ELSEVIER

Journal of Nuclear Materials 313–316 (2003) 263–268

journal of nuclear materials

www.elsevier.com/locate/jnucmat

The conditioning procedures in Tore Supra after CIEL implementation

J. Bucalossi *, C. Brosset, D. Garnier, C. Grisolia, A. Grosman, G. Martin, F. Saint Laurent

Association Euratom-CEA sur la Fusion Contrôlée, DSM/DRFC, CEA Cadarache, 13108 Saint Paul Lez Durance cedex, France

Abstract

After nearly two years of shutdown for the installation of the new inner components of CIEL project, standard conditioning procedures have been carried out (bakeout, D_2GDC and HeGDC) with a new glow discharge cleaning (GDC) hardware. 50 g of water and 20 g of hydrogen were removed during the initial bakeout and 650 A h of D_2GDC and 100 A h of HeGDC have allowed plasma restart. CO production during D_2GDC, about three times higher than in HeGDC, showed a strong dependence on the wall temperature in the 150–200 °C range. Furthermore, it has been possible to restart plasmas after different de-conditioning events when the CO production rate reaches 4×10^{16} molecules/s/A at 200 °C wall temperature. However, D_2GDC led to the removal of large amount of carbon ($\sim 2 \times 10^{24}$ eroded carbon atoms/year). Besides, HeGDC was successfully used to decrease deuterium wall concentration after D_2GDC. The time evolution of the isotopic ratio was found to decrease from 100% to about 60% at the end of the campaign.

PACS: 52.55.Fa

Keywords: Plasma–wall interaction; Conditioning procedures; Glow discharge; Tokamak

1. Introduction

In the frame of the CIEL project, Tore Supra internal vessel went through a major upgrade [1]. New stainless steel protection panels now cover nearly the whole vacuum chamber (~ 70 m^2) and 14 m^2 of CFC plasma facing components (PFC) [2] were installed (Fig. 1). All these new PFCs are actively cooled by a pressurised water loop ($P_{max} = 30$ bars, $T_{max} = 200$ °C) improving also the homogeneity of the baking temperature in the entire vessel, minimising the cold points. In this perspective, the glow discharge cleaning (GDC) hardware has been improved, inspired by JET GDC system [3], and 12 new actively cooled CFC electrodes were placed in the vessel.

In this paper, after a brief description of the new GDC hardware, we report the results of mass spectrometry measurements obtained during the different phases of the vessel conditioning performed during 2001. In addition to the initial restart (1st plasma: 14/9/01), the campaign has been marked out by the following events: a one month vent has been necessary after only one month of helium plasma operation to repair a damaged needle in a TPL sector (3/10/01–30/10/01), an accidental air GDC occurred in the following restart (11/11/01) and, at the end of the campaign, a small air leak, quickly eliminated, stopped plasma operation during one day (6/12/01).

2. The new glow discharge hardware

The GDC hardware has also been greatly improved and 12 new actively cooled CFC electrodes (108×86 mm^2

* Corresponding author. Tel.: +33-4 42 25 32 91; fax: +33-4 42 25 26 61.

E-mail address: j.bucalossi@cea.fr (J. Bucalossi).

0022-3115/03/$ - see front matter
PII: S0022-3115(02)01339-9

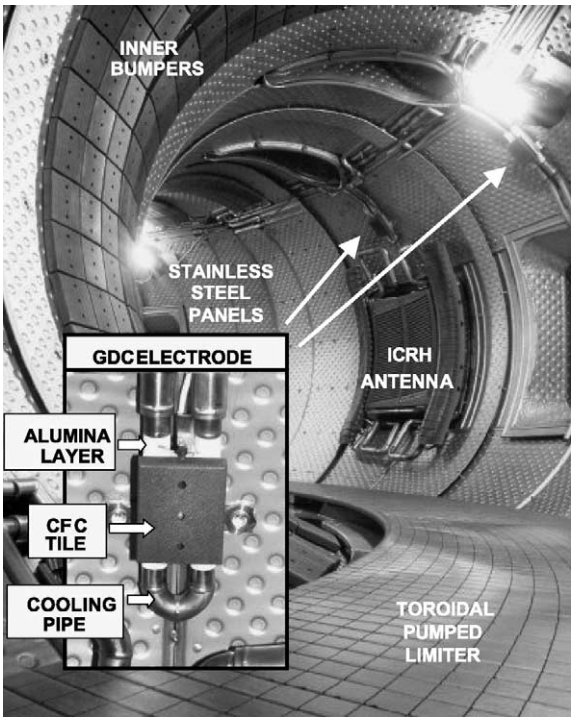

Fig. 1. Tore Supra vacuum vessel after CIEL implementation: main inner components and details of one CFC electrode for glow discharge cleaning.

