*31st EPS Conference on Plasma Phys. London, 28 June - 2 July 2004 ECA Vol.**28G**, P-1.158 (2004)*

Transport analysis of trace Tritium experiments on JET using TRANSP code and comparison with theory-based transport models

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Recently, the trace Tritium (T) transport has been studied on JET by puffing a small amount of Tritium into Deuterium plasmas [1]. The information about the Tritium has been obtained by fitting the 14 MeV neutron emission measured by a neutron camera along 19 chords in the TRANSP simulations and in combined TRANSP and UTC [1] simulations. Here, the three groups of discharges are analysed with the goal to investigate: the effect of plasma density on T transport in H-mode (i); T confinement in Ar seeded H-mode discharge (ii); and T transport in the hybrid scenario (HS) and in the discharge with weak reversed magnetic shear (iii). The parameters of selected discharges are given in Table 1.

1. Tritium transport in H-mode plasma: effect of plasma density

The first three NBI heated H-mode discharges shown in Table 1 are used to test the density effect on T transport. The Tritium was puffed during the stationary phase of the discharge. The discharge parameters are slightly different in three cases, but the plasma density varies strongly from shot to shot. The strong inverse correlation of T diffusion coefficient (D_t) with density is found (Fig. 1 (left), the assumptions for the fits for D_t are stated in caption to this Figure). Similar results have been obtained on other devices [2, 3]. The diffusion losses at low density are partially compensated by strong inward pinch (V_t) (Fig. 1, middle). Such strong correlation with density is not obtained for thermal diffusivity resulting in the density-dependent ratio χ_{eff}/D_t for these three discharges (Fig. 1, right). The low T diffusion and pinch provides slow T penetration at high density as compared to the low density case.

The low density H-mode discharges at JET exhibit the sawtooth oscillations observed also on the 14 MeV neutron emission. The modelling of the sawtooth mixing of plasma species is important for proper interpretation of the evolution of neutron emission (Fig. 2(a, b)). The sawteeth re-distribute the T differently during the rise and decay phase enhancing the T penetration to the core in the first case when the T profile is hollow and its removal in the second case when the profile is peaked (Fig. 2(c, d)). The sawtooth mixing is also able to maintain the core T density later on the decay phase if the density profile inside the inversion radius becomes hollow.

The comparison of the total T flux with the neoclassical T flux shows that the transport is nearly neoclassical in the high density H-mode (shot 61138) while the anomalous transport becomes dominant at low density (Fig. 3). The two ICRH heated

H-mode discharges have larger anomalous flux, but they exhibit the same trend with the density. The predictive modelling of the T gas puff in the discharges shown in Fig. 1 is performed with the ASTRA code using the MMM transport model based on the quasi-linear ITG and TEM turbulence to test the density effect. In the low density discharge, the diffusion coefficient predicted by the MMM model is nearly flat and close to 1 m^2/s (compare to Fig.1) and the anomalous pinch is close to the experimental one. As a result, the agreement with the T density matching the neutron emission in TRANSP is satisfactory until the first sawtooth event occurs. Since the sawtooth T re-distribution (Fig. 2) is not included in the modelling the core T density is underestimated after the crash. At the high density, the predicted diffusion coefficient exceeds the experimental one by the order of magnitude producing too fast T penetration and subsequent decay. This may indicate that the instability threshold is overestimated by the MMM model. The MMM model predicts that the ITG is the dominant instability in the high density plasma. Since the ITG threshold does not depend on collisionality the change of the collisionality with plasma density can not provide the suppression of the anomalous T flux in MMM model for NBI heated H-mode plasma.

