First Measurements of Gas Balance and Chemical Composition in the Mk I Pumped Divertor Phase of JET using the Gas Collection System

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1. INTRODUCTION

Gas recovery measurements in Tokamaks give direct information both on the short and long term hydrogenic in-vessel wall retention; in particular, the determination of the deuterium vessel inventory is essential to extrapolate to D-T operations, as required for the forthcoming JET D-T campaign and for ITER. The measurement of the chemical species present in the gas released from the Tokamak wall provides data for the gas exhaust collection and reprocessing plant.

The new JET Gas Collection System (GCS) measures the time evolution, absolute amount and chemical composition of the gas released from the JET vacuum vessel in the following modes of operation:

1. Natural thermal wall outgassing, 2. After plasma pulses, 3. During divertor cryopump regeneration, and 4. During glow discharge cleaning.

This paper presents GCS measurements carried out during the 1994/95 JET campaign, and illustrates the effects of the introduction of the JET MARK I pumped divertor on the hydrogenic inventory of the machine.

2. THE NEW GAS COLLECTION SYSTEM FOR JET

The GCS measures the amount of gas (H, D, He and volatile impurities produced into the torus such as hydrocarbons of various stoicheiometry) released from the torus, in all conditions of operation of JET. Moreover, the GCS can analyse the composition of the gas released from the torus and allows on-line sampling for off-line chemical analysis.

During the 1994/95 JET campaign, gas recovery measurements and on line gas analysis were carried out. The short term gas recovery was measured and, at the same time, the gas composition was analysed with a high resolution quadrupole mass spectrometer.

3. EXPERIMENTAL RESULTS (MK I CAMPAIGN 1994/95)

3.1. Gas balance measurements and wall retention measurements

Measurements of the short term gas recovery were carried out during the 1994-95 Mark I Experimental Campaign (graphite and Inconel wall, with Be evaporated coating), both with carbon (CFC) and beryllium divertor tiles.

Figure 2 shows the percentage of gas recovered after non disruptive plasma pulses, when the divertor cryopump is not cooled down. The data are compared to previous JET results [1,2] obtained with a first version of JET Gas Collection System. For the Mk I campaign, the average deuterium recovery varies from 30 to 60% of the input, depending on the total gas input, both for C and Be divertor tiles with T_{tile} = 50°C and T_{wall} = 250°C. These values are comparable to previous JET results for a Be coated machine, with walls at 250°C or 320°C. A detailed analysis of the dependence of the gas recovery on the wall temperature showed that at lower temperature less gas is recovered. This is consistent with the measured D inventory in the JET divertor tiles, determined by post mortem analysis [3]. The D inventory in the X-point tiles is greater than in 1991/92, even though the tile surface was a similar composition. It is believed that the factor that makes the difference is the lower temperature of the tiles.

In figure 3, the gas recovery is plotted as a function of the gas input, for pulses run with and without the cryopump, both for disruptive and non disruptive plasmas. The analysis of the gas released after non disruptive plasma pulses shows no appreciable difference between the case with C and Be divertor tiles. This is in agreement with the observation that no significant change in main plasma parameters and fuelling efficiency was observed between C and Be [4]. One reason why the gas release with C tiles is almost the same as with Be tiles can be that the near-surface layer of the exposed wall is, in both cases, a mixture of C and Be. Such a mixture is produced by the periodic conditioning (with Be evaporation and GDC) and by plasma-wall interactions.

When the cryopump is at LHe temperature (cryopump on), the gas released to the GCS is between 5 to 10 times lower than for pulses without cryopump.

For the cryopump off cases, an enhanced release of gas after disruption is observed. The gas recovered is higher than after non disruptive pulses. This is not the case when the cryopump is cooled at LHe temperature. This can be due to three concurrent causes:

1. The cryopump acts as a strong sink during plasma pulses and less fuel is retained into the walls. 2. The cryopump is pumping the excess gas after the disruption. 3. The wall is depleted in-between pulses more than when the cryopump is off because in the latter case the total pumping speed is lower.

The wall retention after 600 s from the plasma pulse is shown in figure 4. The two cases with and without cryopump are compared.