were placed inside the vessel above 12 horizontal ports (Fig. 1). Each CFC electrode is designed to sustain a 3 kV maximum potential and a 5 A maximum GD current. The CFC tile is fixed on the top of a grounded stainless steel support in which the water loop pipes are merged, reusing bumper technology (with a 0.5 mm papyex compliance layer in between). The electrical insulation is obtained through a plasma-sprayed alumina layer (0.7 mm of thickness) deposited on top of the stainless steel support. This set is designed to sustain high radiated power (up to 10 MW/m^2) in steady state, which will be experienced during long duration and high density plasma operation. The GDC are powered by two power supplies (1.5 kV/4A) regulated in current. During the restart, up to six electrodes were used simultaneously (three electrodes connected to each power supply). GDC current measurements are available on each electrode.

3. Results and discussion

3.1. Bakeout

From its initial evacuation (middle of July) to the beginning of its bakeout (middle of August), the vessel was maintained at 40 °C during nearly 15 days. During that period, the residual pressure, dominated by water, was around 5×10^{-5} Pa. The bakeout started on the 12th of august and lasted for 12 days. At that time, satisfactory conditions were met to start the GDC (water partial pressure lower than 10^{-4} Pa to avoid oxygen reimplantation during GDC). At the end of the bakeout, residual pressure was widely dominated by hydrogen. The total removal rate of molecules ($\phi = P \times S$), calculated from a penning gauge pressure measurement, considering a vessel pumping speed of 7.5 m^3/s, is shown in Fig. 2. Due to the numerous changes in wall temperature, the study of the outgassing as a function of the wall temperature is very complex; however from wall temperature plateau periods and mass spectrometer data, one can deduce a time constant for water evacuation in the 15 h range. On the other hand, at 200 °C, hydrogen outgassing has not yet reached its rollover. In total, 50 g of water and 20 g of hydrogen were pumped out during the first bakeout. The study of the second bakeout, after one month of helium plasma operation and October vent, shows similar time constant for water and hydrogen behaviour but only half the time was required to reach similar vacuum conditions (~6 days). During the second bakeout, ≈15 g of water and 5 g of hydrogen were removed.

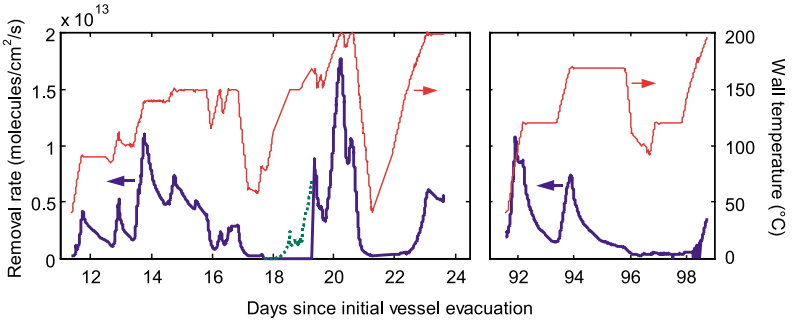

Fig. 2. Time evolution of the outgassing during the first bakeout of the vacuum vessel after CIEL implementation and during the second bakeout taking place after a one month vent for the repair of two needles of the toroidal pumped limiter.

3.2. Deuterium glow discharge cleaning

After bakeout, glow discharge cleaning in deuterium (D_2GDC) is performed to remove strongly bound impurities, particularly hydrocarbons and carbon oxides, taking advantage of the hydrogen chemical reactivity for carbon in addition to physical sputtering [4]. Furthermore, the D_2GDC increases the D concentration in the wall at the expense of the H one.

