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Utilization of SPARC to investigate divertor solutions for fusion pilot-plants

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SPARC is a compact, high-field short pulse ICRF heated tokamak ($B_0 = 12.2$ T, $R_0 = 1.85$ m, $\tau_{flattop} = 10$ s, $P_{rf} = 25$ MW) with a close-fitting tungsten first wall designed to achieve its mission goal of $Q_{fus} > 2$ with significant margin. Construction has begun at a new site in Devens, MA and operations are scheduled to begin in mid-2025. Although the baseline design relies on strike point sweeping, divertor shaping, and inertially cooled divertor targets to facilitate attainment of this primary mission at lowest risk, the device is able to access reactor relevant pedestal and divertor parameters with unmitigated parallel heat fluxes entering the divertor of $\sim$ 10 GW/m^2, pedestal temperatures of $\sim$ 3 keV and separatrix densities $\sim 10^{20}$ m^{-3} ($n_{Greenwald} \sim 8{\times}10^{20}$ m^{-3}). Therefore, in addition to its fusion power goals, SPARC will also be a test bed for exploring the key areas of tokamak physics necessary to design an ARC-class fusion pilot plant. An anticipated focus of experiments will be on identifying what ranges in H_{98} and Q_{fus} are compatible with highly dissipative, low steady state erosion divertor scenarios, that also ensures neutral pumping levels that would be sufficient for helium ash removal.

The inclusion in the SPARC design of a long-leg divertor, magnetic topology flexibility, multiple gas injection locations (fuel, impurities) and neutral pump actuators will facilitate this goal by assessing variations in divertor geometries and operation scenarios being consider for an ARC-class device. The divertor is up-down symmetric, able to achieve standard horizontal- and vertical-target-like neutral recycling conditions on both the inner and outer divertors. The outer divertors also feature highly baffled long legs ($L_{pol} \sim 0.5$ m) with coil control to also enable secondary X-points in the divertor volume at the end of the outer divertor legs to form a X-point target divertor magnetic geometry. Flexibility in gas injection has been included in the design with both main ion and impurity gas seeding nozzles located in the inner and outer divertors as well as at the primary X-point. Each of these injection locations is capable of independent injection control using up to 3 simultaneous gas mixtures. In addition, the divertor neutral pump inlet is located at the end of the outer divertor designed with an adjustable pumping speed of up to $\sim$ 20 m^3/s, though it is not designed to pump helium.

However, due to the closed divertor shape and the need for neutron tolerant systems, diagnostic access will be limited. Hence, a workflow for boundary plasma simulations is being developed both as a means of interpreting experimental observations as well as informing experimental planning. A companion contribution ("SPARC Diagnostics for Use in Plasma Control and Divertor Physics Studies"–M.L. Reinke, *et al.*) will focus on the SPARC divertor diagnostic set. SPARC will provide near-term, invaluable experience with what it takes to diagnose and control the divertor plasma under reactor conditions with limited diagnostic access.

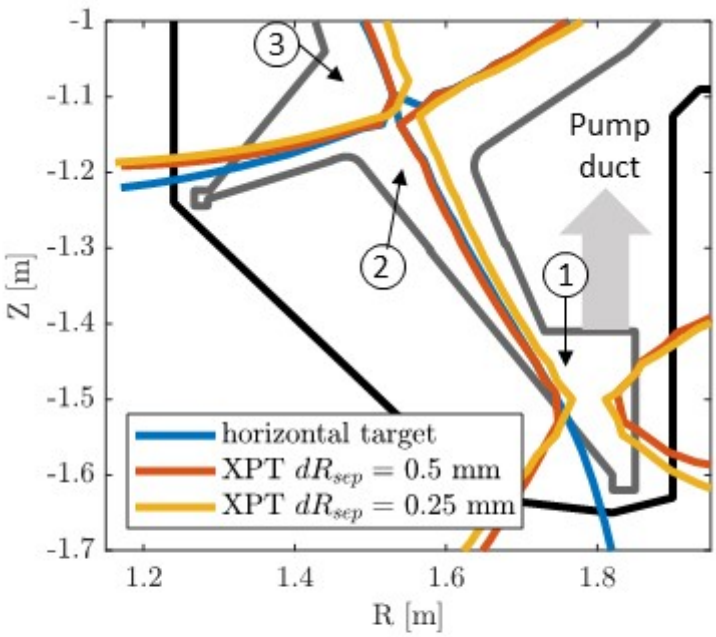

Figure 1: Simplified outline of the first wall contour with a scan in the separation of the two X-point. Numbered arrows shows approximate gas injection locations.

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