TRACE TRITIUM TRANSPORT IN JET

The JET Team[1]
(presented by K-D. Zastrow)

JET Joint Undertaking,
Abingdon,
Oxfordshire,
United Kingdom.

Abstract

Trace amounts of tritium (1-5% of the deuterium content) have been introduced in short puffs (≈40 ms) into the low-field mid plane edge of steady-state deuterium plasmas in JET. The transport properties of the edge and core plasma, and the time evolution of the fraction of tritium in recycling flux, determine the evolution in space and time of the 14 MeV neutron emission following these puffs. Earlier work on TFTR has been in transient, high performance plasmas [1]. The JET experiments offered a unique opportunity to perform measurements of fuel ion transport in an ITER relevant regime. The main objective of these trace tritium transport experiments was to apply the dimensionless parameter approach, used in the study of energy confinement, to particle transport and to connect particle and energy transport in the same data set.

1. OVERVIEW OF EXPERIMENT AND ANALYSIS TECHNIQUE

Following the tritium puff in L-Mode we observe changes in the edge Dα signal as a response of the plasma to the excess fuelling. In H-Mode discharges this is however not the case. Neither the ELM frequency nor the base level react [2]. The 14 MeV neutron signal rises on a fast time scale. The peak of the 14 MeV neutron yield is reached in less than 300 ms for the discharges with the best confinement in these experiments (3MA/3T/14 MW, τ_E=0.5 sec). After a decay phase the neutron yield settles on a steady-state level higher than observed before the puff. This is due to the absorption of tritium by the wall and its subsequent recycling. Typically 5×10^{20} tritons are puffed into the vessel in each experiment. The wall reservoir of hydrogen atoms is $(1.6\pm0.6)\times10^{23}$ [3] and therefore the fraction of tritium in the wall flux increases by about 3×10^{-3} after each tritium puff.

The neutron profile monitor measures 10 horizontal line integrals and the total neutron emission with 10% accuracy [4]. The triton particle transport coefficients and their confidence intervals are computed from a least-squares fit of the model (see below) to the neutron measurements and their errors [5]. Time bins per channel of at least 100 counts are used. In the rise phase 10 ms bins were used if possible, longer if necessary. Further time bins of 100 ms duration are included in the steady-state phase before the puff, and in the decay phase after the puff. The number of these time bins is limited so that the total number of counts does not exceed that during the rise phase. Otherwise the analysis might be biased towards steady-state density profile analysis. This would result in an ambiguity between convective and diffusive transport terms.

The model uses a $1^1/_2$-D transport code with diffusive and convective particle transport terms (SANCO) and a time dependent fraction of tritium in the wall flux using a model which describes the isotopic changes in the wall. The neutron emissivity is modelled with a post processor (CHEAP [6]). The latter has been modified to account for the experimentally observed radial profile of 2.5 MeV neutron emission by adjusting the fast particle density. This modification is part of the least-squares fit [5]. Alternative modifications (for example a change of the dilution) are not consistent with JET data. Without modification all models (CHEAP, TRANSP) typically predict a factor of 3 more neutron brightness in the edge channels (r/a>0.7) than observed. Also finite neutron brightness is predicted for r/a>0.9 whereas the neutron profile monitor detects only a backscattering signal in this region. If the fast particle model

---

[1] See Appendix to IAEA-CN-69/OV1/2, The JET Team (presented by M.L Watkins)

was left unmodified the transport analysis of tritium would have to match the observed 14 MeV neutron brightness with a lower tritium density in the edge instead. The core tritium density would be the same which means that a stronger inward convection velocity would be derived.

2. SCALING OF TRITIUM TRANSPORT WITH DIMENSIONLESS PARAMETERS

Experiments were conducted in L-Mode and steady-state ELMy H-Mode NBI heated plasmas at constant q_{95} (=3.4), and constant minor radius, elongation and triangularity. We mainly varied ρ* and to some extent also ν*. There is some covariance of β with ρ* in the data set (see Figs.1, 2). Energy transport in ELMy H-Modes on JET has been found to be independent of β [7]. Here we assume that the same is true for particle transport. For L-Mode discharges the transport then seems to follow Bohm-scaling throughout the plasma. For H-Mode discharges the transport is best described by gyro-Bohm scaling for $0.3<r/a<0.6$ and Bohm-scaling for $0.6<r/a<0.95$. For L-Mode the convection term in the plasma for $0.3<r/a<0.6$ is zero within the error bars. For H-Mode a finite convection term is found throughout the plasma. For $0.3<r/a<0.6$ it is independent of ρ* while it is found to decrease with ρ* for $0.6<r/a<0.95$ (see section 3 for further discussion of the convection term).

