**Diagnostics for Fusion Gain > 1 Experiments on the NIF**

D.J. Schlossberg1, on behalf of the Indirect Drive ICF Collaboration

*1 Lawrence Livermore National Laboratory, Livermore, CA 94551, U.S.A.*

In December 2022, the National Ignition Facility (NIF) accomplished one of its core missions, which was to achieve controlled fusion ignition – when more energy is released by fusion reactions than energy required to drive the experiment. This scientific milestone was surpassed when 3.15 MJ of fusion energy was generated by a target driven with 2.05 MJ of laser energy (target gain = 1.5), using inertial confinement fusion (ICF).

Fusion ignition by inertial confinement requires compression and heating of the deuterium-tritium fuel to temperatures >5 keV, densities >100 g/cc (>1024 particles/cc) with durations ~100 ps. On the NIF this is achieved through laser indirect drive ICF in which the fusion capsule is surrounded by a high-Z enclosure (“hohlraum”) used to convert incident laser energy into x-rays that symmetrically compress the capsule at ~400 km/s. Fundamentally, this extreme environment presents a challenge for plasma diagnostics; recent advances in fusion performance have even more so increased these challenges.

On the pathway to ignition on the NIF several key advances in understanding have been supported by diagnostic measurements. This talk will highlight those key measurements and summarize the enabling diagnostic techniques. These include diagnoses of: plasma degradation mechanisms due to engineering features (e.g., “fill tube”) and high-Z impurities mixed into the plasma; reduction of compression due to residual kinetic energy of the plasma; and 2D shock velocity measurements to characterize the impact of ablator material structure on implosion quality. These are just a few examples of physics understanding underpinned by diagnostic advances.

Upon achieving an ignited plasma there are several unique diagnostic signatures which clearly indicate the plasma exceeds the Lawson Criterion. A basic metric is provided by neutron diagnostics measuring the number of fusion reactions per implosion. Additional signatures are the time of peak neutron emission, the duration of the plasma “burn,” the plasma spatial size – as imaged by neutrons and x-rays – averaged over its lifetime, and average number of downscattered neutrons. Fascinatingly and somewhat unexpectedly, additional diagnostics measuring drive temperatures and even laser beam energy also observed signatures of ignition.

Finally, we will also discuss next-generation diagnostics needed to explore this new, ignited-plasma regime. As heating from alpha-particles dominates plasma temperature profiles and more significant fractions of DT fuel is burned up, new diagnostics must be developed to explore and understand these dynamics. We will also touch upon the diagnostic upgrades necessary to radiation-harden and ruggedize instrumentation. A few forward-looking diagnostic options are explored and discussed.

\*This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. LLNL-ABS-847465.