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S. Wiesen[1], V. Parail[2], G. Corrigan[2], W. Fundamenski[2], N. Hayashi[3], J. Lönnroth[4]
and JET EFDA contributors*

JET-EFDA, Culham Science Centre, OX14 3DB, Abingdon, UK

[1]Euratom FZJ Association, Institute of Energy Research, IEF-4, 52425 Jülich, Germany
[2]EURATOM-UKAEA Fusion Association, Culham Science Centre, OX14 3DB, Abingdon, OXON, UK
[3]Japan Atomic Energy Agency, Naka, Ibaraki-ken, 311-0193 Japan
[4]Euratom TEKES, Helsinki University of Technology, P.O. Box 4100, 02015 HUT, Finland
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INTRODUCTION

The oscillatory power and particle exhaust in magnetic fusion devices with high confinement (ELMy H-mode) exhibits a strong link between core and edge plasma with the Scrape-Off-Layer (SOL). Generically, the latter acts in a twofold way since it removes power and particles away from the upstream region but it also refuels the core and edge via interaction with the vessel. Thus, any modelling attempt to provide a consistent picture of the transients has to account for the prevailing transport processes and time-scales of the core and the SOL including the neutrals. The integrated transport code COCONUT [1] combines the 1.5D core code JETTO with the 2D SOL code EDGE2D with the separatrix as communicative layer exchanging fluxes between the codes. Previous results of Type-I ELM simulations [2] indicate a strong influence of neutral dynamics on refuelling the edge since it actively affects the ratio of convective to conductive losses from the edge and thus the building up of the pressure gradient within the ETB.

This contribution extends the work from [3] where consecutive ELMs with increasing frequency with increasing pedestal collisionality ν^*_{ped} were modelled consistently. It turned out that the plasma edge was refuelled too early after an ELM crash. Other integrated models for the SOL show [4] that the experimentally observed convective ELM regime [5] with increasing ν^*_{ped} can be achieved if the neutral source from the main-chamber is modelled accurately. Namely, time-dependence in neutral transport is now included to prevent neutral shock waves after ELM crash [6]. The 3D Monte-Carlo code EIRENE [7] recently linked into EDGE2D (substituting NIMBUS) is used to evolve the neutral kinetics in detail by including vessel interaction and atomic physics to control the particle content in divertor and main-chamber more carefully. Also a ballooning-like exhaust of power and particles (poloidal dependence) is now assumed in COCONUT to localise re-fuelling from main-chamber after an ELM.

1. ELM SIMULATION MODEL

The empirical Bohm/gyro-Bohm anomalous transport model is applied here for the JETTO core model. An ETB of 4*cm* width at outer mid-plane comprises a suppression of anomalous transport down to neoclassical level (lower limits for inter-ELM transport are selected: $\chi_i^{ETB} = 0.1\,\frac{\mathrm{m}^2}{\mathrm{s}}$, $\chi_e^{ETB} \approx \sqrt{\frac{\mathrm{m_e}}{\mathrm{m_i}}}\,\chi_i$, $D^{ETB} = 0.025\,\frac{\mathrm{m}^2}{\mathrm{s}}$). ELMs are triggered if the normalised pressure gradient $\alpha = -2\mu_0 q^2 / B_0^2 0\, \varepsilon \nabla p$ within the ETB exceeds a fixed critical ballooning parameter $\alpha_c = 1.5$. The ELMstructure comprises an increase of diffusive transport in the ETB for a short period $\tau_{ELM} = 100\mu s$ to high values ($D_{ELM} = 100\,\frac{\mathrm{m}^2}{\mathrm{s}}$, $\chi_{ELM} = 200\,\frac{\mathrm{m}^2}{\mathrm{s}}$) assuming a Gaussian profile centred at $\rho = 0.97$ (FWHM ≈ 4*cm*). The level of transport at the separatrix is taken over by EDGE2D where the radial transport profile is prescribed by a modified tanh increase or exponential decay towards the vessel wall depending on inter- or active-ELMphase respectively (for details see [3]). Parallel transport is classical plus kinetic corrections via heat-flux and viscosity limiters: $\beta_e = 0.2$, $\beta_i = 10$ and $\beta = 0.4$ respectively [3]. Sheath heat transmission factors at the targets are constant: $\gamma_i = 2.5$ for ions and $\gamma_e = 4.5$ for electrons.

The case chosen is JET Pulse No: 55936 (δ = 0.26, q_{95} = 3.78, NBI-power 14MW). Simulations were considered pure-D, ie. Z_{eff} = 1. A gas puff was applied from the top and a gas-flux scan was pursued up to $\Gamma_{gas} = 10^{22}\ s^{-1}$ to vary the collisionality $\nu*_{ped}$.

