Assessment of ITER start-up limiter power handling on Tore Supra

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1. Introduction. The current design of the ITER start-up limiter consists of two modules located inside two opposite ports, on the outboard midplane [1]. The current choice for the front part of these limiters is beryllium. The two limiters can be misaligned relative to each other by 1 mm. The power load distribution at the limiter surface is estimated from model calculations [2] using assumptions on physical quantities that require to be characterized by experiments on existing devices. Experimental informations from JET and Asdex Upgrade have already been obtained [3]. This paper reports on experiments that have been carried out on Tore Supra to investigate the scrape-off layer (SOL) conditions during current ramp-up and ramp-down at constant edge safety factor (q=4.6), and compare with steady state conditions. Two main issues are addressed: (1) scrape-off layer power flux profiles during transient phases of the discharge (2) which fraction of the power flowing to the plasma boundary is intercepted by the limiter, and what is the effect of an incomplete poloidal coverage of the SOL by the modular limiter.

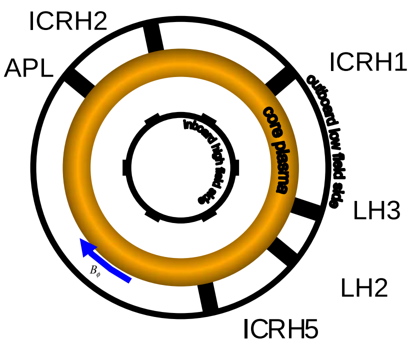


Fig. 1: *Toroidal locations of the modular limiters used in the experiment (1 limiter and 5 RF antennae).*

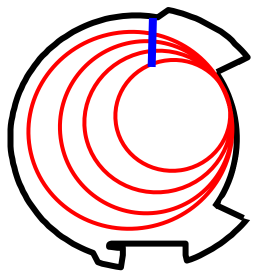
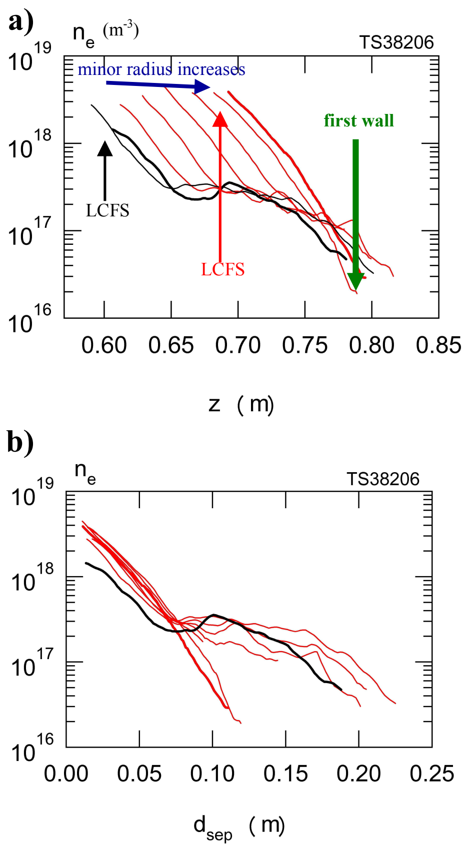


Fig. 2: *poloidal cross-section of Tore-Supra showing the increasing plasma minor radius and the position of the probe.*

2. Tore Supra experiment. Tore Supra is equipped with six modular limiters (one semi-inertially cooled limiter, and five RF antennae with actively cooled side protection tiles that can be used as limiters, since the technology survived tests at 20 MW/m^2), which, combined with a flexible real-time feedback control system, makes it the ideal tokamak in which to perform such experiments. In the experiments reported here, the plasma minor radius is ramped from 0.42m to 0.65m with the plasma current feedback controlled on q=4.6. The SOL profiles are measured by a reciprocating Langmuir probe located on top of the torus. The heat flux to the limiter is measured by infrared thermography. The experiment is performed first using only one limiter, and a radial gap to the wall of 0.12m (sections 3). Section 4 shows the results when two limiters or several limiters are used.

