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Computer Simulations of Laser Hot Spots and Implosion Symmetry Kiniform Phase Plate Experiments on Nova

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Abstract

LASNEX computer code simulations have been performed for radiation symmetry experiments on the Nova laser with vacuum and gas-filled hohlraum targets [R.L. Kauffman, *et al.* Phys. Plasmas **5**, 1927 (1998)]. In previous experiments with unsmoothed laser beams, the symmetry was substantially shifted by deflection of the laser beams. In these experiments, laser beams have been smoothed with Kiniform Phase Plates in an attempt to remove deflection of the beams. The experiments have shown that this smoothing significantly improves the agreement with LASNEX calculations of implosion symmetry. The images of laser produced hot spots on the inside of the hohlraum case have been found to differ from LASNEX calculations, suggesting that some beam deflection or self-focusing may still be present or that emission from interpenetrating plasmas is an important component of the images. The measured neutron yields are in good agreement with simulations for vacuum hohlraums but are far different for gas-filled hohlraums.

1. Introduction

Calculations with the Los Alamos National Laboratory (LANL) version of the LASNEX 2-D Lagrangian radiation-hydrodynamics code have been performed to prepare for and to help understand a series of experiments that were performed on the Nova laser at Lawrence Livermore National Laboratory (LLNL) in the spring and summer of 1997 [1, 2]. The purpose of these experiments is to study how the symmetry of capsule implosions in gas-filled hohlraums is affected by the smoothing of the Nova beams by Kiniform Phase Plates (KPP). All prior symmetry experiments on Nova have used unsmoothed beams, where the laser intensity near focus is highly concentrated in narrow spikes. Coincidentally, in these experiments the laser beam focal spot was seen to "shift" by as much as 150 μ m, making the implosion of the capsule much more compressed along the hohlraum axis (pancake) [3]. The "bending" of the beam is thought to be due to plasma effects in the fill gas that are brought on by the high laser intensity in the spikes. KPPs were installed in Nova in the fall of 1996, which reduced the intensity peaks in the beams [4] [5] [6] [7] This series of experiments measured the implosion symmetry with KPP smoothed beams and study the reduction in the beam bending due to KPP's.

The LASNEX code does not model the beam bending, so one metric of the effect is how calculated implosion symmetry differs from measured results [8]. The LASNEX predictions are usually quite close to the symmetry of implosions in vacuum hohlraums. In the KPP and in past experiments, the implosion is driven in capsules filled with 50 atm of argon doped deuterium gas. The implosion averages the drive symmetry over the pulse, up to the commit time, when the implosion is no longer affected by the drive radiation. The radiation emitted by the compressed gas core of the capsule is observed through a window in the hohlraum by a Gated X-ray Imager (GXI). The GXI provides images of the radiation from the compressed core that are integrated over 80 ps and are separated by 65 ps. Predicted GXI images are calculated with the LANL post-processing code TDG from the LASNEX results. The comparison of the TDG images with the measured GXI images over a range of laser pointing and hohlraum lengths indicate the amount of beam bending.

Another method of studying the beam bending is by observation of the positions of hot spots in the hohlraum. Thin-walled hohlraums, where the gold wall is only 2 μ m thick, allow energetic x rays from hot spots to penetrate the wall and be observed. GXI images can observe the shapes and positions of emission spots at various times. The emission spots are also calculated with LASNEX and TDG, which are then compared with observed GXI images. Both calculated and observed images are processed identically with the IDL visualization software and the LLIRL program. The experimental results are quantitatively compared with calculations. This comparison provides a time-dependent test of LASNEX calculations, while implosion symmetry is time-integrated.