2. Tritium evolution in Ar seeded H-mode discharge

The effect of Ar seeding is analysed by comparing the Ar seeded discharge 61372 with the reference discharge without Ar (61374) [4]. The plasma density increases by 20% when Ar is injected. It was found that the thermal effective diffusivity reduces by a factor **2** in the gradient zone due to reduced thermal ion diffusivity. The time delay of the peak of the 14 MeV neutron emission in the core and its lower peak value has been observed in Ar seeded discharge as compared to the reference discharge [4]. Such evolution of the neutron emission can be explained by lower core reactivity in combination with lower T diffusion. The reduction of the core reactivity produced mainly due to the interaction between the fast Deuterium and thermal Tritium is caused by the larger off-axis absorption of NB typically obtained in high density H-mode also without Ar.

The behaviour of tritons in these discharges is analysed in two steps. First, the T density evolution is adjusted in reference discharge to match the neutron emission profiles. Then, this T density is used as an input to simulate the neutron emission in the discharge with Ar seeding. These simulations give the lower peak of the core neutron emission than the measured one. Therefore, the larger T density in Ar seeded discharge than in reference discharge is required to match the neutron data. In addition, the lower core Tritium transport in Ar seeded discharge is obtained in combined TRANSP-UTC analysis (Fig. 4). Since the Ar seeding leads to the density rise this reduction of transport can be partially explained [5] by the inverse correlation of T transport with plasma density obtained for other discharges (Fig. 3). However, the total flux for these two discharges is above the fitting curve for other scenarios (Fig. 3). The analysis of Ar seeded discharge where the T diffusion is nearly neoclassical shows that the strong anomalous pinch obtained in these discharges (Fig. 4, right) is the reason of this large anomalous flux.

3. T transport in hybrid scenario and in plasma with weak reversed shear

The T confinement in the HS and weak RS scenario is analysed and compared to the conventional H-mode performed in the close density range. The hybrid scenario has the larger energy and particle content while the RS discharge with the weak ITB analysed here represents the intermediate step between the conventional H-mode and HS (Fig. 5). The combined TRANSP-UTC analysis gives close values for the core diffusion coefficient and nearly zero pinch in this three scenarios while the diffusion and pinch are larger for the ITB discharge outside the mid-radius (Fig. 6, left). At the ITB location (around r/a ~ 0.4) the T diffusion coefficient is reduced and the convective velocity through the ITB region is very small (0.55 m/s) (Fig. 6, right). Interestingly, the strong gradient on the T density profile appears in the region of the strong diffusion ($0.5 < r/a < 0.7$) where the T accumulation is produced by the large pinch outside the mid-radius in combination with low T penetration through the ITB region. The T is confined longer in the H-mode plasma due to lower T diffusion outside the mid-radius while it is lost more rapidly in the RS configuration. The T transport in HS and RS plasma also shows inverse correlation with the density found for the H-mode plasmas (Fig. 3). Further analysis of the T behaviour in the discharges with strong ITB is given in Ref. 6.

4. Summary

Our results can be summarised as follows:

1. Strong inverse correlation of the anomalous T transport with plasma density is observed in all analysed discharges. The T diffusion reduces to its neoclassical value in high density H-mode plasma following this density trend.
2. The T pinch is found to be close to the neoclassical value in high density NBI heated H-mode, but it becomes strongly anomalous with the density decrease.
3. The ratio χ_{eff}/D_t varies with plasma density in the H-mode discharges analysed here.
4. The better T confinement as well as the reduced thermal ion diffusivity at mid-radius is obtained in the discharge with Ar seeding as compared to the discharge without Ar. The Ar seeded discharge has nearly neoclassical T diffusion while the T pinch is anomalous.
5. The reduction of the T diffusion coefficient at the ITB location is found for the weak RS discharge along with the small convective velocity through the barrier region. The core T transport is slightly lower in HS than in the low density H-mode and RS while the transport outside the mid-radius is larger in RS plasma and smaller in the H-mode due to different q-profiles [1].

This work was performed under the European Fusion Development Agreement, and partly funded by EURATOM and the UK Engineering and Physical Sciences Research Council.