3. SOL profiles with one limiter. Figure 3a and 3b show the density profiles measured in the SOL during the ramp-up phase of the discharge with q=4.6. The profiles are plotted versus the vertical position of the probe (Fig. 3a), and versus the computed distance at the sepatratrix (Fig. 3b). For the smallest values of the minor radius, a wide SOL is observed, the power flux (Fig. 3c) decaying with λ_Q~2.5cm on a distance of ~ 6-7cm, and then the plasma 'fills' the vessel up to the wall with a much larger decay length. This observed λ_Q~2.5cm is in the upper range of the energy decay lengths that are used in present calculations of the heat load on the limiter surface in ITER (1.0cm<λ_Q <3.0cm) [2, 4].



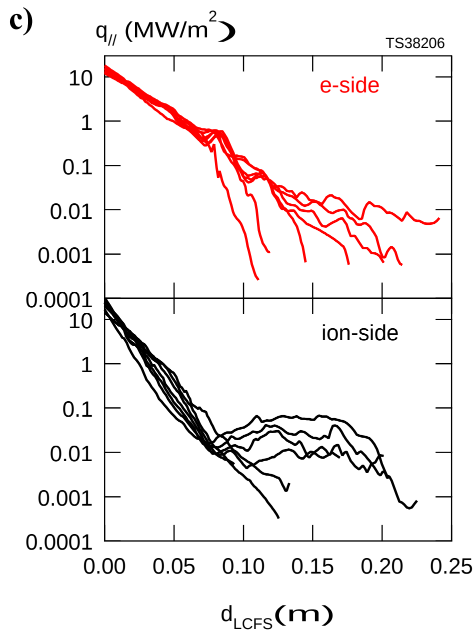


Fig. 3a*(top) and* **3b***(bottom): electron density profiles measured by the reciprocating Langmuir probe during the current ramp-up, plotted versus the vertical position of the probe(top) and versus the computed distance to the separatrix (bottom). The different profiles correspond to increasing minor radius (smallest minor radius in black).*
Fig. 3c*: corresponding parallel heat flux on the two sides of the probe.*

3.1. Current diffusion time. Figure 4 shows the electron temperature and current saturation profiles measured during the current ramp up and steady-state phases, for two values of the plasma minor radius. The scrape-off layer power flux profiles during transient phases of the discharge are very similar to that in the steady-state phase, indicating that the current diffusion time (much longer than the poloidal transit time in the SOL), and the transient terms in the power balance do not play a significant role.

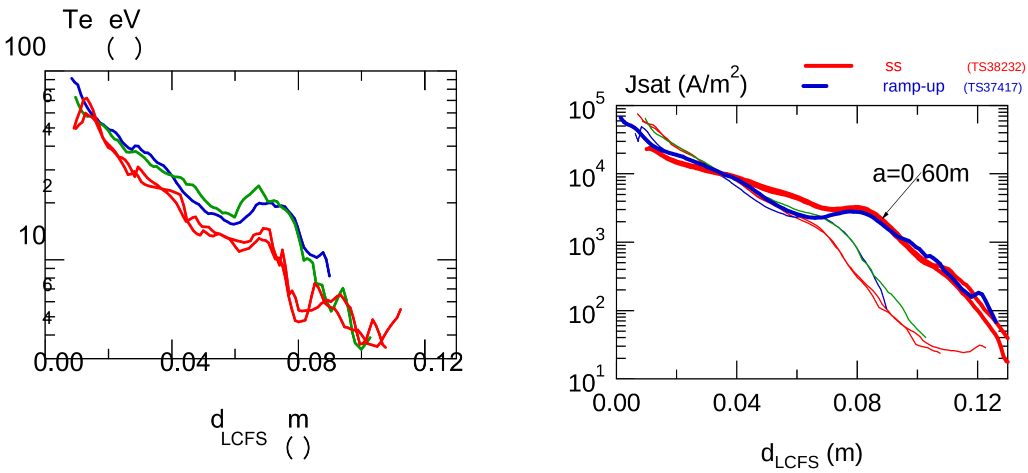


Fig. 4: *Transient and steady-state electron temperature profiles (left) and current saturation profiles (right) measured in the SOL for two values of the plasma minor radius*

3.2. Power flowing to the SOL.

Figure 5 shows that 50 to 70% (depending on the precise connection lengths on the electron or ion side of the probe) of the power flowing to the SOL is deposited within 2cm outside the separatrix. The remaining power (which can be as high as 50% of the power flowing to the SOL) is deposited further in the SOL.

