Integrated core-SOL simulations of H-mode access in ITER SRO scenarios

F. Eriksson[1], X. Bonnin[2], P. De Vries[2], R. Futtersack[1], L. Garzotti[1], S. H. Kim[2], F. Koechl[2], A. Loarte[2], E. Militello Asp[1], V. Parail[1], S. D. Pinches[2], A. Polevoi[2], T. Ravensbergen[2], J. Simpson[1], G. Suàrez Lòpez[1] and E. Tholerus[1]

[1]*UKAEA (United Kingdom Atomic Energy Authority), Culham Campus, Abingdon, UK*

[2]*ITER Organization, Route de Vinon-sur-Verdon, St. Paul Lez Durance Cedex, France*

Introduction

The start of research operation (SRO) in ITER will explore H-mode operation as well as commission control and protection systems including ELM mitigation systems [1]. For successful commissioning of the ELM mitigation systems, operation in stable ELMy H-mode is required. To inform the development of the plasma control system, fully integrated core, edge and scrape-off layer (SOL) divertor simulations are performed with the JINTRAC suite of codes [2] analysing the access to ELMy H-mode across SRO scenarios. The main objectives of this study are: to assess accessibility of the L-H transition across the SRO current and density ranges, to determine the minimum ECRH power required for stationary ELMy H-mode operation, to evaluate divertor operating conditions during H-mode phases, to assess the impact of intermediate ELMs on divertor power loading and tungsten sources and to provide quantitative input for future plasma control system development.

In this paper we concentrate on the results based on simulations of a deuterium plasma at 5 MA/2.65 T. Simulations at different current and field are in progress and will be presented in future. The modelling includes the L-mode, L-H transition and H-mode ELMy phases.

Simulations set-up

The simulations included in this paper scan a range of densities and deuterium gas puff is used to fuel the plasma to the required Greenwald density fraction, f_G, with the potential of adding pellets where gas fuelling is insufficient to provide the required density [3]. In particular, we investigated three density regimes: f_G=0.4 (low density, see also [4]), f_G=0.6 (medium density) and f_G=0.8 (high density). The modelling assumed the totality of the tungsten coming from the divertor with a prompt redeposition factor of 50% and a total auxiliary heating power of 40 MW of ECRH (deposited off-axis), which is foreseen for the SRO phase [5]. The core transport was modelled with the TGLF-SAT2 turbulent transport model. In addition to the main deuterium gas, the evolution of tungsten and neon impurity density was modelled self-consistently with the SANCO impurity transport code. A sawtooth period of 0.1 s was assumed and the sawtooth was modelled with the Kadomtsev full reconnection model. Discrete ELMs

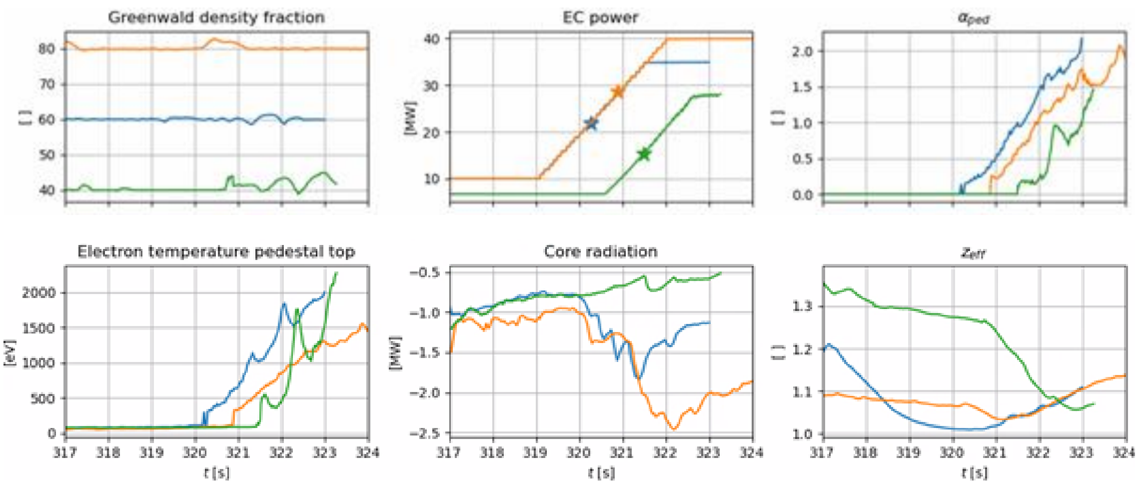

Figure 1: evolution of the main plasma parameters and predicted H-mode accessibility for the 5 MA/2.65 T ITER SRO scenario as a function of Greenwald density fraction.

were modelled by increasing the particle and heat transport coefficients in the edge transport barrier (ETB) for a fixed duration (typically 1-2 ms) and the ELM onset was triggered when the maximum normalized pressure gradient in the ETB, α, exceeded a critical value α_c=1.8 dictated by the ideal ballooning stability threshold.

Simulation results

In terms of accessibility of type-I ELM H-mode regime, the heating requirements for L-H transition and establishment of a robust type-I ELM regime are summarised in table I for different values of f_G.

Table I: predicted ECRH power requirements for H-mode access and type-I ELM regime.

Greenwald density fraction	L-H threshold	Power required for type-I ELMs
40%	~15 MW	~30 MW
60%	~22 MW	~35 MW
80%	~29 MW	~40 MW

The evolution of the most relevant plasma parameters during the ECRH power ramp inducing the L-H transition are shown in figure 1.

A transient increase in tungsten influx was observed during the L-H transition in all cases, demonstrating the importance of impurity monitoring during the transition phase. It was also noticed that the details of the pedestal formation were sensitive to the waveform of the applied ECRH power.

