**Magnetic Recoil Neutron Spectrometry Across the Fusion Landscape: To Ignition and Beyond!**

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For over 15 years, the Magnetic Recoil Spectrometer (MRS) has been used to measure the DT fusion neutron spectrum in inertial confinement fusion (ICF) implosions at OMEGA and the NIF.[1–5] From the measured primary-neutron spectrum (13–15 MeV), yield ($Y_n$) and apparent hot-spot ion temperature ($T_i$) are determined. From the scattered neutron yield (10–12 MeV) relative to $Y_n$, the fuel areal density ($\rho R$) is determined. These measurements have provided essential information about implosion performance that has helped guide the mainline ICF programs to the recent demonstration of hydro-equivalent ignition ($\chi > 1$)[6] at OMEGA and to ignition and target gain ($G > 1$) at the NIF.[7]

Today, there are variants of the MRS being built across private industry, including spectrometers on the SPARC tokamak (expected $Q > 1$, 100 MW)[8] and the Pacific Fusion Demonstration System (expected $G \sim 10$, 100 MJ),[9,10] both with planned electronic detection systems capable of measuring neutron spectra at high repetition rate. Additionally, an upgrade of the existing MRS on the NIF is being planned in which a collimator will be incorporated to extend the MRS measurement ceiling to more than 20 MJ.[11] A study was also conducted to determine the feasibility of building an MRS for Sandia's Z-Machine. Meanwhile, electromagnet upgrades (MRSnext) have been designed to replace, or complement, the existing MRS systems on OMEGA and the NIF. These, plus other upgrades, will result in several notable improvements: significantly smaller focal planes, improved resolution, conversion foils positioned close to the magnet system, and enhanced signal-to-background.[12] Work also continues on a time-resolved MRS (MRSt) at the NIF to understand the temporal evolution of these measurements using a lower cost, passive, backend detector.[13] Finally, as yields continue to climb at the NIF ($G > 4$), the current MRS is providing new insights on alpha heating and burn propagation through novel measurements of the alpha-knock on neutron (AKN) spectrum.[14]

After briefly summarizing the MRS concept and its demonstrated performance, this talk will describe all of these new developments, highlighting the versatility of the technique for diagnosing fusion performance across approaches on the road to multi-MJ yields and commercialization.

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[1] Frenje et al., RSI. 79, 10E502 (2008). [2] Frenje et al., PoP 17, 056311 (2010). [3] Gatu Johnson et al., RSI 83, 10D308 (2012). [4] Casey et al., RSI 84, 043506 (2013). [5] Frenje et al., Nucl. Fusion 53, 043014 (2013). [6] Gopalaswamy et al., Nat. Phys. 20, 751 (2024). [7] Abu-Shawareb et al., PRL 132, 065102 (2024). [8] Mackie et al., RSI 95, 103502 (2024). [9] Alexander et al., PoP 32, 092703 (2025). [10] Ellison et al., PoP 32, 090601 (2025). [11] Gatu Johnson et al., RSI 93, 083513 (2022). [12] Wink et al., RSI 95, 083548 (2024). [13] Frenje et al., RSI 87, 11D806 (2016). [14] Wink et al., Bull. Am. Phys. Soc. presented at DPP (2025).

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