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TuPo2.XX SYMMETRY TUNING OF NIF IGNITION TARGETS

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TuPo2.16

SYMMETRY TUNING OF NIF IGNITION TARGETS

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We present the results of a study in which we reduced the calculated intrinsic radiation asymmetry of a particular indirectly-driven cryogenic DT ignition target design through a series of two-dimensional and three-dimensional radiation hydrodynamic calculations of the integrated hohlraum/capsule system. We reduced the amplitude of the time-dependent P_2 Legendre mode of the radiation flux onto the capsule by adjusting the beam pointing and changing the amount of laser power in the outer cone of beams relative to that in the inner cone of beams. In addition, we reduced the amplitude of a significant Y_{44} mode that peaks early in time by adjusting the relative pointing of the 23.5^o and 30^o inner cone beams.

I. INTRODUCTION

In the past few years we have been using the three-dimensional radiation hydrodynamics code, HYDRA, to calculate the performance of cryogenic DT ignition capsules designed for the National Ignition Facility (NIF).[1] These capsules are driven by x-rays from a laser-heated hohlraum. There are two types of calculations that are typically done: integrated hohlraum/capsule calculations and more highly resolved capsule-only calculations. In the integrated hohlraum/capsule calculations we often solve the entire problem. That is, we invoke no planes of symmetry and thus include the full 4π in solid angle around the capsule. In this type of calculation we can directly calculate the spatial uniformity of the radiation drive onto the capsule and its effect on the capsule implosion, since it is only necessary to resolve perturbations on the capsule that can be described by Legendre polynomial modes up to about l=10. It is not currently feasible (in terms of computer time) to resolve the much smaller capsule surface roughness perturbations in a full 4π hohlraum/capsule integrated calculation, so the effect of those higher modes is studied separately in capsule-only calculations that cover a smaller solid angle.

In this work, we have done a series of integrated hohlraum/capsule calculations aimed at reducing the calculated intrinsic (non-random) radiation asymmetry onto a cryogenic DT capsule with a polyimide ablator. This process is referred to as symmetry tuning. The ignition target we studied is shown in Figure 1. The capsule has an outer radius of 0.1194 cm. The ablator is 160 microns of 1.4 g/cc polyimide. Inside the ablator is a 90-micron thick layer of 0.25 g/cc frozen DT. The capsule is filled with 0.3-mg/cc DT gas. This capsule sits inside a “cocktail” hohlraum made up of a mixture of 35% uranium, 5% niobium, 20% gold, 20% tantalum and 20% dysprosium (atomic fractions). The hohlraum has an inner radius of 0.3036 cm, a length of 1.1 cm, a wall thickness of 100 microns, and a laser entrance hole (LEH) radius of 0.138 cm. The hohlraum is filled with 1 mg/cc He gas. A 0.8-micron thick plastic window across the LEH seals this gas inside the hohlraum. The hohlraum wall near the LEH is lined with 30 microns of plastic, which prevents high-Z wall material from filling the LEH and blocking the incoming laser light. The laser-heated hohlraum creates the time-dependent radiation temperature shown in Figure 1.

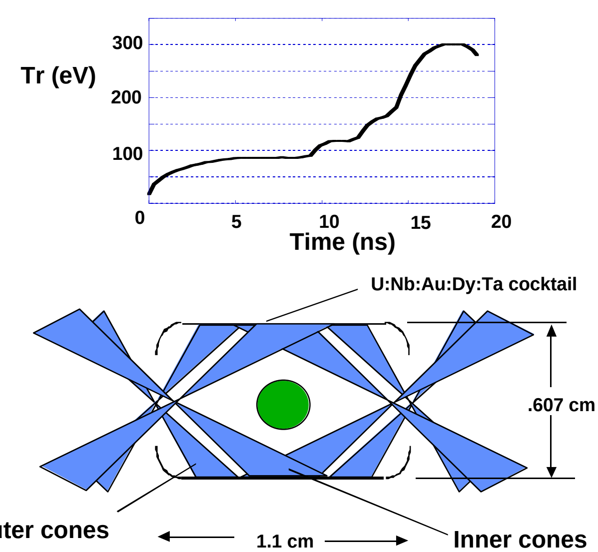

Figure 1 – Indirect drive ignition target consisting of a cryogenic DT capsule inside a laser-heated hohlraum creating a time-dependent radiation drive with a peak T_R of 300 eV.

