

Using HT and DT gamma rays to diagnose mix in Omega capsule implosions

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Abstract. Experimental evidence [1] indicates that shell material can be driven into the core of Omega capsule implosions on the same time scale as the initial convergent shock. It has been hypothesized that shock-generated temperatures at the fuel/shell interface in thin exploding pusher capsules diffusively drives shell material into the gas core between the time of shock passage and bang time. We propose a method to temporally resolve and observe the evolution of shell material into the capsule core as a function of fuel/shell interface temperature (which can be varied by varying the capsule shell thickness). Our proposed method uses a CD plastic capsule filled with 50/50 HT gas and diagnosed using gas Cherenkov detection (GCD) to temporally resolve both the HT “clean” and DT “mix” gamma ray burn histories. Simulations using Hydra [2] for an Omega CD-lined capsule with a sub-micron layer of the inside surface of the shell pre-mixed into a fraction of the gas region produce gamma reaction history profiles that are sensitive to the depth to which this material is mixed. An experiment to observe these differences as a function of capsule shell thickness is proposed to determine if interface mixing is consistent with thermal diffusion $\lambda_{ii} \sim T^2/Z^2\rho$ at the gas/shell interface. Since hydrodynamic mixing from shell perturbations, such as the mounting stalk and glue, could complicate these types of capsule-averaged temporal measurements, simulations including their effects also have been performed showing minimal perturbation of the hot spot geometry.

1. Introduction and background

Suggestive evidence for the detection of 19.8MeV gamma ray emission from the fusion of hydrogen (H) and tritium (T) was recently obtained from experiments on Omega [3] containing a 44.7/5.3/50 percentage mixture of H/D/T. Although the cross section for HT fusion is small, it can still be the dominant (>10 MeV) gamma reaction for capsules filled primarily with HT. Owing to the small branching ratio for DT fusion gamma rays (4×10^{-5}), calculations indicate that equal numbers of HT and DT gamma rays will be obtained in Omega implosions when approximately 1% of the HT fill gas is replaced by deuterium (D). This percentage of D is an order of magnitude greater than the D contamination level (0.1%) present in current 50/50 HT gas supplies for ICF experiments. Consequently, a 49.95/0.1/49.95 capsule gas fill should produce gamma reaction history (GRH) signals where HT- γ s outnumber DT- γ s by an order-of-magnitude or more. Further energy discrimination by gas Cherenkov detection (between the 19.8MeV HT- γ s and the ≤ 16.75 MeV DT- γ s) can increase the relative measurement signal levels to 30 or more.



The ability to measure both HT and DT gamma rays in ICF implosions provides an opportunity to observe the effects of varying distributions and amounts of shell mix on fusion burn in separated reactant experiments, where a CD-lined capsule is filled with HT gas (containing 0.1% contamination D). Here HT gamma rays will be produced by fusion in the clean gas, while DT gamma rays will primarily be produced only through the mixing of the CD shell with the HT gas. This concept has been assessed via simulation of the gamma ray time histories of such implosions using the radiation hydrodynamics code Hydra [2] for an Omega CD capsule where a sub-micron layer of the inside surface of the shell is pre-mixed into the outer half of the gas region. An example is shown in Figure 1 where one can see that the HT gamma signal rises first owing to clean HT fusion burn when the shock reaches the axis, followed by DT burn of the outgoing shock in the in-flowing CD/HT mix, and finally by both HT and DT fusion at full hot spot compression.