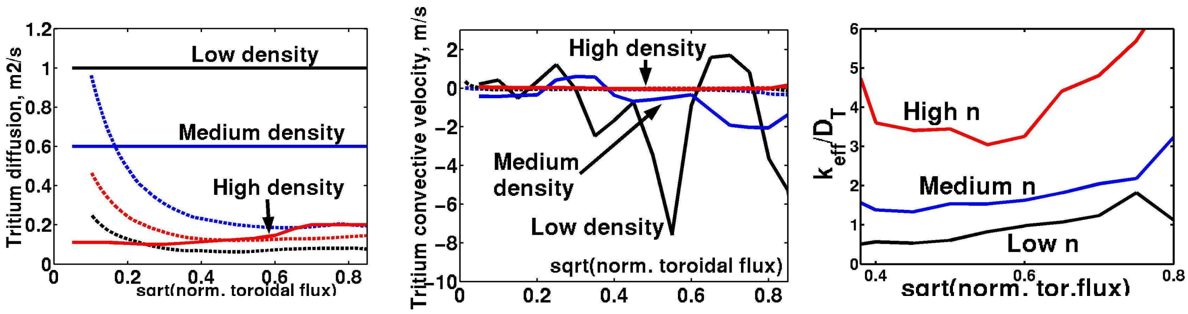
Table 1

Shot #	Bt, T	Ipl, MA	$P_{NBI}/P_{ICRH}/P_{LHCD}$, MW	nl, 10^{19} m-3	regime
61132	**1.9**	**2.35**	**2.3/0/0**	**2.4**	**ELMy H-mode**
61097	**1.65**	**2**	**7.6/0/0**	**5**	**ELMy H-mode**
61138	**2.25**	**2.5**	**13.6/0/0**	**9.5**	**ELMy H-mode**
61374	**2.7**	**2.5**	**13.8/2.74/0**	**7.6**	**ELMy H-mode**
61372	**2.7**	**2.5**	**14.4/2.9/0**	**10**	**Ar seeding**
61398	**3.2**	**1.9**	**13/4/2.1**	**2.8**	**RS, weak ITB**
61161	**2.4**	**2**	**14.9/2.3/1.3**	**3-3.4**	**hybrid**

References

[1] K-D Zastrow *et al*, this conference; [2] K W Gentle *et al*, Nucl. Fusion **32** (1992) 217; [3] J P T Koponen *et al*, Nucl. Fusion **40** (2000) 365; [4] P Dumortier *et al*, this conference; [5] P. Belo *et al*, this conference; [6] J Mailloux *et al*, this conference.

Next page: Fig. 1. T diffusion coefficient D_t, convective velocity V_t and χ_{eff}/D_t ratio for discharges representing the density scan. The fit of D_t has been made assuming constant D_t (low and medium density) and piecewise D_t at high density. The corresponding fit of neutron data is characterised by χ^2 = 2.42 for 61138, χ^2 = 2.53 for 61097, χ^2 = 5.37 for 61132. Neoclassical transport is shown by dashed curves.