The 192 laser beams that illuminate the hohlraum are grouped into 48 "quads" and we model each quad as a single f/8 beam. The beams entering the hohlraum through each LEH are grouped into two cones, and result in a three-ring illumination pattern on the hohlraum wall, as shown in Figure 1. The outer cones are made of up beams with polar angles of 44.5 and 50 degrees. The inner cones are made up of beams at 23.5 and 30 degrees. The inner cones from each side form a single ring at the hohlraum midplane. In this study we varied the radiation symmetry in two ways. We changed the pointing of the beams, and we changed the fraction of laser power in the outer cones relative to the inner cones (cone power fraction).

II. 2D SYMMETRY TUNING

We started with beam pointing and cone power fractions that had not been optimized for this particular hohlraum. The outer cone beams were pointed such that best focus was at the center of the LEH. The 23.5^{o} beams were focused at z = +/-0.308 cm and r = 0.142 cm (where z = 0 defines the hohlraum midplane). The 30^{o} beams were focused at z = 0.363 cm and r = 0.077 cm. An axisymmetric ("2D") calculation with those parameters resulted in a fairly distorted imploded core, as shown in Figure 2. This is a contour plot of the density at the time of maximum compression. This combination of pointing and power fraction results in a waist high radiation drive, which leads to a sausage-shaped implosion. In addition, ablator material piles up at the pole and drives a jet into the fuel. Although the implosion looks distorted, this calculation gives nearly the ideal one-dimensional yield. However, this calculation has perfectly smooth ablator and DT ice surfaces. Other calculations have shown that this level of radiation asymmetry in combination with realistic surface perturbations is marginal for ignition.

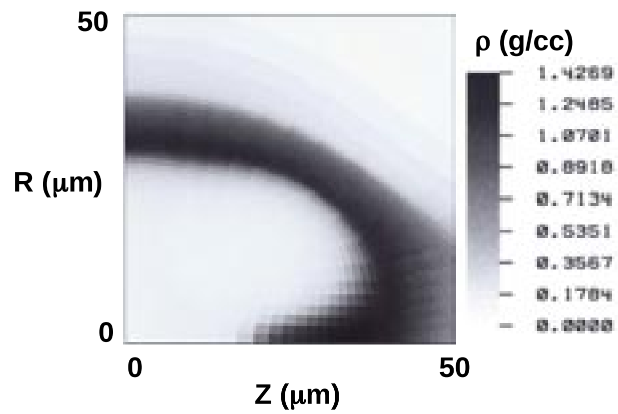

Figure 2 – Contour plot of density at time of maximum compression for original design

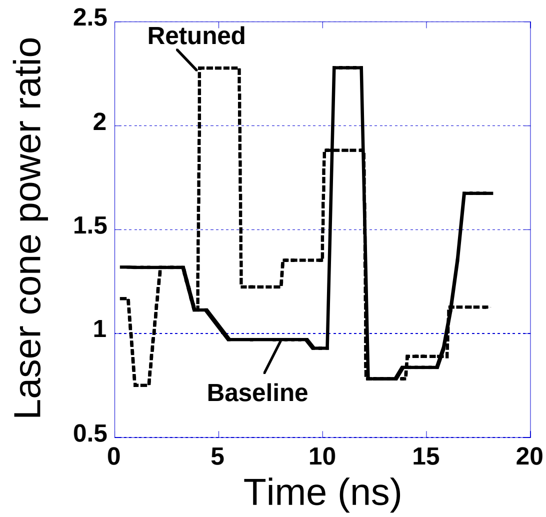

Figure 3 – Ratio of outer cone beam power to inner cone beam power for original design (solid line) and retuned design (dashed line).

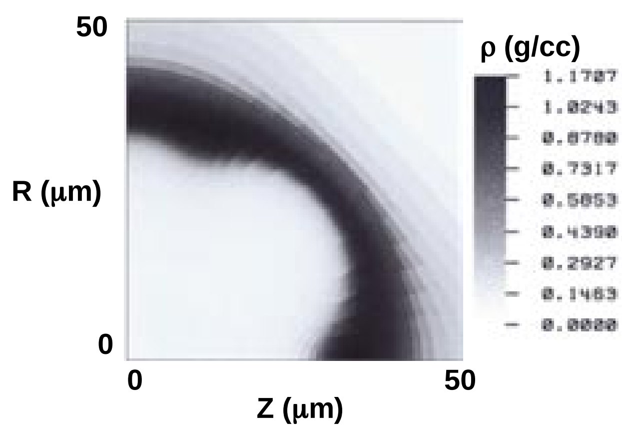

Figure 4 – Contours of density at time of maximum compression for calculation with improved m=0 radiation symmetry