The Monte-Carlo code EIRENE was used in EDGE2D tomodel the neutrals dynamics.Kinetic neutral atoms and molecules are followed stochastically and source-terms for plasma particle, momentum and energy are derived by a book-keeping of their trajectories. Neutral sources are defined by plasma flows recycled at the targets or at the vessel walls or gas-puff surfaces de- fined. To avoid neutral shock-waves after an ELM-crash the time-dependent mode of EIRENE was used: neutrals hitting a certain time-barrier (t0 defined by one or more fluid-time-steps) are stopped and saved on a census-array [7]. The latter defines another neutral source for the next EIRENE call. This approach involves heavy memory-consumption (ie when t0 decreases strongly). The total number of particle histories was adapted by variations of t0 (ie. N_{hist} = min (400000, τ_0^{ref} / τ_{i0} * 40000) where $\tau_0^{ref} = 2 \cdot 10^{-5}\ s$) and following the recommendation from [8] the number of histories allocated per stratum was flux-weighted.

Pumping surfaces in the simulation were assumed to be located in the corners of the divertor where the total pumping speed was matched to the experimental value of $\approx 120\ \frac{\mathrm{m}^2}{\mathrm{s}}$. A poloidally averaged neutral flux crossing the separatrix is provided to JETTO as boundary condition.

2. INTEGRATED MODELLING RESULTS

With increasing collisionality gas-flux Γ^{gas}, the ELM-frequency f_{ELM} rises as expected perceivable from the time-traces for top pedestal density n_e^{ped} and temperature T_e^{ped} (cf. Fig.1). ELMs occur quite regularly and pronounced compound ELMstructures (small ELMs following a big ELM-crash) are found especially for the low-ν^*_{ped} cases.When comparing to experimental plasma data, n_e^{ped} is too low and T_e^{ped} too high just before the ELM. The reason for this is to be found in an improper choice of inter-ELM transport coefficients (ie a too low χ_e^{ETB}). But generally, the trend of increasing f_{ELM} with ν^*_{ped} is achieved (as opposed to results from [3]).

This is a direct consequence of using a time-dependent model for the neutrals which avoids neutral shock-waves and thus prevents a too early edge refuelling after the ELM. Table shows the relative drops in n_e, T_e andW_{ped} as function of pedestal collisionality ν^*_{ped}:

At a first glance, ν^*_{ped} is too low as expected from experiment which stems mainly from the fact that T_e^{ped} is too high. At a gas-flux threshold $\approx 0.6 \cdot 10^{22}\ s^{-1}$, $fELM$ increases and the energy confinement, reflected by energy content W_{ped}, decreases strongly. The relative energy drop $\Delta W_{ELM}/W_{ped}$ varies only slightly and is in the region of 10%. $\Delta T/T$ is comparable to $\Delta n/n$ (around 30%–40%, both not dropping with ν^*_{ped}) and thus reflects already a convective ELM regime. After exceeding the threshold for high f_{ELM} the edge density profile becomes nonmonotonic (cf. fig.2) which results in a minimisation of the convective flux in the ETB as the neutrals push into the edge. Simultaneously, the same heat is coming from the core and a stronger T-gradient builds up leading to a peaking of the pressure gradient deeper in the core.

With the selection of a constant α_{crit} this leads to higher f_{ELM}. This is also supported by the fact that with increased inter-ELMparticle diffusivity D^{ETB} (ie with enhanced inter-ELMconvective flux) f_{ELM} is diminished at the same level of gas-flux Γ^{gas} [3] .

The non-homogeneous poloidal redistribution of ELM power in the SOL did not resemble any asymmetry of target power loads. A delay between inner and outer target power deposition of at least 0.3*ms* is expected from JET. The model predicts only a fraction: ≈ 0.01*ms*.

CONCLUSIONS

A monotonic increase of f_{ELM} with ν^*_{ped} has been achieved by including time-dependent neutral dynamics avoiding early neutral shock-waves in the edge. COCONUT integrated model resembled a convective ELM-regime already at low ν^*_{ped} with the model parameters chosen. Re-assessment of the latter should render a better agreement with experiment. Access to a less convective ELM-regime (ie. $\Delta T/T$ deviating from $\Delta n/n$) and less strongly pronounced degradation of confinement $\Delta W/W$ with increasing ν^*_{ped} is probably only achievable with variation of the actual ELMstructure by means of duration, amplitude and radial extent. For this a reevaluation of MHD-stability for varying ν^*_{ped} is needed as already suggested in [4].