In terms of divertor heat loads, the simulations performed indicate that even in the worst case, at low plasma density, they never exceed 10 MW m^{-2}, the operational limit beyond which

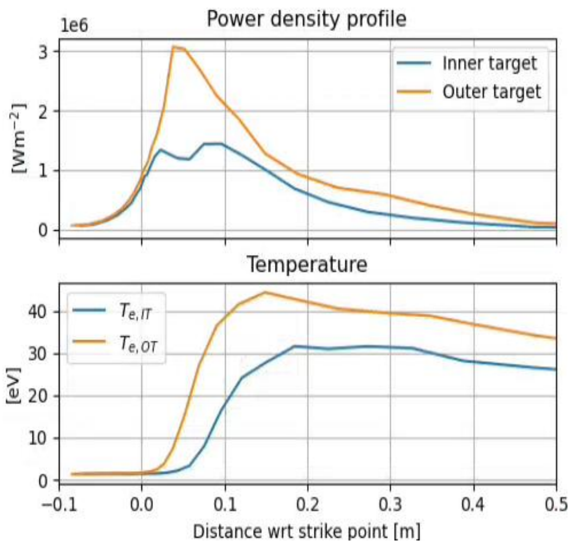

Figure 2: power density and temperatures profiles along the divertor inner and outer targets for an ITER deuterium plasma at 5 MA/2.65 T in the ELM-free H-mode phase and for f_G=60%.

damage to the divertor plates becomes possible. The main divertor parameters for the medium-density scenario are illustrated in figure 2, where we show the power density and the electron temperature profiles for the inner and outer divertor target, showing that predicted peak heat loads remain comfortably below the operational limits during both L-mode and ELM-free H-mode phases and strike-point electron temperatures remain below 5 eV, ensuring negligible physical sputtering of tungsten and therefore a minimal risk of tungsten core contamination. Moreover, the region where volumetric recombination exceeded ionisation was confined to the private flux region, indicating that detachment remained limited and well controlled and the plasma maintained a semi-detached divertor state throughout the scenario. In the high-density simulations we obtained significantly lower divertor heat loads with comparable ELM frequencies.

The ELMs characteristics for the medium and high-density scenarios are summarized in table II.

Table II: ELM parameters for medium and high-density simulations.

	Medium density	**High density**
Greenwald fraction	60%	80%
Absorbed ECRH	35 MW	40 MW
ELM frequency	30 Hz	28–30 Hz
ELM energy loss	0.6 MJ	0.45–0.57 MJ

Conclusions

Simulations of an ITER SRO scenario at 5 MA/2.65 T in deuterium performed so far show that even for the lower current scenario at 5 MA/2.65 T at f_G=60% the plasma is marginal for pedestal development using 30 MW of ECRH, assuming that the Martin scaling law holds. At the same current a high-density plasma at f_G=80% Greenwald density fraction needs at least 40 MW of ECRH to access a good quality H-mode.

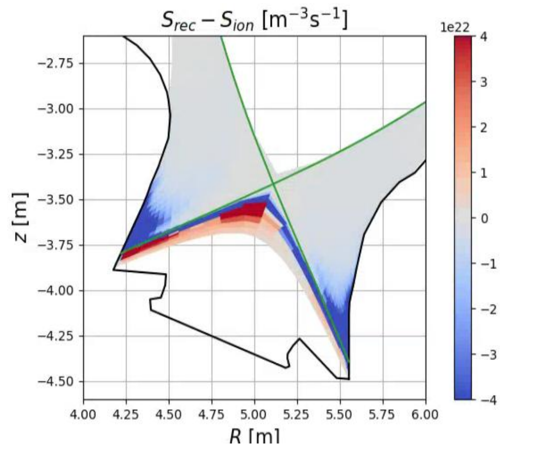

Figure 3: 5 MA/2.65 T ELM-free H-mode f_G=60%. Recombination rate dominating over ionisation rate limited to the private region.

In particular, the simulations demonstrate that ITER plasma control system operation during SRO will need to accommodate strong density dependence of H-mode accessibility and pedestal formation. Key findings include: H-mode access is achievable over the full density range investigated, ELMy H-mode requires approximately 30-40 MW of absorbed ECRH power, the pedestal formation is highly sensitive to the details of the ECRH deposition, intermediate ELMs remain compatible with divertor protection limits when 50% tungsten prompt redeposition is assumed, semi-detached divertor conditions can be maintained throughout the simulated scenarios, high-density operation significantly reduces transient divertor loading.

In summary, integrated JINTRAC simulations have demonstrated that it is possible to access and sustaining H-mode operation in ITER 5 MA/2.65 T SRO scenarios. The required ECRH power threshold for L-H transition increases substantially with plasma density, ranging from approximately 15 MW at f_G=40% to 29 MW at f_G=80% for H-mode access. Sustained ELMy H-mode operation requires between 35 MW and 40 MW of absorbed ECRH power. Divertor operation remains within acceptable limits throughout the scenarios considered, with average peak heat loads between 4 and 10 MW m^{-2}. The results provide a quantitative basis for future development of plasma control strategies and for extension of the analysis to the ongoing 7.5 MA/2.65 T SRO simulations.

References

[1] A. Loarte *et al.*, *Plasma Phys. Contol. Fusion*, **67** 065023 (2025)
[2] M. Romanelli *et al.*, *Plasma Fusion Res.* **9** 3403023 (2014)
[3] L. Garzotti *et al.*, this conference
[4] G. Suàrez Lòpez *et al.*, Core-edge integrated modeling of SRO plasma scenarios in the new ITER research plan using JINTRAC, to be submitted.
[5] M. Henderson, *Phys. Plasmas*, **22** 021808 (2015)