EUROPEAN FUSION DEVELOPMENT AGREEMENT
JET

EFDA–JET–CP(03)01-36

T. Loarer, E .Tsitrone, C. Brosset, J. Bucalossi, J. Gunn, E. Joffrin, A Loarte,
P. Lomas, P. Monier-Garbet, J. Ongena, B. Pégourié, P. Thomas,
Tore Supra Team and JET EFDA Contributors

Particle Retention During Long Discharges in Tore Supra and JET

Particle Retention During Long Discharges in Tore Supra and JET

T. Loarer[1], E .Tsitrone[1], C. Brosset[1], J. Bucalossi[1], J. Gunn[1], E. Joffrin[1], A Loarte[2], P. Lomas[3], P. Monier-Garbet[1], J. Ongena[4], B. Pégourié[1], P. Thomas[1], Tore Supra Team and JET EFDA Contributors*

[1]*Association EURATOM-CEA, DSM-DRFC, CEA-Cadarache, 13108 Saint Paul lez Durance, France.*
[2]*EFDA-CSU–Garching, Max-Planck-Institut für Plasmaphysik D-85748 Garching bei München Germany*
[3]*EURATOM/UKAEA Fusion Association, Culham Science Centre, Abingdon,OX14 3DB, UK*
[4]*Laboratoire de Physique des Plasmas-Laboratorium voor Plasmafysics ERM-KMS, B-1000 Brussels, Belgium*
**See Annex of J. Pamela et al., "Overview of Recent JET Results and Future Perspectives", Fusion Energy 2000 (Proc. 18th Int. Conf. Sorrento, 2000), IAEA, Vienna (2001).*

Preprint of Paper to be submitted for publication in Proceedings of the
EPS Conference on Controlled Fusion and Plasma Physics,
(St. Petersburg, Russia, 7-11 July 2003)

INTRODUCTION

Particle retention is a major constraint in today's tokamaks and will be in future fusion devices like ITER in which the amount of tritium will be strictly limited for safety considerations. Global particle balances have been performed for long discharges to gain a global understanding of the particle inventory for steady state operations.

In Tore Supra, long discharges (up to 265 s) have been carried out in steady state conditions on the toroidal pump limiter (TPL). In JET, long diverted discharges (up to 50s) have also been achieved in L-mode. Gas injection scans performed during H mode discharges at JET for "medium" (16 sec) and "short" (~6sec) durations have been investigated as well as H mode in reversed B configuration. The particle balances and the associated particle retentions for the long discharge experiments performed in Tore Supra and for the L and H mode discharges carried out in JET are reported in this paper.

1. EXPERIMENTS IN TORE SUPRA

Long discharges in steady state have been performed in Tore Supra with the new limiter configuration [1]. Figure 1 shows a discharge of duration longer than 4 minutes, maintained by Lower Hybrid (LH) power between 2.2 and 2.8MW. For this discharge (I_p = 0.65MA, B_T = 3.8T) the typical gas puff rate, Γ_{puff}, is around 1 Pam^3s^{-1} (1 Pam^3=2.47 10^{20} at 293K) of D_2 while the exhausted flux, Γ_{exh}, is about 0.4 Pam^3s^{-1}. All the plasma parameters are kept constant for the overall plasma duration, but it can be seen (Fig.1) that a steady state ratio of $\Gamma_{puff}/\Gamma_{exh}$ ~2 has to be maintained to keep the density constant and that no sign of «wall[a] saturation ($\Gamma_{puff}/\Gamma_{exh} \rightarrow 1$) occurs after 4 mn 25s.

