Measuring the Dynamics of Thermonuclear Burn in Inertial Confinement Fusion

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A central aspect of understanding hot-spot ignition is observing the process of fusion ignition in the central hot-spot plasma and propagation of the thermonuclear burn into the surrounding compressed DT fuel layer. Due to the fast timescales (~ 50 ps) of the process of ignition and burn propagation, few diagnostics are able to provide measurements to constrain models of the temporal evolution of the gamma rays emitted from the hot-spot plasma. The Gamma Reaction History (GRH) diagnostic at the National Ignition Facility (NIF) can achieve temporal resolutions of 8-10 ps through advances in the Pulse-Dilation Photomultiplier Tube (PD-PMT) technology[1]. Historically, the GRH has been used to provide the nuclear bang-time and burn-width measurements to constrain radiation-hydrodynamics simulations of NIF experiments. Recent work has focused on measuring the true temporally resolved reaction rate and analyzing the shape of the reaction history using the “α-curve”.[2] This has led to significant insights into the process of ignition and burn propagation on the NIF and has enabled, for the first time, the temporal dynamics of a burning plasma to be measured in the laboratory. This required significant forward modelling and understanding of the uncertainty propagation and high-frequency noise contained in reaction history signals. Although the processes of burn propagation and quenching can be distinguished in the NIF data, the signal dynamic range of the GRH detector is not large enough to realize the full potential of the a-curve analysis and limits the measurements to ± 50 ps from bang time. Recent OMEGA implosion experiments with time-resolved, gamma-ray diagnostics have been used to demonstrate an increase in the signal dynamic range by two orders of magnitude by temporally multiplexing the measurements of multiple gamma-ray diagnostics, which enabled the temporal resolution of the shock and compression dynamics of OMEGA-scale implosions. This work demonstrates the state-of-the-art of reaction history diagnostics have advanced significantly beyond bang-time and burn-width measurements in both temporal resolution and dynamic range. The method of data analysis of the reaction history measurements of burning plasmas on the NIF will be presented, along with the OMEGA experiments supporting the multiplexing techniques to overcome the signal dynamic range limitations of the current GRH diagnostic at the NIF.

1. H. Geppert-Kleinrath et al,” Commissioning the new pulse dilation Gas Cherenkov Detector at the National Ignition Facility”, High Energy Density Physics Volume 37, November 2020, 100862. DOI: https://doi.org/10.1016/j.hedp.2020.100862
2. K. D. Meaney, et al; Simple analytic fusion hot spot models for fusion reaction history. Phys. Plasmas 1 December 2025; 32 (12): 122703. https://doi.org/10.1063/5.0284406

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