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* See annex of F. Romanelli et al, "Overview of JET Results",
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ABSTRACT

In ITER the plasma position control system has a relatively slow (~2 s) reaction time to sudden changes in plasma parameters like a rapid H-L transition. In burning plasma this transition to low confinement state is exacerbated by the drop in the alpha-heating which could decrease plasma beta and lead to a swift inward movement of plasma position [1]. This paper describes the development of a simulation and its validation on existing JET H-mode experiments to predict the H-L transition for ITER [2].

INTRODUCTION

A study is made of a database of 229 JET pulses, with a range of JET operation parameters but all beginning in Type I ELMy H-mode during the high power phase and having constant plasma current after the end of the main heating phase until the L-mode back transition (JET plasmas where plasma current is varied after the main heating phase are studies in ref [3].) Four different classes of back transitions are found after the step down of the auxiliary heating. The transition a) Type I → ELM free → Type III → L-mode is more common in the high triangularity plasmas (68% in $\delta > 0.3$ at the time of the H-L mode transition), while b) Type I → Type III → L-mode is more common in the low triangularity plasmas (54%). The c) Type I → L-mode back transition, possibly the most challenging for a plasma position control, is only observed in the plasmas with Greenwald density fraction ($<n_e>/n_{eGW}$) > 0.6. The fourth, d) and least common (3% in $\delta > 0.3$ and 11.5% in $\delta \leq 0.3$) back transition is a steady increase in frequency and decrease in amplitude of the ELMs before the return to the L-mode.

MODELLING

The temporal evolution, from the end of the main heating phase to the L-mode back transition (~100ms), of the thermal energy (Wth) is modelled using the equation:

$$\frac{dW}{dt} = (P_{in} - P_{loss}) \frac{W}{\tau_e}$$

where τ_e is the energy confinement time. In the model, τ_e is determined by the IPB98(y,2) [4] scaling during the high power phase. After the step down of the input power, τ_e is determined using three different scalings: IPB98(y,2) [4], ITER89-P L-mode [5] and Goldston [6]. The simulated time evolution of Wth is closest to experiment over the whole database when τeIPB98(y,2) is used.

Four JET pulses, two low (Pulse No's: 72207, $\delta = 0.18$ and 76466, $\delta = 0.21$) and two high triangularity (Pulse No's: 77118, $\delta = 0.38$ and 77293, $\delta = 0.45$) plasmas, representing the most common classes of back transition in the database, are simulated using JINTRAC, see figure 1. The 1.5D JETTO transport code and the Monte Carlo orbit following ASCOT, to simulate the NBI particle and energy deposition, are used. In the simulations the experimental density and electron temperature profiles from HTRS and the ion temperature profile from CXSM are used. Figure 1

show that the simulated slowing down of the NBI fast particles varied between 25-100ms depending upon the density and temperature of the plasma. The time interval between the step down of the NBI and the transitions to L-mode are between 200-500ms, approximately equal to the confinement time. This indicates that the fast particle energy decay time is not the main factor for the plasma to stay in H-mode after the step down of NBI.