2. Calculation Method

In these calculations, the original LASNEX generator decks were obtained [8] for simulations of symmetry experiments without KPP smoothing. These decks were then modified in several ways. More group structure was added in the regions of the gold M-bands [9] to better model the leakage of few keV photons, particularly important for thin-walled hohlraums, and to better model the recorded GXI image calculated by TDG. New laser beam profiles to represent the KPP-smoothed beams were devised in consultation with scientists at LLNL. Changes were made to gas densities, hohlraum geometries, EOS, and chemical composition of window material after discussions with many people on the LANL symmetry team. For thin-walled hohlraums,

Nova Pulse Shape 22



Figure 1. Nova laser power versus time; Pulse Shape 22.

the zoning was modified to include a thick epoxy layer outside of a 2 μ m gold case with the same inner surface position as in the thick-wall hohlraums. Finally, to better resolve the hot spot emission images, finer zoning along the hohlraum wall was used in some of the thin-walled hohlraum calculations. In all of these LASNEX runs, extensive re-zoning of the Lagrangian mesh is required; the flow of plasma toward the Laser Entrance Hole (LEH) leads to shear and extreme distortion of the mesh near the end of the LEH.

In these experiments, Nova laser intensity Pulse Shape 22, shown in Figure 1,was used. Pulse Shape 22 includes an initial foot or pre-pulse and a main pulse. The foot pulse has a peak laser power for all 10 Nova beams of about 7.5 TW. The main pulse reaches its peak of 18 TW about 1.5 ns after the peak of the foot.

3. Laser Profiles

The focus of Nova beams is quite different with KPP smoothing than without. Two different profiles were used in these calculations to test the sensitivity of the implosion symmetry

to the focal spot shape. The position of the focal spot has also been varied. Traditionally, the beams have been focused to a spot 1 mm in front of the plane of the LEH. The KPP focus is wider, so focus at the LEH plane is also considered.

The laser beam profile models in LASNEX have been tested by running the code of 1 cycle and recording the laser intensity profiles at the window and on the inside surface of the case. To avoid refraction of the beam, the mass density of the window and gas are set to a very low value. To give good statistics 1000 laser rays were used.

The recorded profiles are shown in Figures 2 and 3. At focus, the KPP laser beam profile is approximately constant out to 0.3 mm from the beam axis, where it begins to fall and effectively vanishes 0.5 mm from the axis. At the inner surface of the case, the effect of the focal spot position is seen in Figure 3. By focusing KPP smoothed laser beam at the LEH, the intensity profile becomes more peaked and narrower on the case because there is less distance for the beam to expand when the focus is at the LEH. This also leads to a skewing of the intensity when the beam is focused at the LEH. The higher intensity could lead to higher leakage of M-band photons in the thin-walled hohlraums.

4. Pointing Scan

A series of LASNEX calculations have been performed to study laser pointing, hohlraum geometry, hohlraum fill gas and laser smoothing effects on hohlraum drive symmetry. The results are summarized in Table 1 and Figures 4. In Figures 4, Nova experiments without KPP smoothing and with gas-filled and vacuum hohlraums are compared with LASNEX simulation results. The distortion, a/b, is the ratio of the length of the imploded core image in the direction transverse to the hohlraum axis, a, to the length along the hohlraum axis, b. When a/b > 1, the imploded core is flattened along the hohlraum axis and resembles a disk or "pancake". When a/b < 1, the core is elongated along the hohlraum axis and resembles a "sausage". When a/b = 1, the implosion is symmetric. All experiments used a 270 μ m outer radius capsule with a 50 atmosphere deuterium core gas seeded with argon. The implosion of these capsules is dependent on the radiation symmetry. In gas-filled experiments, the hohlraum is filled with 1 atmosphere of methane at room temperature and the laser entrance holes are covered with 35 μ m thick polyimid windows. The vacuum hohlraums have no windows. Some of the calculations were not run to peak implosion as they were intended to examine the hot spot shapes and positions.

The results of these simulations show that the implosion symmetry is not greatly sensitive to the beam profile or focusing. The results of the earlier experiments with unsmoothed are slightly more sausage than the simulations presented here. The reasons for this are not yet known. The vacuum calculation, KPPV2, is close to the gas-filled calculation, KPPG3, which has a similar distortion to the vacuum experiment. In fact, the vacuum experiments generally agree with all of the gas simulations. If beam bending is reduced in the KPP experiments, the results will be closer to the calculations than the data shown here. The one calculation that does not agree with the others is the thin-walled gas-filled run, KPPG15, which is more pancake that its thick-walled equivalent, KPPG10.

