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ABSTRACT.

A new method combining a free-form solution for the neutron emissivity and ratio method [16] is applied to the investigation of tritium transport in JET plasmas. The Minimum Fisher Regularization (MFR) method [14, 15] which is being developed and studied alongside a range of other methods at JET, was used to obtain the neutron emissivity. The tritium concentration or fuel ion density ratio n_T / n_D in the core plasma was derived from both 2.45MeV D-D neutron profiles and 14.07MeV D-T neutron profiles using the ratio method. By using a new anisotropic smoothing constraint in the MFR method 2D neutron emisivity profiles were significantly improved as compared to first results obtained with this method. 1-D profiles of tritium concentration suitable for transport analysis were then obtained by subsequent poloidal integration (fig.2). The tritium transport was studied for a set of discharges with trace tritium puffs selected from the JET trace tritium experiments [4, 5, 6]. Local tritium transport coefficients were derived from the particle flux equation $\Gamma = -D\nabla n_T + Vn_T$, where D is the particle diffusivity and V the convection velocity. First results for the transport coefficients are presented and discussed. Preliminary comparisons show that the obtained core tritium diffusivity values are comparable to neoclassical ones at high collisionalities and decrease with increasing collisionality.

1. INTRODUCTION

Particle transport is crucial for the density control and burn control in a fusion reactor. Critical issues include the helium ash removal and central impurity accumulation. The density profile peaking is also an important issue because it will directly have an impact on fusion performance in ITER [1-3]. The use of tritium is a valuable tool for particle transport study. For diagnostic purposes, it is convenient to use 'trace' quantities of tritium ($n_T/(n_D + n_T) < 3\%$) in order to balance neutron flux from deuterium-tritium fusion reactions (energy of neutrons 14.07MeV) with neutron flux from less probable deuterium-deuterium fusion reactions (energy of neutrons 2.45 MeV). Trace tritium experiments haven been conducted on JET[5,6] in 1997 and 2003, and on TFTR [7,8]. Using JET neutron emission profile monitor, the time evolution of tritium spatial distribution can be detected in trace quantities by observation of the 14.07MeV neutron emission e.g. after tritium puff, allowing non perturbative transient experiments[4]. In the transport analysis method on which previous JET publications are based [4-6,10-12], the 14.07MeV D-T neutron line integrals absolute measurements were simulated and the transport coefficients varied until good fit were obtained. In this paper, a new approach [13] is presented in which direct knowledge of the local tritium concentration or fuel ratio nT/nD is obtained using all neutron profile information available, e.g both 2.45MeV D-D neutron profiles and 14.07MeV D-T neutron profiles [16]. This is performed in two steps. First, the local neutron emissivity is calculated from line integrated measurements as inputs using the Minimum Fisher Regularisation (MFR) method [14]. In the second step, the local neutron emissivity for 2.45MeV D-D neutrons and 14.07MeV D-T neutrons is combined to obtain the local tritium concentration or fuel ratio n_T/n_D. Tritium particle transports are then derived without any modelling of the neutron emission.

2. METHOD

2.1 JET NEUTRON EMISSION PROFILE MONITOR

Compared to other neutron flux measuring instruments available at medium or large-size fusion tokamaks, the JET neutron profile monitor (fig.1) is unique in terms of number of line of sights, detectors, space and time resolution. The instrument is well described in [9]. The primary function of this instrument is to measure the fusion neutron emission as a function of time and position in a poloidal section through the plasma. It provides data which are independent of all other diagnostic measurements. D-D and D-T neutrons are detected along 19 lines of sight with ~15cm spatial resolution and 10ms time resolution. The detectors: 1) NE213 organic liquid scintillators (for D-D and D-T neutrons) 2) BC418 fast plastic scintillator (D-T neutrons only) - are absolutely calibrated. The γ/n separation is controlled with movable ^{241}AmBe neutron sources. Energy calibration is taken from embedded ^{22}Na γ –ray sources. Upon completion of an important electronics upgrade, a new digital γ/n separation with14 bits- 200 MS/s PC-based digitizers [17-19] will process NE213 detector signals.

