SOLPS modelling of controlled ELMs for ITER.

D.P. Coster[1], A.V. Chankin[1], H.-J. Klingshirn[1], X. Bonnin[2], A. Kukushkin[3], A. Loarte[3]

[1] *Max-Planck-Institut für Plasmaphysik, EURATOM Association, Garching, Germany,*

[2] *CNRS - LSPM, Université Paris 13, Sorbonne Paris Cité, 93430 Villetaneuse, France*

[3] *ITER Organization, Route de Vinon sur Verdon, 13115 St Paul Lez Durance, France*

Introduction

The impact of controlled ELMs on ITER edge plasmas is explored using the 2D multi-fluid edge transport code SOLPS5.0-B2. Controlled ELMs in ITER are defined so that they produce transient loads on the divertor that do not lead to macroscopic material erosion (evaporation, melting). These ELMs will still give W influxes by physical sputtering caused by the high energy particles expelled by the ELM.

Simulations

The 2d edge plasma fluid code SOLPS5.0-B2[1] was used to simulate the edge region of ITER, figure 1, left. Steady state transport coefficients were chosen to match those used by the ITER team in the SOL and divertor, but lowered in the region inside the separatrix to give an approximately 6cm pedestal where a continuous small pellet particle fueling source was also used, figure 1, middle. The simulations include D and T as the main ion components, with noble gases He (produced by fusion power) and Ne (as extrinsic impurity for stationary divertor power load control), and sputtered sources of Be (from the main chamber wall) and W (from the targets) — 98 separate fluids in total.

Two values of the core input power were used: 100 MW to emulate 15 MA, Q = 10, H-mode, DT operation, and 40 MW to emulate 7.5 MA, low activation, H-mode plasmas. For the 40MW cases, in addition to cases with predominant DT, cases with predominant He were also simulated. A scan in electron density and Ne concentration was performed in order to build a

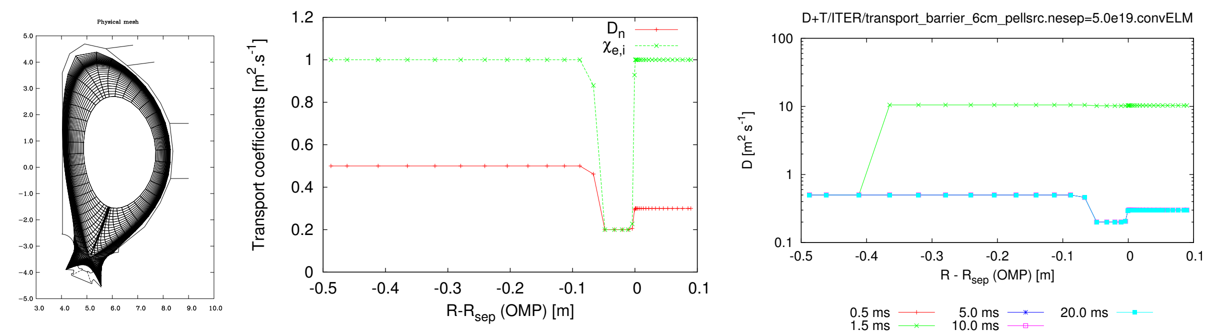

Figure 1: From left to right: the simulation grid used for the SOLPS simulations; the transport coefficients used for the steady state simulations; the transport coefficients used during the ELM at various times.

