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Preparing disruption solutions for tokamak power plants

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Realizing tokamak power plants requires reducing the frequency and impact of disruptions sufficiently to accept them as a part of operations. SPARC is a high field tokamak [1] ($B_o = 12.2$ T, $I_p = 8.7$ MA) designed to demonstrate Q>1 and to explore divertor and disruption solutions for the ARC power plant. Significant disruption work is ongoing in hardware, software, operational planning, and science to prepare for SPARC and to realize the disruption strategy for ARC. Much of the physics work is common to all tokamak concepts and Commonwealth Fusion Systems (CFS) seeks to engage the community on these topics.

The SPARC Disruptions Team is developing and publishing physics-based and machine learning off-normal warnings (ONWs) for the plasma control system (PCS) and off-normal simulations (ONSIMs) for stress-testing the PCS and calibrating the predictors. The soon-to-be open-source MOSAIC framework as well as the DEFUSE code [2] facilitate sharing ONWs and ONSIMs to pool efforts and enable cross-validation. Tokamak power plants will naturally accrue a large database of repeat pulses, or many samples of the steady-state, both of which provide an opportunity for detecting variation from nominal which is a conceptually simpler problem than detecting disruption boundaries. Pulsed power plant prediction algorithms and disruptivity might be assessed by running repeat discharges in relevant plasmas.

The Runaway Electron Mitigation Coil (REMC) will be operated on SPARC providing a critical test of this runaway prevention technique. To increase the likelihood of runaway solutions for future machines and to provide optionality, the community is encouraged to continue to explore alternative runaway prevention techniques. Better quantifying the runaway risk is also important, including modeling runaway impacts and further benchmarking runaway models on empirical data where runaways are and are not observed.

Next generation machines, including SPARC and ITER, will access power plant relevant disruption heat fluxes on tungsten, steel, and other in-vessel materials. Material testing facilities might be leveraged to complement and accelerate our understanding of the degradation of tungsten-based materials from unmitigated thermal quenches, halo current heat fluxes, and runaway impacts.

Important physics questions remain unresolved in the ITPA scalings including the effect of the plasma-vessel mutual inductance on the shortest current quench duration [3], a scaling for the longest current quench duration, and the expected correlation of the poloidal arc length on the maximum halo current fraction.

Collaboratively identifying the greatest risks and motivating the greatest opportunities in disruptions is expected to accelerate the realization of fusion power plants. This talk will discuss how CFS intends for SPARC to be a member of this ecosystem and solicit active support from the community in preparing for operations and beyond [4].

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[1] A.J. Creely, et al. J. Plasma Phys. 86.5 (2020) 865860502
[2] A. Pau, et al. IAEA FEC (2023)
[3] T. Yokoyama, et al. Nucl. Fusion 63 (2023) 126049
[4] A.J. Creely, et al. Phys. Plasmas 30.9 (2023)
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