A quantitative analysis of the effects of neutral trapping and total flux expansion in TCV and MAST-U

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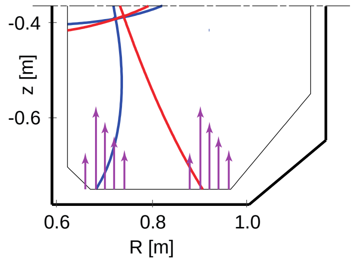

Reduction of the detachment threshold in upstream plasma density or impurity concentration, as well as accessing detachment at higher power into the SOL, P_{SOL}, is needed in order to access detachment in a tokamak fusion reactor, reduce the impurities in the core and keep the divertor detached. Total flux expansion, a divertor magnetic topology design characteristic embodied in the Super-X divertor, is predicted through simple analytic models [1] and SOLPS calculations [2] to reduce the upstream plasma density detachment threshold, $n_{u,d}$, as the outer divertor strike-line position (R_t) is increased: $n_{u,d} \propto 1/R_t$. TCV experimental results [3] contradict expectations with a detachment threshold opposite to that expected. Utilizing the SOLPS-ITER code, we are able to match recent TCV experimental results, demonstrating that for TCV the effect of total flux expansion is counteracted by two other divertor geometry design characteristics that affect neutrals: a) the effect of physical baffles that reduce the amount of neutrals escaping from the divertor; and b) the strike point angle to the divertor surface (β_{sp}). We quantify the role of those neutral effects through developing and applying a definition of neutral trapping which we introduce in [4].

A similar investigation has been performed into the relative roles of total flux expansion and neutral trapping for upstream density scans in MAST-U where the divertor chamber, compared to TCV, is quite closed to neutral escape. The simulations show that both total flux expansion and neutral baffling (a) are enhanced and work together to lower the Super-X detachment threshold. The results of this study on two different tokamaks indicate that to improve a divertor design or optimize an existing one for detachment, one needs to properly understand and apply the three design characteristics discussed above, such that all effects are additive and all reduce the detachment threshold, i.e increase R_t as much as possible while simultaneously maximizing the neutral trapping through maximal baffling and utilizing the 'vertical target' strike point angle incidence. A second implication of this study is that any assessment of alternative topologies (e.g. snowflake or X-divertor) must separate out the effects of magnetic topology from design choices which influence neutral gas recycling.

[1] B. Lipschultz, et al., Nuclear Fusion 2016, 56, 056007
[2] D. Moulton, et al., Plasma Phys. Control. Fusion 2017, 59, 065011.
[3] C. Theiler, et al., Nuclear Fusion 2017, 57, 072008.
[4] A. Fil, et al., Submitted to Plasma Phys. Control Fusion