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TITLE: **PRELIMINARY ANALYYSIS OF CORE CAPSULE X-RAY SPECTROSCOPY AND IMAGE RESULTS FOR MEDIUM-TO-HIGH GROWTH FACTOR IMPLOSIONS**

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Preliminary Analysis of Core Capsule X-Ray Spectroscopy and Image Results for Medium-to-High Growth Factor Implosions

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Abstract. Recent capsule implosions using indirect drive on NOVA have probed core and near-core capsule T_e, ρ and mix structure using non-trivial pulse shapes (i.e. with a foot). These experiments have been performed using smooth as well as artificially roughened capsules. They have been performed using basically 3 non-trivial pulse-shapes with 3 different types of capsules with correspondingly different growth regimes for Rayleigh-Taylor instabilities. These experiments have employed time-dependent spectroscopy, gated imaging and <u>absolutely calibrated</u> time-integrated imaging as x-ray diagnostics. We compare nominal and "modified" 1D calculations with the spectroscopic and time-integrated image results. We find that the core T_e is less than calculated (not surprising), but also that the T_e of the inner pusher is substantially higher (at least 20%) than predicted, with perhaps some enhanced mix of the PVA layer towards the core.

INTRODUCTION

This paper compares experimental and theoretical results for x-ray diagnostics of imploding indirectly-driven ICF capsules. The 2 diagnostics which are analyzed in some detail here are a streaked, spatially integrated, crystal spectrometer and time-integrated, absolutely calibrated pinhole camera which simultaneously images thru 6 different filters.

In this discussion only 1 of the 6 filters will be analyzed : 4µm of silver. Silver has two important characteristics which merit emphasis. The first is that it will truncate transmission above an L edge of 3.351 kev. This allows the He and H α ($2 \rightarrow 1$) lines of Ar (which some of the capsules are doped with) thru, but not the β ($3 \rightarrow 1$) lines. More importantly, the active film material for the camera is AgBr, and, because of the same Ag L edge, the film undergoes sharp discontinuities and fluctuations in its response to photons above this energy. Below the edge the frequency dependence of the differential response is smooth and linear. In both diagnostics there are Ti patches and a Be blast shield which also need to be taken account of.

The theoretical analysis is done in two parts. In the first part, the code LASNEX is run in a 1D spherical mode, including any prescribed mix. Periodically, dumps from LASNEX are written which contain T_e, density, grid, and species fraction information. These dumps are then read by the postprocessor TDG/DCA[1]. This postprocessor does a number of things. The DCA portion calculates non-LTE opacities using a sophisticated detailed configuration accounting procedure (with essentially no approximations), and it calculates a radiation field self-consistently with these opacities and iterates the opacity/photon field calculations to some user specified degree of convergence. The TDG portion of the postprocessor calculates the x-ray image or spectra seen by a detector by doing various line-of-sight source/sink integrals.

Two different pulse shapes and capsules are considered here. One, known as PS 22, is approximately 2.2ns long and has a foot that produces a radiation temperature (T_r) of ~165ev in a NOVA standard holhraum. The peak of the pulse produces a T_r of between 200 and 215ev. The capsule has a pusher thickness of ~55μm of which the inner ~3.5μm are polystyrene (which may be doped with 1% Cl) and a adjacent layer of 2.5μm of PVA (CH_2O). The 2nd pulse shape (PS26) has a lower foot at ~145eV and a higher peak ~220eV. The total laser energy in the UV for the first pulse is ~25KJ→28KJ, and 32KJ→36KJ for the 2nd pulse shape. The 2nd capsule has a total pusher thickness of ~45μm, with 2 inner layers as for the 1st capsule, except that the dopant in the inner layer is Ti (.07%). Generally, the main outer layer of the 2nd capsule is doped with a significant amount (1→2%) of either Br or Ge. In the capsules considered here, the dopant was Br at ~1.8%. The first capsule experiences "moderate" growth of surface roughness-induced instabilities; the 2nd capsule experiences "high" growth--mostly due to the Br dopant (which reduces ablative and scale length stabilization) and the thinner shell (which increases in-flight aspect ratio)[2].

ANALYSIS

We shall first consider the spectra. Fig. 1a) is a typical spectra from a PS22 capsule near peak compression. The 4 major lines (from left to right) are Heα, Hα, Heβ and Hβ. There are two important points to note concerning the spectra. One is that the line intensities are increasing the higher the line energy (for the Heα, Hα, Heβ lines). This is unusual, and has been traced to two facts: the pusher has a decreasing attenuation with increasing photon frequency; and the β lines are abnormally strong because of n=2→3 collisonal excitation in the high density ($Ne \cong 10^{24}$) environment in the core[1]. The 2nd important point is that there is a non-zero continuum background. Fig. 1b) gives the result of a simulation in which the drive is reduced ~15% compared to the theoretically calculated hohlraum drive. Note that the line ratios are approximately correct, but that there is essentially no continuum background. It is known from the time-dependent data that the background turns on and off approximately in accord with the Ar lines, so the capsule is the source of the background. By looking (calculationally) lower down in photon energy, it was observed that such a continuum was present, but was essentially zero in the spectrometer window.