In the figures we show the scaling of data points with respect to a reference case at 2MA/2T/10MW (#42517) since ratios in dimensionless parameters exhibit a smaller variation with radius than the quantities themselves. The error bars in dimensionless quantities represent radial and temporal variations. In all cases the errors in transport coefficients for $0.6<r/a<0.95$ are dependent on the errors of the edge and wall model parameters. In addition the neutron statistics are worse in the edge. Therefore the error bars in this zone are significantly larger than for $0.3<r/a<0.6$. For the innermost zone, $0<r/a<0.3$, scaling is not possible, since the chordal data across this zone are affected by sawteeth. For the outermost zone, $0.95<r/a<1.0$, dimensionless quantities cannot be calculated.

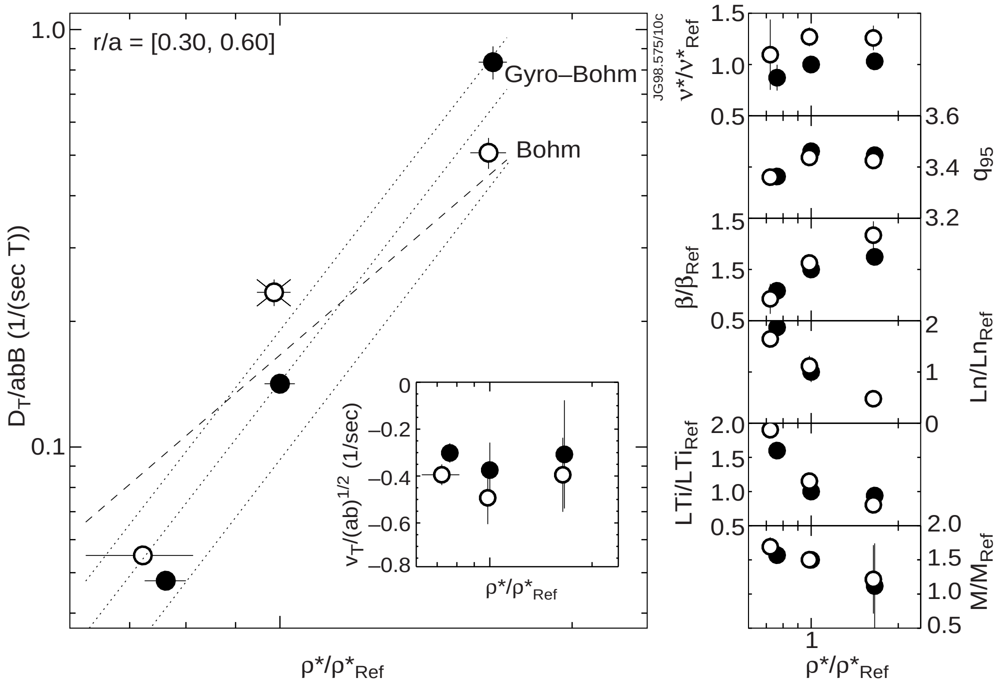

Fig.1: Scaled tritium diffusion coefficient (a and b are the horizontal and vertical minor radius, B is the toroidal magnetic field) in ELMy H-Modes for $0.3<r/a<0.6$ as function of the ratio of $\rho^*=(T_i/ab)^{1/2}/B_{tor}$ to that in discharge 42517. Open symbols are the higher $\nu^*=n/T_i^2$ discharge at each ρ. Discharge 42511 (excluded from the scaling) is marked by a special symbol. The insert figure shows the convection velocity. To the right (from top to bottom): ratios of ν*, q_{95}, $\beta=nT/B_{tor}^2$, density and temperature scale lengths $Ln^{-1}=d(\ln n_e)/dr$, and $LT_i^{-1}=d(\ln T_i)/dr$ and Mach number $M=v_{tor}/v_{th}$ to that in discharge 42517. The data*

are best represented by a gyro-Bohm scaling (all 5 used data points within a ±30% band). Bohm scaling is worse (± 50% band).