5. Thick Walls Versus Thin Walls

As mentioned above, the one thin-walled calculation that has been completed is more pancake than the exact same calculation for a thick wall. The thin-wall calculation has 2 μ m

Laser Intensity at Target Window



Figure 2. Laser beam profiles at outer edge of window for KPP. Beams focused at LEH and 1 mm before LEH are compared with unsmoothed beam.



Laser Intensity at Inner Wall

Figure 3. Laser beam profiles at inner edge of case for KPP. Beams focused at LEH and 1 mm before LEH are compared with unsmoothed beam.

| Hohlraum Length (μ m) | 2100 | 2300 | 2500 | 2700 |
|--|---------------------|--------------------|----------------------|---------------------|
| Pointing (μm) | 1025 | 1125 | 1225 | 1325 |
| vacuum, KPP, focus at LEH, thin-wall | | KPPV1 a/b=0.367 | KPPV2 a/b=1.094 | |
| gas, KPP, focus 1 mm before LEH, thick-wall | KPPG1 a/b=0.351 | KPPG2 a/b=0604 | KPPG3 a/b=1.152 | KPPG4 a/b=2.136 |
| gas, KPP, focus at LEH, thick-wall | KPPG10 a/b=0.343 | KPPG11 a/b=0673 | | KPPG13 a/b=2.126 |
| gas, KPP, focus at LEH, thin-wall | KPPG15 a/b=0.429 | | | |
| gas, KPP, focus at LEH, thick-wall, fine zoning, minimal glint | | | KPPG42 spots only | |
| gas, KPP, focus at LEH, thin-wall, fine zoning, minimal glint | | | KPPG47 spots only | |

Table 1. Calculated distortions for KPP Nova experiments.



Figure 4. Calculated distortions for KPP gas-filled and vacuum Nova experiments compared with unsmoothed Nova experiments.

| | Nova | LASNEX |
|---------------------------|-------------------------------|-------------------------------|
| Absorb Laser Energy (kJ) | $23.8 - 27.7^*$ | 26.3 |
| Laser Smoothing | KPP | KPP |
| Pulse Shape | $\mathrm{PS22}\pm2.5~\%$ | PS22 |
| Laser Focus | at LEH | at LEH |
| Hohlraum Length | \pm 40 $\mu {\rm m}$ | Exact |
| Capsule OD (μm) | 538 - 560 | 540 |
| Capsule Gas | $50~\mathrm{atm}~\mathrm{DD}$ | $50~\mathrm{atm}~\mathrm{DD}$ |
| | +.0013 Ar | +.0013 Ar |
| * 6% lost to SRS and SBS. | | |

Table 2. Parameters for Nova experiments and LASNEX runs.

of gold, backed by 80 μ m of epoxy. Thin-walled hohlraums allow the observer to simultaneously observe the motion of the hot spots, by viewing leaked gold M-band radiation, and implosion symmetry. But if the leakage affects the symmetry, then experiments must be designed with that in mind.

The peak temperature of the drive radiation is reduced by a few eV meaning there is some late time energy loss. This can be understood by studying the Rosseland mean-free-path late in time in the laser hot spot. The gold cases in thin-wall hohlraums have a much reduced opacity late in the laser pulse. The effect is more subtle than radiation burn-through, because the leakage of M-band photons occurs throughout. A comparison of the gold motion at beam laser power can be seen in Figures 5 and 6. The are perhaps some minor differences in the gold around the LEH, but there are no large differences.

6. Experiments

Experiments with KPP-smoothed beams were performed in the spring and summer of 1997 on the Nova laser [1, 2]. Experiments were performed for gas-filled and vacuum hohlraums and for a range of pointings. In these experiments, GXI images were observed for both the imploded images and the laser hot spots. Initially, mis-alignments in the laser pointing were observed that required correction. Iterations in the pointing led to a pointing asymmetry, where the beams were systematically shifted as much as 70 μ m in the same direction along the hohlraum axis. This may have led to an observed first mode asymmetry in the implosions. Implosion distortions were calculated as the amplitude of the p=2 mode in the measured implosion asymmetry. These measured asymmetries are compared with LASNEX calculations in the next section.

