Assessment of alternative divertor configurations for a European DEMO

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The European roadmap for fusion energy has identified plasma exhaust as a major challenge towards the realisation of magnetic confinement fusion. To mitigate the risk that the baseline scenario with a single null divertor (SND) and a high radiation fraction adopted for ITER will not extrapolate to a DEMO reactor, the EUROfusion consortium is assessing the feasibility and potential benefits of alternative divertor configurations.

A range of alternative configurations that rely only on conservative extrapolations of currently available technologies that could be readily adopted in the European DEMO design, are identified. They include the X divertor (XD), Super-X divertor (SXD), Snowflake divertor (SFD) and the double null divertor (DND). Basic engineering constraints on poloidal field (PF) coil current densities and forces, however, restrict XD and SFD characteristics to the outer divertor and limit the achievable poloidal and toroidal flux flaring to factors of ~1.5. All alternatives require additional conductors, which translates into higher capital costs, with the SXD requiring ~20% more toroidal field (TF) coil conductors and SXD and SFD ~50% more PF coil conductors. Structural analysis of the TF coil shape and remote maintenance requirements add further constraints that are used in a second step to refine the configurations.

Boundary models with varying degrees of complexity are used to predict the exhaust performance. Desired effects are a facilitated access to detachment, resilience of the detachment front to move along the divertor leg and an increase in divertor radiation without excessive core performance degradation. The extended 2-point model and achievable geometric variations indicate that SXD and SFD have the largest potential to decrease the SOL radiation required for the onset of detachment. A systematic study using the divertor transport code TECXY predicts similar trends, but with a more modest gain for the SFD. The predictions are further refined with the SOLPS and SOLEDGE2D-Eirene codes, which employ more sophisticated models for geometry and neutral particles. A SOLEDGE2D-Eirene scan, also including the DND, shows a stronger increase of the tolerable residual power $\propto(1-f_{rad})$ for all alternatives ranging from +30% to +50%. It also confirms that a significant part of the improvement in the outer divertor of XD and SXD comes at the price of higher power loads directed to the respective inner divertors. Additional benefits of the SFD, not yet captured in the models, may be an ability to increase f_{rad} without adverse effects on the core performance and a potential SOL broadening in the low poloidal field region.

Next steps must address the controllability of each configurations. It should also include an assessment of the engineering challenges posed by placing PF coils inside the TF coils and a decrease of the admissible grazing angle of the field line at the target, which both promise further significant increases of the power exhaust potential of alternative configurations.