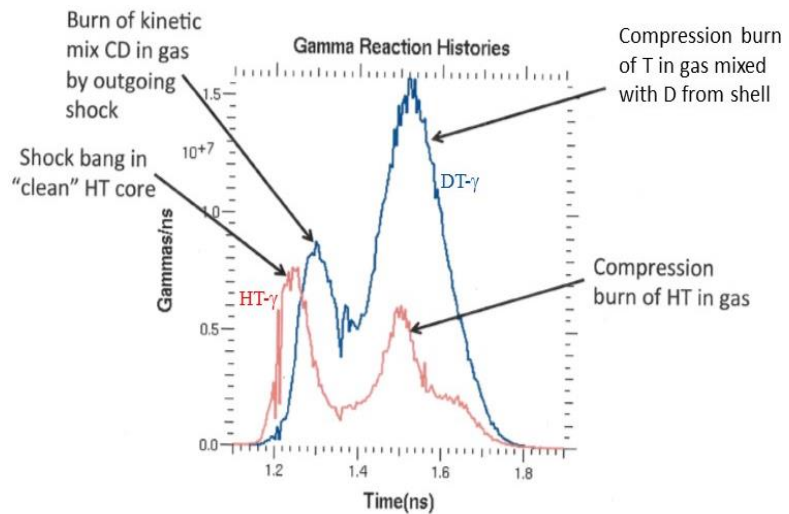


Figure 1 Gamma reaction histories for both HT (red) and DT (blue) gamma rays from a separated reactants capsule with 0.5 μm of CD pre-mixed into the outer half of the gas region.

2. Experiment definition

To probe how shell interface temperature (and its commensurate diffusion) affects early implosion mix, one must construct a capsule platform where the interface temperature can be varied. This can be done by varying the shell thickness. Figure 2 shows the time histories of the interface temperatures for both 9 μm and 15 μm CH capsules (driven by the Omega laser) simulated using Hydra. Here the interface temperature differs by a factor of two between the two capsule thicknesses. Using the standard scaling [4] for the ion mean free path, λ_{ii} , given by

$$\lambda_{ii} \propto T_i^2 / Z_i^2 \rho$$

where T_i is the ion temperature, Z_i is the ion ionization state and ρ is the ion density, we should expect a factor of 4 difference in the diffusion of shell material into the gas.

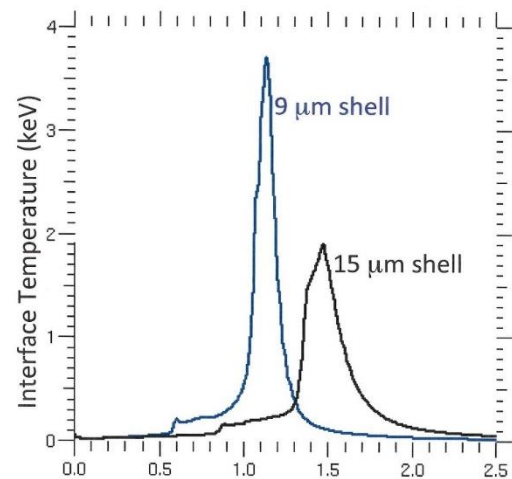


Figure 2 Temperature at the inside gas/shell interface for 1ns laser pulse Omega CH capsules.

3. Simulation design

Optimization of an experiment to use gamma reaction histories to characterize mix requires simulation of signal time histories for different levels of mix. Here we use Hydra for both 1D simulations (to assess gamma signal levels) and 2D simulations (to look at perturbations from mounting the capsules). Simulations assume an 870 μm x 15 μm plastic CD-lined CH capsule (preheated on inner half to 70eV to reduce compression) filled with 10 atmospheres of HT gas (including 0.1% D contamination) and driven by a 27kJ, 1 ns laser pulse (scaled by 0.6 to emulate the experimentally absorbed laser fraction).

3.1 1-D Hydra Particle Monte Carlo burn simulations with pre-mixed gas layers

Simulations were performed to assess the relative magnitudes of the HT and DT gamma ray signals for various amounts of shell pre-mix in the gas. For these calculations a 0.5 mm thick CD layer of the inner shell surface was assumed to atomically mix into the HT gas fill. The results of three simulations, each with different depths of pre-mix, are shown in Figure 3.