6.1. Results

All of the experiments were performed with thin-walled hohlraums, which allowed the measurement of energetic x-ray emission from laser hot spots. These x rays were observed with a GXI. The images have been processed and stored electronically. Examples are show in Figures 7 and 8 for a gas-filled and vacuum hohlraum. For comparison, an image from



Figure 5. Lagrangian mesh of thick-walled gas-filled hohlraum at 1.83 ns. Rays of laser beams are seen depositing their energy in the gold blow-off plasma (red).



Figure 6. Lagrangian mesh of thin-walled gas-filled hohlraum at 1.83 ns. Rays of laser beams are seen depositing their energy in the gold blow-off plasma (red).

$(10) \text{ for } 0.5 \\ -0.5 \\ -1.5 \\ -1.0 \\ -$

Figure 7. Nova GXI images for a gas-filled hohlraum irradiated with KPP-smoothed lasers, with a laser pointing of 1225 μ m. The image was recorded over a 80 ps period centered at 1830 ps.

an earlier gas-filled hohlraum experiment with unsmoothed beams is shown in Figure 9. For comparison, LASNEX/TDG simulations of KPP smoothed gas-filled and vacuum experiments are shown in Figures 10 and 11. Qualitatively, one can see for the vacuum example that the experimental image (in Figure 8) and the LASNEX/TDG image at the same time (Figure 11) are similar. Both include wings of emission extending toward the hohlraum center that may be due to emission from the stagnation between the expanding capsule plasma and the gold blow-off from the case. The experimental and calculated images for a gas-filled experiment (Figures 7 and 10) are not qualitatively similar; the LASNEX/TDG prediction has stagnation emission wings while the experiment does not. In the next section, this difference will be explored quantitatively.

6.2. Analysis Method

In order to quantitatively compare the Nova data, like that shown in Figures 7, 8 and 9 and the LASNEX/TDG results (Figures 10 and 11), all are processed in the same manner. The LLIRL scripts for the IDL commercial visualization software have been used to provide wide lineouts of the GXI images. First, a "wedge" transform is applied to the raw experimental images to remove the effect of variation in the gold photocathode voltage in the GXI. This is not required for the calculations. The KPP experiments all use a P11 special McPigs wedge transform. The LASNEX/TDG results are obtained from the SUNIDL file generated by TDG, which must be converted to an unformatted file by a small utility program before it can be read by IDL. From this point on, both experimental and calculated results are treated the same. LLIRL scripts product wide line-outs of all images, where the GXI exposure is integrated across the width of the hohlraum. The line-outs from experiments and calculations are then stored and presented graphically.



Figure 8. Nova GXI images for a vacuum hohlraum irradiated with KPP-smoothed lasers, with a laser pointing of 1225 μ m. The image was recorded over a 80 ps period centered at 1830 ps.



Figure 9. Nova GXI images for a gas-filled hohlraum irradiated with unsmoothed lasers, with a laser pointing of 1075 μ m. The image was recorded over a 80 ps period centered at 1830 ps.



Figure 10. LASNEX/TDG GXI images for a gas-filled hohlraum irradiated with KPP-smoothed lasers, with a laser pointing of 1225 μ m. The image was recorded over a 80 ps period centered at 1830 ps.



Figure 11. LASNEX/TDG GXI images for a vacuum hohlraum irradiated with KPP-smoothed lasers, with a laser pointing of 1225 μ m. The image was recorded over a 80 ps period centered at 1830 ps.

