Effect of the initial ELM on impurity transport in hot ion H mode plasma

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Introduction

The high pedestal temperature H-mode experiment at JET gave a good opportunity to study
the effect of a single ELM on the particle transport, because these H-mode plasmas are
characterized by a long ELM free period after the L to H transition and the 2nd ELM occurs
several 100 ms later [1]. It is apparent from figure 1 that in all of these pulses the nₑ and the
Zₑff increase slowly in time before the first ELM and significant increase of the nₑ and Zₑff at
the time of the 1st ELM. At the first sight this contradicts the previous experimental
observation that ELMs remove impurities from the plasma core [2]. Then what is the
difference between these high pedestal H-mode plasmas and the typical H-mode plasmas at
JET and other machines? We will try to answer this question using the 1.5D core transport
code JETTO/SANCO.

Modelling

To simulate a high pedestal temperature we used the pulse 75417 as a template and we started
the JETTO/SANCO simulations just after the L to H-mode transition at 53.5 s and ended the
simulation at 55.0 s, half a second after the first ELM for this pulse. The high temperature
plasmas do not reach the steady state before the first ELM, which leads to an extra unknown
into the simulations, the neutral sources. To fit the time traces of the Zₑff and the line average
nₑ, (figure 2), C was introduced at the wall in all the JETTO/SANCO simulations (with and
without ELMs) with ΓᵥₑC = 8.0×10¹⁹ 1/s during the ELM free period to fit the experimental
time evolution of the Zₑff. To mimic an extra influx of C observed in figure 1d we increased
ΓᵥₑC to 3.0×10²² 1/s just before the ELM during 70 ms. SANCO has a rude description of the
transport in the SOL and the fast parallel transport is not included. ΓᵥₑC at the edge and the

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¹ See the Appendix of F. Romanelli et al., Proceedings of the 22nd IAEA Fusion Energy Conference, Geneva,
Switzerland, 2008
\( \Gamma_{\text{inD,NBI}} = 1.2 \times 10^{21} \) 1/s in the plasma core were not sufficient to fit the time evolution of the line average \( n_e \), it was necessary also to introduce an extra gas through the LCFS of \( \Gamma_{\text{inD}} = 4.0 \times 10^{20} \) 1/s, while experimentally, was used \( \Gamma_{\text{inD}} = 2.0 \times 10^{21} \) 1/s. In all these simulations \( R = 1 \) was used for impurities and main ions; therefore in these plasmas the through put is around 20% and the effect of the \( \Gamma_{\text{inD}} \) is not negligible.

The transport model we used in the plasma core was the Bohm/GyroBohm empirical model, defined as [3]:

\[
\chi_c = c_c \left( 0.5 \chi_{BG} + 0.5 \chi_B + \chi_{neo} \right); \quad \chi_i = c_i \left( 0.5 \chi_{BG} + 0.5 \chi_B \right) + \chi_{i,neo};
\]
\[
D = c_c \frac{\chi_i}{\chi_c + \chi_i}; \quad V = 0.5 D \frac{\nabla q}{q} + V_{neo}; \quad c_i, c_c, c \begin{cases} \ll 1 & \rho < \rho_{\text{top}} \\ \rho \geq \rho_{\text{top}} & \end{cases} \quad L_{\text{ETB}} = (1 - \rho_{\text{top}}) a \approx 3 \text{ cm}
\]

Within the ETB the transport factors were determined by the time evolution of the \( \dot{W}_{\text{th}} \) before the first ELM, (figure 2).

