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A strategy to develop power exhaust solutions for tokamaks beyond ITER

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Predictions for the scrape-off layer (SOL) in future fusion devices based on empirical scalings imply extremely large parallel heat flux, q|| ˜10 GW/m2, which is exacerbated for high-field concepts that may enable a Compact Pilot Plant (CPP) as recommended by a recent US strategic planning assessment. Here we discuss the framework of a proposed ˜10 year program to more firmly establish the basis for power handling in tokamaks by extending the paradigm of solid (likely high-Z) walls using noble gas seeding to increase impurity radiation. This is intended to take relatively mature science and technologies relevant to power exhaust and particle control (PFCs, pumping) and demonstrate the combined physics and engineering basis for a divertor solution for a tokamak-based CPP. The aims of this program are to a) establish the predictive basis for projecting heat flux and the conditions for its mitigation; b) develop core confinement scenarios that minimize exhaust requirements on the divertor; c) test the interaction between radiative divertor and high-pressure pedestals at-scale; and d) explore the potential of alternative divertor geometries as risk mitigation should the conventional geometry employed in ITER prove to be insufficient for CPP requirements.
Although there are important distinctions, many of the goals of a CPP are similar to other tokamak-based pathways (e.g. EU-DEMO, CFETR), which should allow for collaborative pursuit of power exhaust solutions. Significant progress has been made in understanding the SOL heat flux width, and recent studies have focused on how the solution to the heat flux challenge scales, for example through the impurity fraction fZ required for detachment [1,2]. Developing and confirming these predictions is essential, especially for CPP-scenarios which may stress higher-field approaches. It is also necessary to develop exhaust scenarios that are compatible with core confinement requirements. With the operation of burning plasma experiments on the horizon via ITER and SPARC, the compatibility of the divertor and pedestal can be studied nearly at-scale, with reactor-like dimensionless and dimensional parameters. In parallel, new core scenarios should be developed that demonstrate tradeoffs between sustaining high confinement in the presence of strong core radiation versus raising PSOL. While multiple members of the worldwide program are actively developing alternative divertor geometries these focus primarily on the high poloidal flux expansion branch of advanced divertors, e.g. snowflake and x-divertors. A new experimental capability is emphasized as being necessary to explore the physics of long-legged, tightly baffled divertors at high heat flux, testing for example the predicted access to new regimes with dominant roles of divertor turbulence [3] that may dramatically lessen the power exhaust challenge.

[1] M.L. Reinke, Nucl. Fusion 57 (2017) 034004.
[2] R.J. Goldston, M.L. Reinke and J.A. Schwartz. PPCF 59 055015 (2017)
[3] M.V. Umansky et al, Phys. Plasmas. 24 (2017) 056112.

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