2.2 NEUTRON EMISSIVITY

A large class of methods can potentially solve the neutron emissivity problem (see in [20, 21] for past and in [22] for more recent JET work). Minimum Fisher Regularisation (MFR) method provides for robust analysis of sparse data in plasma diagnostics. MFR was successfully validated at JET for both spatial analysis of neutron emissivity and in spectral analysis of neutrons measured by the NE213 compact spectrometer [24, 25]. Being fully based on matrix operations, fast MFR is particularly efficient and adequate when a large number of neutron emissivity reconstructions are needed, i.e for the data analysis of trace tritium gas puff experiments. Previous works [20] showed that emissivity reconstructions were easily improved by constraining further the free-form solution. In the new MFR version, individual terms of the smoothing matrix B_{jk} [14,15] are transformed into components parallel and perpendicular to the magnetic flux surfaces, which are uploaded from the EFIT reconstruction [29] of the magnetic equilibrium. This constraint proves to eliminate major artefacts [13]. The downside is systematic errors introduced by magnetic reconstructions. The ratio method [16] allows in specific cases to calculate directly the tritium concentration profile from 14.07MeV D-T and 2.45MeV D-D local neutron emissivities. The tritium concentration or fuel ratio n_T/n_D is given by:

$$\frac{n_T}{n_D}(\mathbf{r}) = \frac{Y(\mathbf{r})_{DT,\,bt} \langle \sigma v \rangle_{DD,\,bt}(\mathbf{r})}{Y(\mathbf{r})_{DD,\,bt} \langle \sigma v \rangle_{DT,\,bt}(\mathbf{r})} \; (1 + k(\mathbf{r})) \qquad (1)$$

In expression(1), the $Y(r)_{DT,bt}$, $Y(r)_{DD,bt}$ are the beam-thermal local neutron emissivities respectively for DT and DD neutrons and $<\sigma v>_{DT,\,bt}$, $<\sigma v>_{DD,\,bt}$ are the main components of the beam-thermal fusion reactivities. The coefficient k (r) is a few percent correction taking into account the various beam energies of the injector and half and third beam ion energies and the beam ions deposition

profile [16]. Radial profiles of the n_T/n_D ratio - suitable for tritium transport analysis (see in figure 2)- were obtained from poloidal integral along magnetic flux surfaces of 2D distributions of the ratio of D-T/D-D neutron emissivities. Both D-T and the D-D emissivity distributions were determined using MFR method.

2.3 TRITIUM TRANSPORT COEFFICIENTS

Tritium diffusion and convection velocity transport coefficients (assumed time-independent) were obtained from the dynamic response of the 1-D tritium profile (fig.2) to the tritium gas puff by fitting the transport relation (2) while M was obtained from the local particle balance (or continuity equation).

The procedure is illustrated in figure 3.

$$\Gamma = -D \frac{\partial n}{\partial \rho} + V \cdot n \tag{2}$$

A dedicated Monte-Carlo algorithm was developed in order to assess errors in the particle transport coefficients [13]. Likelihood distribution calculated using multi-variate fast gaussian sampling [30] is plotted in figure 4 for diffusion coefficient D ($\rho = 0.1$) for Pulse No: 61138 (Note the logarithmic axis))

SUMMARY

A novel analysis method which uses all available neutron profile information was developed for tritium transport studies. The method also provides a direct visualisation of the plasma dynamic response to the tritium gas puff. Some preliminary results about tritium diffusion collisionality P* dependence were presented. For the data set analyzed, core tritium diffusivity decrease with increasing collisionality and values are comparable to neoclassical ones at high collisionalities. More results (e.g comparison with the ITER IPB98(y,2) particle scaling confinement) can be found in the paper. More data are to be analyzed and benchmarking with other methods [4-6] whenever possible will be continued. Finally, improvements in the quality of data for potential future Trace Tritium experiments are expected from the upgrade of the neutron profile monitor electronics.

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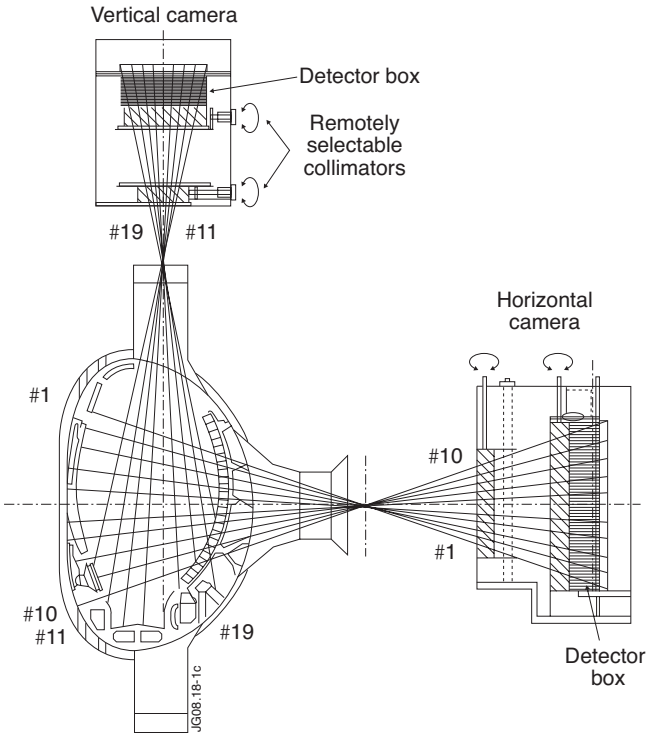

Figure 1: The JET neutron profile Channel numbers are indicated. The (viewing) camera recors the emissivity profile and vice versa.

