Coupled Core/SOL Modelling of Fuelling Requirements During the Current ramp-up of ITER L-mode plasmas

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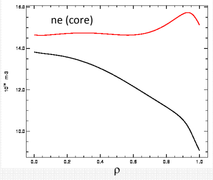
Introduction

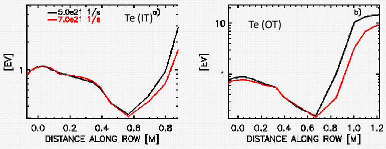
Is it possible for the plasma to reach minimum density during the current ramp up for the NBI to be switched on and avoid shine through with just gas puff alone?

- A Series of simulations with increasing gas injection-rates has been carried out with the integrated Core/SOL suite of codes JINTRAC [1]
- The currents used for this study are:, 5 MA, 10 MA and 15 MA; with Electron Cyclotron Heating (ECRH) of 5 MW, 10 MW and 20 MW respectively.
- If it is not enough than what changes are needed to satisfy the NBI shine through criteria:
  - Increase the input power, 20 and 40 MW of ECRH power for 10 MA plasma current
  - Decrease the heat and the particle diffusivities within the SOL for the 10 MA plasma current

JINTRAC Simulations settings for 5, 10 and 15 MA

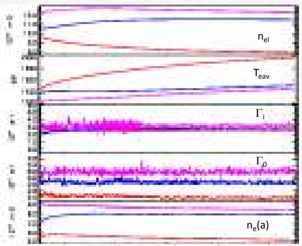
- The grid for 5 and 10 MA were adapted from the 15 MA.
- At the SOL, optimized EDGE2D/EIRENE code settings obtained by a dedicated benchmark between SOLPS and EDGE2D were used.
- In the core, JETTO simulations were set by previous ITER simulations in L-mode plasma with 25% of the Greenwald limit.
- The gas rate limit was set when the plasma was fully detached
  - At fully detached plasma the, Te < 1eV for a region of $r\text{-}r_{sep} > 50$ cm.
  - Incrementing the gas beyond detachment the density goes out of control.





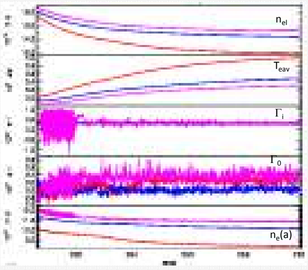
- The simulations have been continued until steady state was reached for a given input power and main gas inlet rate. Steady state conditions correspond to a steady core density during at least one energy confinement time, which for L-mode ITER plasmas is around 3s. In average the simulations took 10 s of plasma time to reach steady state.

5 MA density scan and 5 MW ECRH power

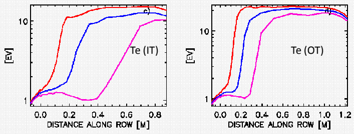


- Time traces of the simulations with: 1.0e21 1/s; 3.0e21 1/s and 5.0e21 1/s
  - The plasma reaches detachment with a neutral flux of 5.0e21 1/s
- The minimum required for the line average density for the NBI to be switched ON is 2.5e19 m-3. The maximum density reached was 1.25e19 m-3

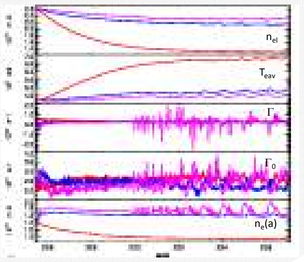
10 MA density scan and 10 MW ECRH power



- Time traces of 10 s of the simulations with: 3.0e21 1/s; 6.0e21 1/s; 1.0e22 1/s
  - There is no significant increase of the density in the core, while the temperature at the target decreases quite significantly.
- The maximum density reached was 1.55e19 m-3



