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INTRODUCTION

Global particle balance gives insight into the exchanges of particles between the wall and the plasma leading to a better understanding of the plasma density behaviour. In addition, it gives access to the evolution of the wall particle inventory, which is crucial in the tritium experiments as demonstrated in the D-T campaign on JET in 1997-1998 [1].

In JET, the particle balance equation can be written:

$$\int_0^t Q_{gas}dt + \int_0^t Q_{NBI}dt + \int_0^t Q_{pellet}dt = \langle n_e \rangle V_p + \int_0^t P_{ves}S_{ves}dt + \int_0^t P_{div}S_{div}dt + N_{Wall}. \qquad (1)$$

where Q_{gas}, Q_{NBI} and Q_{pellet} are the particle injection rates associated respectively with gas puffing, neutral beam injection and pellet injection, $<n_e>$ is the volume averaged plasma density, V_p the plasma volume, P_{ves} the neutral pressure in the vessel, S_{ves} the global pumping speed of the vessel (including vessel turbo-pumps and neutral beam boxes), P_{div} the neutral pressure at the divertor cryo-pumps, S_{div} the pumping speed of the divertor cryo-pumps and N_{wall} the amount of particle trapped in the wall. The equation is verified at any time during and between the pulses. In principle, the only quantity not accessible to direct measurement is N_{wall}. The knowledge of the other terms can give, as a function of time, an estimation of the amount of particles trapped or released by the wall. Dynamic wall particle retention for a few typical plasma discharges and long-term retention over the last experimental campaigns are estimated and analysed in this paper.

1. DETERMINATION OF THE PUMPING SPEEDS

Due to the presence of the divertor cryo-pumps [2] and the neutral beam box cryo-pumps, the pumping speeds play a major part in the particle balance and their determination is one of the key factor of the accuracy of the balance. Daily dry runs have been used to estimate the pumping speeds, referenced to a neutral pressure measurement, according to the expression

$$S^P = \frac{\int Q_{gas}dt}{\int P dt}. \qquad (2)$$

As the product pressure-pumping speed is the relevant value in the particle balance, that integral method limits the pressure gauge calibration problem and gives the effective pumping speed (not absolute) needed to calculate the exhaust. The obtained values are given on Table I.

However, the comparison of the amount of gas released by the divertor cryo-pumps during regeneration and the amount of gas calculated by the time-integrated (over the same period of operation) divertor neutral pressure multiplied by the divertor pumping speed given in table I, implies that the pumping speed value found during dry run is not valid during X-point plasma. The location of the pressure gauge in the sub-divertor and the different pressure distribution in the vicinity of the cryo-pump in X-point plasma (due to leakage from the sub-divertor to the main chamber ~$100m^3/s$) can explain that fact. As the network of conductance in the sub-divertor is not well known (MkII-GB), the effective pumping speed during X-point plasma has to be worked out from cryo-pump regenerations. A value of $110m^3/s$ has been found (referenced to KT5P to be compared to $250m^3/s$ in dry-run, Table I).

2. PARTICLE BALANCE FOR TYPICAL DISCHARGES

Using the pumping speed previously etimated, the particle balance has been performed extensively over a wide range of discharges. Figure 1 shows the results for two typical JET discharges.

In the ELMY H-mode, after the X-point formation, a strong gas injection (421 $Pa.m^3$) is necessary to rise the plasma density to the requested level (up to ~$0.6n_{Greenwald}$). The gas injection continuously loads the wall and the divertor cryo-pumps while the plasma content remains small (4-5 $Pa.m^3$) in comparison with the injection. At the end of the discharge, nearly 60% of the injected particles are trapped in the wall. In the optimised shear discharge, different phases can be observed. In the first phase, a strong gas injection slowly builds up the plasma density while strongly increasing the wall inventory. At t = 4.5s, the gas injection is stopped and the neutral beams start to fire. The plasma density rises immediately and the wall begins to release particles. At t = 8s, the beams are stopped, the gas injection resumes and the wall is filling up again until the end of the gas puffing. At the end of the discharge 35% of the injected particles is dynamically retained in the wall (39.5 $Pa.m^3$). The following pulse ends up with a disruption (Pulse No: 51448) and the balance indicates a consequent wall depletion (48.5 $Pa.m^3$ have been released), characteristic of a disruption.

