*31st EPS Conference on Plasma Phys. London, 28 June - 2 July 2004 ECA Vol.**28G**, P-1.169 (2004)*

Role of impurity and deuterium fuelling in evolution of trace tritium in JET ELMy H-mode: transport analysis and predictive modelling

P. Belo[1], V. Parail[2], G. Corrigan[2], D. Heading[2], L. Garzotti[3], P. Monier-Garbet[4], J. Ongena[5,a], G. Bonheure[4], I. Voitsekhovitch[2] and JET EFDA contributors [b]

[1]EURATOM/IST Fusion Association, Centro de Fusão Nuclear, Av. Rovisco Pais 1049-001 Lisbon Portugal
[2]EURATOM/UKAEA Fusion Association, Culham Science Centre, Abingdon OX14 3DB, UK;
3 Consorzio RFX, Associazione EURATOM-ENEA sulla Fusione, Padova, Italy
[4] Association Euratom-CEA, Cadarache 13108 SAINT PAUL LEZ DURANCE, FRANCE
[5] Laboratoire de Physique des Plasmas-Laboratorium voor Plasmafysica, Association EURATOM-Belgian State, Ecole Royale Militaire-B-1000 Brussels, Koninklijke Militaire School[c], Belgium

I. Introduction

Predictive modelling of a number of ELMy H-mode JET plasmas with a trace tritium puffing was done using a combination of transport codes JETTO and SANCO. The main aim of this analysis was to study the tritium particle transport and to compare it with the neo-classical one. Previous study of deuterium transport in JET ELMy H-mode [1] showed, that at least the convective velocity was of the order of the neoclassical ware pinch for H mode plasmas. It follows from the neo-classical theory that both the diffusion coefficient and the convective velocity of trace tritium ions should increase with Z_{eff} and with the main ion density. This should lead to a faster propagation of trace tritium towards plasma centre, which translates into a shorter time to peak in the measured neutron yield for these plasmas if transport is indeed neo-classical. The experimental evidence gives the opposite trend with a longer time to peak for high-density plasmas both with and without additional Argon gas puff.

The empirical Bohm/gyroBohm model for anomalous transport [2] is used in JETTO code to model the anomalous diffusion and pinch, with NCLASS [3] providing the neo-classical diffusion and convective velocity for all ion species. Two theory motivated models for anomalous convective velocity are used in JETTO [1] which associate pinch velocity with either relative magnetic shear or with temperature gradient [4, 5, 6]. Three JET pulses from the trace tritium campaign were chosen with different densities and Zeff for the tritium transport modelling. The result of simulations will be compared with the measured neutron data.

II. Experimental observations

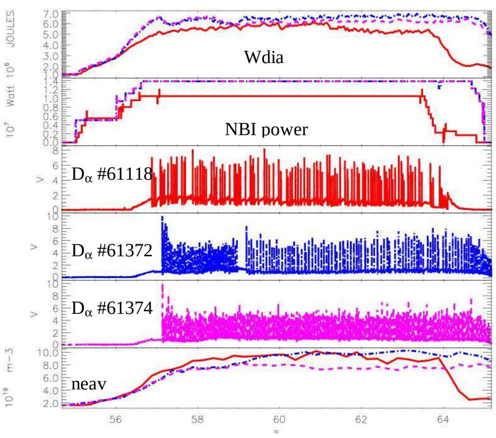

Figure 1: Time traces for the pulses: #61374, #61372 and #61118

Three pulses were chosen for this study: #61118 with q_{95} = 3.01, P_{NBI}= 10.5 MW, Ip = 2.5 MA, B_t = 2.25 T; #61372 with q_{95} = 3.64, P_{NBI}= 13.8 MW, Ip = 2.5 MA, B_t = 2.7 T with Ar puff and #61374 has q_{95} = 3.64, P_{NBI}= 13.8 MW, Ip = 2.5 MA, B_t = 2.7T. It is worth noting that discharge #61118 has lower toroidal field, which translates into a lower safety factor q (at least in the outer part of plasma volume). Since anomalous transport can depend on toroidal magnetic field, this implies that the transport for the shot #61118 might be lower than the shot #61372. The time evolution of relevant plasma parameters for these three pulses i plotted in

[a] Researcher at FWO Vlaanderen
[b] appendix of J.Pamela, JET-EFDA Team in Fusion Energy 2002 (Proc. 20th Int. Conf., Lyon, 2002), IAEA Vienna 2001 CD-Rom file PD/1