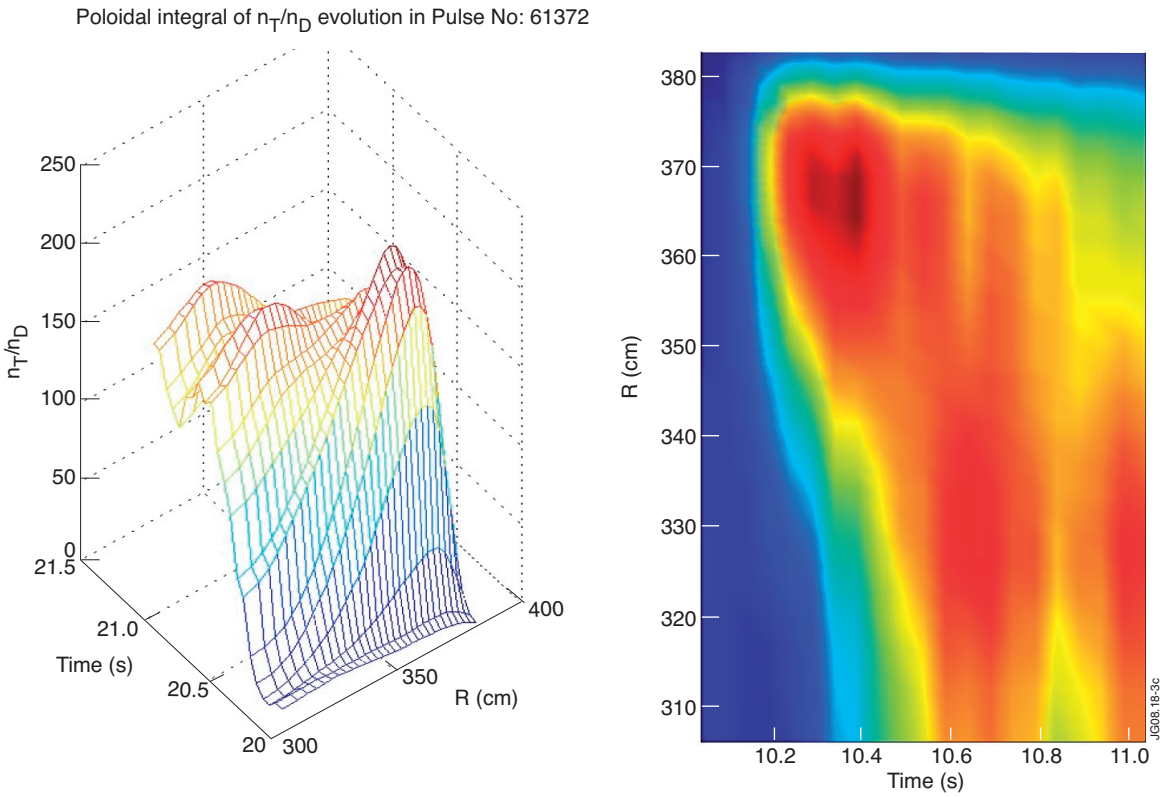

Figure 2: Tritium diffusion in Pulse No: 61372 (time and radial evolution of the n_T/n_D poloidal integral) shortly after a tritium gas puff.

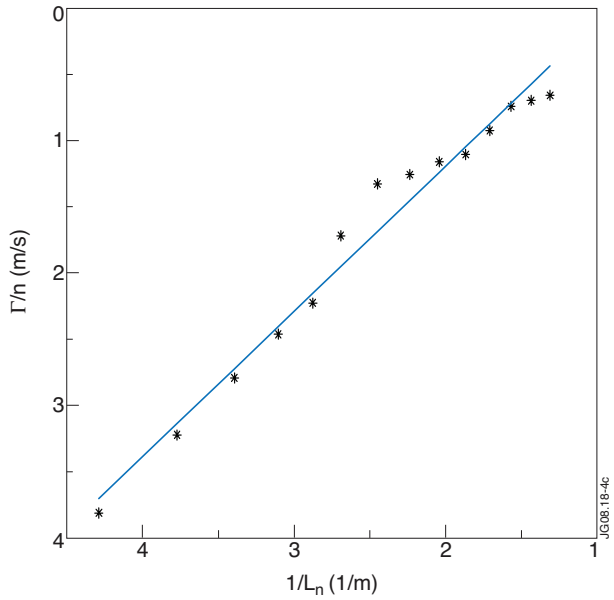

Figure 3: Tritium concentration flux normalized to the tritium concentration (Γ / c_T) is plotted versus inversed gradient length of the tritium concentration ($1/L_c$) at ρ = 0.1 t = [22.15 – 22.3] in Pulse No: 61110. Note that tritium concentration $c_T = n_T/n_D$ was used instead of tritium density n_T in the transport relation(1). Therefore, D -> D_T and V -> V_T only in limit cases. See detailed discussion in paper [13]

