Although these calculations show the designs are sensitive, they add to our confidence that NIF can achieve ignition.

Acknowledgments

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