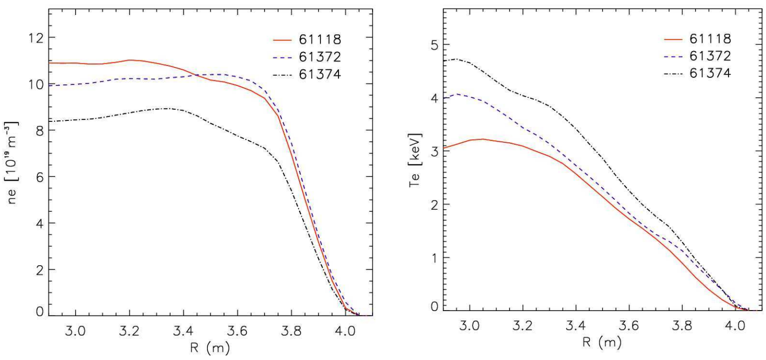

Figure 2: Electron density and temperature from LIDR diagnostic averaged between the start of tritium puff and 500 ms later for the three pulses, #611374, #61372 and #61118.

figure 1. The figure shows that the energy content for #61118 was slightly lower than for the other two pulses (mainly due to a lower level of NBI power). The line average electron density was similar for #61118 and #61372 and lower for #61374. The ELM frequency was significantly higher for the low-density shot #61374. The average electron density and temperature profiles between the start of the tritium puff and 500 ms later for three selected pulses are plotted in figure 2. This figure allows concluding that the density profile was slightly more peaked for #61118 than for #61372 (which uses Ar seeding to increase density) and the density was lower for #61374. As expected the electron temperature for #61374 was higher. Electron temperature was lower for #61118 than for #61372 because the input power was lower for this pulse. Figure 3 shows two horizontal camera channels data (a central and the edge one) for the three pulses. The signal at the edge is higher for #61118 and the core channel shows a difference between pulses in time to peak, which is slower for the high-density pulses. This delay was also seen in the central channels of the neutron vertical camera.

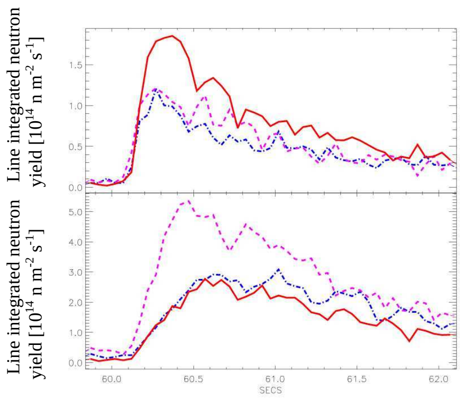

Figure 3:Time traces of the 2 horizontal camera channels. Edge channel number 1 (top figure), and core channel number 4 (bottom figure), for the pulses #61118 (red continuous line), #61372 (blue dash dotted line) and #61374(magenta dashed line)

III. Modelling the tritium puff

The ion and electron temperatures were taken from experiment, only the densities of deuterium, tritium and impurities were simulated. The following assumptions about particle transport used in JETTO+SANCO code were made. Since edge transport barrier (ETB) is included into simulation, different assumption about transport coefficient were made for transport inside and within ETB. Deuterium diffusion coefficient: $D_D = c_{ETB} c_D D_{JETTO} + D_{Dneo}$, where D_{JETTO} is the anomalous particle diffusion determined from the Bohm/gyro Bohm empirical model [2], D_{Dneo} is the neoclassical diffusion for deuterium from NCLASS [3], c_D is the multiplier for the anomalous contribution in all the plasma. C_{ETB} is the multiplier defined by: $c_{ETB} = \begin{cases} 1 & \rho \le \rho_{Top} \\ 0.00001 & \rho > \rho_{Top} \end{cases}$, where ρ_{Top} corresponds to a radial position of top of ETB. This multiplier is important to describe the diffusion that is closer to neo-classical values within the ETB for H-mode plasmas. The characteristic width of the ETB is defined by: $L_{ETB} = (1 - \rho_{Top})a \approx 3cm$, where a is the minor radius. The particle diffusion for tritium is: $D_T = c_T / c_D\, D_D - D_{Dneo} + D_{Tneo}$ and for impurity $D_{imp} = D_{impneo}$.

The convective velocity for deuterium is $V_D = V_{Dneo} - c_{Dq} D_D\, \nabla q / q - c_{DT} D_D\, \nabla T / T$, for tritium is $V_T = V_{Tneo} + c_{Tq} D_T\, \nabla q / q - c_{TT} D_T\, \nabla T / T$ and for impurity is $V_{imp} = V_{impneo}$. Where

c_{Dq}, c_{DT}, c_{Tq} and c_{TT}, are the variable anomalous multipliers for the anomalous convective velocity for deuterium and tritium respectively and q is the safety factor.

