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Tungsten transport in tokamaks: towards real-time kinetic-theory-based plasma performance optimisation

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Tungsten is foreseen as plasma facing material in next generation tokamaks (ITER/DEMO). It is thus crucial to understand and predict tungsten transport to prevent detrimental behaviour such as central tungsten accumulation leading, in worst scenarios, to disruptions.

In the framework of integrated modelling, ASDEX Upgrade and WEST discharges (both machines operating in full tungsten environments) are studied. Temperature and density profiles are evolved according to heat/particle sources and transport. Neoclassical transport is computed from NEO 1 and turbulent transport from the kinetic transport model QuaLiKiz 2. A faster, 10 dimensional Neural Network version of QuaLiKiz [3,4] is also used to tackle the real-time transport modelling challenges.

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In modelled AUG NBI heated H-mode plasmas, within the transport solver ASTRA [5], the W accumulation and its avoidance are found to be determined by a competition between two mechanisms, i.e., the central particle source produced by NBI heating and the electron heating from ECRH. The former causes central peaking of the plasma density and the subsequent inward tungsten neoclassical convection. This accumulation can be compensated by the increase of r/a with ECRH heating, resulting in increase central turbulent diffusion, thus reducing the effect of the central particle source (Fig.1) [6]. The competition of these two mechanisms is reproduced in a control oriented integrated modelling framework with the transport code RAPTOR [7], including fast turbulent transport modelling via Neural Networks of QuaLiKiz. In Fig. 2, the central and midradius electron normalised density gradients (T_e/T_i) are shown for increasing ECRH power. It is observed that the central $T_e/T_i \sim 1$ decreases with $R/L_{n_e} = -R/n_e(\partial n_e/\partial r)$ due to the increased central turbulent transport. On the other hand $r/a = 0.1$ at midradius increases due to reduced collisionality [8] and reduced impact of the particle source compared to the turbulent pinch. Such fast and robust predictive capabilities with respect to central density peaking with the ECRH power, paves the way towards real-time core tungsten density mitigation.

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Long pulse WEST L-mode plasmas with dominant radio-frequency electron heating and low torque are also modelled within ASTRA. These plasmas are particularly relevant considering scenarios of the Pre-Fusion Power Operation phase 1 of ITER where cyclotron resonance heating will be used (20 to 30 MW of ECRH), without neutral beams. It is found that predictions of the electron density and temperature profiles, modelled with QuaLiKiz, are inconsistent with experimental observations. Comparisons with first principle gyrokinetic simulations (GKW [9]) identified the reduced model for the collision operator as the main culprit [10]. Predictions of the midradius turbulent particle peaking (no central particle source) between GKW and QuaLiKiz for such collisional plasmas feature discrepancies in both high and low ion temperature gradient (Fig. 3) due to overstabilisation of Trapped Electron Modes driven by the electron temperature gradient. These discrepancies contributed to spurring development of the QuaLiKiz collisionality model to alleviate this issue.

Reduced kinetic-theory-based models (QuaLiKiz neural network) for transport modelling in view of plasma scenario optimisation and tungsten accumulation avoidance, are proven to be powerful and accurate tools. In specific regimes relevant for ITER operations, additional development are still required with constant validation against first principle modelling.

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