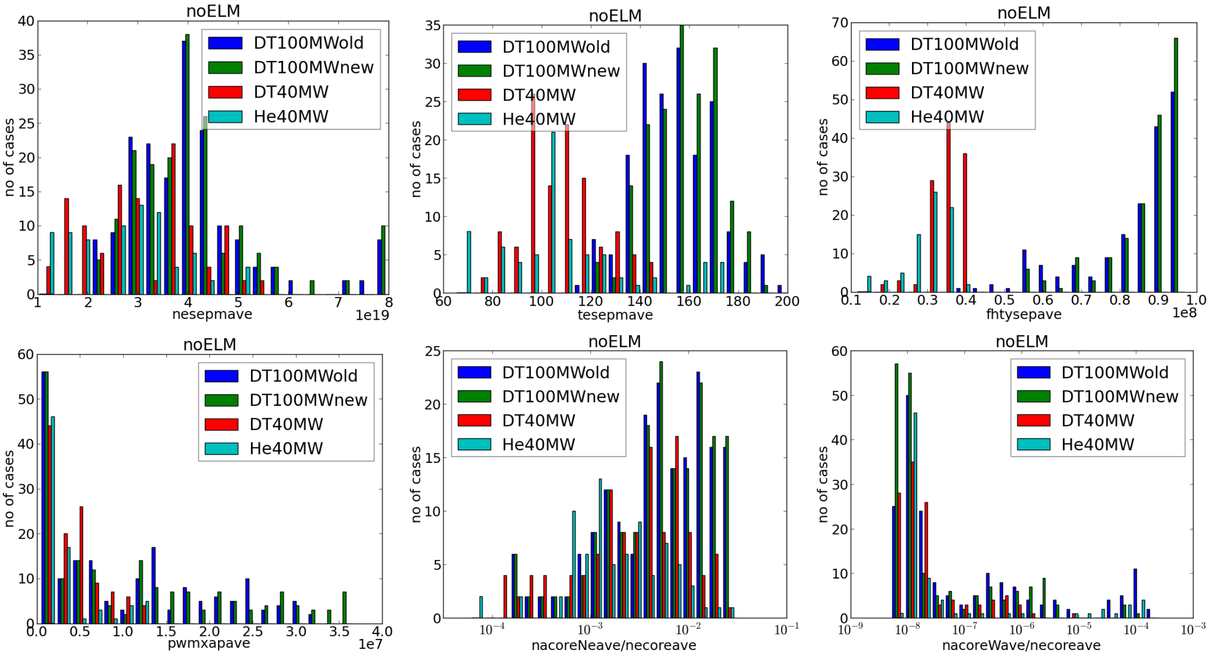

Figure 2: Characterization of the "steady-state" D+T+He+Be+Ne+W SOLPS5.0-B2 simulations. Histograms of average upstream separatrix electron density ("nesepmave"), average upstream electron temperature ("tesepmave"), total power crossing from the core into the SOL ("fhtysepave"), average peak power to the outer target ("pwmxapave"), average core Ne concentration ("nacoreNeave/necoreave") and average core W concentration("nacoreWave/necoreave"). The “new” and “old” for the DT100MW cases refers to a modification of the sheath transmission factors where old refers to typical values used in SOLPS5 and “new” is a better match to the values used by ITER for their modelling with SOLPS4; the 40MW cases were all done with the “new” sheath boundary conditions.

large database of potential ITER plasma edge conditions as starting points for the ELM solutions, as shown in figure 2. The simulations were carried out under the assumption of no prompt redeposition of W, as well as a model taking into account prompt redeposition of the W ions in their first Larmor orbit[2], figure 3. The prompt redeposition model used takes into account only the effect of the ionization of neutral W to the once-charged ion. A more sophisticated model including multiple ionizations and the effect of the electric potential in the magnetic sheath (currently in preparation[3]), provides for a similar degree of prompt redeposition as the simpler model.

The ELMs are modelled[4] by a transient increase in the particle diffusion coefficient during the ELM event (a “convective” ELM) with the transport increase designed to give $\Delta W_{ELM} \approx 1MJ$ which is the level expected for 15 MA, Q = 10 plasmas with mitigated ELMs, figure 1, right. In addition “large” ELMs were simulated by enhancing both the particle and energy diffusion coefficients to give an approximate 10 MJ ELM (of the order of the size of the “natural” ELMs). Figure 4 shows the normalized energy fluxes for typical small and large ELMs. Figure 5 shows the core “source” of W — actually the W flux from the SOL into the core plasma — as

