SOLEDGE2D-EIRENE simulations of WEST H-mode plasmas: divertor regimes and heat deposition pattern

G. Ciraolo[1], H. Bufferand[1], G. Dose[1], J. Bucalossi[1], D. Galassi[2], Ph. Ghendrih[1], J. Denis[1], N. Fedorczak[1], G. Giorgiani[1], J. Gunn[1], Y. Marandet[3], E. Serre[2], P. Tamain[1]

[1]*CEA, IRFM, F-13108 Saint-Paul-Lez-Durance, France.*

[2]*Aix-Marseille Université, CNRS, M2P2, F-13451 Marseille, France.*

[3]*Aix-Marseille Université, PIIM CNRS, F-13013 Marseille, France.*

Heat deposition onto plasma facing components is regarded as one of the open issues to be addressed by ITER. Complex non-linear mechanisms are at work such as transverse and parallel transport, multi-species interactions and radiation. Important changes of regimes are known to occur for relatively weak changes of the core plasma conditions making prediction most uncertain. Several parameters are however clearly identified as being important for relevance to the fusion program. First, operation with metallic walls, with no carbon leak, is mandatory. Second, the slow evolution of tungsten radiation in leading experiments such as JET indicates that long steady state pulses are required to assess regimes of interest. Third, matching to ITER constraints requires operation with little margin with respect to the H-mode threshold. In that framework, WEST operation offers a unique opportunity to investigate regime that comply with these constraints. It is also a challenge for the modeling community since predictions will soon be confronted to experimental evidence at the device comes into operation.

In view of the first experimental campaign of the WEST tokamak [1], we make predictions regarding the divertor operation with the transport code SOLEDGE2D [2], a multi-species plasma solver for edge and SOL plasma coupled to EIRENE [3] for neutrals. SOLEDGE solves equations for densities, parallel velocities, temperatures and electric potential in realistic wall geometry and flexible magnetic configuration (SN, DN, SF+, SF-…). Thanks to advanced numerical scheme it is able to model the plasma up to the main chamber wall as shown for example on Fig. 1 (left panel).

Heat deposition pattern

Using edge transport codes in a predictive way is a challenge since turbulent transport is not modeled self-consistently. Even for WEST that lies within the range of present devices, one faces a challenging issue.

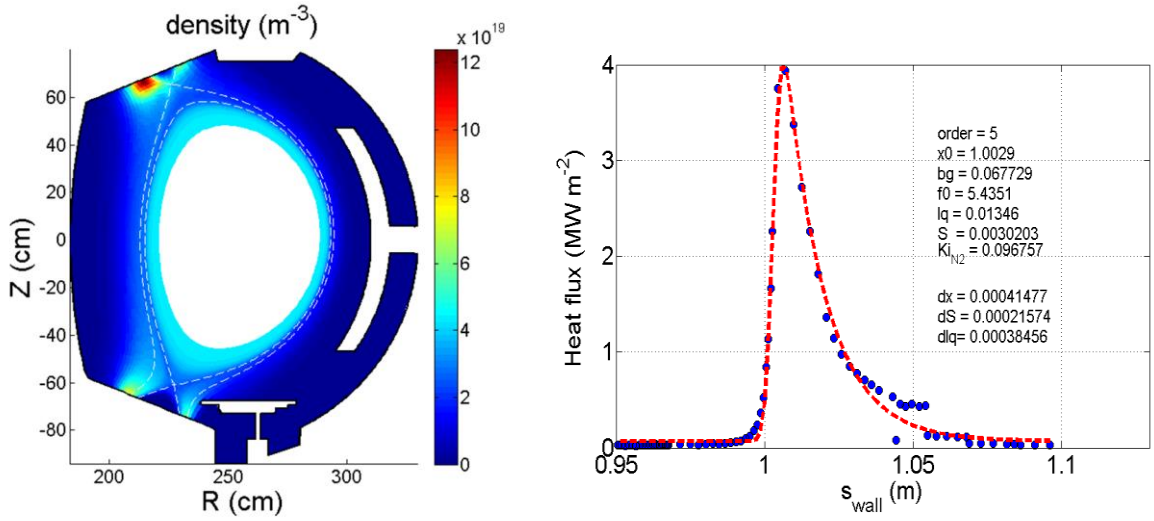

Figure 1: Left panel: Example of a 2D contour plot of electron density in a poloidal section of WEST computed with SOLEDGE2D-EIRENE for a pure deuterium discharge with P_{sol}=4MW and AUG-like transport barrier. Right panel: corresponding heat flux profile along the wall coordinate on the outer strike point of the bottom divertor.

For this reason, the radial transport coefficients have been chosen taking into account parameters which have been adjusted to match experimental mid-plane profiles of H-mode ASDEX Upgrade plasma [4]. In a previous work the validation of SOLEDGE2D-EIRENE on this ASDEX Upgrade discharge has been reported, showing a very good agreement between numerical and experimental results [5]. Using the same radial transport coefficients, simulations of WEST H-mode divertor scenarios have been performed for pure deuterium discharge (see also [6]). The input power entering the SOL is set to 4MW equally distributed between ions and electrons. The wall material is tungsten and we set the recycling coefficient equal to 100% on the entire wall apart from the pumping zone region under the baffle. The outboard midplane density is controlled via gas puffing from the private flux region. On Figure 1, right panel, we report the heat flux profile on the outer strike point of the bottom divertor obtained for outboard midplane density of 2.5e19 m^{-3}. Heat deposition on divertor targets is analyzed in terms of the scrape-off layer power fall-off length, λ_q, and of the spreading factor S which takes into account a local spreading in the machine-specific divertor volume, as expressed by the following expression [see Ref. 7]

$$q = \frac{q_0}{2} exp\left(\left(\frac{S}{2\lambda_q}\right)^2 - \frac{s_{wall}}{\lambda_q f_x}\right) * erfc\left(\frac{S}{2\lambda_q} - \frac{s_{wall}}{\lambda_q f_x}\right) + q_{BG}$$