For all the long discharges using the same plasma parameters (I_p, B_T...) the required Γ_{puff} is always the same to maintain the plasma density constant. The same ratio of $\Gamma_{puff}/\Gamma_{exh}$ is also observed independently from the previous discharges (and of its associated wall loading) and from the conditionning during the night (helium glow discharge cleaning). This is illustrated on figure 2 which displays the time traces of Γ_{puff} for long discharges having the same plasma parameters but performed on different days. Defining the retention as Ret = $\int(\Gamma_{puff}-\Gamma_{exh})/\Gamma_{puff}\,dt$, at the end of these discharges (or during the steady state phases), ~60% of the particles injected are retained in the vessel independently from the plasma duration. However, for a constant density throughout the discharge, two phases can be distinguished in the particle balance. In the first phase, from the plasma break down to ~50sec, a slow decrease of the gas injection, Γ_{puff} is always observed. This drop is attributed to both the feedback system on Γ_{puff} to attain the target density and to the saturation of the limiter area in strong interaction with the plasma (recycling area) up to 4 Deuterium for 10 atoms of Carbon (0.4D/C) [2]. For these experiments, the number of particles necessary to saturate this area varies from shot to shot in the range of 1 to 5 10^{21}D in agreement with the energy of the particles in the plasma edge (~100eV) and the recycling area on the limiter (~2m^2) which lead to a saturation around 3 10^{21}D and corresponding to the saturation range. When this area is saturated and when the target plasma density is obtained, Γ_{puff} remains constant up to the end of the discharge. Independently from these two phases, Γ_{puff} is always larger than Γ_{exh} within a ratio of ~2 demonstrating that the retention takes place during the entire discharge duration. Moreover, the outgasing between discharges (Vessel temperature of 120^{o}C) is not significantly modified by the plasma duration and the associated retention, showing that the particle recovery between shots becomes negligible in the particle balance when long plasma discharges are performed.

Finally, the active pumping does not appear to modify the retention flux [3]. Previous results from long discharges in Tore Supra already demonstrated that in absence of active pumping [4] the retention flux was 100% of Γ_{puff} for discharges of 1mn duration.

2. EXPERIMENTS IN JET

Long discharges in L mode ($I_p = 1.7$MA, $B_T = 1.7$T) have been performed in JET, using different auxiliary heating systems (NBI, ICRH and LH) as shown on figure 3. The plasma density was kept roughly constant with a low Γ_{puff} (~2 10^{21}Ds^{-1}) for JET experiments but due to the different heating Γ_{puff} is modified all along the discharge. However, the global retention at the end of the plasma is low and around 10%.

A series of H mode discharges ($I_p = 1$MA, $B_T = 1.2$T, NBI = 6MW) has been analysed with a flat top of about 16 sec for a gas scan from 1.25 10^{22} to 7.6 10^{22}Ds^{-1} which corresponds to a gas rate about 2 to 20 times larger than for the L mode discharge and up to 140 larger than for the reported experiments of Tore Supra.

For all the discharges of the series the global particle balance shows a steady state situation about 3-4 sec after both Γ_{puff} and the NBI are turned on. Figure 4 displays the time evolution of Γ_{puff}, the NBI flux, Γ_{NBI}, Γ_{exh}, and the resulting wall particle flux Γ_{wall} for a typical H mode discharge of the series. It can be seen that Γ_{puff} is constant and significantly larger than Γ_{exh} within a ratio around 2. The saturation of the area in strong interaction (about 3 m^2 in the JET divertor) with the plasma (~0.4D/C) after a few seconds ($T_{e,edge}$ ~15-20eV) is illustrated by the drop of Γ_{wall}. As in Tore Supra, and from shot to shot no sign of saturation of the "wall" is observed indicating that the total number of particles retained in the vessel is also directly proportional to the discharge duration.

Particle balances have been performed for a gas scan in H mode with higher auxiliary heating ($I_p = 2.5$MA, $B_T = 2.7$T, NBI = 13.5MW and ICRH = 2.0MW) for 6sec of plateau and also for H mode with reversed B. In terms of global particle balance, the same behaviour is always obtained. This is illustrated on figure 5 which displays the ratio $\Gamma_{exh}/\Gamma_{puff}$ and the retention as a function of Γ_{puff} for all the reported discharges. The global trend is similar for these discharges, showing an increase of the particle retention with Γ_{puff}. For the strongest Γ_{puff} (Pulse No: 57868, G_{puff} ~7 10^{22} Ds^{-1}), the resulting retention rate is 0.78 which corresponds to 0.184g Ds^{-1}. The data for the discharges performed just after a disruption are also plotted (smaller Γ_{puff} for "similar" plasma), showing the same behavior and suggesting that the wall conditioning does not affect the retention for a given Γ_{puff}. Finally, the resulting neutral pressure in the vessel at the end of the discharge is not modified with the total gas injected. As in Tore Supra, this demonstrates that the recovery of particles between discharges remains roughly constant and becomes negligible in the global particle balance, in spite of a higher wall temperature of 200∞C in JET leading to a larger gas desorption compared to Tore Supra.