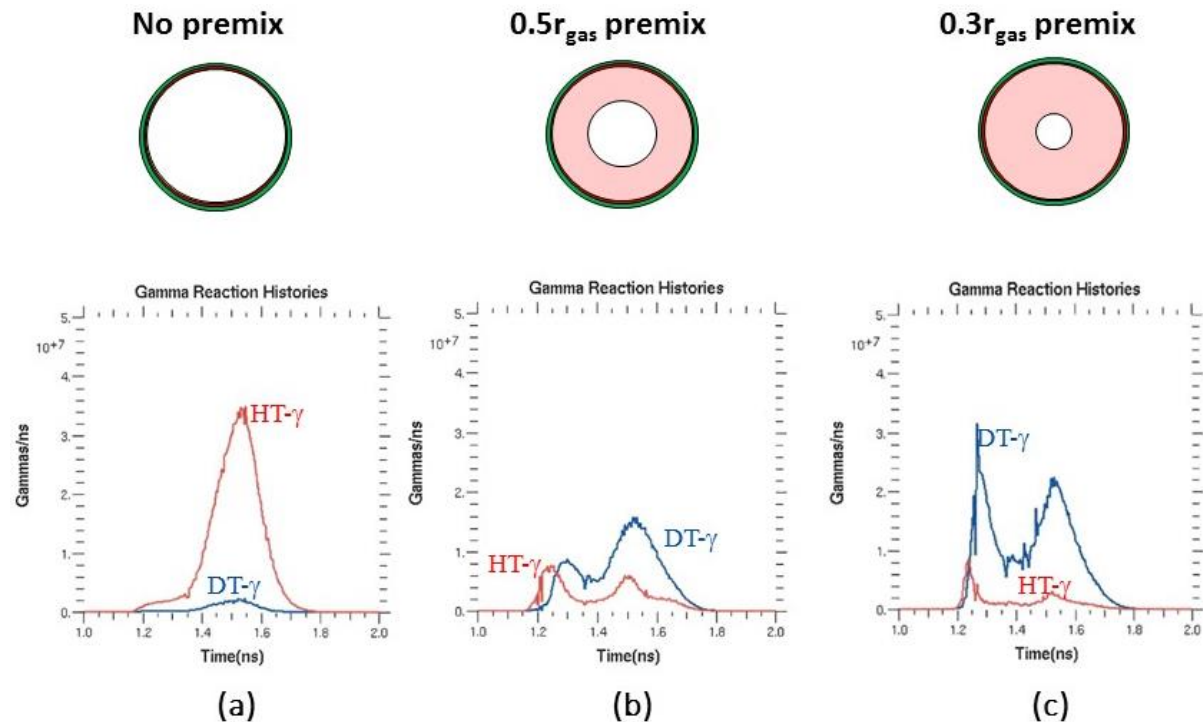


Figure 3 Gamma reaction history profiles for both HT (red) and DT (blue) gamma rays shown for a HT-filled CD capsule with (a) no CD pre-mix case, (b) CD shell pre-mixed half way to the core, and (c) CD pre-mixed 70% into the core.

Note that there are characteristic changes in the shape of the reaction time histories dependent on the variations of the pre-mixed material depth, making this a sensitive diagnostic for the mix conditions in the capsule during burn. A plot of the total HT- γ and DT- γ flux as a function of pre-mix depth is shown in Figure 4. Interestingly, both signal levels change inversely by an order-of-magnitude over the mix range. The DT- γ signal at 0% pre-mix is caused by the 0.1% D contamination in the HT gas fill. Reduction of the DT- γ flux increase with pre-mix depth could be achieved by either reducing the thickness of the CD layer on the inside of capsule, or by reducing the isotopic percentage of D in the CD layer, for example by having a layer that is 90% CH and 10 % CD. This would aid in constraining the dynamic range of the combined GRH signals.

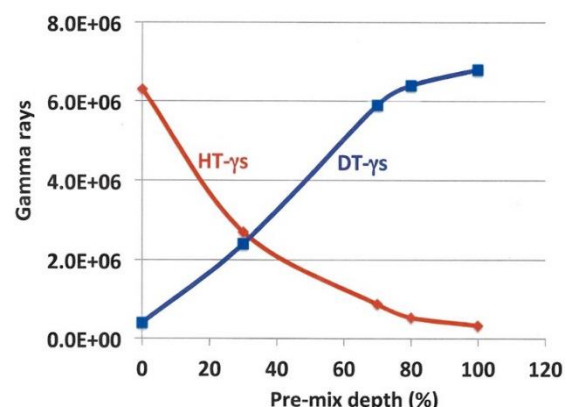


Figure 4 Plot of the variation in HT and DT gamma fluxes as a function of the pre-mix depth percentage.

