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Complex hydrodynamics in heated and shocked conditions

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ABSTRACT

In inertial confinement fusion double-shell designs, the inner shell experiences heating that can amplify non-uniformities and consequently enhance mixing, which degrades capsule performance. Recent OMEGA experiments study the time-dependent evolution of mix under heated and shocked conditions. In each experiment, a cylindrical Be tube was filled with a layered system of a BeCu disk and low-density CH foam. The BeCu disks were machined with a multi-mode perturbation representative of the target surface roughness present in ICF capsules. The targets were heated from one end using a hohlraum and subsequently shocked using direct-drive from the opposite end. X-ray radiography was used to quantitatively diagnose the transmission profiles of the disk/foam interface. We focus primarily on an assessment of the applicability of the radiation transport models available in the RAGE (Radiation Adaptive Grid Eulerian) hydrodynamics code. These include grey diffusion, several types of multi-group diffusion, and a new frequency-dependent source capability that addresses the NLTE nature of the laser energy deposition.

1. Introduction

In double-shell designs for Inertial Confinement Fusion (ICF), capsule performance can be degraded due to the heating experienced by the inner shell, which can modify non-uniformities and consequently affect mixing. The effect of this heating is poorly understood. In an effort to quantify this effect, experiments have been designed to study the time-dependent evolution of mix under heated and shocked conditions. Radiographic data of the expanding mix layer were collected and compared to the radiographs from simulations calculated with shot-specific geometries and drive conditions. Los Alamos National Laboratory's RAGE hydrodynamics code [1] was used for the modeling. The experiments, which evolved from the defect work of Lanier et al. [2], were fielded at the University of Rochester's Laboratory for Laser Energetics. A key part of the experimental design effort stemmed from the necessity of having diagnosable effects from mix. This experimental data provided the means by which to assess the predictive capability of both the radiation transport models available in RAGE and the BHR-2 turbulent mix model. This paper focuses primarily on an assessment of four radiation transport models available in RAGE and how well they perform in matching the experimental data.

2. Experiment

The experimental geometry, as seen in Fig. 1, allows heating and/or shocking of a cylindrical target. A 2.2 mm long and 600 μm diameter Be tube is filled with 60 mg/cc foam with a 100 μm thick BeCu disk placed at one end of the tube. A tin hohlraum is attached at the opposite end of the tube from the BeCu disk. The hohlraum provides the heating drive, due to laser energy deposition, which occurs over a 1 ns duration. The energy spectrum is NLTE, and consists of both high-energy radiation and lower-energy modes. A Be filter between the hohlraum and the Be tube is used to filter out the low-energy radiation. The remaining high-energy radiation moves very quickly through the foam, heating the BeCu disk, which is machined on one side with a rough multi-mode perturbation in order to seed the instability growth. The main contribution to the heating of the BeCu disk is tin M-shell emission in the spectral region from 250 to 2250 eV and tin L-shell emission from 3750 to 4750 eV. At the opposite end of the tube, a plastic ablator is used to accept a laser-driven shock, which is timed to occur over the same duration as the hohlraum laser drive. The resulting shock reaches the perturbed side of the BeCu disk interface after the high-energy radiation from the tin hohlraum has arrived. A foam pad is placed between the ablator and the BeCu disk, in order to act as a "shock-shaper" for flattening the shock before it reaches the back end of the disk.

Experiments were fielded in August 2008 and February 2009 to test a variety of heating and shocking combinations, as well as