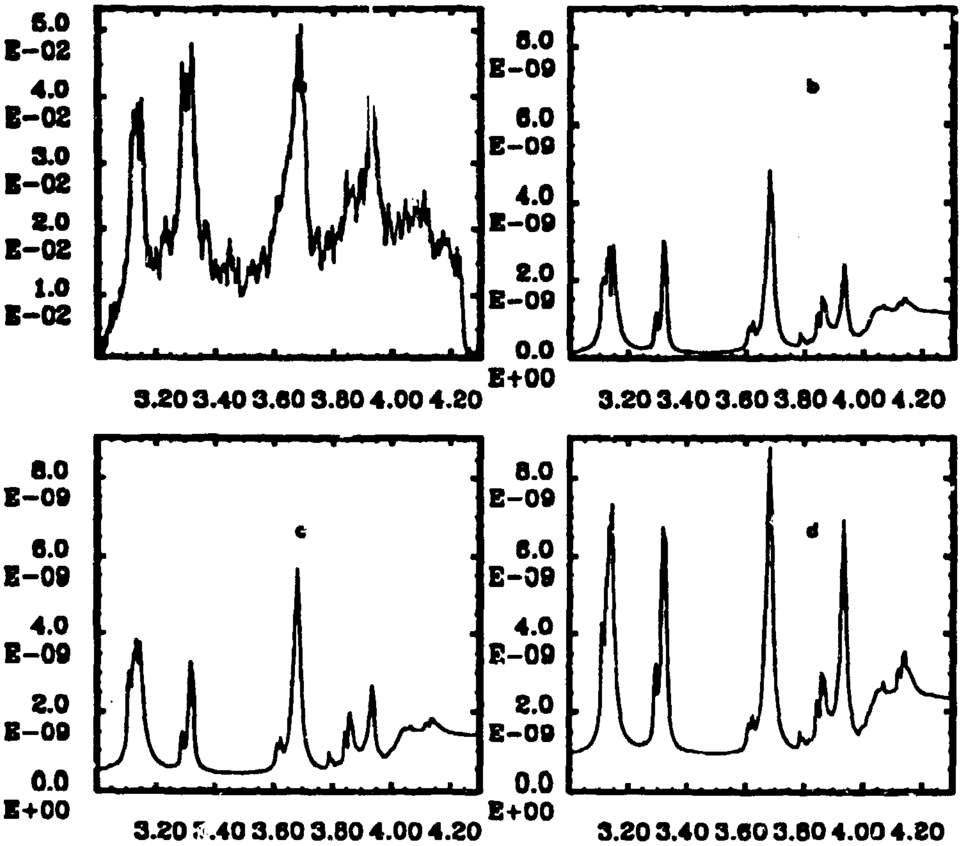

Figure 1. Core-pusher capsule spectra for PS22 pulse shape (X-axis units=kev, Y-axis units=arbitrary) a) Experiment b) Theory-no pusher T_e increase c) Theory-30% uniform pusher T_e increase d) Theory-50% ramped pusher T_e increase

Fig. 1c) gives the calculational result for the same case as in 1b), except the pusher T_e has been artificially enhanced by a multiplicative factor of 1.3. This gives substantially better agreement with Fig. 1a). Fig. 1d) gives the calculated result for a case where the T_e enhancement is ramped in space, being nominal at the center and far out in the pusher, and with a maximum enhancement of 50% at the inner PVA boundary.

Figures 2a), 2b), 2c) and 2d) are equivalent results for PS26. The spectrometer window in these shots is higher in energy than in the corresponding PS22 shots because it was desireable to detect the Heα line from the Ti dopant in the inner pusher (at ~4.75 kev). Here Fig. 2c) gives the results for a uniform 20% enhancement, while Fig. 2d) is for a uniform 30% enhancement. Note the