CONCLUSIONS

From the reported experiments, the same particle retention behaviours are observed in spite of the differences between the plasma geometry and the confinement mode in Tore Supra and JET (respectively limiter L-mode and divertor H-mode). A particle retention rate up to 70-80% of Γ_{puff} for the larger gas injection has been obtained in JET. The particle retention behavior observed with the gas puff appear to be strongly dominant in the particle retention process. Indeed, no influence has been noticed from the active pumping, the saturation of the recycling area (0.4 D/C), the precedent discharges history (in terms of total "particles retained" in the vessel) and even from the disruptions (conditioning). Also, the outgasing between discharges becomes negligible in terms of particle recovering when Γ_{puff} and/or the discharge duration are increased.

Finally, for ITER, the particle retention has to be strictly limited and from the presented results it seems that strong gas injection should be avoided. Pellets and/or NBI as particle source leads to a negative wall retention (necessarily limited in the time) and will likely lead to a limited particle retention.

REFERENCES

[1]. Jacquinot J and Tore Supra Team IAEA 2002, Lyon

[2]. Wilson K et al., Nuclear Fusion, Vol.1, "Atomic and Plasma material interaction data for fusion", p.41, 1991.

[3]. E Tsitrone et al., this conference.

[4]. Van Houtte D and Tore Supra Team, Nuclear Fusion, Vol.**33**, No1, p.137 (1993)

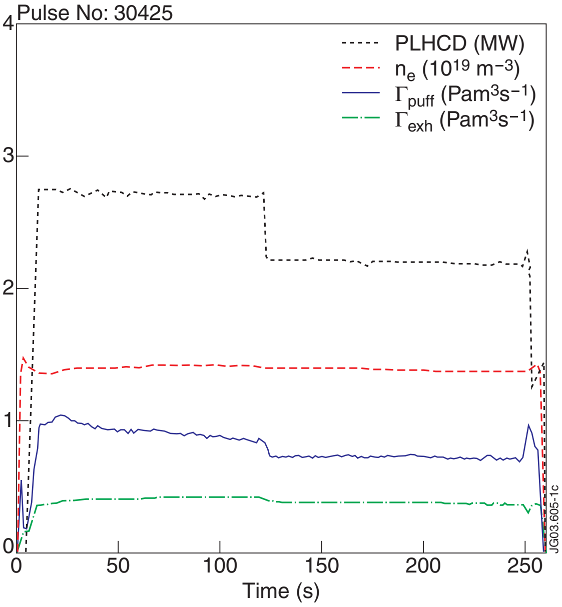

Figure 1: Long discharge operation: Steady state and $\Gamma_{puff}/\Gamma_{exh}$ ~2.

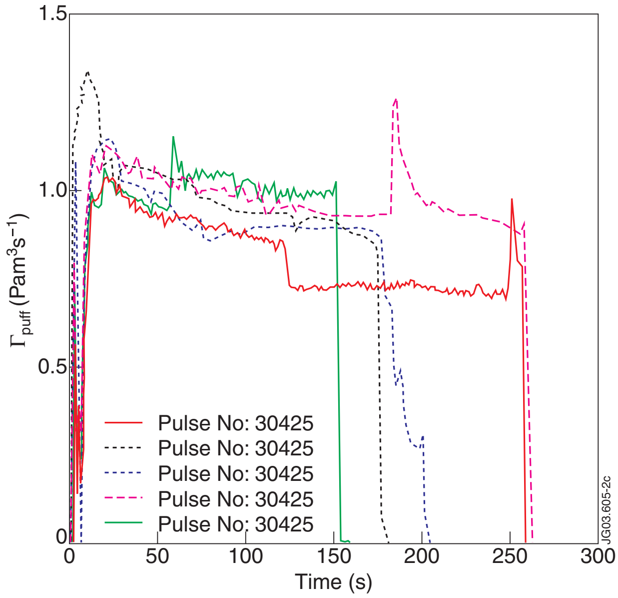

Figure 2: Gas puff rates for 5 long discharges performed at different days. Γ_{puff} is the same for all these discharges independently of the wall loading.