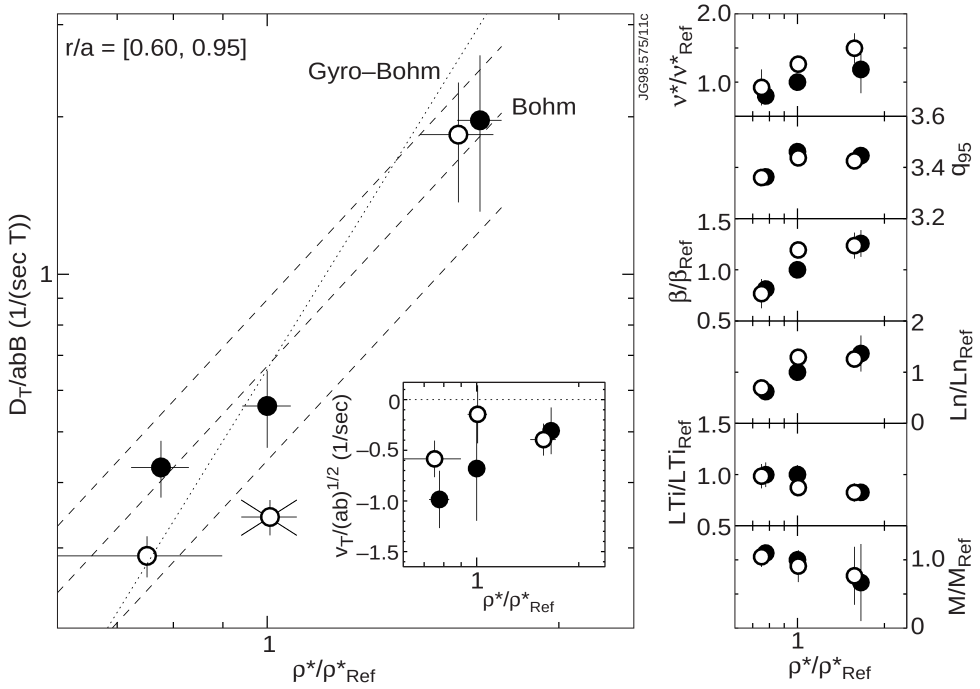

Fig 2: Like Fig 1, but for 0.6<r/a< 0.95. The data are best represented by a Bohm scaling (all 5 used data points within a ±35% band). Gyro-Bohm scaling is worse (± 55% band).

One discharge in this series of experiments at 2MA/2T/18 MW (#42511) does not fit the observed scaling in diffusion coefficient and convection velocity. It also deviates in its energy transport properties from the observed scaling (see section 3.). On the other hand it lies well within the range in all dimensionless parameters except for its value of β (0.6<r/a<0.95). While this could influence the scaling in this region it is not clear why it should influence the scaling further inside the plasma. This suggests that the set of parameters used for the dimensionless scaling approach is incomplete at present.

3. COMPARISON WITH DEUTERIUM AND ENERGY TRANSPORT

We have used the derived tritium transport model to predict the steady-state deuterium density profile. The beam deposition profile is computed by CHEAP. For the wall influx we have used the horizontal Dα signal, with a Johnson-Hinnov factor of 20, which also accounts for molecular emission. It is interesting to note that this results in the correct density within ±30% in spite of the strong poloidal asymmetry in the Dα emission (especially in the divertor region).

The main conclusions from this calculation are drawn from the deuterium density profile shape. We find that the convection term for tritium for r/a<0.6 is inconsistent. To be consistent the convection term needs to be about an order of magnitude smaller. On the other hand we find that the convection term for r/a>0.6 is required to explain the deuterium density gradient in this region. Further studies are necessary to determine whether the convection term in the centre, derived from these transient experiments, is real or due to systematic errors in the analysis.

A further outcome of the calculation is that the deuterium density profile is consistent with the weak mass scaling found for energy transport [7]. Three mass scalings have been tested, gyro-Bohm scaling $D_D/D_T=(2/3)^{1/2}$ and Bohm scaling $D_D/D_T=1$ for the whole plasma, and a mixed model using the derived scaling in each zone (see section 2). All of these assumptions give results within the range of experimental deuterium density profiles.

The results for 0.3<r/a<0.6 of the transient transport analysis for tritium are compared to the result of the TRANSP analysis of the steady-state density and temperature profiles in Fig. 3. The figure shows that the scaling of the inverse of the energy confinement time (gross conductivity) is weaker than the scaling of D_T. We find good correlation with the heat conductvities, however $D_T \approx \chi_e < \chi_{eff} < \chi_i$, except for the 2MA/2T/18 MW (#42511) discharge. Also we find a good correlation with the effective electron particle diffusivity, i.e. $D_T \approx D_{e,eff} = \nabla n_e / \Gamma_e$, again with the exception of the 2MA/2T/18 MW (#42511) discharge. In the outer region, 0.6<r/a<0.95, we have set the diffusion coefficient constant in radius and we find a diffusive transport barrier in 0.95<r/a<1.0. TRANSP on the other hand derives transport coefficients with strong radial variation and does not find a transport barrier. A detailed comparison of results in these two regions is therefore not meaningful.