An analytical model of the time-dependent P_2 asymmetry for a two-ring-per-side illumination geometry[2] shows that a negative P_2 drive can be fixed either by putting more power to the outer cones or by moving the outer cone pointing farther out toward the LEHs. After some iteration, we ended up doing both in order to reduce the P_2 asymmetry. We moved the outer cones out by 400 microns and adjusted the cone power fraction to reduce the time-dependent changes in P_2. The net result of the cone fraction retuning was to put more power to the outer cones during the foot of the pulse, as shown in Figure 3. Figure 4 shows the density contour at time of maximum compression with the changes to pointing and cone power fraction described above. We see that the overall shape of the core is rounder and that the magnitude of the jet at the pole is reduced. Figure 5 is a plot of the time-dependent integral of the P_2 component of the capsule ablation pressure, which is proportional to the radiation flux. This shows that the symmetry tuning has significantly reduced the P_2 distortion.

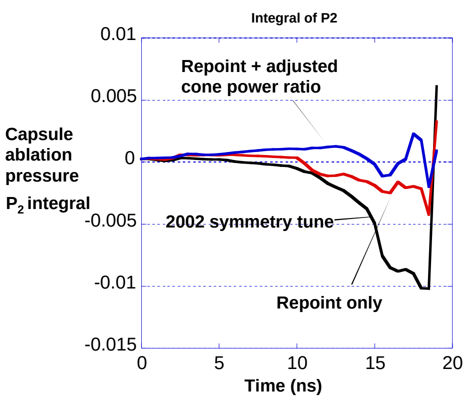

Figure 5 – Integral of the P2 component of the capsule ablation pressure before and after the symmetry tuning.

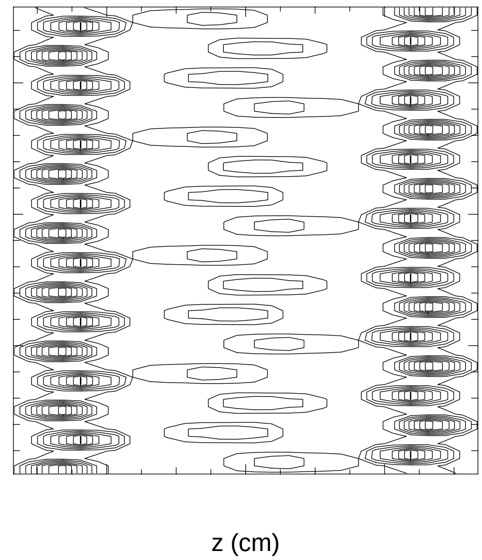

Figure 6 – Illumination pattern on cylindrical portion of hohlraum wall used for viewfactor calculation.

III. 3D SYMMETRY TUNING

In reality the lasers do not form continuous rings of illumination in the hohlraum wall as in the axisymmetric approximation. The finite width of the spots leads to a number of intrinsic three-dimensional spherical harmonic modes. We initially estimated these modes using a radiation viewfactor model. When the baseline beam pointing positions are projected onto the hohlraum wall, they yield the illumination pattern shown in Figure 6. The NIF beam geometry is such that the lowest intrinsic three-dimensional modes have an azimuthal mode number (m) of m=4 and m=8. In particular, note the m=4 pattern formed at the midplane by the alternating 23.5^o and 30^o beams coming from each LEH. This illumination pattern forms a noticeable Y_{44} pattern in the x-ray flux onto the capsule, as shown in Figure 7.

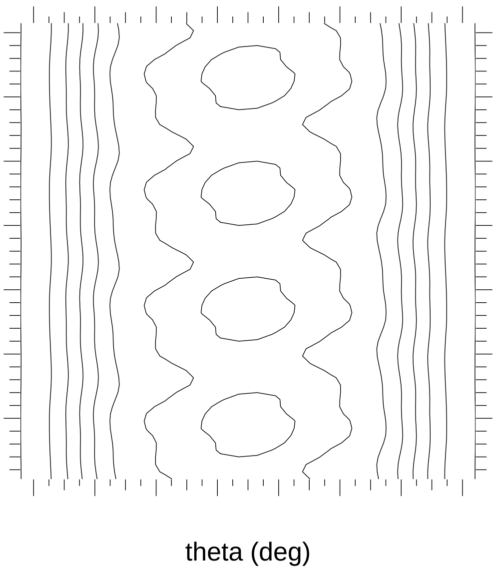

Figure 7 – Flux onto capsule at 1 ns with standard pointing according to radiation viewfactor estimate.

