Neutral transport behavior expected for the first limiter plasmas in W7-X

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1. Introduction

The first W7-X plasmas will be operated with five local limiters periodically positioned on the inboard midplane of the bean-shaped cross-sections, each having a dimension of ~0.1m (toroidal) × 0.85m (poloidal) [1]. In comparison to the more sophisticated divertor modules, which will be installed somewhat later on the top and bottom of the bean-shape planes, the inboard limiters have the geometric features of a much shorter distance to the plasma centre and a much smaller plasma-coverage (see figure 1). Moreover, no specific baffle arrangement is taken to prevent the limiter-recycled and the CX-induced neutrals from escaping from the recycling zone into the main chamber. The inboard limiters present a completely different recycling environment and thus provide a useful reference for assessing the neutral control performance of the island divertor started later. This paper presents an EMC3-Eirene evaluation on how differently the recycling neutrals are expected to behave between the limiter and a divertor configuration.

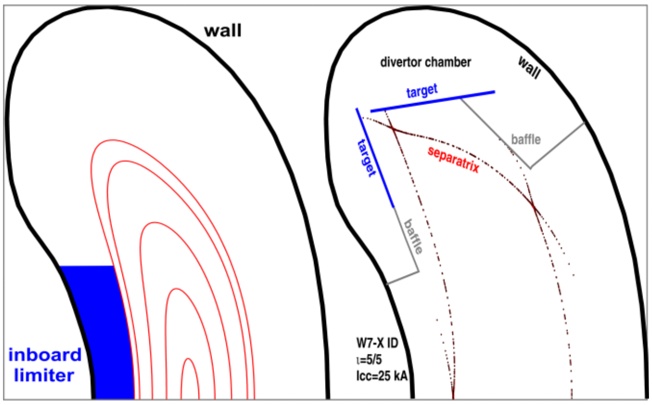

Fig.1: inboard limiter (left) vs island divertor.

2. Boundary conditions

The inboard limiters are optimized for a standard configuration with 13% field contribution from the planar coils which shifts the ι=5/5 resonance outwards far beyond the limiters. The limiters are positioned at the r~50 cm flux surface over several decay lengths in front of the not-yet-finished divertor and other in-vessel components. First EMC3-Eirene simulations have shown that ~99% of the SOL power and more than 97% of the ion efflux are intercepted by the limiters, with the rest ions practically making no contributions to the recycling and sputtering processes. For these reasons, the not-yet-tiled divertor frame is not taken into account in the

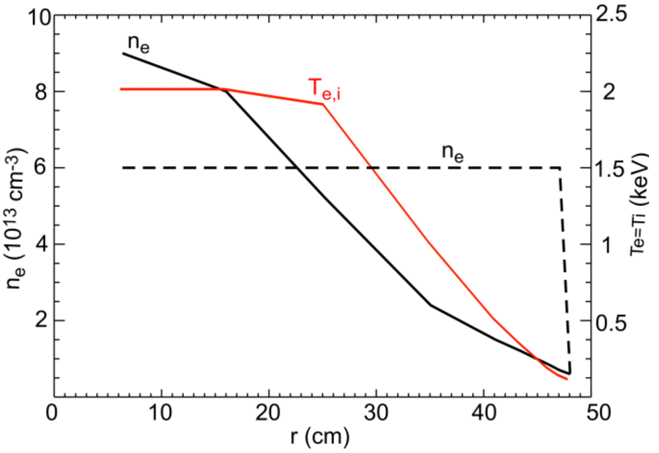

Fig.2: core plasma profiles assumed in EMC3-EIRENE simulations.

computations presented in this paper. Neutrals are traced throughout the whole device from the plasma centre all the way to the wall, while plasma transport is simulated in the edge region starting from a flux surface 2-3 cm inside the LCFS. Core plasma (hydrogen) profiles are prescribed, as shown in figure 2. Here, it is assumed that T_e=T_i. Because of uncertainties in anomalous transport, two extremely-different n_e-profiles are assumed (see figure 2). Cross-field transport coefficients are fixed in all the calculations as D=1 m^2/s and $\chi_i=\chi_e=3\times D$. The power entering the SOL is set to be 2 MW, being a compromise between limiter and divertor plasmas to be compared. This value of SOL power might be the maximum allowed in the initial limiter phase, but is considered to be the minimum for a later divertor operation with regard to its neutral transport control performance.

The divertor configuration chosen for comparison is a standard one without the planar coils, but with the island control coils (Icc=25kA) in order to get a similar confinement volume to that of the limiter configuration. Both configurations are based on vacuum fields.

Impurity radiation is not taken into account. Related works are referred to in [2].

