On the physical principles of power exhaust and a novel divertor solution for tokamak fusion reactors

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Safe removal of the power generated in a fusion reactor without damaging the inner wall elements of the device is one of the most important research objectives of magnetic fusion. The most important physical mechanisms by which the energy of the plasma is dissipated before it reaches the plasma facing components and the divertor detaches from the plasma are known. Various divertor concepts make use of them to find an optimal solution for energy removal without compromising the performance of the core plasma.

A particularly attractive divertor configuration has recently been proposed that comes with a detached divertor. It bases on the occurrence of a dense, cold and strongly radiating plasma volume on closed magnetic flux surfaces near the magnetic X-point, known as X-point radiator (XPR) [1,2]. The XPR was studied in detail on ASDEX Upgrade and was also established on other tokamaks and in D-T experiments at JET [3]. The physics of this phenomenon is described by a reduced power balance model [4] and by comprehensive SOLPS-ITER transport simulations [5]. The position of the XPR can be real-time controlled. When the radiating zone expands up to 10 cm above the X-point into the domain of the hot plasma, harmful edge localized modes are suppressed. Such plasmas are compatible with important reactor requirements.

Due to the highly dissipative nature of the XPR, once it is established, the heat and particle fluxes are low enough to expanded the plasma until the X-point comes to lie on the divertor surface, resulting in a so-called compact radiative divertor (CRD) [6]. The CRD features a number of further advantageous characteristics with regard to a reactor: it works in a much simplified divertor geometry and results in a larger and more stable plasma. Successful CRD operation was demonstrated with high-power discharges on ASDEX Upgrade [6]. Identifying the elementary physical processes that lead to an XPR will help predict its applicability to reactor-scale plasmas, as it is indicated by SOLPS-ITER simulations [7].

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