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Modelling radiative power exhaust in view of DEMO relevant scenarios

S. Wiesen[1], M. Wischmeier[2], M. Bernert[2], M. Groth[3], A. Kallenbach[2], M. Siccinio[2], M. Dunne[2], S. Saarelma[4], D. Boeyaert[1], H. Reimerdes[5], F. Reimold[2], S. Brezinsek[1], W. Biel[1]
[1] Forschungszentrum Jülich GmbH, Institut für Energie- und Klimaforschung – Plasmaphysik, 52425 Jülich [2] Max-Planck-Institut für Plasmaphysik, 85748 Garching bei München, [3] Aalto University, Espoo, Finland, [5]CCFE, Culham Science Centre, Abingdon, OX14 3DB [4] Swiss Plasma Center, Ecole Polytechnique Fédérale de Lausanne, Station 13, CH-1015 Lausanne
e-mail (speaker): s.wiesen@fz-juelich.de

Power exhaust in future electricity producing fusion device like DEMO features difficulties which, compared to ITER, are harder to tackle in terms of operational control requiring an improved physics understanding. Primarily, for a given P_{loss}/R, with P_{loss} being the power arriving from the core into the pedestal region, the heat flux problem must be solved in order to allow plasma facing components (PFCs) to withstand a maximum heat flux not exceeding 5MW/m^2 in steady state on timescales lasting days or weeks. For DEMO a pronounced or even completely detached divertor regime is to be exploited to allow for the required pressure loss along the field that induces a roll-over of the target particle flux Γ_t [1]. Consequently, the heat flow towards the target can be mitigated and the deposited energy of recombining particles at the surface is minimized. Low divertor temperatures $T_{e,div}$ < 1-2 eV are thus required to keep the total target heat loads and erosion yields within material limits. In such low-T_e/high-n_e divertor regime strong interaction with neutral particles (D, T, He-ash and impurities) is inevitable. With transport of neutral particles being disconnected from the magnetic field and the presence of a highly non-linear interacting plasma-neutral regime, coupled plasma-fluid/neutral-kinetic transport model approaches are indispensable. Validated 2D/3D numerical tools like SOLPS-ITER, EDGE2D-EIRENE or EMC3-EIRENE are required to predict potential operational regimes in varying geometries (single-null, double-null, snowflake) [1,2].

For a DEMO sized device a total dissipated fraction $f_{diss}=P_{diss}/P_{loss}$ close to 95% or higher is required to reduce the total target heat load qt. Already from two-point models it is demonstrated [3] that the amount of achievable radiation loss in the scrape-off layer (SOL) is limited by the amount of removable pressure along the connection length. Hence in DEMO, P_{diss} must not only cover the diverted plasma edge region and SOL, but also part of the confined core region to reduce the upstream pressure p_u.

Recently, the so-called high-field side high-density (HFSHD) region [4] has been identified in various tokamaks. The HFSHD region is formed by a combination of high recycling at the inner target and power crossing the separatrix allowing ionization of recycled neutrals. In response of the change in SOL ionization pattern the poloidal fueling profile into the core region is affected [5]. The main impact of the HFSHD is on the separatrix density with the effect of an inward shift of the density profile inside the confined region and hence, a quantitative change in peeling-ballooning stability within the pedestal [6]. An interlink with significant radiation loss in the same region must lead to additional constraints for performance relevant parameters as for example top pedestal density (and thus fusion product) as well as the distance to the H-to-L transition threshold. The understanding of the HFSHD region has progressed recently by modelling. However the impact on the pedestal fueling (that may also include transient effects from ELMs in H-mode) can only be tackled rigorously by using integrated models that merge the different transport regions together, i.e. plasma core, SOL/divertor and plasma-wall interaction (PWI).

From the engineering point of view reduced models are required to design the operational and control parameters of a future device design like DEMO [7]. The pathway to control power and particle exhaust without losing main plasma performance in a future device is still hampered by unknowns in the underlying plasma physics effects. To what extent the models for the complex interplay of core/SOL/PWI can be reasonably reduced is a current field of interest. Fundamental for a plausible model reduction is the existence of databases that map out the operational parameters in existing devices (system size R, heating power P_{heat}, current I_p and field B_t, Greenwald fraction n_{GW}, impurity compression and concentrations c_z, divertor closure and neutral pressure/fluxes, etc.), complemented by a series of numerical simulations based on exhaust similarity experiments.

This paper portrays the state-of-the-art of modelling capabilities within the fusion community in view of a future DEMO device. An update on the important validation process of numerical tools is presented. Missing model features that are required for a credible numerical model for DEMO are highlighted as well as the gaps in physics understanding are discussed.

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