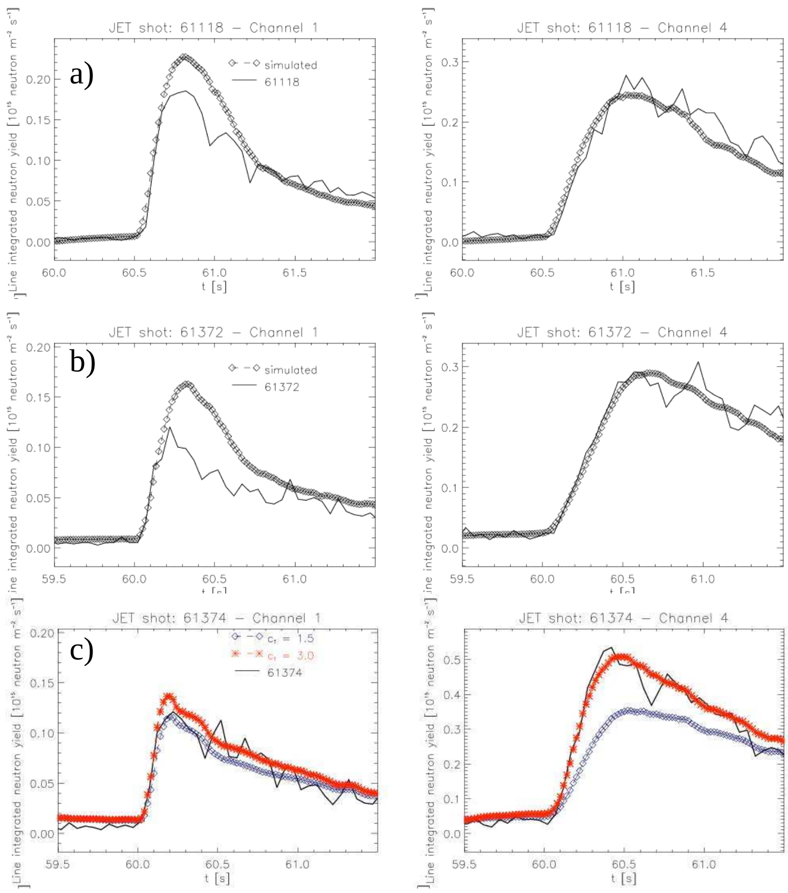

Figure 4: Experimental and simulated neutron line average emissivity for an edge channel 1 (left) and central channel 4 (right) for the three pulses: #61118, #61372 and #61374

We adjusted transport for deuterium and impurity so that their profiles stay close to experimentally observed profiles (same coefficients were used for all three discharges). Deuterium density at the boundary was constant and equal to its initial value for all simulations. The anomalous multipliers for tritium diffusion, convective velocity and tritium puff rate were varied throughout simulations to find the best fit with experimental data.

A post-processing tool was made to calculate the line integrated neutron yield from the JETTO+SANCO simulations, which allows a direct comparison between simulated and measured signals.

The best fit for the shot #61118 is shown on figure 4: it was obtained by using the anomalous diffusion and convective velocity multipliers c_T = 1.0 and c_{Tq} = 1.7 and zeff=2.3. For the shot #61372 the multipliers were the same but c_T = 1.5 with the lower level of Zeff=2.1. Argon was used as the main impurity. These settings were also used for the lower density pulse #61374 and the result was that the simulated time to peak was longer than experimentally observed (see figure 4c). To increase the neutron yield in the core and shorten the time to peak a much higher diffusion multiplier was required, c_T = 3.0 and Zeff = 1.8.

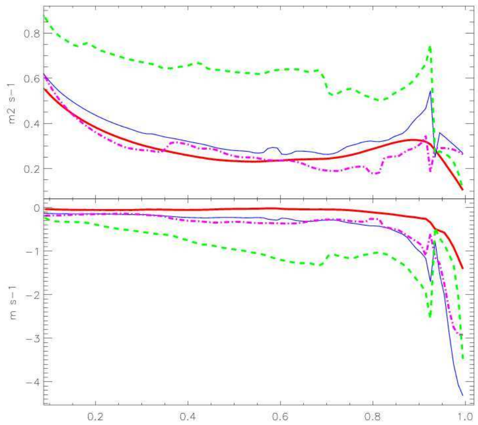

Figure 5: Tritium diffusion (top) and convective velocity (bottom) for the pulses #61118 (red neo-classical, blue neo-classical plus anomalous, continuous line), #61372 (magenta dashed and dotted line) and #61374 (green dashed line)