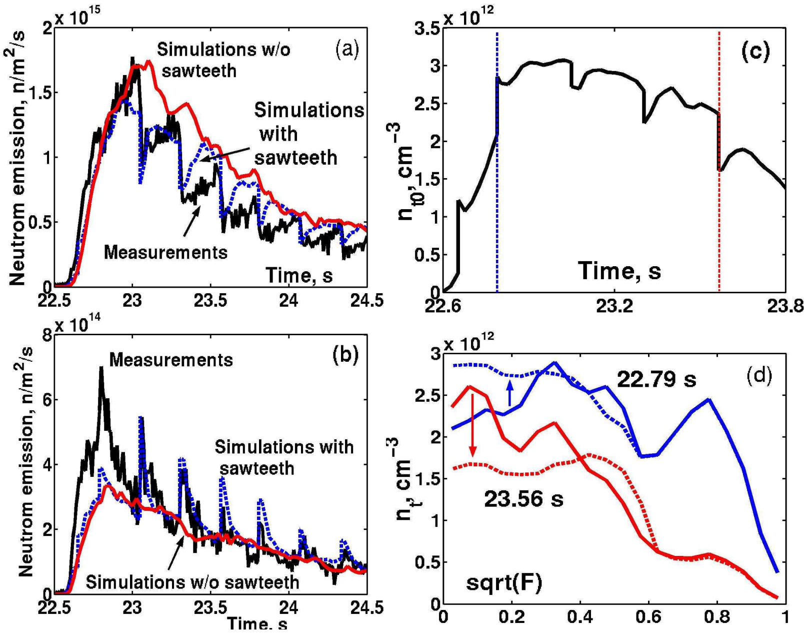


Fig. 2. (a) and (b): Experimental (black) and calculated with (blue) and w/o (red) sawteeth neutron emission in the core (a) and outside the inversion radius (b); (c) and (d): Evolution of central T density n_{t0} (c) and T density profiles n_t before (solid) and after (dashed) the sawtooth crash occurring during the rise (blue) and decay (red) phase (d). Arrows indicate the modification of the density profile during the crash.

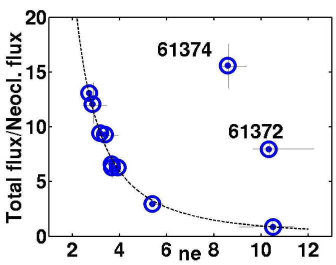


Fig.3. The ratio of total T flux to the neoclassical flux as a function of density n_e averaged over 0.2< r/a < 0.4 for H-mode and local n_e (r/a=0.2,0.3,0.4) for HS and RS shots.

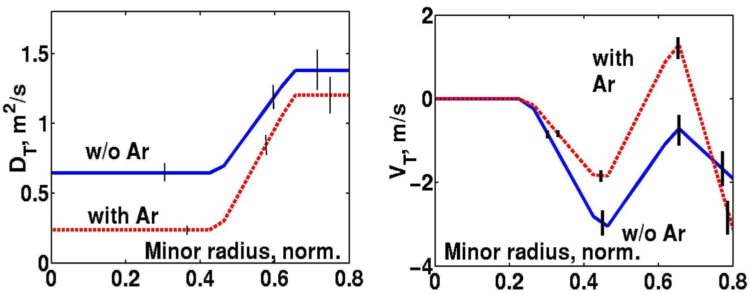


Fig. 4. T diffusion (left) and convective velocity (right) for discharges 61374 (blue) and 61372 (red).

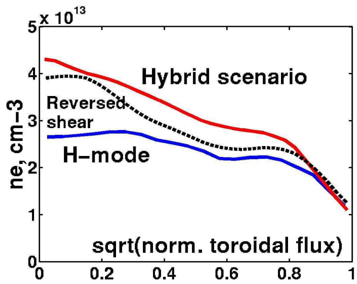


Fig. 5. Electron density profile: in three scenarios during T puf

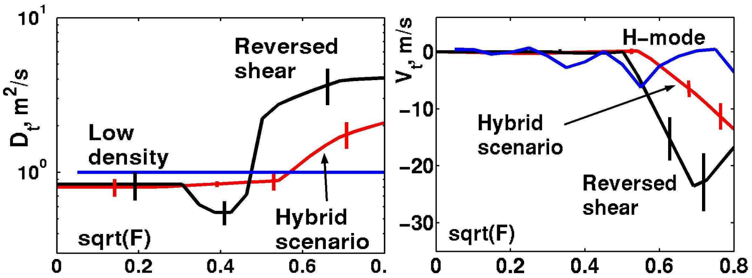


Fig. 6. T diffusion (left) and convective velocity (right) for discharges 61132 (blue,) 61161 (red) and 61398 (black).