The L-H transition model implemented in JINTRAC evaluates the sum of the electron and ion heat fluxes at the top of the pedestal, $P = P_e + P_i$, and compares it with a threshold power for the L-H transition, P_{L-H}, to determine whether the plasma is in H-mode or not. In this case, the L-H power threshold is defined from the scaling from Martin et al. J. Phys 2008: $P_{L-H} = 0.0488 n_{e,20}^{0.717} B_T^{0.8} S^{0.941}$ $(m/2)^{-1}$ [7]. The Bohm/GyroBohm (BgB) empirical model is used for the L and H-mode phases [8], for the heat diffusivities and $\frac{1}{D} = \frac{1}{\chi_i} + \frac{1}{\chi_e}$. In the H-mode phase the transport model includes a reduced transport coefficient locally within the Edge Transport Barrier (ETB) width of 4 cm to ion neoclassical levels. In JINTRAC the ELMs are simulated by an increase of 200× of the transport within the ETB region during a ELM duration of 1ms, and are trigged when $\alpha_{crit} (\rho = 0.9)$ exceeds $\alpha \equiv \frac{-2u_0 R q^2}{B_\phi^2} \cdot \frac{\partial p}{\partial r}$ [9]. In the simulations, αcrit is chosen as such that the level of the experimental Wth is reached during the NBI phase. The type III phase starts when $P_{III-I} = A*P_{L-H}$ where A is a free parameter of the model. A is chosen as such the time of the transition from type I H-mode → type III H-mode coincides with the experiments. The density and temperature profiles are predicted except the NBI power deposition that is calculated previously by PENCIL. The JINTRAC simulations are performed for two well diagnosed JET plasmas: one low (Pulse No: 76466, δ = 0.21) and the other high triangularity (Pulse No: 77293, δ = 0.45). The plasma parameters at the boundary (last closed flux surface) are taken as constant throughout the simulations with $T_i(\rho = 1) = T_e(\rho = 1) = 100eV$, $n_i(\rho = 1) = 5.0 \times 10^{18} \, m^{-3}$, for δ = 0.21 and $T_i(\rho = 1) = T_e(\rho = 1) = 110eV$, $n_i(\rho = 1) = 1.5 \times 10^{19} \, m^{-3}$ for the δ = 0.45 plasma. In both plasmas the measured $T_i(\rho) \cong T_e(\rho)$.

Figure 2 and 3, show the simulations and experimental times traces for the JET Pulse No's: 76466 and 77293 respectively. These figures show that the predicted ELM frequency of ≈48Hz is similar to the experiment of ≈55Hz but only for the δ = 0.21 plasma with a $\alpha_{crit}(\rho=0.9) = 1.9$, while for the δ = 0.45 plasma, even with a higher $\alpha_{crit}(\rho = 0.9) = 2.1$, the predicted ELM frequency is two times higher than experimentally observed. The Type III ELMs are trigged at a lower pressure gradient and to best follow the experimental Wth time decay after NBI step down $\alpha_{crit}(\rho=0.9)=0.8$ is used. In the simulations for the δ = 0.21 plasma is found that the power ratio of A = 1.4 matched the experimental time of the back transition between type I → type III H-mode phases, see figure 2. In this figure also shows that the model also predicts the time of the transition between Type III H-mode → L-mode at ≈22.5s. Although the same parameters are used, A = 1.4, the type III ELMy H-mode phase is not observed in the δ = 0.45 plasma simulations, as it is observed experimentally. The simulated plasma changed from Type I ELMs → L-mode plasma, see figure 3. A higher value of A=1.5 is used but the plasma stayed in type III ELMs even during the NBI phase, in figure 3 clearly

2

shows that it is not the case. This model also does not predict the back transition time to L-mode it is 300 ms earlier than experimentally observed. A possible reason to underestimate transition time is overestimation in the $\delta = 0.45$ plasma simulations of P_{L-H} in comparison with P_{L-H} calculated from the experimental parameters (see figure 3). P_{L-H} goes like $n^{0.717}$ and the core transport model does not predict correctly the volume average density (n_{eav}) decay after the NBI step down. To model n_{eav} correctly the Scrape of Layer 2D modelling has to be included. In more recent JET H-mode simulations a variation of the BgB [8] has been used, in which a local multiplier $<L_{Te}>^{-1}$ is included to reduce χ_e. More refined simulations for these plasmas using the model recent BgB model in the core coupled with edge are planned.