7. Comparisons of LASNEX Against KPP and Unsmoothed Experiments

7.1. Implosion Distortion

The smoothing of Nova laser beams with KPP plates has greatly improved the agreement between LASNEX predictions and experiments for gas-filled hohlraums. The experimental parameters and assumptions in the LASNEX calculations are compared in Table 2. The assumed absorbed energy is within the range measured in the experiments. There is some experimental variation in the laser pulse shape and in the target geometries. The experimental and calculated distortions are compared in Figure 12. In this plot the distortions for un-smoothed and KPP-smoothed experiments are compared with LASNEX simulations. For un-smoothed beams there was a "shift" between calculated and experimental values of about 150 μ m, meaning LASNEX simulations would agree with gas-filled hohlraum experiments if the laser pointing in the simulations were moved inward by 150 μ m. With the KPP smoothing in place, there is a "residual" shift of 35 μ m. The source of the residual shift can be differences between the experiment and LASNEX modelling in any or all of the following:

- laser beam deflection or self-focusing due to ponderomotive forces.
- atomic physics of gold plasma.
- collision between expanding ablator plasma and gold plasma from case.
- laser reflection from critical surface.
- laser deposition in gold plasma.

7.2. Laser Hot Spots

Laser hot spots on the walls of hohlraums are the source of drive radiation. The radiation emitted from these hot spots is more intense (higher radiation temperature) than the parts of the case that do not get directly illuminated by the laser beams or of course the laser entrance holes. Therefore the shapes and positions of laser hot spots must be correctly calculated by LASNEX for it to properly predict the drive symmetry. Because the hohlraums in these experiments have thin walls the spot emission can be observed from outside the case. The hot spot emission images obtained in experiments have been compared with images calculated and with the method described above.

In Figure 13, broad line-outs from an experiment with a gas-filled hohlraum and a laser pointing of 1225 μ m are shown at several different times. Also plotted are line-outs from a LASNEX simulation with TDG post-processing at some of the same times. Early in time (260 ps), one can see that the calculated hot spot profile is broader and shifted outward toward the LEH. At later times (760 ps, 1330 ps, 1760 ps, and 1830 ps), the calculated profiles remain broader, but they are shifted more inward (away from the LEH) relative to the experimentally measured profiles. The relative shifts become larger as time progresses.

In Figure 14, broad line-outs from an experiment with a vacuum hohlraum are shown. As for the gas-filled experiment, LASNEX/TDG line-outs are also shown. For the most part, the agreement here between calculated and experimental profiles is good. The widths and centroids of the hot spots are similar at all times. Since the same laser profile was used in vacuum and gas-filled calculations, these vacuum results give confidence that the discrepancy between the laser



Figure 12. Comparison of implosion distortions for vacuum and gas-filled hohlraum irradiated with KPP smoothed lasers. Nova measurements are compared with LASNEX simulations.

hot spot profiles for gas-filled hohlraums is due to some physical effect and not poor definition of the lasers in the simulations.

Similarly, in Figure 15, line-outs for an unsmoothed Nova gas-filled hohlraum experiment are shown and compared with the same LASNEX simulation as in Figure 13. The comparison has a minor flaw because the laser focus is 1 mm before the LEH in the unsmoothed experiments, while the laser focus is at the LEH in the smoothed experiments and simulations. Also, there were no thin-walled gas-filled experiments done for unsmoothed beams at a pointing of 1225 μ m. To compare the unsmoothed experiments with a pointing of 1075 μ m with a smoothed simulation at 1225 μ m, the calculated profiles are shifted inward by 150 μ m, so the LEH's are aligned. If the effects of the capsules on the hot spots are not large, this should not induce significant errors. One sees here that the unsmoothed beams lead to a large shift outward in the hot spot positions. In Figure 16, the hot spot profiles are shown for smoothed and unsmoothed gas-filled experiments and a smoothed LASNEX simulation at 1830 ps. Here, the unsmoothed experimental profile is shifted by 150 μ m, so the LEH's are aligned. One clearly sees that the shift in centroids is much worse when the beam is unsmoothed, showing the improvement due to KPP plates.

