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A New Scaling for Divertor Detachment[1]

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The ITER design and future fusion power plant designs depend on divertor detachment, whether partial, pronounced or complete, both to limit heat flux to plasma-facing components and to limit surface erosion due to sputtering. Generally the parallel heat flux, estimated as proportional to P_{sep}/R or $P_{sep}B/R$, is used as a proxy for the difficulty of achieving detachment. Here we argue that the impurity cooling required for detachment is strongly dependent on the upstream separatrix density, which is limited by Greenwald scaling. Taking this into account self-consistently, along with the Heuristic Drift (HD) model for the SOL width, and using a Lengyel radiation model that includes non-coronal effects, we find[2] that the relative impurity concentration, $c_z \equiv n_z/n_e$, required for detachment scales dominantly as $c_z \propto P_{sep}/B_p(n_{sep}/n_{GW})^2$. The absence of any explicit favorable size scaling is concerning, as P_{sep} must increase by an order of magnitude from present experiments to an economic fusion power system, while increases in the poloidal magnetic field strength are limited by magnet technology and MHD stability. This result should not be surprising, as it follows from the simplest scaling, $P_{sep} \propto c_z n_e^2 V_{SOL}$, taking into account the Greenwald density limit and the HD SOL volume scaling. Reinke[3] has combined a similar approach with the requirement to maintain H-mode, which sets a lower limit on P_{sep}, and also arrives at an incentive for high field and disincentive for large size. These results should be challenged by comparison with 2D divertor codes and with measurements on existing experiments. In particular measurements are required for extrinsic divertor impurity concentration over a range of power and density conditions far from the regime where detachment can be achieved with deuterium puffing and intrinsic impurities alone. Nonetheless, these results suggest that higher magnetic field, stronger shaping, double-null operation, advanced divertor magnetic and baffle configurations, as well as lithium vapor targets merit greater attention.

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[2]RJ Goldston, ML Reinke, JA Schwartz, Plasma Phys. Control. Fusion 59 (2017) 055015
[3]ML Reinke, Nucl. Fusion 57 (2017) 034004