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	Shots	a) (%)	b) (%)	c) (%)	d) (%)
$\delta > 0.3$	65	67.7	23.1	6.2	3.1
$\delta \leq 0.3$	164	20.1	54.3	14.0	11.6

Table1: Table of the back transition classes observed in 229 JET pulses where: a) Type I → ELM free → Type III → L-mode; b) Type I → Type III → L-mode; c) Type I → L-mode and d) steady increase in frequency and decrease in amplitude → L-mode.
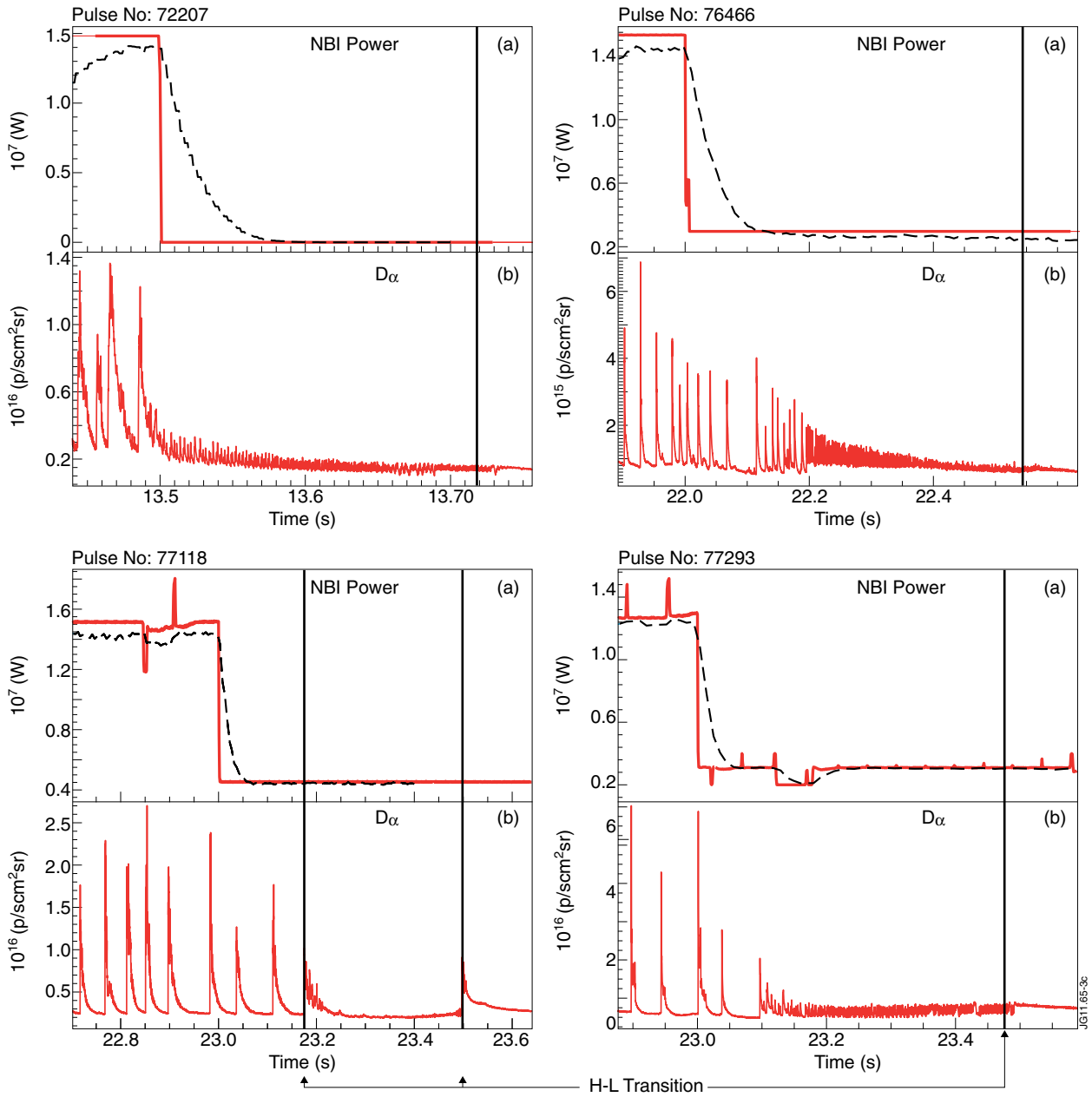
Figure1: a) Time traces of the Injected NBI power (red) and total NBI power deposited in the thermal plasma calculated by JINTRAC (black); b) the respective D_α time trace from the outer divertor target for the JET Pulse No's:: 72207; 76466; 77118 and 77293. The H-L back transition is represented by a vertical black line
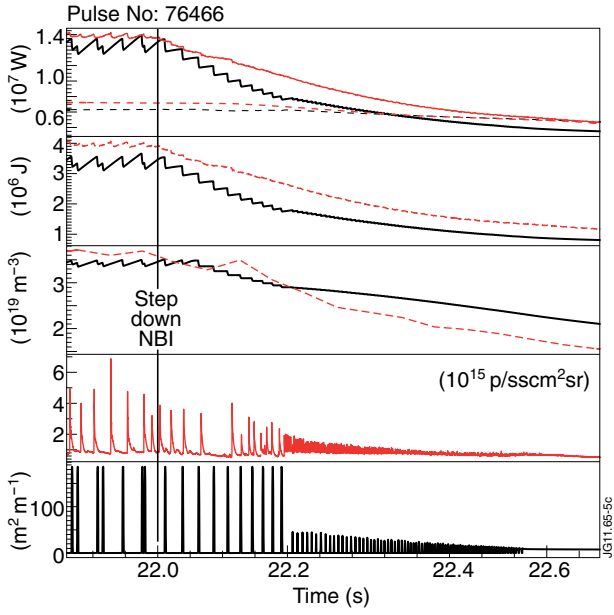
4