**ELMs**

To simulate the ELM in JETTO/SANCO \( \chi_i \) and \( D \) are increased within the ELM perturbed region (\( d_{\text{ELM}} \)). In this model the ELM is trigged when the parameter \( \alpha \) defined by [5],

\[
\alpha = -\frac{2 \mu_0 R q^2}{B_r^2} \cdot \frac{\partial \rho}{\partial r}, \quad \alpha_{\text{crit}} = 1.54 \text{ in these simulations}. \quad \dot{W}_{\text{th}} \text{ drop and the } \chi_i \text{ (figure 3a) due to the ELM are dependent not only on the enhancement of the transport factors but also on } d_{\text{ELM}}. \quad \text{Figure 3d and figure 3c show that the jump of the line average } n_e \text{ and the } Z_{\text{eff}} \text{ increases are also dependent on the } d_{\text{ELM}}. \quad \text{For this reason the enhancement of the } c_i, c_c \text{ and } c \text{ were determined by the } \dot{W}_{\text{th}} \text{ drop of the ELM with the perturbed region of 33 cm (figure 3b).}
\]

Although \( d_{\text{ELM}} \) is much wider than it is observed in typical JET H-modes plasma (\( d_{\text{ETB}} = d_{\text{ELM}} \)). Figure 4 shows that the simulated change of the \( n_e \) and \( n_{\text{imp}} \) and \( T_e \) profiles due to an ELM describes well the change observed experimentally.

Figure 3d shows a slower increase of the \( Z_{\text{eff}} \) for the simulation without the ELM than the simulations with the ELMs. Hence the ELM removes impurities from the edge to the plasma core. In addition the increase of the \( n_e \) at the time of the first ELM is also observed, (figure 3c), and is mainly due to the influx of C. The 2\text{nd} simulated ELM reduces the \( Z_{\text{eff}} \), indicating removal of impurity from the plasma core. This leads us to the conclusion that the ELMs leads to a fast impurity penetration into the plasma core when the impurity density at the edge is higher than in the plasma core, and vice versa. Furthermore, after the first ELM the recovery of the \( \dot{W}_{\text{th}} \) is slower for the experimental plasma than for the simulated one, thus the plasma confinement is reduced after the first ELM.

**Conclusion**
It is clear from these JETTO/SANCO simulations that the high pedestal temperature plasmas are more transparent to the D in the SOL than expected [6]. The increase of the $Z_{\text{eff}}$ effect observed experimentally is indeed due to the C released from the walls. The ELMs leads to a fast impurity penetration into the plasma core, observed in the $Z_{\text{eff}}$ signal, when the impurity density at the edge is higher than in the plasma core, and vice versa.

Acknowledgments

This work, which has been supported by the European Communities and the Instituto Superior Técnico (IST) under the Contract of Association between the European Atomic Energy Community and IST, was performed under the European Fusion Development Agreement. This work was also partly funded by the United Kingdom Engineering and Physical Sciences Research Council and by the European Communities under the contract of Association between EURATOM and UKAEA. The views and opinions expressed herein do not necessarily reflect those of the European Commission and IST.

References


Figure 1: Time traces relative to the time of the first ELM for the high pedestal temperature plasmas of: a) $D_n$, b) line average $n_e$, c) $Z_{\text{eff}}$ and d) $C^{+2}$ spectral line intensity.
Figure 2: Time evolution of the: a) $W_{th}$, b) line average $n_e$ and c) $Z_{eff}$ from CX. The traces are experimental (black) and the simulated cases: $\Gamma_{inC} = 0 \text{ s}^{-1}$ and with $\Gamma_{inD} = 4 \times 10^{20} \text{ s}^{-1}$ (green); $\Gamma_{inC} = 8 \times 10^{19} \text{ s}^{-1}$ and $\Gamma_{inC} = 0 \text{ s}^{-1}$ (purple) and with C and D sources (red).

Figure 3: a) ELM perturbation width at the $\chi_i$ profile and time evolution of the: b) $W_{th}$, c) line average $n_e$ and d) $Z_{eff}$ from CX. The traces are experimental (black) and the simulated cases without ELMs (red) and with ELMs perturbed region of: 3 cm (blue); and 33 cm (pink).

Figure 4: Simulated (continuous line) and experimental (dashed line) profiles of the: a) $n_e$; b) $n_{imp}$ and c) $T_e$, before the ELM (red) and after the ELM (blue).