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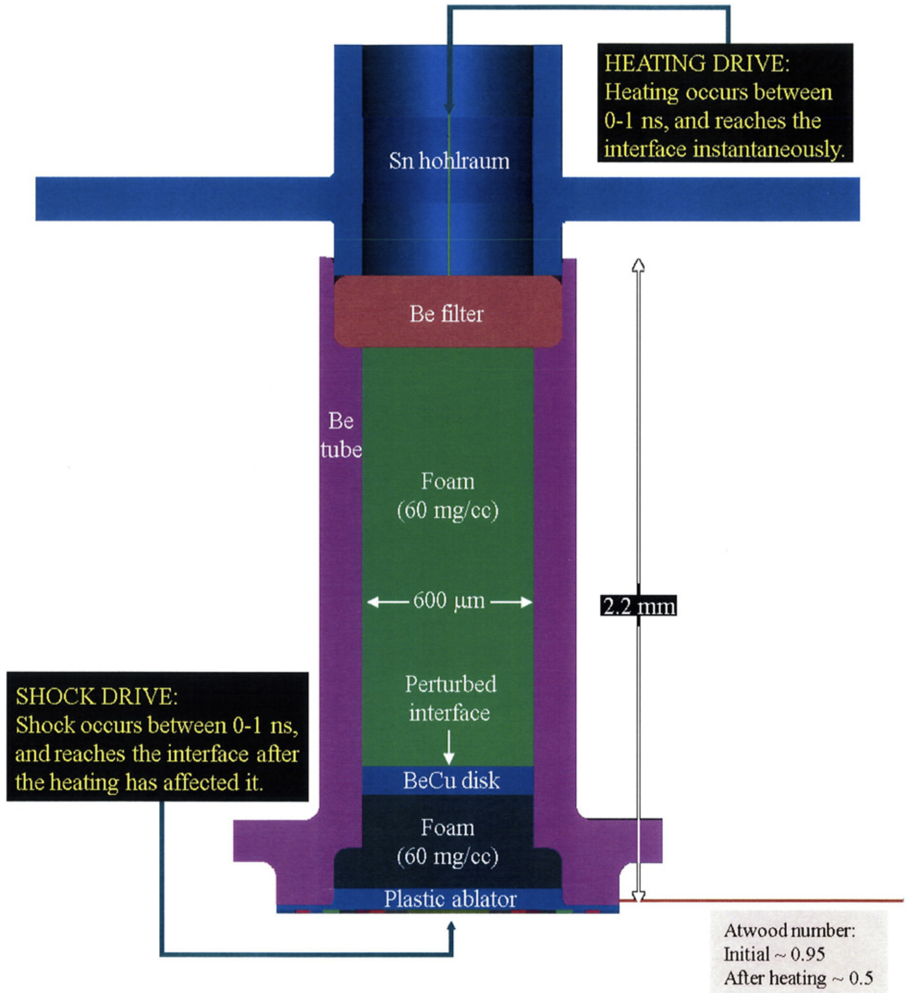

Fig. 1. Cross-section of the cylindrical target geometry used in the experiments. The hohlraum is driven between 0 and 1 ns, and the perturbed side of the BeCu interface experiences almost instantaneous heating.

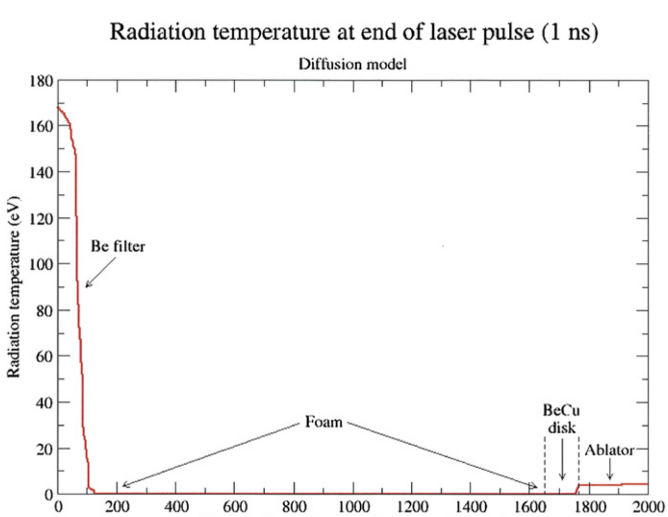

Fig. 2. Calculated radiation temperature as a function of distance from the tin hohlraum for the grey diffusion model.

various surface roughnesses machined onto the BeCu disk. The experimental regime was chosen such that turbulent mixing is anticipated.

3. Modeling

To ultimately compare modeling results to the experimental radiographs, it is vital to ensure consistency between the computational and experimental geometries. This is accomplished by building geometries for each specific shot, accounting for initial as-shot geometries in the simulation setup.

The RAGE radiation hydrodynamics code [1] was used to model these experiments. The BHR-2 mix model [3] was used to calculate the mixing which occurs at the interface between the foam and the BeCu disk. BHR-2 is a turbulent mix model based on the Reynolds (and Favre) Averaged Navier Stokes (RANS) equations in a way that seeks to accurately capture the effects of large density variations. A full description of the model can be found in Ref. [3].

RAGE has several options for radiation transport. For this experimental application, the simulations are quite sensitive to the radiation transport model, since the tin plasma from the hohlraum heating source is NLTE, and hence non-Planckian. In this paper, four different radiation transport models will be discussed: grey diffusion, multi-group diffusion, a multi-group analytic opacity model, and a frequency-dependent source model.