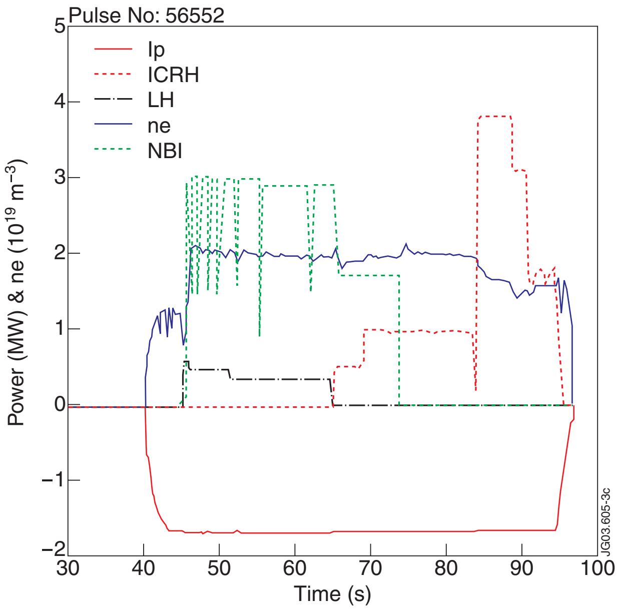

Figure 3 : Long L mode discharge in JET, I_p, ICRH, LH, n_e and NBI as a function of time.

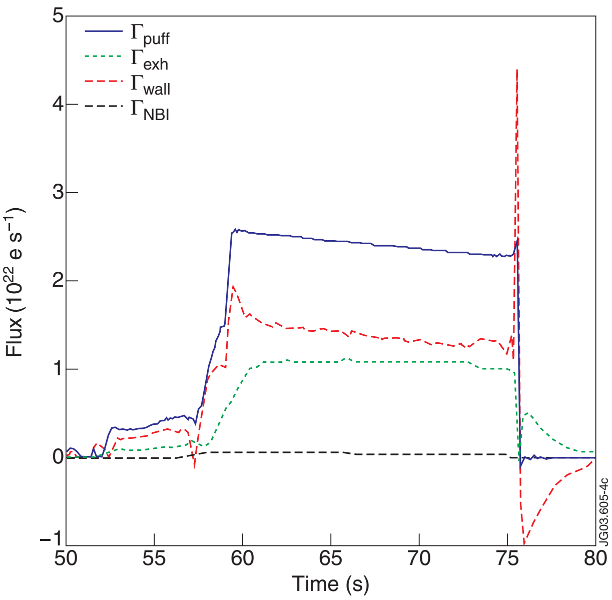

Figure 4: Time evolution of particle fluxes Γ_{puff}, Γ_{NBI}, $\Gamma_{exhausted}$, and resutling wall particle retention Γ_{wall} for an H mode.

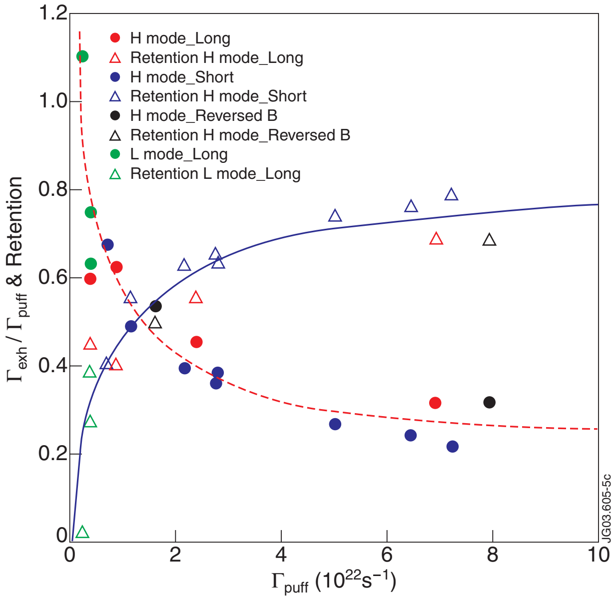

Figure 5: Ratio $\Gamma_{exh}/\Gamma_{puff}$ (Dashed line) and retention (Plain line) as a function of Γ_{puff} for the series of L mode discharges (filled symbol) and H-mode (opened symbols).