In the average, 50% of the injected particles is dynamically retained in the walls at the end of the discharge and then slowly released between the pulses while the other 50% is pumped during the discharge by the divertor cryo-pumps. From this study, the effect of the decrease of the wall temperature (320°C 200°C) on the wall behaviour during the pulses is not obvious as the history of the wall can be misleading.

3. PARTICLE BALANCE FOR LONG-TERM ANALYSIS

The same calculation can be extended between the pulses and during the night to access the long-term gas retention. Figure 2 displays the vessel pressure measurement during one particular week of operation (mainly dedicated to task force S1 : ELMy H-mode). During that week, 230 bar.l of gas (deuterium = 98%) have been injected in the torus (94.7% gas puffing, 5.3% neutral beams). The results of the particle balance are presented on Table II.

The amount of particle pumped during the discharges is comparable to the amount of particle pumped between the discharges and residual outgassing during the night represents less than 5% of the total pumped particle. During its regeneration, the divertor cryo-pumps releases 195 bar.l of gas which is in good agreement with the calculated value. Finally at the end of the week, the wall retention reaches 3.5%. The same analysis has been carried out over the experimental weeks of JET C1-C4. Overall results are reported on Fig. 3.

The weekly pattern of the retention changes drastically from very high retention (up to 100 bar.litres) to modest depletion (up to 20 bar.l). This behaviour appears to be coupled with the experimental program : high density H-mode discharges (TF-S1) tends to lead to high retention while optimised shear programs (TF-S2) tends to reduce the wall retention. Finally, at the end of week 9 (C4) wall retention reaches 8%. Unfortunately, no direct comparison with other data (from AGHS) is possible but the result is consistent with previous works [3]. The error on the *P.S* product implicates on error of 5-10% on the retention. Other problems with gauges or data acquisition leads to higher error bars for some weeks of experiment. GDC effects on wall inventory have not been taken into account in that study.

4. SUMMARY AND CONCLUSION.

The pumping speeds of the different exhaust systems have been estimated for the deuterium giving access to the particle balance. During JET C1-C4, dynamic retention was generally in the range of 50% while long-term retention was around 510%. The method developed in this paper is easy to implement and could be a useful tool to study the wall behaviour and monitor reservoir inventories in real-time.

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REFERENCES

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	Vessel Turbo-pumps	NBI Cryo-pump/box	Divertor Cryo-pump
S/TT03 (Vessel Mid-plane)	9 m³/s	40 m³/s	125 m³/s
S/KT5P (Sub-divertor)	-	-	250 m³/s

JG03.453-1c

Table I: Effective pumping speeds for deuterium (assuming T_{gas} = 320°C).

	Vessel	NBI	Divertor	Total
Pulses	0.8	5.4	126	132
Between	3.4	28.6	47	79
Night	0.7	0	10.1	10.8
Total	4.9	34	183	222

JG03.453-4c

Table II: Calculated gas exhaust in bar.l for week 26 of JET C1.