3. Particle refueling

Based on the flat density profile (see figure 2), respective SOL density scans are performed for the limiter and divertor configuration. The results are shown and compared in figures 3 and 4, where the neutral influxes across each flux surface are plotted as a function of effective radii. Outside the separatrix of the divertor configuration no closed flux surfaces exist and the "effective" radius is then defined by cylindrical approximation of the mesh surfaces. The limiter SOL is too thin to stop the recycling neutrals, being the reason for the flat particle flux profiles outside the LCFS. Increasing the separatrix density and the recycling flux thereby leads to a linear growth of the core-refueling particle flux. The form of the profiles does not change (see explanation later). In contrast, the edge islands in the divertor configuration capture most of the recycling neutrals, causing significant decays of the neutral penetration flux before reaching the confinement region – a basic divertor function element. This neutral screening effect is strengthened with raising the plasma density in the SOL and can become so strong that the neutral penetration flux into the core even drops with increasing the total recycling flux. For the parameter setup given in section 2 the neutral penetration flux reaches a maximum at $n_{es}=1\times10^{13}$ cm^{-3}. After this point, the core refueling capability of the recycling neutrals reduces. The limited refueling capability of the divertor neutrals offers a possibility for the core plasma density to be controlled independently by

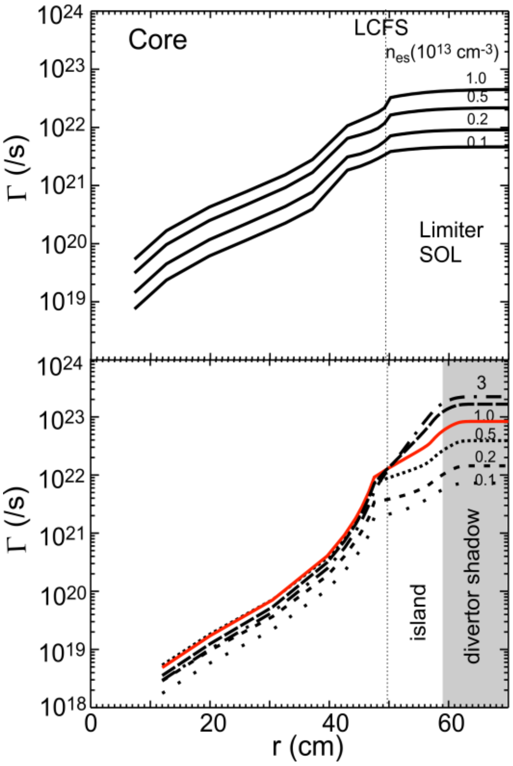

Fig.3: Neutral penetration flux profiles for limiter (top) and divertor configuration.

extra core fueling like pellets, presenting, however, also a challenge for the divertor, i.e. to pump out the external sources – the most critical issue of the island divertor concept.

The particle flux profiles inside the confinements differ between the limiter and divertor because of the completely different recycling locations around the bean-shaped plane (see figure 1). The distance of the limiter to the plasma centre is by about a factor of 2 shorter than that of the divertor targets, easing the neutral penetration. Consequently, the limiter results in flatter particle flux profiles than the divertor, as expected. The neutrals originating in the SOL or directly from the targets have relatively-low energies and cannot penetrate very deeply into the core, even in the limiter case. The neutrals populating the core, in particular the inner region, are predominantly the “high-energetic” CX-neutrals born in the confinement region. Their transport is largely determined by the core plasma and less sensitive to the SOL plasma condition. The former determines the form, while the latter is responsible for the level of the neutral particle flux profiles inside the core, as seen in figure 3. This is further confirmed by new computations using the peaked n_e-profile to replace the flat one. The results are shown in figure 4 where the limiter is compared to the divertor under the two different n_e-profile assumptions. The respective separatrix densities for the limiter and divertor are 5×10^{12} cm^{-3} and 1×10^{13} cm^{-3}. The reason for this choice is that we want to fix the total particle refueling rate (the particle flux across the LCFS). Here, we are interested in the core region only. In both limiter and diveror case, the flat n_e-profile decreases the neutral penetration length and reduces the neutral population in the inner core region significantly. Purely from the point of view of the neutral refueling source and without involving the core particle transport, a flatter core plasma density profile leads to a more hollow source profile and, in turn, would flatten the core profile further, and vice versa. If one assumes a flat core density profile for divertor plasmas and a peaked one in the limiter case, for a comparable total refueling rate, the limiter recycling neutrals provide a central plasma refueling rate that is almost by two orders of magnitude higher than that of the divertor neutrals.

