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Test of the predictive capability of B2-Eirene on ASDEX-Upgrade

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For optimization of divertor operation, e.g. for ITER, 2D scrape-off layer simulation codes are used to study different target plate and baffle geomtries and their effect on power and particle exhaust and SOL characteristics.

We report 2D multifluid simulations, using the coupled B2-Eirene code package to study the effect of geometry changes for the divertor of ASDEX Upgrade. Starting from validated results for the old divertor I of ASDEX Upgrade [1–3], the modelling predictions for the new divertor II will be compared with the actual experimental results.

ASDEX-Upgrade is in particular suited for this purpose, because it has a rather sophisticated setup of divertor diagnostics allowing a detailed experimental characterization of the divertor. This allows a critical check of code predictions even in details like flow patterns.

As already seen from the modelling of divertor I, a proper description of the detachment process requires the inclusion of volume recombination [4,5,3]. In the original predictive calculation [6] this process was missing. Therefore, the B2-Eirene calculations for the new divertor II were redone with the inclusion of this process, which becomes important at temperatures of about 1-2 eV.

The new divertor II is characterized by strongly inclined target plates reflecting the neutrals towards the separatrix. This effect introduces a rather early detachment close to the separatrix with subsequently strongly reduced maximum power loads. However, the experimental results of thermography, calorimetry and Langmuir measurements show this power load reduction also for attached conditions. This effect is also seen in the code predictions, but only if the anomalous transport is assumed to be a diffusion process determined by the local gradient in real space. Then the larger compression of the flux surfaces in the divertor for the divertor II results in larger anomalous radial fluxes especially close to the separatrix. This produces already for attached conditions a considerable broadening of the profile and by this a reduction of the power load maximum. If the diffusion process is assumed to be constant in flux-coordinates, this effect disappears.

The L-mode density limit is interpreted for clean plasmas as a global detachment limit [5,2]. As confirmed by experiment the density limit remains unchanged, because even when the separatrix detaches a factor 2 below the global density limit the outer SOL stays attached. With the operation of additional neutral beam injection ASDEX Upgrade has now access to operation at high input powers (up to 14 MW in hydrogen, up to 20 MW in deuterium). This allows the checking of the prediction for higher net input powers that a transition from a square-root power dependence to a much weaker one should occur.

The analysis of impurity transport in the scrape-off layer is one of the most challenging topics, both for experiments and for modelling, due to the complexity of the problem, because motion of neutrals and ions are two dimensional at least. Also, understanding the important aspects of the impurity transport means the need for a validated model accounting for the impurity generation at the plates and side-walls, proper description of the transport process (including atomic/molecular processes), especially adequately describing the delicate balance of thermal force (trying to push away the impurities from the divertor) vs. parallel electric field and friction force (entraining the impurities towards the plate) determing the transport along the field line plus the anomalous diffusion across flux surfaces.

The detailed spectroscopic divertor diagnostics allow a quantative check of the predicted losses as measured with bolometry, H_α, CII and CIII lines. One gets good agreement with the bolometry results and enhanced losses compared to coronal values due to limited residence time of impurities close to the plate and radial transport resulting in a larger radiation volume [7]. The agreement with the specific spectroscopic lines is within a factor of 2 in absolute values and very good agreement of spatial profiles. The experimental measurement of flow velocities of neutrals and ions allows even check of rather subtle details like flow patterns. Here, an experimental confirmation of the predicted flow reversal of impurities was possible.

As important as the power exhaust is the particle exhaust for any reactor, because removal of the helium ash is necessary to avoid extinguishing the burning plasma and good pumping is necessary to do burn control and feedback operation. Therefore, a check of the predictive capability for divertor impurity compression and pumping is important. B2-Eirene was able to describe the compression of deuterium, helium and neon qualitatively and quantatively for the Divertor I [8,2]. The predicted improved compression of helium for Divertor II [9] was confirmed. Hydrogen compression and pumping is not determined by direct reflection of neutrals into the pumping plenum but through multiple CX collisions, whereas neon and helium are dominated by this ballistic effect. Therefore, a z-shift of the plasma upwards away from the divertor baffles should not affect the compression and pumping of hydrogen, but should change for neon and helium. An experimental campaign for this is under way.

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