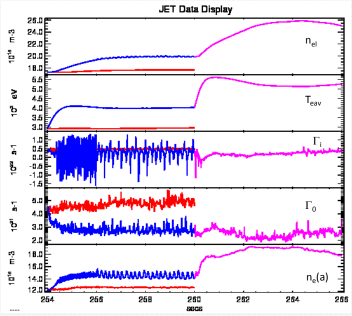
15 MA density scan and 20 MW ECRH power

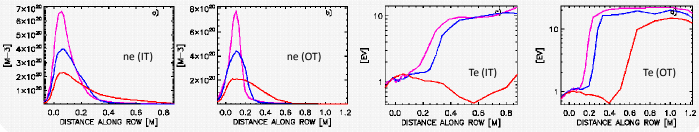


- Time traces of the simulations with: 3.0e21 1/s; 1.0e22 1/s; 2.0e22 1/s
- The minimum density to avoid shine through was only reached when 2.0e22 1/s puff rate was used.
- It is clear from the current ramp up that it is possible to increase the inlet rate by increasing the input power. The plasma detachment occurs at the much higher rate

10 MA power scan

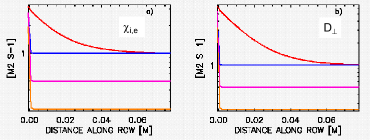
- Time traces with 1.3e22 gas rate and different input power of ECRH:
  - 10 MW; 20 MW; 40 MW
- The density increase starts at the edge and propagates to the plasma core.
- The density increases with input power because the density in the main SOL and mainly in the divertor increases.
- The minimum line average density for the NBI shine through was achieved with 40 MW of ECRH



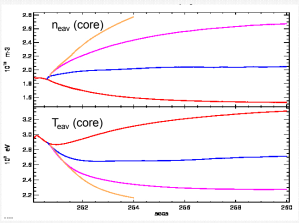


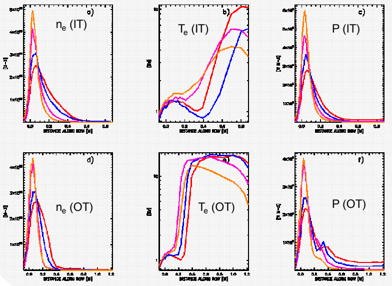
10 MA SOL transport coefficients scan

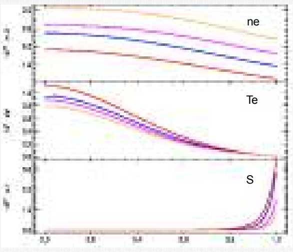
- Tanh decay to the far scrape off layer to :
  - $\chi_{i,e} = 1.0$ m²/s and $D_\perp = 0.3$ m²/s
- Different transport outside the last closed flux surface with constant transport coefficients:
  - $\chi_{i,e} = 1.0$ m²/s and $D_\perp = 0.3$ m²/s
  - $\chi_{i,e} = 0.5$ m²/s and $D_\perp = 0.15$ m²/s
  - $\chi_{i,e} = 0.25$ m²/s and $D_\perp = 0.07$ m²/s



- The average core density decreases and the average core temperature increases with the transport in the SOL
- The density increase is mainly due to the density at the separatrix and not to the neutral flux
- The divertor conditions changed with the SOL transport. The density and power width at the divertor targets decreased with the transport at the SOL
- Simulations for the JET in L-mode plasmas at high recycling regime with different edge codes reached similar of transport coefficients, $\chi_{i,e} = 0.5$ m²/s and $D_\perp = 0.15$ m²/s, in order to match the density and temperature profiles at the outer mid plane separatrix and at the outer divertor target [1,2].







Conclusions

- During the current ramp up not only the input power has to increase but also the gas fuelling rate.
- For a given input power the density increases with the gas inlet rate until an optimum density. Further increase of the gas decreases the temperature in the divertor but the density does not increase at the separatrix
- The input power increases the density for a given deuterium puff because the density in the main SOL and mainly in the divertor increases.
- The plasma also can be feed by the neutrals but on the cost that the divertor becomes unstable and very cold
- The plasma density is dependent on the assumption of the plasma transport not only in the plasma core but also in the SOL

[1] Groth, M., et al, 38th EPS, Strasbourg, France 2011, [2] Wiesen, S., et al, 19th PSI San Diego, USA, 2010

This work was funded jointly by the RCUK Energy Programme and F4E

Grant 502 (under ITER Task Agreement C19TD51FE)..