Fitting the numerical profiles with this expression and remapping to the midplane location taking into account the flux expansion f_x, equals to 3 in this case, we obtain an estimation of

λ_q, of about 4.5 mm, in the range of the expected values for WEST as derived from scaling laws [8]. Looking at the profile along the wall, we observe a drop in the heat flux around the value s_{wall} =1.05. This is due to the presence of the baffle located in the Low Field Side bottom divertor region which intercepts a part of the heat flux flowing in the far SOL from the midplane region along the magnetic field lines toward the target plates.

The numerical results obtained for several midplane densities, indicate that the spreading factor S increases linearly with the upstream density, in agreement with a recent scaling law [9]. The associated physics is twofold. On the one hand the midplane density increase governs a nonlinear drop of the divertor temperature, increasing the transit time to the target plate and thus favoring cross-field transport mechanisms in the divertor volume. On the other hand, heat conductivity is strongly decreased with the temperature so that the coldest point along the field lines acts as a heat flux limiter, again favoring cross field transport mechanisms. The relative weight of these two mechanisms is under investigation.

Density ramp, divertor regimes and detachment rollover

We have performed a density ramp injecting 1e22 deuterium atoms per second from the Private Flux Region with the same setting of simulation parameters considered in the previous section. We report on Fig. 2, left panel, a snapshot of the 2D contour plot of the ionization pattern in the divertor region showing the front moving from the divertor plates to the X-point region. More quantitative informations can be derived from the evolution of target quantities as a function of the upstream (or midplane) density. On Fig.2, right panel, the maximum electron temperatures on the inner and outer target as a function of the midplane density are reported.

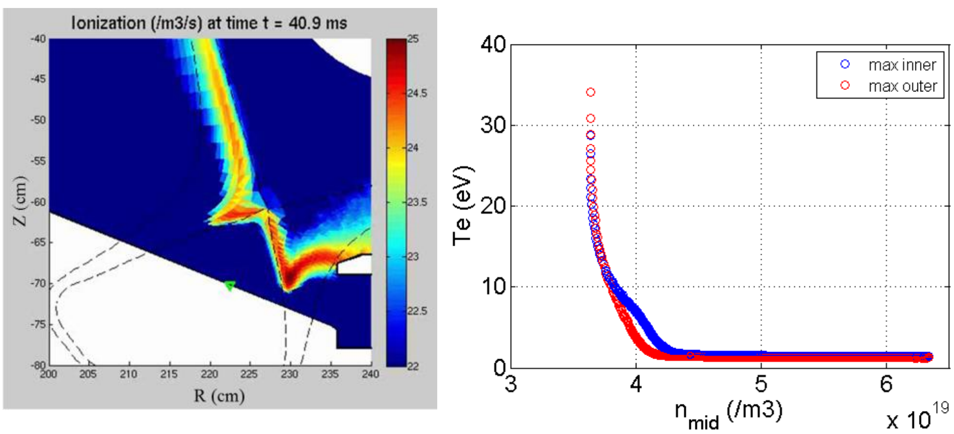

Fig.2 Left panel : 2D contour plot of the ionization pattern in the divertor region. Right panel: evolution of target temperatures as a function of upstream density.

Finally, on Fig 3, we show the evolution of particle flux and density on divertor targets as a function of the midplane density. We observe the expected behavior with first a strong increase of target density and particle flux when the transition from sheath limited to high recycling regime takes place and second a rollover and the following decrease of these quantities at the target when the detached regime is reached.

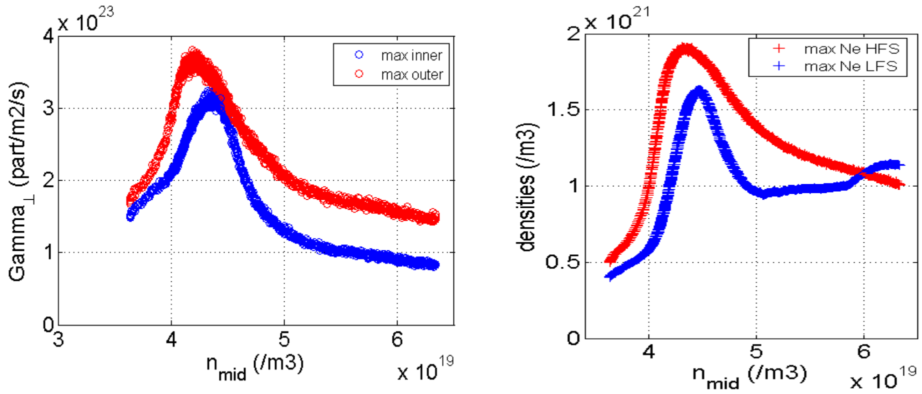

Fig. 3. Left panel: particle flux on the inner and outer target as a function of midplane density. Right panel: evolution of the density on inner and outer target as a function of the midplane density.

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