HELIOS Benchmark Calculation:
Indirect-Drive ICF Implosion With In-Line Collisional-Radiative Modeling

INTRODUCTION

K-shell emission spectroscopy of mid-Z elements is an important tool for hot dense plasma diagnostics, allowing for inferring temperatures, densities, instability growth, and fuel-pusher mix[1,2,3]. Recently, a set of experiments at the OMEGA laser facility has been performed in order to infer plasma temperature and density distributions at the collapse of an ICF implosion by simultaneously recording time-resolved spectra and monochromatic images[4,5,6]. These experiments provide valuable information for benchmarking and validating radiation-hydrodynamics codes. In this memo, we present results from *HELIOS* simulations, with a particular emphasis on accurate accounting for atomic kinetics and radiation transport.

In the OMEGA indirect-drive experiments, thirty laser beams were used to deliver a total of 15 kJ of energy to the hohlraum, in a 1-ns square laser pulse. The beam pointing was chosen to achieve a high degree of radiation uniformity on the target surface. In order to calculate time-, and frequency-dependent radiation flux on the target surface, we utilize *VISRAD*[7], a 3-D view factor code which computes fluxes and radiation temperatures using characteristic laser beam profile parameters, hohlraum albedos and x-ray conversion coefficients. We estimate peak radiation temperature at the capsule surface to be ~190 eV, with small variations from the equatorial plane to the poles of the target.

The *VISRAD* radiation flux data is used to drive the *HELIOS* implosion calculation. The targets are 220 μm inner radius, plastic, micro-balloons with a 35 μm wall thickness, filled with 50 atm DD and 0.1 atm Ar. The *HELIOS* simulations were performed using the inline collisional-radiative model. Conventionally, radiation-hydrodynamics codes employ diffusion algorithms and LTE multi-group opacities to compute radiation transport in plasmas. For these systems, however, this approximation may not be valid since the plasma is not diffusive at all times and not necessarily in LTE[8]. It is known that, even in small quantities, Ar line radiation contributes significantly to plasma cooling[9]. In order to carefully quantify this effect, we use time-dependent atomic kinetics with multi-angle short-characteristics radiation transport inline within the hydrodynamics calculation. At every hydrodynamics time step, NLTE populations and the radiation field are computed and used to calculate plasma cooling and heating rates. This allows us to treat energy transport in the plasma with a high level of accuracy.

The argon atomic model includes ground and singly excited states up to $n=6$ for each ionization stage, since a vast variety of temperatures and densities is expected while the system goes from its initial state though implosion to the stagnation phase. Satellites to Lyα and Heα lines (with spectator electrons in $n=2$) are also considered, because they may affect K-shell emission and population distributions at stagnation[10]. Calculations include the effects of bound-bound, bound-free, and free-free contributions to the plasma emission and opacity. Atomic processes include electron collisional ionization, recombination, excitation, and deexcitation; spontaneous emission; radiative recombination; autoionization, electron capture, dielectronic recombination, photoionization and photoexcitation. Lineshapes include the effects of natural, Doppler and Stark broadening. All energy level structures, rates, and cross-sections are computed with the code *ATBASE*. *HELIOS* utilizes a two-temperature plasma model ($T_e \neq T_i$), and *SESAME* equations of state.

RESULTS

An accurate prediction of radiation drive flux is crucial for indirect-drive implosion simulations. Hohlraum dimensions and orientation, and laser parameters are based on experimental conditions[5]. *VISRAD* estimates the peak radiation temperature at the target surface to be ~ 190eV, which drops at the end of the laser pulse. *VISRAD* predictions are benchmarked against experimentally measured hohlraum temperatures for similar conditions[11]. Figure 1 illustrates Lagrangian zone boundary positions as a function of time, along with the radiation drive temperature for the 0.1 atm Ar filling pressure. The time of the peak plasma temperature, associated with the collapse of the main shock wave, agrees well with the experimentally measured peak neutron flux (1.5 – 1.6 ns with respect to the leading edge of the laser pulse). Peak compression occurs approximately 200 ps later.

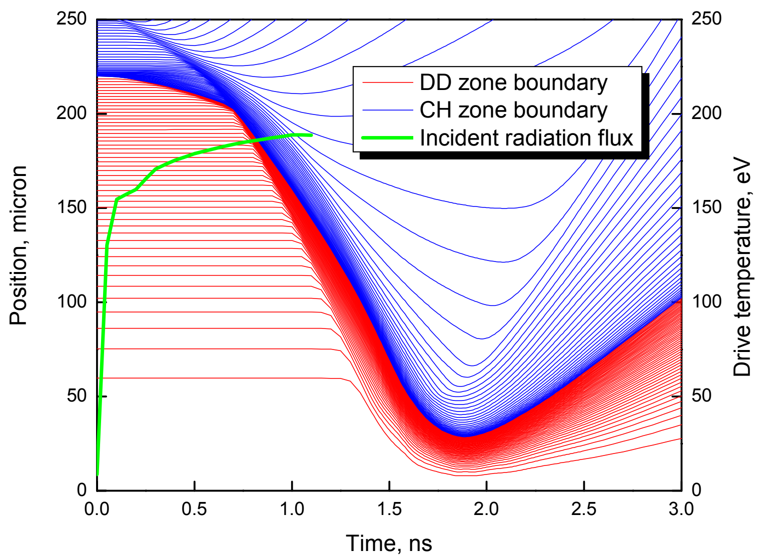

Figure 1. Radius-time diagram of implosion calculation driven with time-dependent radiation drive.