The calculated and experimentally measured hot spot shapes and positions can be compared more quantitatively by calculating the centroid positions,

$$Z_{centroid} = \frac{\int_0^{Z_{LEH}} I(z') \, z' \, dz'}{\int_0^{Z_{LEH}} I(z') \, dz'} \,, \tag{7.1}$$

and the hot spot widths,

$$\Delta x = \left(\frac{\int_0^{Z_{LEH}} I(z') \left(z' - Z_{centroid}\right)^2 dz'}{\int_0^{Z_{LEH}} I(z') dz'}\right)^{1/2} .$$
(7.2)

Using the line-outs shown in Figures 13 and 14 the centroids and spot widths have been calculated as functions of time for gas-filled and vacuum hohlraums. The results are shown in Figures 17 through 20. In Figure 17, one sees that the centroids for gas-filled move outward toward the LEH. The motion predicted by LASNEX is less than that measured in Nova experiments, though the positions remain close enough that the predicted and measured implosion symmetry is close. A similar situation for centroids for vacuum hohlraums is shown in Figure 18, where the predicted motion is less than the experimental values but once again the difference is not great enough to change the implosion symmetry much. The spot widths for gas-filled hohlraums, Figure 19 show a major difference between LASNEX predictions and Nova measurements. Except for one data point, the LASNEX predictions are consistantly 50% higher than the measured values. For vacuum hohlraums, Figure 20, the spot widths are in good agreement. This is an indication that the laser profiles used in LASNEX are consistant with Nova with KPP smoothing. The hot spot broadening in gas-filled hohlraum simulations has some other source.

7.3. Neutron Yields

The neutron yields predicted by LASNEX are higher than those measured in the Nova experiments. The neutron yields are plotted for all KPP-smoothed implosion experiments and LASNEX simulations against laser pointing in Figure 21. For vacuum hohlraums, the maximum ratio of measured yield over calculated yield (YOC) is 0.8. For gas-filled the maximum YOC is 0.2. The neutron bang time measurements have a very large spread and have unphysically low values. Until the discrepancy in the bang time data is better understood, they are of little use.



Figure 13. Broad line-outs of GXI images for gas-filled hohlraums irradiated with KPP smoothed lasers, with a laser pointing of 1225 μ m. Nova measurements are compared with LASNEX simulations at various times.



Figure 14. Broad line-outs of GXI images for vacuum hohlraums irradiated with KPP smoothed lasers, with a laser pointing of 1225 μ m. Nova measurements are compared with LASNEX simulations at various times.



Figure 15. Broad line-outs of GXI images for gas-filled hohlraums irradiated with unsmoothed lasers, with a laser pointing of 1075 μ m. Line-outs correspond to the images in Figure 9.

GXI Exposure Line-out



Figure 16. Broad line-outs of GXI images for gas-filled hohlraums illuminated with smoothed and unsmoothed Nova laser beams and calculated with LASNEX for a smoothed beam. The smoothed beams have a laser pointing of 1225 μ m, while the unsmoothed experiment was for a laser pointing of 1075 μ m. The unsmoothed beam curve has been shifted so the LEH positions on all curves coincide.



Figure 17. Nova measurements and LASNEX simulations of centroid positions for laser hot spots in gas-filled hohlraums.



Figure 18. Nova measurements and LASNEX simulations of centroid positions for laser hot spots in vacuum hohlraums.



Figure 19. Nova measurements and LASNEX simulations of laser hot spot widths in gas-filled hohlraums.



Figure 20. Nova measurements and LASNEX simulations of laser hot spot widths in vacuum hohlraums.



Nova and Lasnex Neutron Yields

Figure 21. Comparison of neutron yields from Nova experiments and LASNEX simulations for gas-filled and vacuum hohlraums with KPP-smoothed laser beams.

