Development of Compact Reactor Use Cases to Inform Transport Studies

C. Holland, X. Jian, D. Orlov, E. M. Bass, Center for Energy Research, UC San Diego
J. McClenaghan, B. C. Lyons, General Atomics
N. T. Howard, P. Rodriguez-Fernandez, MIT Plasma Science and Fusion Center

Recent National Academies [1,2] and US fusion community strategic planning [3,4] reports have identified the need for significant new design and physics studies to support the goal of constructing and operating a fusion pilot plant (FPP) at low cost and accelerated schedule. Towards this end, the OMFIT STEP [5] integrated modeling workflow has been used to develop self-consistent use cases (core plasma equilibria and kinetic profiles) for compact inductive and steady-state tokamak fusion reactors. These use cases are intended to be starting points for more detailed exploration of transport and stability physics in parameter regimes relevant to the US vision of an FPP, as well as for future optimization studies and extensions to include additional physics and engineering considerations. The initial use cases target an up-down symmetric reactor able to produce roughly 200 MW or more net electric power with $B_0 = 8$ T, R = 4 m, a = 1.4 m, elongation $\kappa = 2$, triangularity $\delta = 0.5$, and $Z_{eff} = 2$, with the expectation that these parameters would evolve in future studies. For this starting work, only the core plasma (i.e. inside the separatrix) is modeled without inclusion of divertor or wall geometry, and only a simple model of electron heating and current drive sources is utilized with prescribed Gaussian deposition profiles and $\eta_{CD} = 0.4$. Starting from pedestal pressure predictions made with EPED, the workflow iterates between the CHEASE equilibrium solver, ONETWO transport code (for current evolution), and TGYRO transport solver to develop self-consistent core plasma scenarios. Potentially viable inductive (I_p = 16 MA, P_{aux} = 50 MW, $q_{95} \sim 4.9$) and steady-state ($I_p \sim 12$ MA, $P_{aux} \sim 100$ MW, $q_{95} \sim 6.0$) scenarios capable of nominally meeting the power production goal are identified for $n_{ped}/n_{GW} \sim 0.8$ (equivalent to $\langle n \rangle / n_{GW} \sim 0.9 - 1.1$), where $\langle n \rangle$ the volume-averaged density, and $n_{GW} = I_p/\pi a^2$ is the Greenwald density. Although almost all heating goes to the electrons, and T_e/T_i is slightly larger than unity across most of the plasma, the combination of strong collisional coupling and radiation makes the ions the dominant transport channel in both scenarios, and ion temperature gradient modes the primary instability. In both scenarios, the dominant uncertainty and sensitivity arises from the amount of density peaking predicted, with significant differences possible depending on whether electromagnetic fluctuations are included in the transport calculations (performed using the TGLF SAT1 [6] model). Additional work on global stability, impurity impacts, and benchmarking of gyrokinetic results to the TGLF predictions is underway and will be reported.

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[1] NASEM Final Report of the Committee on a Strategic Plan for U.S. Burning Plasma Research
[2] NASEM Consensus Study Report "Bringing Fusion to the U.S. Grid"
[3] APS-DPP Community Planning Process Strategic Plan
[4] 2020 FESAC report "Powering the Future: Fusion & Plasmas"
[5] O. Meneghini *et al*., Nucl. Fusion **10** 1088 (2020)
[6] G.M. Staebler *et al*., Phys. Plasmas **23** 062518 (2016)