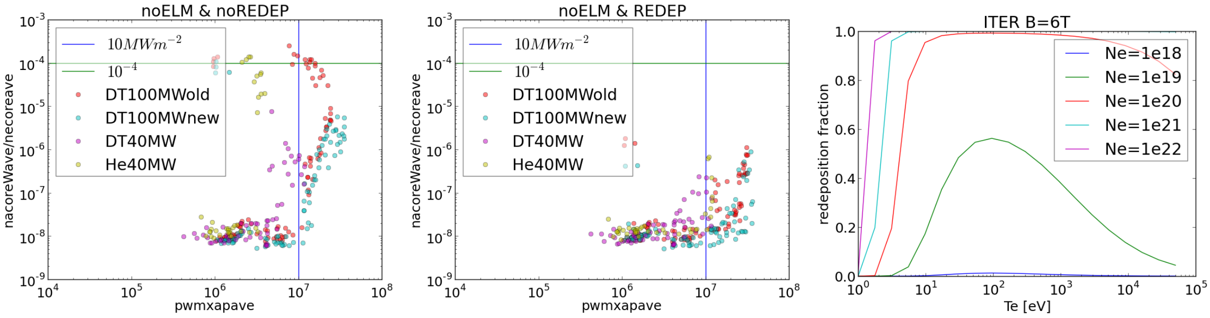

Figure 3: Plots of W core concentration versus peak outer target power, without and with prompt redeposition; prompt redeposition fraction as a function of electron temperature for a range of electron densities.

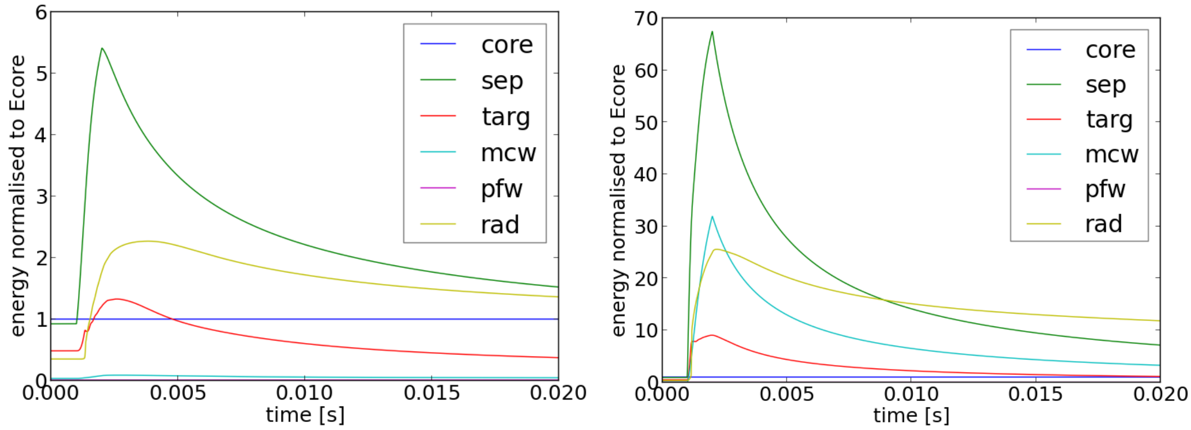

Figure 4: Time traces of energy fluxes normalized to the core energy flux for convective (left) and large (right) ELMs.