8. Discussion

8.1. Laser Physics

The shape of the laser hot spot may be explained by ponderomotive bending of the laser beam or by self-focusing. To study this possibility, we have used Rose's formalism to estimate the strength of these effects. In this approach, the strength of the effect is measured with a figure of merit:

$$FOM = 0.4F^2 (\frac{\lambda}{1 \ \mu \text{m}})^2 (\frac{I_l}{1 \ \text{PW/cm}^2}) (\frac{n_e}{n_{crit}}) (\frac{1 \ \text{keV}}{T_e}) .$$
(8.3)

Bending of the beam would occur when the figure of merit is high and the flow of plasma transverse to the direction of the laser beam is high. Using the LASNEX calculations presented in this paper, we have calculated the figure of merit along a typical laser ray in a gas-filled hohlraum simulation. We have also determined the transverse Mach number of the plasma along the same ray. The results are shown in Figure 22 for Nova parameters (F=4.3, $\lambda = 0.35 \ \mu m$). The positions along the laser ray where the beam crosses the end of the laser entrance hole and the critical surface



Figure 22. Figure of merit for ponderomotive beam deflection and transverse Mach number from a LASNEX calculation for a gas-filled hohlraum with 1225 μ m pointing and Nova laser conditions.

are shown as well. The figure of merit has a significant level beginning just inside the LEH, falls, and then reaches its maximum at the critical surface. The transverse Mach number is very small outside the LEH because the hohlraum end cap impedes axial plasma flow in that region. Since beam deflection occurs only when the figure of merit and Mach number are significant, there is only the possibility of beam bending in the region just inside the LEH. Outside the LEH there is the possibility of self-focusing. The figure of merit reaches a maximum of about 0.05 and extends over a region of the ray path of about 1 mm. This analysis shows that ponderomotive effects may still be present, enough to cause changes to the laser hot spot shape that are not accounted for in LASNEX. Certainly more extensive theoretical analysis is required to resolve this issue.

8.2. Stagnation

Stagnation of the expanding capsule ablator and hohlraum case plasmas may lead to emission that is not accounted for in LASNEX [10] [11] [12] [13] [14]. The electron temperature

| | T_e | \mathbf{n}_i | \mathbf{Z}_i | \mathbf{Z}_j | $\lambda_{i,j}$ | $\Delta \mathbf{x}$ | $\lambda_{i,j}/\Delta \; \mathrm{x}$ |
|---------------------|-------|----------------------|----------------|----------------|----------------------|---------------------|--------------------------------------|
| | (keV) | (cm^{-3}) | | | (cm) | (cm) | |
| | | | | | | | |
| Vacuum hohlraum | 2.25 | 6.3×10^{20} | 74 | 6 | 0.0009 | 0.002 | 0.45 |
| | 2.25 | 6.3×10^{20} | 74 | 1 | 0.0054 | 0.002 | 2.7 |
| | 2.25 | 6.3×10^{20} | 74 | 74 | 7.3×10^{-5} | 0.002 | 0.037 |
| | 2.25 | 6.3×10^{20} | 6 | 6 | 0.011 | 0.002 | 5.5 |
| | 2.25 | 6.3×10^{20} | 6 | 1 | 0.067 | 0.002 | 33 |
| | 2.25 | 6.3×10^{20} | 1 | 1 | 0.402 | 0.002 | 200 |
| | | | | | | | |
| Gas-filled hohlraum | 2.6 | $1.0{	imes}10^{21}$ | 77 | 6 | 0.00073 | .002 | 0.37 |
| | 2.6 | $1.0{	imes}10^{21}$ | 77 | 1 | 0.0044 | 0.002 | 2.2 |
| | 2.6 | 1.0×10^{21} | 77 | 77 | 5.7×10^{-5} | 0.002 | 0.029 |
| | 2.6 | $1.0{	imes}10^{21}$ | 6 | 6 | 0.0094 | 0.002 | 4.7 |
| | 2.6 | 1.0×10^{21} | 6 | 1 | 0.056 | 0.002 | 28 |
| | 2.6 | 1.0×10^{21} | 1 | 1 | 0.34 | 0.002 | 170 |

Table 3. Collisional mean-free-paths for hohlraum plasmas.

for gas-filled and vacuum hohlraums at stagnation from LASNEX are shown in Figures 23 and 24. The hydrodynamic motion of plasmas in LASNEX is calculated as a fluid, where plasmas do not interpenetrate. In reality, the plasma ions of species i and j have a finite collisional mean-free-path, as calculated by:

$$\lambda_{i,j} (\mathrm{cm}) = 0.5 \frac{T_e^2 (\mathrm{keV})}{n_i (10^{20} \mathrm{cm}^{-3}) Z_i Z_j} .$$
(8.4)

