Alternative divertor configurations for energy and particle exhaust

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Energy and particle exhaust is one of the key challenges of the tokamak approach towards fusion energy. It remains, in particular, not obvious that an exhaust solution based on a single-null, poloidal divertor, as envisaged for ITER, will extrapolate to DEMO and ultimately to an attractive fusion power plant [1]. Power exhaust generally scales unfavourably with size and, there is the concern that it also scales unfavourably with magnetic field, while a high magnetic field may be necessary for an economical power plant. Research on alternative, better performing, divertor configurations is, therefore, performed world-wide and has become a priority of the EUROfusion programme. This paper reviews a wide range of proposed alternatives to the conventional, single-null divertor that aim at reducing the heat and particle loads at the plasma-material interface and further improving the economical attractiveness of fusion energy.

Prominent proposed alternatives include concepts such as the “snowflake” [2], “X divertor” [3], “Super-X divertor” [4] and “X-point target divertor” [5] configurations but also further variants and up-down symmetrisations. All are based on a highly dissipative divertor relying on a partially detached divertor operating regime, similar to ITER, or even on full detachment. They employ geometric modifications of the magnetic configuration and the optimisation of the divertor target geometry and, in some cases, of gas baffles. Their differences lie in their power and particle exhaust handling. Improved performance can be manifested as a reduction of the peak heat to the targets, easier access to divertor detachment (e.g. with less impurity seeding), stable feedback mechanisms to keep the detachment or radiation fronts from moving into the main plasma, or an increase of the radiated power in the SOL whilst retaining sufficient core confinement. The main concepts are described and their underlying physics mechanisms exposed. While some mechanisms have been identified in experiments, a wider range of proof-of-principle experiments is still outstanding. Similarly, divertor transport codes can support some of the invoked mechanisms, but key issues such as the scaling of the cross-field transport and the stability of radiation patterns in the proximity of the X-point are not understood and limit our ability to predict and quantify the benefits in reactor conditions. These benefits will have to outweigh the increased complexity of a fusion power plant with an alternative divertor configuration. Among the discussed complications are the need for additional magnets, greater mechanical forces between magnets and larger toroidal field coils than in the conventional approach. Significant efforts are being undertaken to close the physics gaps, evaluate the engineering challenges and ultimately propose a compelling conceptual DEMO design.

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