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Experimental studies of spatial characteristics of tritium transport on JET

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INTRODUCTION

The Joint European Torus JET provides an essential contribution to research and development in the field of neutron diagnostics, including neutron data analyses and validation [1]. In this respect, JET Neutron profile monitor [2] collects priceless data in determining spatial distribution of neutron emissivities. Its two neutron cameras feature ten and nine collimated channels in horizontal and vertical fan-shaped views, respectively. The spatial coverage is therefore rather sparse however it was demonstrated that inverse (tomographic) reconstruction via Minimum Fisher Regularisation (MFR) [3] provides dependable 2D neutron emissivity profiles (poloidal cross-sections). Separate data on neutrons from DD fusion (2.5 MeV) and DT fusion (14.1 MeV) are collected in each of the 19 channels of the monitor. This information led to crucial results in particular in particle transport studies after tritium puffs at JET [4]. Recently, a novel method of transport analysis has been introduced, based on the evolution of the ratio of DT and DD neutron emissivites [5,6] reconstructed by MFR. Notice that although the transport coefficients are expected to depend on the radial coordinate only i.e. to be fully determined by 1D profiles, 2D profiles of the neutron emissivities must be reconstructed due to significant poloidal assymetry linked to fast trapped particles from the beam heating. This assymetry is common to both D-D and D-T emission so it is removed in the ratio process within experimental errors [6]. However, in the actual data analyses a residual poloidal assymetry is often observed, which decays typically in a few tens of miliseconds, see Fig. 1. Detailed analyses have not identified any artifacts that would lead to this result, i.e. the assymetry may actually carry new information on spatial characteristics of tritium transport, which is in current analyses [5, 6] lost in poloidal averaging of the emissivity ratio. An assymetry is qualitatively expected by models of turbulent tritium transport in the plasma edge [7]. This paper contributes to the ongoing discussion on the interpretation of the observed poloidal assymetries in the DT / DD emissivity ratio by studies of their temporal characteristics in relation to selected plasma parameters.

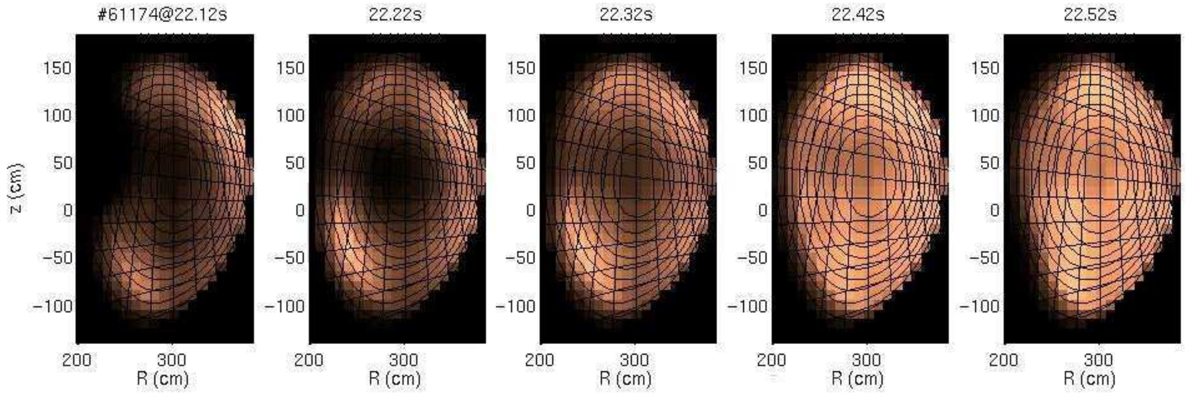

Fig. 1: Typical evolution of the DT/DD neutron emissivity ratio after T puff (JET discharge #61174)

RATIO METHOD AND RAPID MINIMUM FISHER REGULARISATION

The ratio method [5,6] is a straightforward method to obtain tritium transport coefficients after tritium puffing, based on the fact that the local tritium density is at first order proportional to the local ratio of DT to DD neutron emission. This measured ratio is then normalised with the ratio of beam-target reactivities in order to get the value for the ratio of fuel densities n_T / n_D. The technique applies only to selected plasma scenarios where beam-target emission is the dominant contribution in the neutron emission. In this paper the ratio method has been used to analyse seventeen ELMy H-mode plasmas from the Trace tritium experiments, with target-beam contribution to neutron emissivity higher than 2/3. The main advantage of this novel method is that that no assumptions are required concerning plasma density and temperature profiles, plasma impurities, beam deposition properties and the tritium fluxes and sources.

Local neutron emissivities – the key input for the ratio method – are reconstructed from the Neutron profile monitor data by tomographic inversion based on Minimum Fisher Regularisation (MFR), a relatively simple but dependable algorithm for solving ill-conditioned and under-determined problems. MFR belongs to the class of Philips-Tikhonov regularisation methods, which determine a direct reconstruction matrix M that links projections f_i to emissivities in a grid of rectangular pixels $g_j = \sum M_{ji} f_i$ and constrain a norm of the solution i.e. favour smooth results. In the case of MFR, the smoothness is determined by minimising $\frac{1}{2}\chi^2 + \lambda I_F$ where χ^2 is goodness-of-fit, λ a regularisation (smoothing) parameter and I_F the Fisher information of the emissivity distribution g_j [3]. In the presented work, the same MFR version as in [6] has been applied, i.e. the rapid MFR [8] that allows for a smooth reconstruction of emissivity evolution in time, with preferential smoothing along magnetic flux surfaces and zero emissivity from the plasma edge.