Temporal evolution of temperature and density is displayed in Figure 2. Computed plasma conditions agree well with the temperature and density distributions obtained from the analysis of experimental data. The temperature in the experiment peaks at 1000 eV at the center, and drops smoothly to 500 eV towards the core edge. The electron density stays at 1.2×10^{24} cm^{-3} rising sharply to 1.6×10^{24} cm^{-3} at the fuel-pusher interface. Calculated plasma conditions lie well within uncertainty intervals of the analysis. Experimental values for temperature and density gradients in the core were obtained using simultaneous fitting[12] of time-integrated Ar emission spectra and monochromatic images. Therefore, they represent the plasma distributions effectively averaged over the duration of Ar emission. The details of the experimental data analysis are currently being prepared for publication[13].

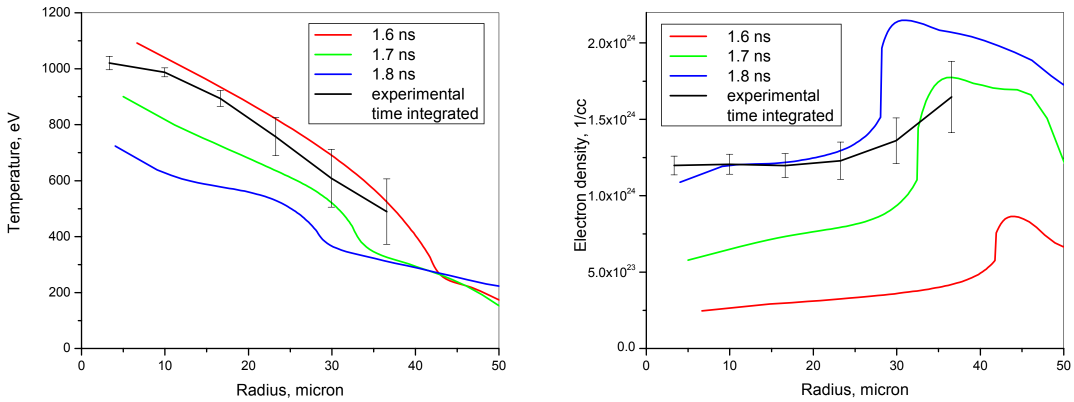

Figure 2. Imploding core electron temperature and density evolution.

Another important aspect of the calculations is the quality of radiative transfer. To this end, we compare the results of the simulations using time-dependent NLTE atomic kinetics and multi-angle short-characteristics radiation transport with the model where multi-group flux-limited diffusion is utilized (Figure 3). The calculations were performed for 0.1% Ar concentration. As the figure indicates, the diffusion approximation significantly overestimates the amount of cooling due to Ar line emission at the time of stagnation.

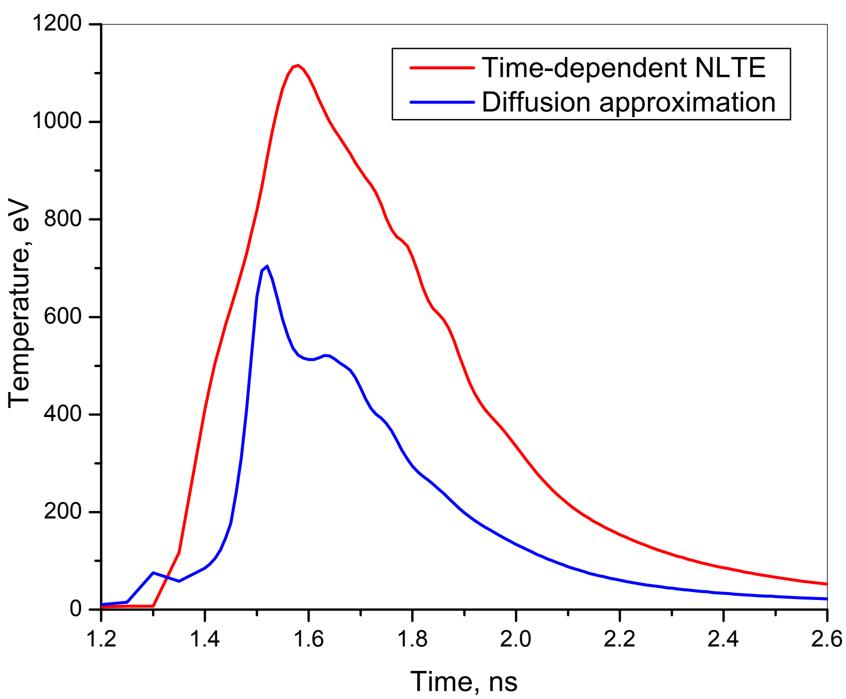

Figure 3. Peak electron temperatures for the calculations with atomic kinetics models.

CONCLUSIONS

The above *HELIOS* results exhibit good agreement with the temperature and density distributions determined from the OMEGA diagnostics, both in terms of absolute values and gradients. They also show that, at times near peak compression, NLTE atomic kinetics effects and radiative transfer modeling are extremely important in simulating the capsule implosion.

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