The net wall retention was calculated from the equation:

$$R_{wall} = Gas_{input} - [Gas_{out}(GCS) + K_{cryo} \times Gas_{out}(GCS)\ ] - Gas_{cryo}$$

$$Gas_{cryo} = S_{cryo} \times \int P_{cryo}(t)\ dt$$

The estimated uncertainty in the calculation of R_{wall} is ± 50%.

$Gas_{out(GCS)}$ is the gas exhausted from the vessel and measured by the GCS. K_{cryo} represents the ratio between the gas pumped by the cryopump and the gas going to the GCS in a 600 s period after pulses. Gas_{cryo} is the amount of gas pumped by the cryopump during the discharge, P_{cryo} the pressure at the cryopump and S_{cryo} the cryopump pumping speed [5].

Globally, within the experimental errors, the increment to the net D wall inventory, after plasma pulses run with the divertor cryopump on, is close to zero for most of the discharges. This result would explain why the amount of gas released from the machine after a disruption is not larger than the gas released after a non disruptive plasma (see figure 3). The apparent wall retention was calculated not including the cryopump effect during plasmas (Gas_{cryo} = 0). The apparent wall retention is much higher than the net wall retention, showing that the particle removal during the X-point phase of the pulse is dominant over the particle removal by thermal outgassing after the plasma.

The net wall retention at low input gas, for pulses with the cryopump on, is generally lower than for the cryopump off case. The discharges with highly negative wall retention (i.e. high wall depletion) at low gas input are identified to be ELMy H-mode, NBI fuelled with an extended X-point phase, during which the recycling gas is compressed into the divertor and efficiently removed by the cryopump. Net wall depletion occurs also at high gas inputs, for long high density L or H-mode plasmas, which are characterised by high neutral pressure in the divertor. This result is in agreement with the observation that the amount of gas pumped by the cryopump during pulses with ELMs or at high density can equal or exceed the gas input [5].

3.2. Gas balance measurements with nitrogen seeding

Nitrogen seeding was used at JET to obtain high radiation in the divertor region and consequent cooling of the plasma reaching the divertor target plates.

From the analysis of pulses run with the cryopump on, it is observed that the output gas (collected over a 600 s period) is further enriched in nitrogen, when compared to the gas input (mixture of nitrogen and deuterium). One explanation is that during the pulse more deuterium is pumped in proportion to nitrogen. This is, nevertheless, in contrast to the result that the composition of the gas in the divertor chamber during the plasma is the same as the input gas [6]. A possible explanation is that the thermal desorption rate after the pulse is higher for nitrogen than for deuterium. This needs further investigation.

4. CONCLUSIONS

1. When the divertor cryopump is off, the results of the gas balance and short term wall retention are in good agreement with results found in previous JET campaigns (1989-92) for a Beryllium coated machine, both for C and Be divertor targets tiles.

2. The cryopump reduces the wall retention after pulses. This implies a low D (and T) inventory, despite the large fuelling required to maintain a set plasma density when the cryopump is on.

3. It is observed that long ELMy H-mode pulses, run with low input gas and NBI heating, deplete the wall from the deuterium reservoir. Net wall depletion occurs also during long high density near detachment L-mode plasmas.

4. For pulses with nitrogen seeding the measured composition of the output gas is different from the input gas, and in particular is enriched in nitrogen.

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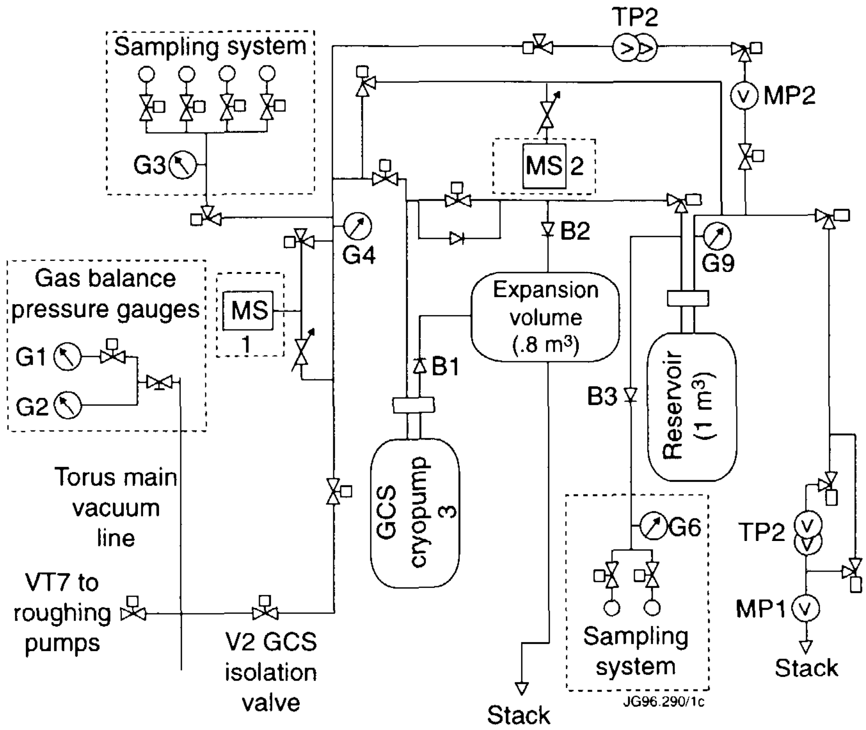