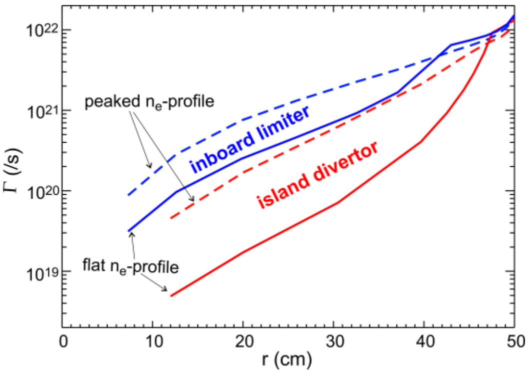

Fig.4: Sensitivities of neutral flux profiles to core density profile and SOL configuration.

4. Main chamber neutrals

Neutrals escaping from the recycling zones into the main chamber is harmful not only from the thermal point of view but also in view of their sputtering potential. Without a baffle system the first wall is fully exposed to the limiter recycling neutrals and, in particular, those induced by charge-exchange processes. The main target of bombardment of the neutrals is the naked cooper tiles surrounding the limiter. In this paper we are interested in the high-energetic neutrals hitting the wall and capable of producing impurities by means of sputtering processes. Here, we use the stainless steel wall as a representative target to filter out the low-energetic neutrals of less interest by calculating the total Fe-yield, Y_{Fe}, under hydrogen bombardment. For the limiter to be better compared with the divertor, we use the total particle refueling rate Γ_a as an independent parameter. It must be mentioned that the results shown in figure 5 are not self-consistent ones because the core density profiles are fixed while raising the SOL density. For simplicity, neutrals hitting the wall can be divided into two groups – one originating from the SOL and the other from the core region. Despite their small population, the neutrals escaping from core make comparable or even dominant contributions to Y_{Fe} because of their high energies. The significance of the core neutrals in Fe-production is clearly shown in figure 5. For the same SOL plasmas, switching from the peaked to the flat n_e-profile strongly reduces the neutral population in the inner hot core region (see figure 4 and 2) and, accordingly, the Fe-yields, almost independent of the edge configuration and recycling conditions (see figure 5). On the other hand, for a given core plasma, increasing n_{es} lowers the SOL temperature and thereby the sputtering contribution of the SOL neutrals. However, this reduction usually cannot compensate the increment of Y_{Fe} resulting from the core neutrals. As a consequence, the total Fe yield grows with increasing the recycling flux. It is particularly the case for the limiter where Y_{Fe} gradually increases throughout the scan range of Γ_a. This it is, however, only partially true for the divertor. With increasing the recycling flux and the divertor density thereby, more and more neutrals will be trapped in the recycling zone by the target and baffle plates so that the growth of Y_{Fe} can be stopped. This happens at $\Gamma_a \sim 6\times10^{21}$/s, before rollover of Γ_a. After the rollover of Γ_a both the SOL and core neutral contributions decrease, leading a rapid drop of Y_{Fe}, at a price of sinking refueling rates, however.

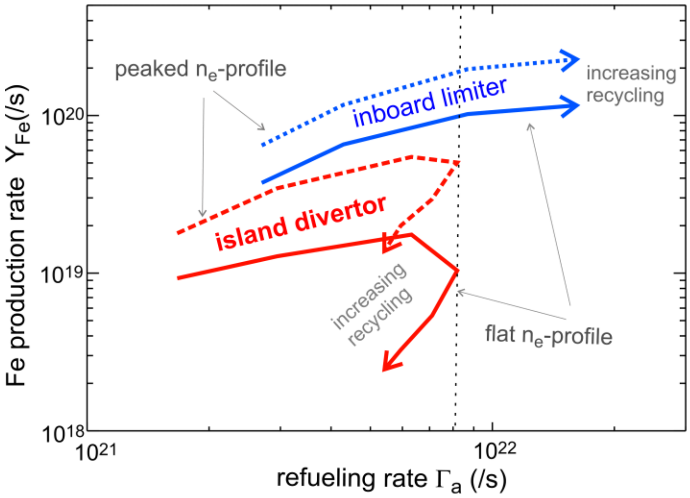

Fig.5: Fe-yield as a representative parameter for high-energetic neutral flux on the wall against particle refueling rate for different core density profiles: limiter vs divertor. The vertical dashed line indicates a reference case for which detailed particle flux profiles are given in figure 4.

In experiments, the particle source profile is usually constrained by establishing a desired core density profile, whatever via recycling or external fueling. Divertors, including the island divertor, cannot efficiently prevent the core CX-neutrals, particularly those from the inner core region, from entering the main chamber. Pay attention to the two curves shown in figure 5, i.e. the one for the limiter with flat n_e-profile and the other for the divertor with peaked n_e-profile. At $\Gamma_a \sim 8\times10^{21}$/s (indicated by the vertical dashed line), the limiter and divertor have similar particle flux profiles (see figure 4). In this case, the difference in Y_{Fe} between the divertor and limiter is within a factor of 2.

References

[1] S. Bozhenkov et al, this conference
[2] F. Effenberg et al, this conference