The first breakdown with the new GDC system was achieved in a 2 Pa nitrogen atmosphere. During the initial operation of the glow discharges (and after the vent), transitions to arcs were frequent (tracks were observed in the vessel). From two to six electrodes were used and GDC current ranged from 2 to 5 A which gives, projected on the whole vessel surface, a current density of 2–5 μA/cm^2. At the usual operating pressure of 0.5 Pa, the anode voltage was ~400 V.

The presence of a mixture of hydrogen, deuterium, hydrocarbons and various oxides makes the analysis of the mass spectra particularly complex. However we were able to identify some classical gases (H_2, CO, CD_4 and C_2D_x) by selecting some relevant masses: the mass 2 is representative of the hydrogen discharge content. The mass 28, de-correlated from nitrogen using mass 14, is assumed to be representative of the CO production while the $C_2H_xD_y$ contribution remains negligible. According to cracking patterns [5], $C_2H_xD_y$ contribution can be derived from the mass 30. Finally, the mass 20 is representative of CH_xD_y hydrocarbons production, D_2O contribution to mass 20 has been neglected. Indeed the ratio between mass 20 and mass 18, corrected from H_2O contribution (taken at the level in the following He-GDC), indicates a low contribution of D_2O (according to H_2O and CD_4 cracking patterns). The time evolution of these masses, converted in removal rate during all the D_2GDC performed in 2001 is shown in Fig. 3. The quantitative results have been obtained using in situ calibration carried out with pure nitrogen, deuterium and helium injections and taking into account the measured specific pumping speeds of those gases. The calibration factors for hydrocarbons have been extrapolated from these calibrations using relative probabilities of ionisation and cracking patterns of CD_4 and C_2D_6 species [5].

The effect of the wall temperature is clearly visible in Fig. 4. Even in the limited temperature range between 150 and 200 °C, CO production was multiplied by a factor of ~3 (in nearly the same state of wall conditioning). Besides, hydrocarbon production is weakly dependent on the wall temperature variations in this range compared to CO production.

Typical values of CO and hydrocarbon production rates are given in Table 1 during initial CIEL restart and

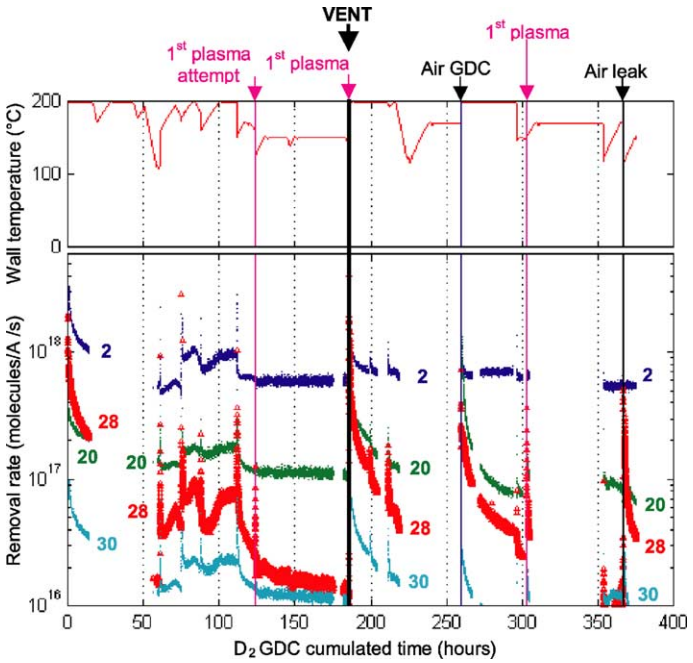

Fig. 3. Removal rates for the mass 2 (H_2), 20 (C_1 hydrocarbons), 30 (C_2 hydrocarbons) and 28 (CO) and wall temperature as a function of the integrated D_2GDC time during the D_2GDC performed in 2001 (some data are missing out due to problems with the mass spectrometer acquisition system). Each spike in the removal rates corresponds to the start of a new D_2GDC as time is compressed in between.