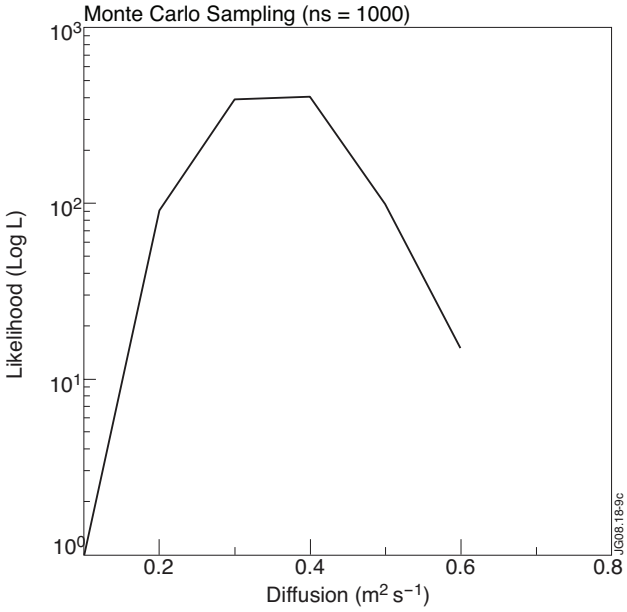

Figure 4: A dedicated Monte-Carlo algorithm was developed in order to assess errors in the particle transport coefficients[13]. Likelihood distribution calculated using multi-variate fast gaussian sampling[30] is plotted for diffusion coefficient D(ρ = 0.1) for Pulse No: 61138 (Note the logarithmic axis)).

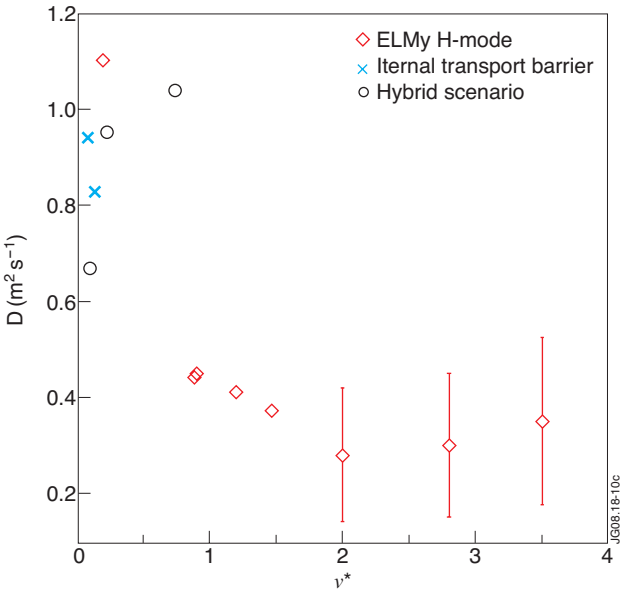

Figure 5: Tritium diffusion coefficient D (core region ρ < 0.3) versus collisionality [26,27] $\nu^* = \nu_{ie} R/a\, \omega_{Tbi}$ for a set of 13 JET plasmas with Tritium puff

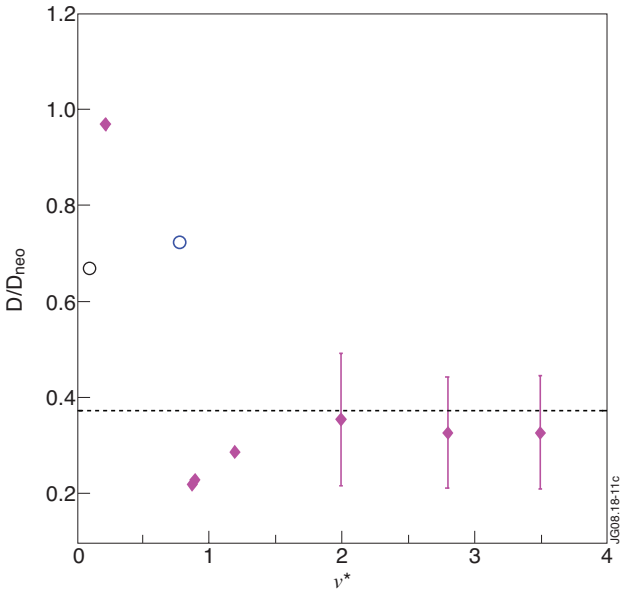

Figure 6: Tritium diffusion coefficient D (as in fig.6) normalized to its neoclassical value. Neoclassical values are from JETTO code [31]