1 – Mass spectrometer for oxygen monitoring
2 – Mass spectrometer for chemical analysis
3 – GCS cryopump (700 barl maximum capacity)
4 – Non return valve (.5barg)

B1 – 5bar bursting disk
B2 – 1.3bar bursting disk
B3 – 5bar bursting disk

G1 – 1mbar Baratron
G2 – 100mbar Baratron
G3 – 1000mbar Baratron
G4 – 1mbar Baratron
G6 – 1000mbar Baratron
G9 – 1000mbar Baratron

TP – turbopump
MP – membrane pump

Fig.1 Layout of the JET New Gas Collection System

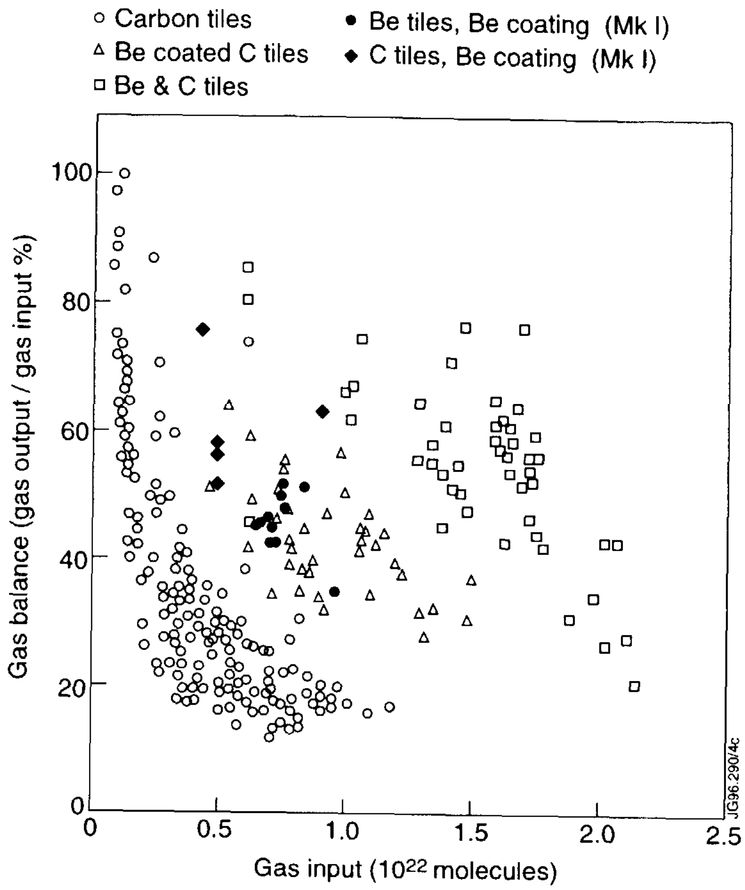

Fig. 2 JET data on the recovery of gas during a 600 s period after the discharge (T_{wall}=250°C and T_{wall}=320°C)