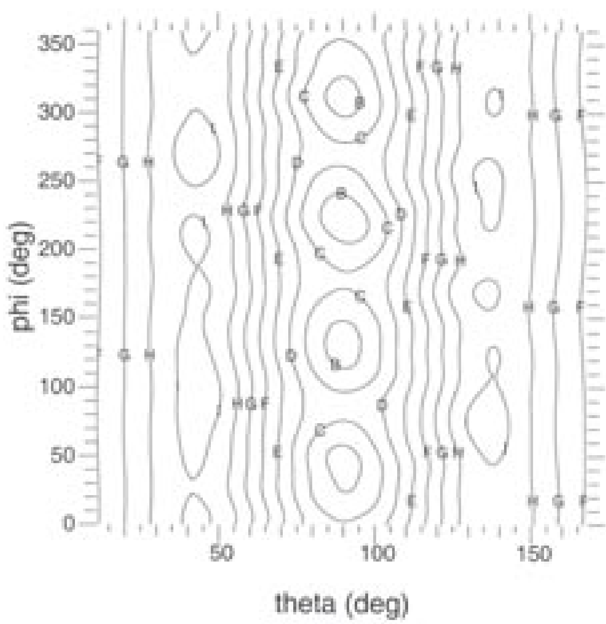

Figure 8 – Flux onto capsule at 1 ns with standard pointing derived from HYDRA calculation.

We then ran 3D HYDRA simulations with this laser pointing, and post-processed the results to determine the spatial variation of the flux at the initial capsule radius. We found roughly the same m=4 pattern seen in the viewfactor calculations (that is, the four features equally spaced in azimuthal angle, phi, at the capsule equator). This is shown in Figure 8.

We then repointed the inner cone beams so that the 23.5 and 30 degree laser beam spots would have approximately equal spot areas (and thus intensities) at the hohlraum midplane in an attempt to reduce the fairly large Y_{44} mode. The 23.5^o beams were repointed such that best focus is at z = 0.264 cm and r = 0.169 cm. The 30^o beams were repointed to have best focus at z = 0.458 cm and r = 0.012 cm. Figure 9 shows the flux on the capsule at 1 ns. The repointing has reduced the m=4 asymmetry as expected.

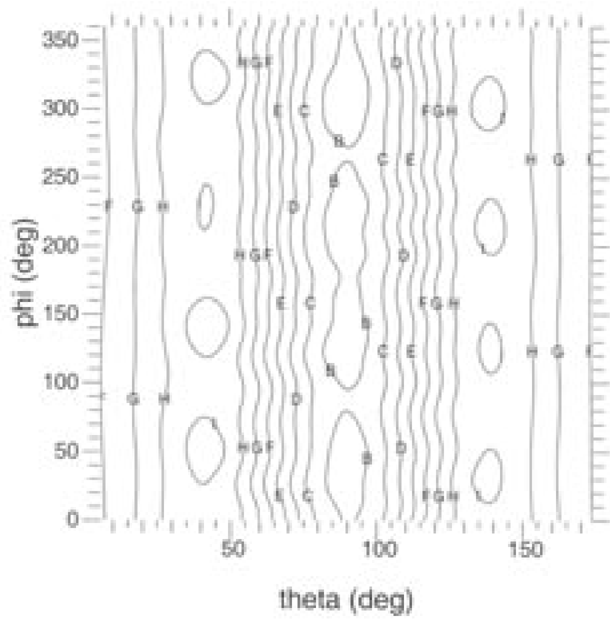

Figure 9 – Flux onto capsule at 1 ns with repointed inner cones to reduce m=4 asymmetry (from HYDRA calculation)

SUMMARY

In this paper we have studied the calculated intrinsic radiation symmetry of an indirectly driven cryogenic DT ignition capsule with a polyimide ablator. This capsule sits inside a cocktail hohlraum made up of a mixture of 35% uranium, 5% niobium, 20% gold, 20% tantalum, and 20% dysprosium. The symmetry was determined via calculations of the integrated hohlraum/capsule system using the radiation hydrodynamics code HYDRA.

By varying the pointing of the outer cone of laser beams and by varying the ratio of power between the inner and outer cones of beams, we were able, through a series of axisymmetric calculations, to reduce the integrated P_2 distortion of the capsule ablation pressure when compared to our non-optimized starting point calculation. This led to a rounder (less distorted) shell of compressed fuel at the time to maximum compression.

In addition, we found from fully three-dimensional calculations of the hohlraum/capsule system that with our baseline-pointing configuration there was a noticeable Y_{44}

distortion in the radiation flux onto the capsule early in the foot of the laser pulse. By repointing the inner cone beams to make the spot sizes of the 23.5^o and 30^o beams approximately the same, we were able to reduce this distortion.

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