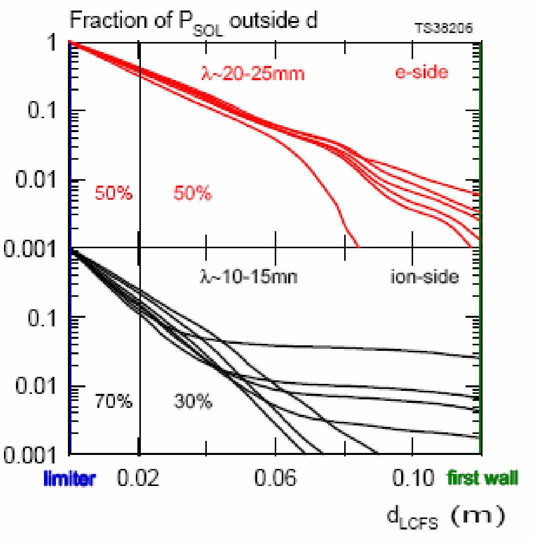


Fig. 5: *measured fraction of the power flowing in the SOL deposited outside d to the separatrix.*

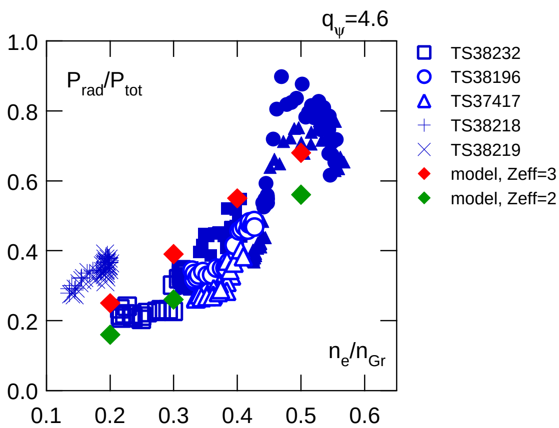


Fig. 6: *fraction of radiated power versus fraction of Greenwald density, measured in the ramp-up phase of the discharge*

3.3. Density regimes for constant q=4.6.

A possible issue of the startup phase in ITER may be that during a purely Ohmic ramp-up at high densities (n_e/n_{Gr} ~ 0.4–0.5, where n_{Gr} is the Greenwald density) the source of heating may not be enough to offset radiative losses. Figure 6 shows that in the Tore Supra experiment with carbon as main radiating impurity, P_{rad}/P_{tot} reaches ~0.9 for n_e/n_{Gr} ~ 0.5, and ohmic power P_{tot}~0.8MW. The measured total radiated power, and the plasma effective charge are consistent with the multi-machine scaling [4].

4. Several poloidal limiters

The SOL profiles measured using two limiters in opposite ports and with a radial misalignement of ~ 1.0cm are very similar to that observed with only one limiter. When six limiters are used, only the steep decay region is observed (Fig. 7) consistent with a picture of short connection lengths.

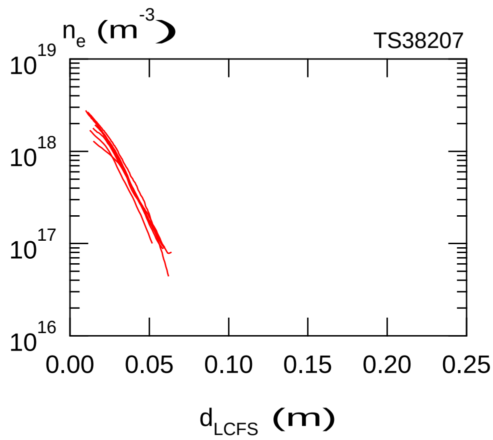


Fig. 7: *electron density profile measured in the SOL when 6 limiters are used.*

5. Conclusion. Experimental information has been obtained to provide additional basis for the design of the ITER start-up limiters. Two radial regions are observed in the SOL during minor radius ramp-up: 1) a region with short power decay length : λQ~20-25mm e-side / 10-15mm ion-side, 2) a region with much larger decay length extending further to the wall. Transient / steady-state SOL profiles are very similar. Very similar results are obtained for 2 limiters misaligned by ~1cm. Radiative losses reach 90% of the ohmic input power for n_e/n_{Gr}~0.5, and a roll over in the radiation increase (indicative of detachment) is observed for n_e/n_{Gr}~0.55.

References

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[2] M. Kobayashi et al., Nuclear Fusion **47** (2007) 61-73.

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