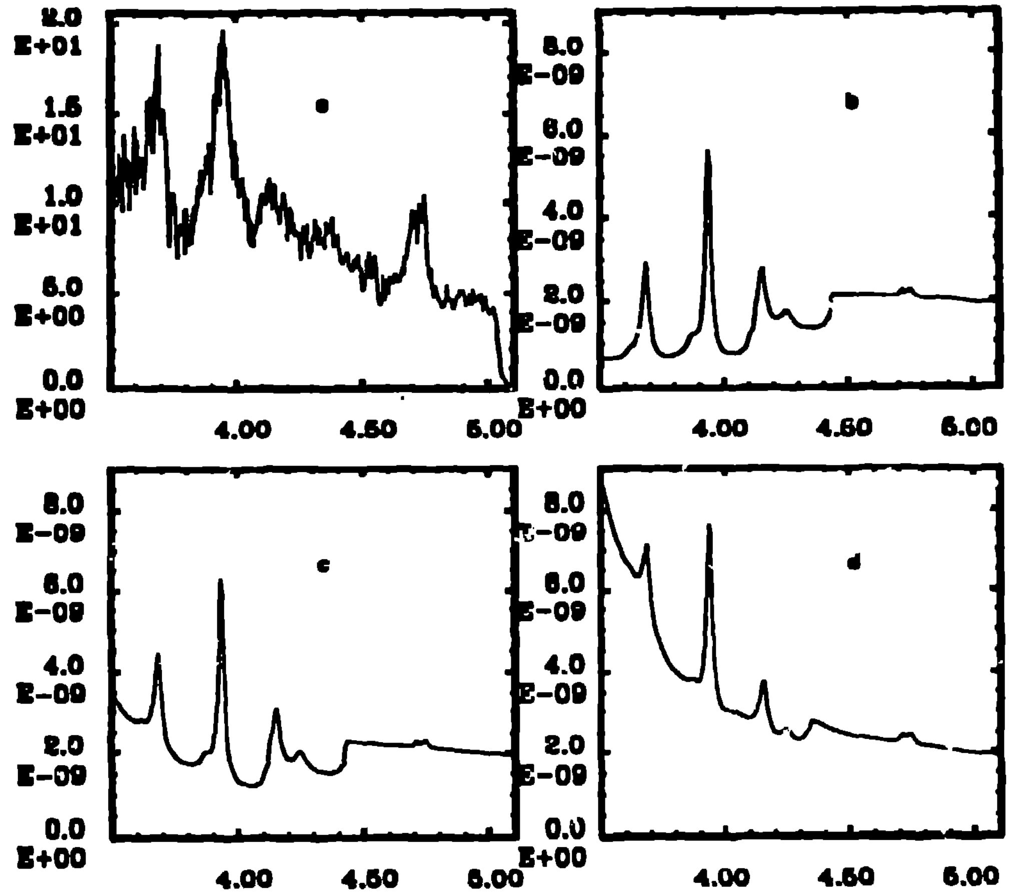

Figure 2. Core-pusher capsule spectra for PS26 pulse shape (X-axis units=keV, Y-axis units=arbitrary) a) Experiment b) Theory-no pusher T_e increase c) Theory-20% uniform pusher T_e increase d) Theory-30% uniform pusher T_e increase

experimental result appears to be bracketed by these 2 calculations. Note the same issues are present for the continuum background as in PS22, except that the background is now quite strong and has an obvious slope.

In order to better understand the nature of this effect, the image diagnostic results for PS22 were modeled. Table 1 gives results for total (time-and space-integrated) photon yield and 2 σ, where σ is the standard deviation of a gaussian fit to the spatial image. Two capsules are analyzed: a completely undoped capsule, and a capsule with Ar in the core. Both experimental and calculated results are given. The calculated results include an unmodified run as well as runs where the pusher T_e has been multiplied by a spatial-and time-dependent multiplier. In one such modified run, the multiplier was .8 on the central core T_e, 1.3 at the outer edge of the PVA layer, 1.0 far out in the pusher, with linear ramps between these points. This is a modest enhancement to the pusher T_e. From the results we can see there is large disagreement between unmodified theory and experiment for both photon yield (~100x) and width (~3x) for the undoped capsule. Modifying the T_e brings the undoped capsule characteristics into better agreement with experiment, but there are still substantial discrepancies. For the doped capsule the discrepancies are less severe for total photon yield (~6x), but are still as bad for the width (~3x). It should be noted that the calculations have been done using theoretically calculated hohlraum drives, and the measured drives are lower, especially for PS26. If the measured drives had been used, the reduction in core T_e needed to match data would have been less, but the increase in pusher T_e would have been higher. This effort to use measured drives in the calculations is currently ongoing.

TABLE I. Key results for image analysis (Ag filter)

	Experiment Pinhole camera		Theory LASNEX TDG/DCA	
	Yield (ergs)	Width (μm)	Yield (ergs)	Width (μm)
No Ar, no Cl	1.0^{-2}	44	9.5^{-5}	15
No Ar, no Cl, increased pusher T_e decreased center T_e	1.0^{-2}	44	4.9^{-4}	22
Ar, no Cl KDCA Ar fine photon bins	1.5^{-2}	36	2.2^{-3}	12
Ar, no Cl-DCA increased pusher T_e decreased center T_e	1.5^{-2}	36	2.7^{-3}	14

Another possibility for the enhanced emission is mix of the oxygen in the PVA layer in towards the core resulting in non-LTE free-bound recombination radiation. Preliminary analysis of this possibility suggests a maximum enhancement of 2x or 3x in photon yield from pre-peak compression mix for the undoped capsule. This is substantial but no-where near what is needed. Late time mix offers some possibility for somewhat more significant emission and is under study.

CONCLUSION

We conclude that there is substantial evidence from both the continuum background in the spectroscopy and from the photon yield and image width that the inner pusher is emitting more strongly than predicted. By zeroing the pusher absorption opacity, the possibility can be ruled out that the pusher has been partially breached and that the enhanced emission is core emission (this can enhance Ar lines but does not change the continuum background much). Mix of the PVA layer and subsequent emission of recombination radiation by the oxygen can probably only account for a small fraction of the peak compression emission. That leaves only enhanced pusher T_e as the source of the excess emission. There are, in-turn, two obvious sources of enhanced T_e: turbulent viscous heating; and non-local heat transport effects (e.g. Fokker-Planck). Both of these are under current investigation.

REFERENCES

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