Measurements for Fusion Power to Demonstrate Q > 1 on SPARC

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Achieving and demonstrating a net fusion energy gain (Q) is the goal of the first campaign for the SPARC tokamak. The "breakeven (Q>1) campaign" at SPARC will aim for an ICRF heated, multi-second DT plasma, producing powers near 8–10 MW. A comprehensive diagnostic and analytical framework linking plasma conditions, neutron yield rate, and energy accounting, is being developed for Q>1 verification.

SPARC uses a physics-based definition of Q, as $P_{fus}/(P_{RF,launched} + P_{Ohmic} + dW/dt)$. Here, P_{fus} is the total fusion power from the relevant D–T, D–D, and D–^{3}He reactions – dominated by the D-T power, $P_{RF,launched}$ is the net ICRF power launched, P_{Ohmic} is the Ohmic heating power, and dW/dt accounts for changes in the stored plasma energy. This talk will discuss the numerator, i.e., the SPARC strategy to measure P_{fus} using three independent methodologies. Two of the methods utilize the four neutron diagnostics of SPARC, namely, neutron flux monitors (NFM), neutron activation system (FOIL), poloidal neutron profiler (NCAM), and a core-viewing neutron spectrometer (NSPC).

NFM provides a high time-resolution ($\Delta t \leq 10$ ms), neutron flux utilizing industrially proven power-range detectors: compensated ^{10}B ionization chambers. It renders a high DT energy response employing a moderator-shielding design. FOIL complements NFM using DT-responsive dosimetry foils activated at an in-vessel position ~70 cm from outer closed flux surface. A high intensity (>1e8 n/s) DT neutron generator, with independently calibrated energy and angular emission profiles, will be used for an in-situ calibration of NFM and FOIL. Supported by detailed neutronics models of the SPARC device and facility, NFM and FOIL enable estimation of absolute P_{fus}, targeting uncertainties of order 10%, comparable to the best results achieved on JET.

As demonstrated on NIF and JET, the second method utilizes SPARC's collimated neutron flux diagnostics. NSPC exploits a magnetic-proton recoil (MPR) method to assay a high-resolution (dE/E~1%) spectrum of core neutrons. Combined with the DT neutron emissivity profile derived from an inversion of 7 to 10 lines of sight from NCAM's diamond-detectors, it allows accurate reconstruction of P_{fus}. NSPC will be ab-initio calibrated and its Hodoscope using an in-situ alpha source, and the NCAM detectors' response matrices known from benchtop testing.

The third measure of P_{fus} is obtained from the kinetic reconstruction of the volume-integrated neutron emissivity, computed from tabulated reactivity rate data. SPARC kinetic diagnostics provides T_e profile shape from electron cyclotron emission, line-averaged T_i from X-ray Doppler spectroscopy (supplemented by NCAM), line-averaged density from interferometer, edge density from reflectometry, and Z_{eff} and $\langle Z \rangle$ from spectroscopy to estimate n_i/n_e. The fuel ion (D/T) ratio for all three methods are provided by the spectroscopy diagnostics.

This work was supported by Commonwealth Fusion Systems.

Specify category: Magnetic confinement fusion, SPARC, Nuclear Diagnostics