This equation is used with values from LASNEX simulations to get $\lambda_{i,j}$ in the stagnation region. In Table 3, the mean-free-paths of various ions are calculated and compared with the Lagrangian mesh size in LASNEX. This comparison has been performed for the conditions in the region where the expanding plasmas from the hohlraum case and the capsule collide. For example, the electron temperatures are taken from Figures 23 and 24 in a zone positioned at Z = -0.04 cm and R =0.03 cm for the vacuum and the gas-filled hohlraums. This position is actually inside the gold blow-off region in the vacuum hohlraum and in the methane fill gas in the gas-filled hohlraums and represents regions where the stagnation emission originates. The collisional mean-free-paths have been calculated for all combinations of gold, hydrogen and carbon ions. The carbon and hydrogen are fully ionized. The gold charge states have been determined from the LANL SESAME equation-of-state data base. The mean-free-paths for vacuum and gas-filled hohlraums are close to the same. For vacuum hohlraums, because the capsule plasma is directly interacting with the gold plasma the most important values are those for carbon on gold, gold on gold, and hydrogen on gold. In the gas-filed hohlraum the capsule collides with the methane fill gas, so hydrogen on hydrogen, carbon on carbon, and hydrogen on carbon are also important. In both cases, the hydrogen on gold mean-free-paths are about twice the Lagrangian zone size, the carbon on gold values are half the zone size, and for gold on gold the value is much smaller. The mean-free-paths for hydrogen on hydrogen, carbon on carbon, and hydrogen on carbon and much larger than the

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Figure 23. Electron temperature contours at stagnation for a gas-filled Nova hohlraum from LASNEX.

zone size. Because these low atomic number collisions are important to the gas-filled hohlraums and not the vacuum hohlraums, the LASNEX predictions for stagnation emission are more reliable for vacuum hohlraums. LASNEX will underpredict the size and overpredict the temperature of stagnation regions in gas-filled hohlraums, which is consistent with the disagreement in the laser hot spot observations and predictions. Predictions for vacuum hot spots should be and are in better agreement with Nova experiments. Colliding plasma experiments could isolate this effect and resolve this issue.

8.3. Neutron Yield

The calculated neutron yields show a greater discrepancy from measured results for gasfilled than for vacuum hohlraums. The gas-filled hohlraum experiments consistently have a much lower neutron yield than the LASNEX calculations predict. This may be due to either of two causes: drive temperature or drive symmetry. The laser energy absorbed in the hohlraum in the gas-filled experiments differs from the values used in the simulations [15]. The strength of the

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Figure 24. Electron temperature contours at stagnation for a vacuum Nova hohlraum from LASNEX.

implosion and the neutron yield would then be different. If the drive symmetry is affected by the differences in the laser spots, the calculated implosion symmetry may be better than in the experiments. There is still a shift in the pointing scan between calculations and experiment as shown in Figure 12. However, there is no shift seen in the neutron yield data (Figure 21); the calculated values are always well above those measured, which indicates that a pointing shift is probably not the cause.

9. Conclusions

In general, the smoothing of Nova laser light with KPP plates has substantially improved agreement between the LASNEX-calculated and measured drive symmetry. The measured implosion symmetries from KPP-smoothed beams in Figure 12 are in much better agreement than in the unsmoothed experiments in Figure 4.

Some disagreement remains in the shape of the laser hot spot, in the neutron yield and in the implosion symmetry. Though these disagreements are small compared to what was seen in the unsmoothed experiments, they need to be resolved for the high compression experiments planned on NIF. Other smoothing techniques could improve the laser beam quality and improve the agreement for drive symmetry. Some of these methods are in place on the Nike and Omega lasers and experiments at those facilities. The x-ray emission by the stagnation hot spots is probably the largest uncertainty in the LASNEX calculations for gas-filled hohlraums because of long collisional mean-free-paths. Colliding plasma experiments can further resolve this issue.

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