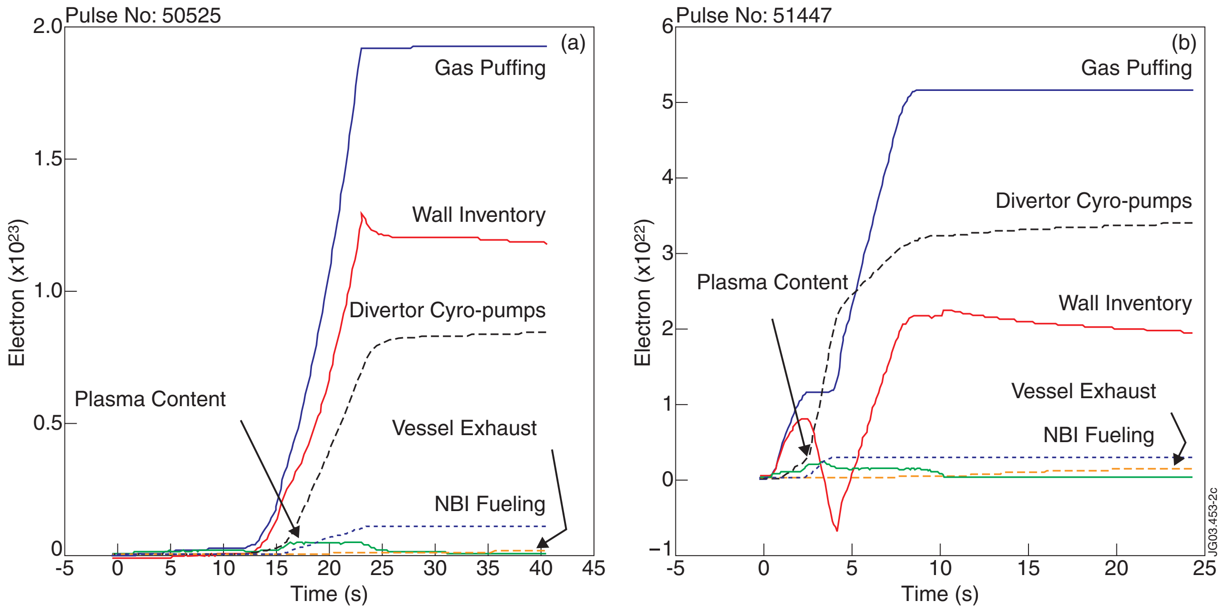

Figure 1: Particle balance for two typical JET discharges : (a) ELMy H-mode (2.8MA/3.0T); (b) ITB discharge (2.3MA/2.6T).

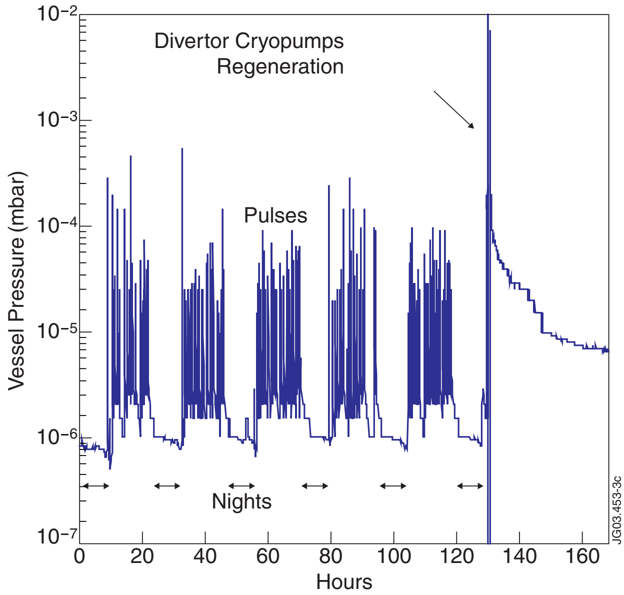

Figure 2: Vessel pressure measurement during week 26 of JET C1.

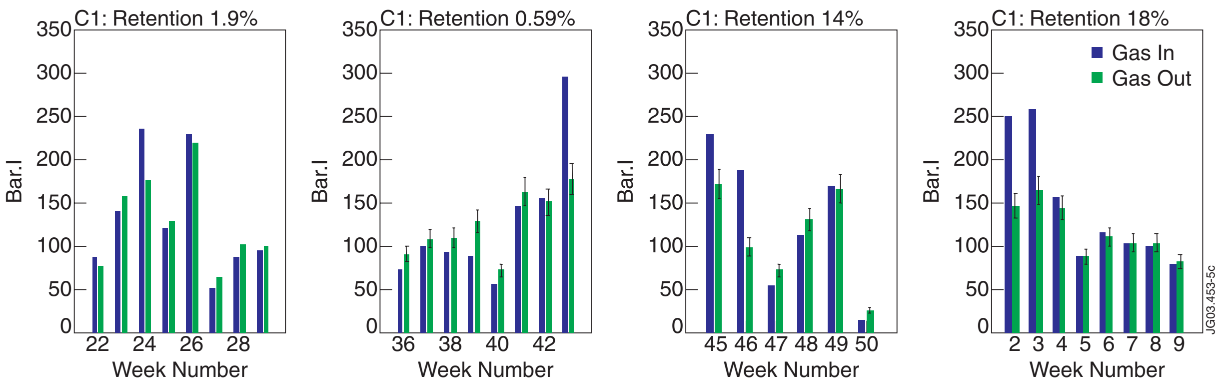

Figure 3: Gas balance results for JET C1-C4.