3.2 Hydra 2-D simulations including stalk and glue perturbations

A potential issue affecting separated reactant capsule experiments is the effect of the mounting stalk and its glue on the implosion dynamics. Hydra 2D simulations of a plastic capsule (full 180°) were

performed using 0.2° angular resolution (chosen to obtain several angular zones in the stalk). The geometry is depicted in Figure 5(a) for the $15\ \mu\text{m}$ thick CH capsule driven by a 1ns, scaled 27kJ laser pulse. Simulations were performed for 4 cases: (1) no stalk nor glue, (2) stalk only, (3) stalk plus nominal $80\times 100\ \mu\text{m}$ glue fillet, and (4) stalk plus a double wide, $160\times 100\ \mu\text{m}$, glue fillet. Elongation of the hot spot in the direction of the stalk was observed at bang time, with more elongation seen as more glue was added. This can be observed in Figure 5(b) where the density of capsule at bang time (1.5ns) is shown for the nominal glue fillet case (where inner shell preheat of 70eV was used). Note that there is a P2 low-mode perturbation of the hot spot, but no significant jetting of material into the core is present. When the same simulation was run without preheat, Rayleigh-Taylor spike growth at the gas-shell interface and the beginnings of a stalk jet are seen at bang time. Since Hydra does not have a predictive mix model, only the variation of the DD burn in the shell was analysed which showed only a small, 20% change in yield over all stalk/glue cases run.

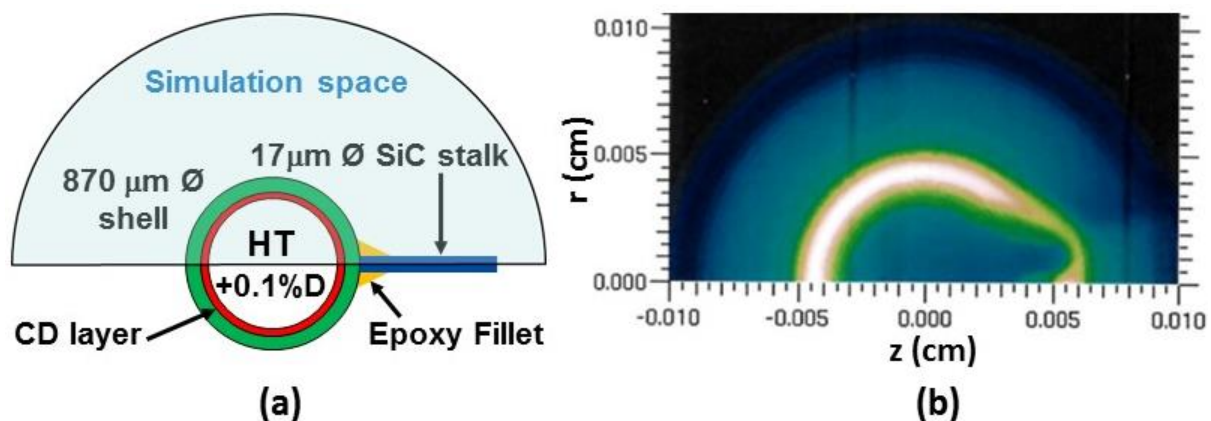


Figure 5(a) Geometry for the 2D capsule simulations with a SiC stalk and epoxy glue fillet, and (b) capsule density at bang time (1.5ns) for the stalk with nominal glue fillet case.

4. Summary

Variations in the yields and temporal histories of HT and DT fusion γ -rays in separated reactant Omega capsule implosions have been characterized via Hydra “pre-mix” simulations indicating that the amplitudes of the HT- γ and DT- γ burn histories are of similar magnitude and have temporal variations consistent with measurements using existing GRH diagnostics. Simulated yields show order-of-magnitude variations versus pre-mix depth that can provide evidence of the burn/mix morphology during Omega capsule implosions. Experimental results will be important for validating current theories on mix evolution described in the literature. Hydra 2D simulations indicate only small changes in yield due to mounting stalk & glue perturbations for separated reactant capsules using 1 ns laser drive (with a pre-heated inner capsule shell to limit convergence). CD mix layer experiments on Omega are planned for early 2016.

Acknowledgments

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