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Γ^{gas} (s^{-1})	ν^{*}_{ped}	f_{ELM} (Hz)	n_e (m^{-3})	$\Delta n_e/n_e$	T_e (eV)	$\Delta T_e/T_e$	W_{ped} (MJ)	$\Delta W_{ELM}/W_{ped}$
$0.4 \cdot 10^{22}$	0.009	20	$2.32 \cdot 10^{19}$	0.44	3182	0.38	1.45	0.134
$0.6 \cdot 10^{22}$	0.013	51	$2.14 \cdot 10^{19}$	0.35	2593	0.33	1.09	0.111
$0.8 \cdot 10^{22}$	0.016	77	$2.15 \cdot 10^{19}$	0.34	2351	0.33	1.00	0.110
$1.0 \cdot 10^{22}$	0.018	87	$2.23 \cdot 10^{19}$	0.32	2230	0.33	0.99	0.105

Table 1: shows the relative drops in n_e, T_e and W_{ped} as function of pedestal collisionality n^{*}_{ped}:

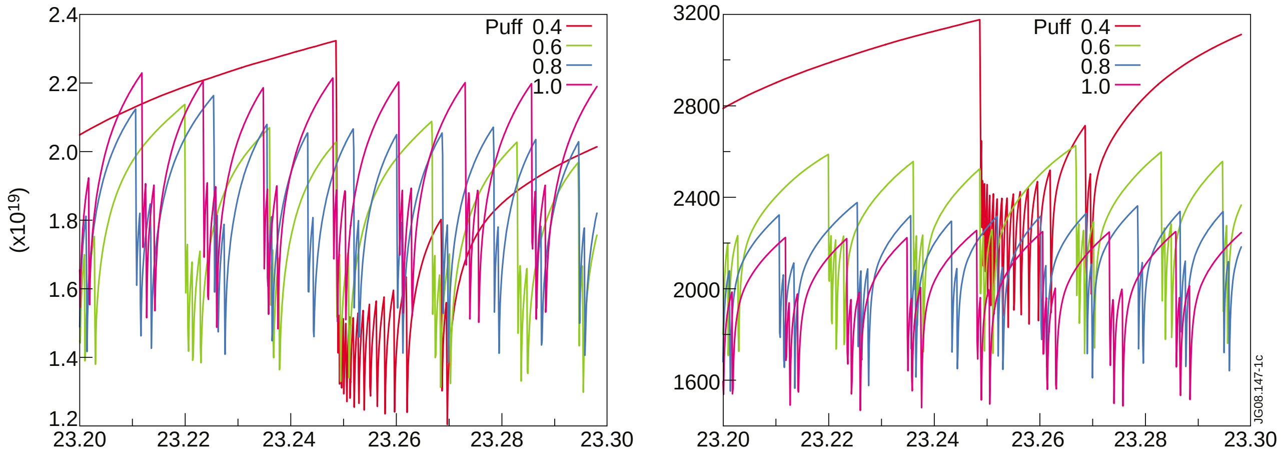

Figure 1: n_e^{ped} and T_e^{ped} time-traces evaluated at $\rho = 0.90$

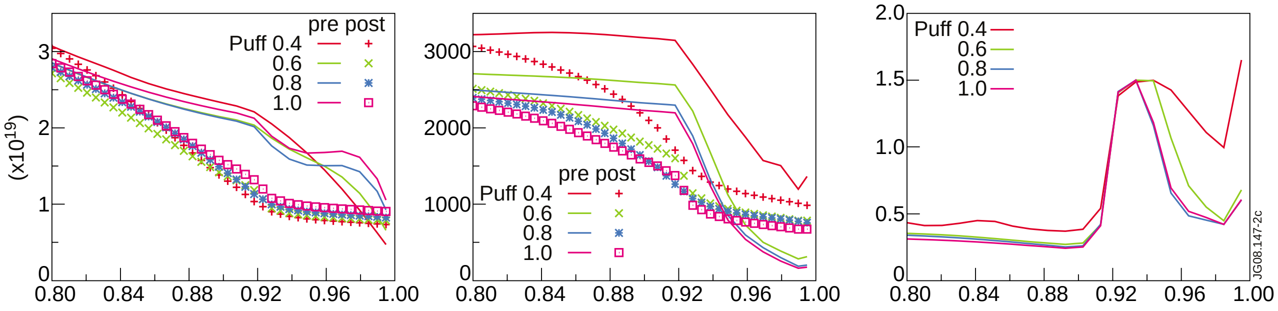

Figure 2: Radial n_e (left) and T_e (middle) profiles, before (solid) and after (symbols) ELM.
Right: normalised pressure gradient before ELM