Pulse No: 76466

Step
down
NBI

$(10^{15}\ p/sscm^2 sr)$

JG11.65-5c

Pulse No: 77293

Step
down
NBI

$(10^{16}\ p/sscm^2 sr)$

JG11.65-4c

Figure2: Simulated (black) and experimental (red) time traces of JET Pulse No: 76466 with δ = 0.21. a) $P=W_{th}/\tau_{eIPB98(y,2)}$ (continuous line) and the P_{L-H} threshold (dashed line); b)Thermal energy; c)Volume averaged electron density; c) D_α; d)χ_i (ρ = 0.95)
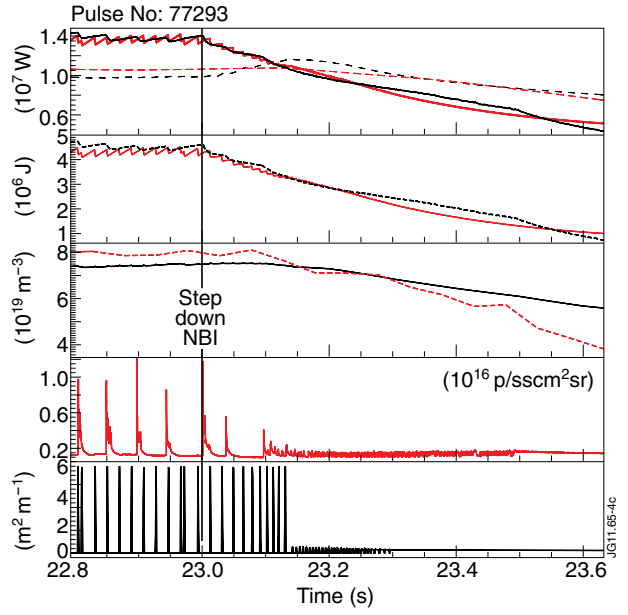
Figure 3: Simulated (blue) and experimental (red) time traces of JET Pulse No: 77293 with δ = 0.45. a) $P=W_{th}/\tau_{eIPB98(y,2)}$ (continuous line) and the P_{L-H} threshold (dashed line); b)Thermal energy; c)Volume averaged electron density; c) Dα; d)χi(ρ = 0.95);