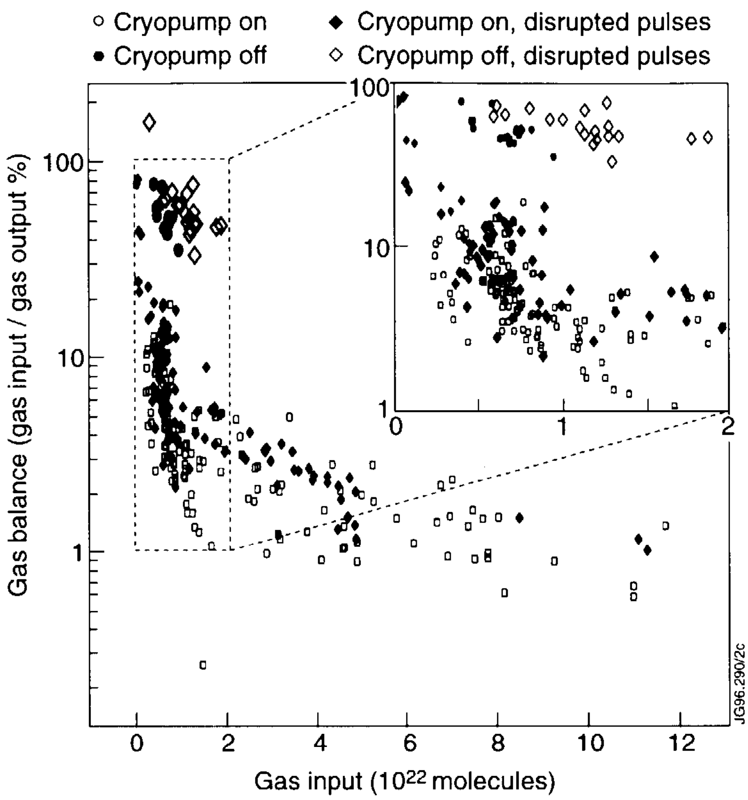

Fig. 3 JET data on the recovery of gas during a 600 s period after the plasma (T_{wall} = 250°C) during the JET MARK I campaign 1994/95. Comparison divertor cryopump on/off.

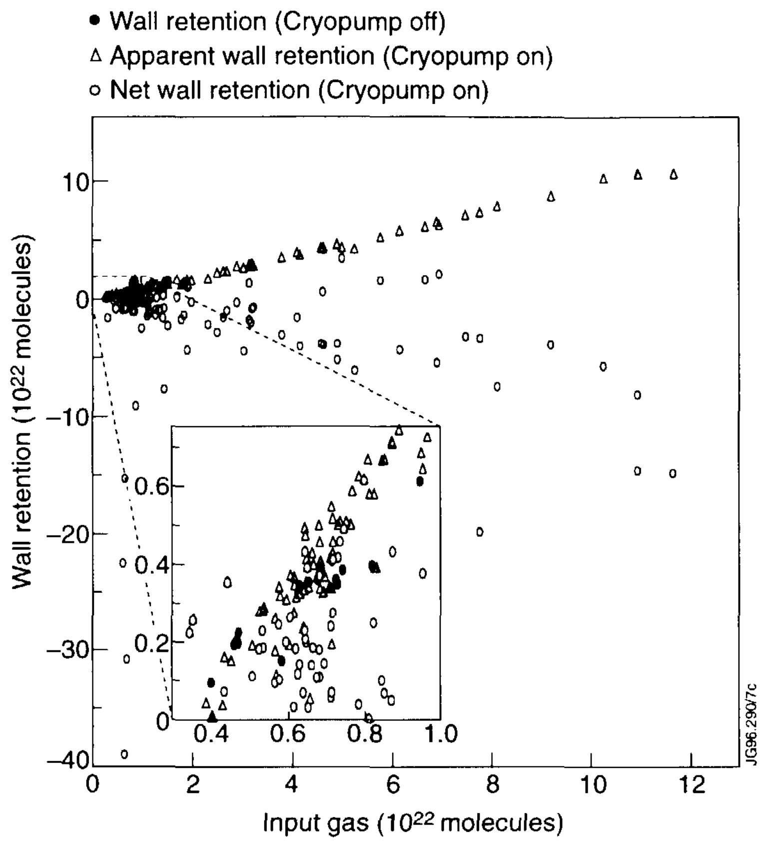

Fig. 4 JET data on the absolute wall retention after 600 s from the plasma pulse for non disruptive pulses. Comparison between divertor cryopump off (± 10%) and on case (± 50%).