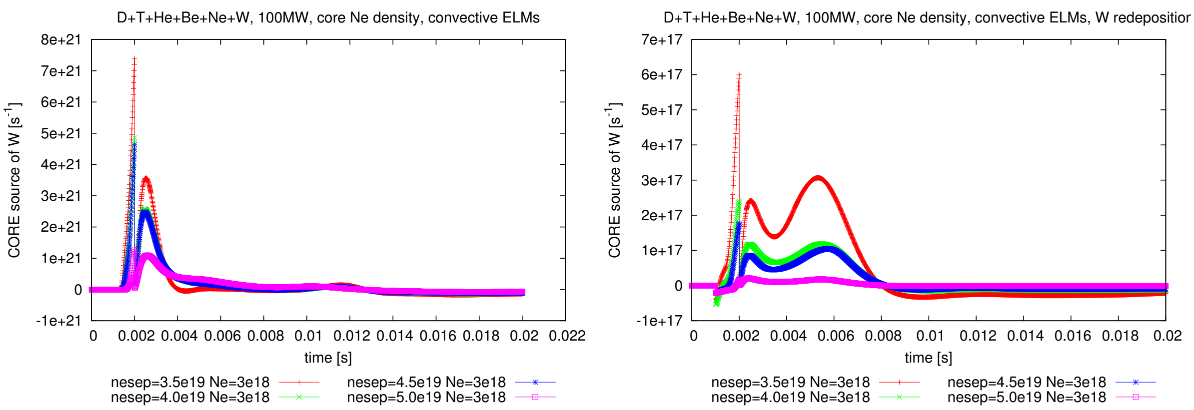

Figure 5: The flux of W across the separatrix into the core plasma as a function of time for, left, cases without prompt redeposition and, right, with prompt redeposition. For these convective ELM cases the Ne boundary conditions were kept fixed and the pre-ELM upstream separatrix electron density varied.

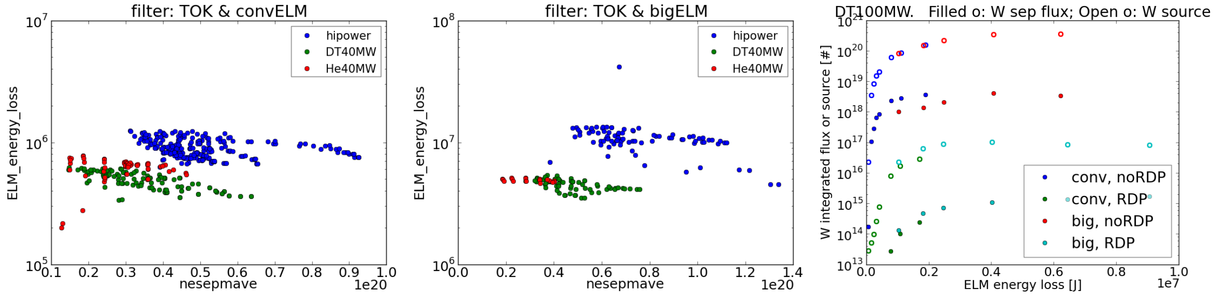

Figure 6: Left and middle, ELM energy loss for small, convective ELMs and large ELMs, plotted against the average upstream electron separatrix density. Right: the W sputter source and core influx of W for an ELM size scan.

a function of time for a subset of the convective ELM cases. The reduction of W from prompt redeposition can be clearly seen. Figure 6 shows the ELM energy loss for small and large ELMs across the database, as well as the W sputtering source and flux across the separatrix into the core for a dedicated ELM size scan.

Results and Discussion

For the steady-state simulations, the limit of 10 $MW \cdot m^{-2}$ peak power tends to be a stronger constraint than the W concentration in the core, and this becomes even more true in the case of prompt redeposition. In the case of ELMs, prompt redeposition provides for at least a 10^4 reduction in the amount of W arriving in the pedestal from an ELM event. Prompt redeposition has a particularly large effect in ITER because of the high plasma density ($> 10^{21} m^{-3}$), and correspondingly low ionization mean free path for neutral W, expected in the vicinity of the divertor targets.

Thus, if the magnitude of W prompt redeposition in ITER proves to be as large as estimated by the modelling presented in this paper and the other modelling assumptions are appropriate to describe ITER plasma behaviour, W divertor sources do not seem to pose a critical problem for ITER operation.

Acknowledgments

This work was supported by the European Communities under the contract of Association between EURATOM and IPP and CEA, and F4E-GRT-267. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

References

[1] R. Schneider, X. Bonnin, K. Borrass, D. P. Coster, H. Kastelewicz, et al., Contrib. Plasma Phys. 46 (2006) 3, DOI 10.1002/ctpp.200610001.

[2] R. Dux, A. Janzer, T. Pütterich, and ASDEX Upgrade Team, Nuclear Fusion 51 (2011) 053002.

[3] A. Chankin, R. Dux, and D. Coster, On tungsten redeposition at the divertor target, to be submitted to Plasma Physics and Controlled Fusion.

[4] D. P. Coster, Journal of Nuclear Materials 390–391 (2009) 826.