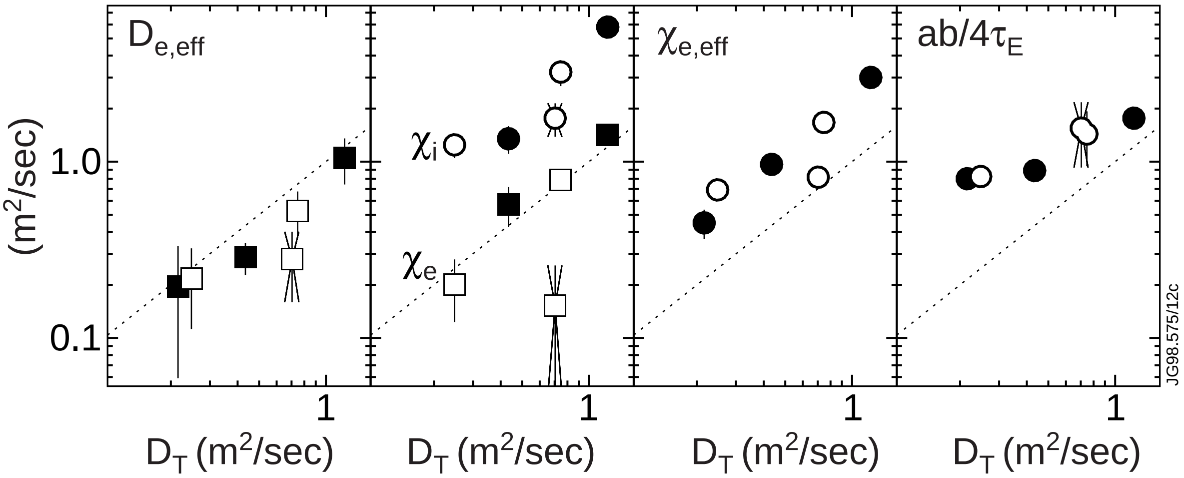

Fig. 3: Scaling of confinement and steady-state transport quantities (analysed using TRANSP) plotted against the tritium diffusion coefficient for 0.3<r/a<0.6 from transient transport analysis. Open symbols are the higher $\nu^* = n/T_i^2$ *discharge at each* ρ^**. Discharge 42511 is marked by a special symbol. Left: Effective electron diffusivity, Middle: Ion, electron and effective heat conductivity, Right Gross conductivity.*

4. CONCLUSIONS

Trace tritium transport experiments were conducted in L-Mode and steady-state ELMy H-Mode plasmas. For L-Mode discharges the transport seems to follow Bohm-scaling throughout the plasma. For H-Mode discharges the transport is best described by gyro-Bohm scaling for 0.3<r/a<0.6 and Bohm-scaling near the edge (0.6<r/a<0.95). For 0.3<r/a<0.6 a non-zero convective transport term is obtained only in H-Mode. This is however not consistent with the observed deuterium density profile shape. The convective transport term for 0.6<r/a<1.0, on the other hand, is required to explain the observed deuterium density gradient. In the plasma core we find that tritium particle diffusivity, effective electron diffusivity and electron heat conductivity are about equal whereas the ion heat conductivity is correlated but much larger.

REFERENCES

[1] P EFTHIMION *et al,* Phys. Rev. Lett. **75**, 85 (1995)
[2] G F MATTHEWS *et al.*, 13th Int. Conf. on Plasma Surface Interactions, San Diego, May 1998
[3] P ANDREW *et al.*, 13th Int. Conf. on Plasma Surface Interactions, San Diego, May 1998
[4] M J LOUGHLIN *et al.*, 12th Topical Conf. on High Temp. Plasma Diagnostics, Princeton, June 1998
[5] K-D ZASTROW *et al*, 25th EPS Conf. on Contr. Fusion and Plasma Physics, Prague, June 1998
[6] M G VON HELLERMANN, *et al*, in Diagnostics for Exp. Fusion Reactors, Plenum Press, p. 281 (1996)
[7] THE JET TEAM (presented by J G Cordey), this conference, IAEA-CN-69/EX7/1