Although the anomalous multipliers for tritium diffusion were different for #61118 and #61372 the total diffusion (neo-classical plus anomalous) was similar, see figure 5. This means that the tritium transport is very similar for these two pulses and that neo-classical transport plays an important role in high density H-mode shots. This cannot be said about shot #61374: tritium diffusion and convective velocity were both significantly above the neo-classical level. A number of possible reasons for high anomalous particle transport in lower density plasmas have been identified and tested in predictive modelling. It was shown that neither variation in the boundary conditions, nor different assumption about edge recycling are able to explain the observed difference in the level of anomalous transport. Generally the level of the gyroBohm transport should increase with the temperature. Also the inward convective velocity scales inversely proportional to plasma collisionality [7, 8, 9]. We however were unable to confirm this trend using Weiland model. An observed difference in ELM frequency between high and low density plasma (which was more than two times higher for #61374 than for the other two pulses) is another possible reason for faster tritium redistribution in lower density plasma. It was also tested in predictive modelling.

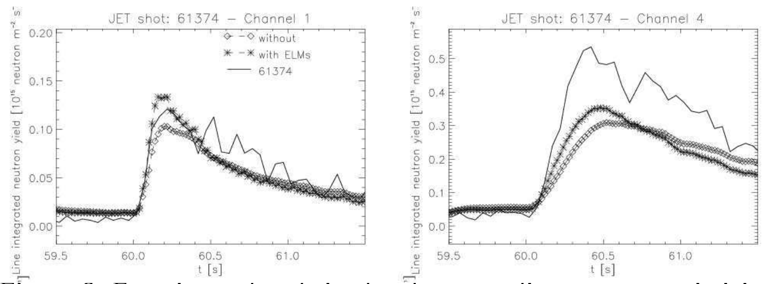

Figure 6: Experimental and simulated neutron line average emissivity for an edge channel 1 (left) and central channel 4 (right) for for #61374. The simulated results are for two extreme cases without ELMs and with the highest ELM frequency.

ELMs

The model used for ELMs was a simple one based on the ideal ballooning instability. The code checks the normalised pressure gradient within the ETB and compares it with the critical parameter α_{crit}, which controls the ballooning stability. The code increases all the anomalous coefficients within the ETB for a short period of time Δt (with $\Delta t \leq 0.3$ msec) to simulate ELM. The study of how the tritium transport is influenced by ELM frequency was done by changing the α_{crit}. We use plasma parameters for the shot #61374 to do a systematic scan in ELM frequency (the lower is the α_{crit} the higher is the ELM frequency). Figure 6 shows the edge and the core experimental and simulated neutron yield for two limiting cases: without ELMs and with the highest ELM frequency. It is clear that the ELMs increase the effective diffusion and shorten time-to-peak for lower density plasma, although this effect is not very strong. Note that the level of anomalous tritium transport used in these simulation was the same as it was used for higher density shots: c_T=1.5.

CONCLUSIONS

Predictive modelling of a number of JET ELMy H-mode plasmas reveals that trace tritium diffusion and convective velocity is close to the neo-classical values for high-density plasmas [10, 11]. Lower density H-mode requires higher level of anomalous transport to be consistent with experimental findings. ELMs can make a significant contribution to this observed increase in effective tritium diffusion.

ACKNOWLEDGMENT

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. The views and opinions expressed herein do not necessarily reflect those of the European Commission and IST.

REFERENCES

[1] Garzotti, L., et al, *Nuclear Fusion*, **43** (2003) 1829; [2] Erba M., et al., *Plasma Phys. Control. Fusion*, **39** (1997) 261; [3] Houlberg, et al, *Phys. Plasma*, **4** (1997), 3230; [4]Yankov, V.V., *JETP Lett*, 60 (1994), 171; [5] Baker, D.R., Rosenbluth, M.N., *Phys. Plasmas*, **5** (1998) 2936; [6] Dominguez, R.R., *Phy. Fluids* B, **5** (1993) 1782; [7] Angioni, C. et al, Phys. Plasmas, **10** (2003) 3225; [8] Valovic, M. et al, *Plasma Phys. Control. Fusion*, **44** (2000) 1911; [9] Weisen, H., *et al*, 31st EPS conference, London 2004; [10] Voitsekhovitch, I, *et al*, 31st EPS conference, London 2004; [11] Zastrow, K. *et al*, 31st EPS conference, London 2004;