EXPERIMENTAL RESULTS

The observed assymetries have been quantified in their radial and poloidal components. In the radial component, the horizontal distance of the centre-of-mass of the emissivity ratio from the magnetic axis has been found and normalised to the plasma minor radius ($\Delta R / a$) in order to evaluate the fact that higher levels are observed on the low field side. In the poloidal component, the standard deviation of the emissivity ratio on a flux surface has been computed (σ), quantifying the importance of poloidal structures. Except some low density plasmas that give symmetric emissivity ratio right after the tritium puff (e.g. JET discharges #61161, #61387) it is evident that both $\Delta R / a$ and σ decrease in time. Fig.2 demonstrates that the amplitude of the initial assymetry as well as its time duration clearly depend on the amount of puffed tritium N_T. The amplitude and time gradient of both $\Delta R / a$ and σ (linear fit to their evolution after the T puff) has been studied systematically against N_T, plasma volume averaged density n_e, edge pressure gradient ∇p_{edge} and plasma toroidal rotation V_Φ. Results of quantitative correlation analysis correspond very well to the qualitatively identified functional dependencies. The probabilities of no-correlation hypothesis are given in Tab. I, which identifies (in red boxes) that $\Delta R_0(n_e)/a$ and $d\sigma(N_T)/dt$ are manifestly significant, see Fig. 3 and Fig. 4. Only minor, doubtful role of velocity of toroidal rotation has been found, and it is actually not possible to discuss ∇p_{edge} role given its strong correlation to n_e. Interestingly, $d\Delta R / dt$ is not correlated to plasma density while it is rather well correlated with N_T when two points are removed (see Tab. I for details). In these two experiments the assymetry offset dissapeared in much shorter time than in all the other 15 tritium puff events. Although it is beyond the scope of this brief paper to provide any physical interpretation of these results, it seems that in particular the strong dependence of “poloidal structures” on the amount of tritium puffed indicates that tritium recycling from the wall is important.

Acknowledgement

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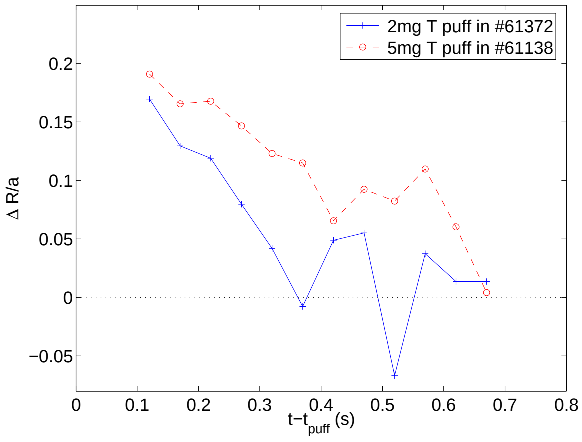

Fig. 2: Evolution of radial assymetry of the DT/DD emissivity ratio in two almost identical JET discharges after different level of tritium puff.

	N_T	n_e	∇p_{edge}	V_Φ
$\Delta R_0 / a$	0.045	0.003	0.006	0.014
$d\Delta R / dt$	0.40 (0.004)	0.65	0.98	0.19
σ_0	0.030	0.25	0.33	0.48
$d\sigma / dt$	0.001	0.94	0.91	0.083

Tab. I : Probablility of no correlation between variables (columns) and observations (rows). The value in paranthesis correspond to data from JET discharges #61103 and #61398 removed.

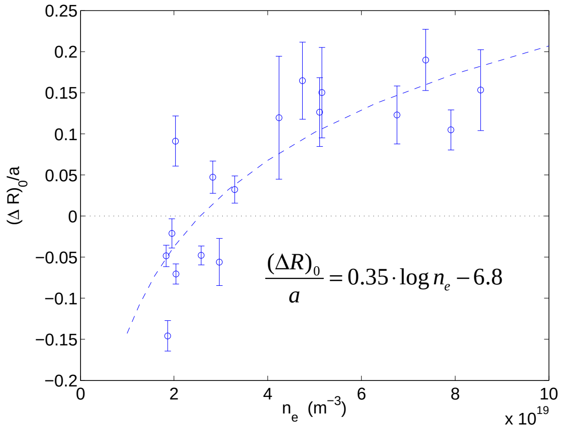

Fig. 3: Initial radial offset of the DT/DD emissivity as a function of plasma density. A tentative logarithmic fit to the experimental data is shown (dashed line).

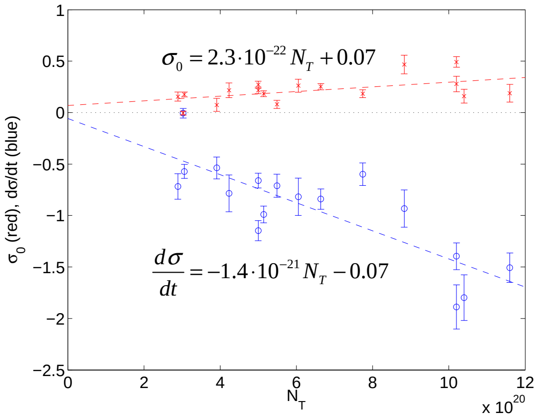

Fig. 4: Initial offset (in red) and time derivative (in blue) of the standard deviation of the poloidal component of the emissivity ratio as a function of the amount of puffed tritium. Notice that linear fits (dashed lines) extrapolate to zero at zero puff.

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