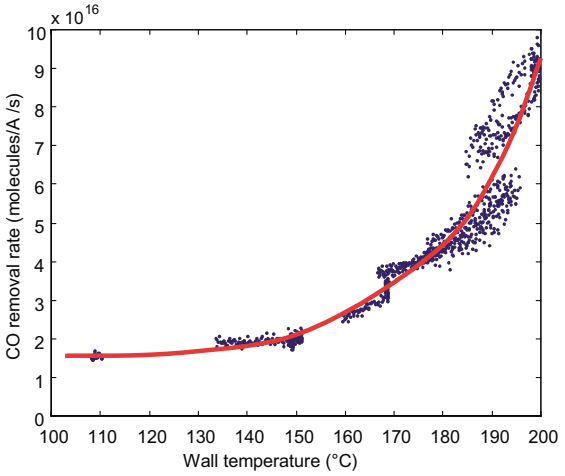

Fig. 4. CO removal rate during D_2GDC as a function of the wall temperature. The curve is given as a guideline to indicate the trend. The data (points) are taken in the interval 60–110 of cumulated hours of D_2 GDC in which several significant temperature excursions occurred (see Fig. 3).

after different de-conditioning events: vent for TPL repair, air GDC and air leak. The corresponding net sputtering yield (production rate per electrical charge) and the number of A h carried out before each restart of the plasmas are also mentioned in Table 1. These results are in agreement with previous studies on hydrogen GDC [6].

The analysis of the different restart attempts showed that when the CO production rate during D_2GDC reaches 2.5×10^{16} molecules/A/s at 150 °C (or 4×10^{16} molecules/A/s at 200 °C) plasma initiation was possible. Taking into account the hydrocarbon production rates during D_2GDC, which induces a small carbonisation, the prolongation of the glow beyond that limit is questionable. Furthermore, assuming an averaged sputtering yield of 5% for CO and hydrocarbons (see Fig. 3 and Table 1), 5 monolayers/h/A are removed from the 14 m^2 of CFC surfaces which gives over the whole D_2GDC carried out in 2001 (1650 A h) a total amount of 1.85×10^{24} net eroded carbon atoms (~37 g of carbon – 2.5 μm/year).

3.3. Helium glow discharge cleaning

The final phase of the conditioning procedure is the helium glow discharge cleaning (HeGDC), carried out to remove the large amount of deuterium trapped in the carbon wall during D_2GDC.

The operating pressure has been raised to 0.65 Pa to keep the same glow voltage (~400 V) than in D_2GDC while current lies in the same range.

The time evolution of the deuterium removal rate during the HeGDC is shown in Fig. 5 together with the hydrogen, mass 20 and mass 28 removal rates. As in Fig. 3, mass 20 and 28 are respectively representative of CD_4 and CO partial pressures. Within HeGDC, the deuterium partial pressure is derived from mass 6 coming from D_3^+ produced in the ion source of the mass spectrometer. During HeGDC, D_2 production strongly decreases with time following a polynomial law: $q = q_0 t^{-\alpha}$ with $\alpha \sim 0.5$ deduced from the first part of the campaign, indicating a desorption limited by a diffusion process. As expected, the level of the hydrocarbons in HeGDC are much lower than in D_2GDC (more than one order of magnitude). CO production is also observed but at a smaller rate than observed in D_2GDC: a reduction factor of ~2 is measured at the gas changeover to helium at the end of D_2GDC.

Typically, 100 A h of HeGDC are programmed before plasma restarts. HeGDC are also used to de-saturate the wall after deuterium plasmas. The evolution of the isotopic ratio $(n_H/(n_H + n_D))$ of the wall during HeGDC, deduced from mass spectrometer measurements, is shown in Fig. 6. This ratio was about 60% at the end of the campaign after 1650 A h of D_2GDC and only two weeks of D_2 plasma operation. It indicates that months of operation will be probably necessary to restore a ratio value in the 20% range. When the isotopic

Table 1
Typical CO and hydrocarbons production rates and sputtering yields during D_2GDC

	Initial CIEL conditioning	After the vent	After the 12 h of air GDC	After the small air leak (at 120 °C)
CO production at the beginning of the D_2 discharge	1.5×10^{18}	1.5×10^{18}	5×10^{17}	5×10^{17}
CO production after 4 h	4×10^{17}	2.5×10^{17}	1.7×10^{17}	5×10^{16}
CO sputtering yield after 4 h (%)	6.5	4	2	0.8
Hydrocarbons production at the beginning of the discharge	4×10^{17}	1×10^{18}	1.5×10^{18}	3×10^{17}
Hydrocarbons production after 4 h	2.5×10^{17}	3×10^{17}	2.5×10^{17}	7.5×10^{16}
Sputtering yield after 4 h (%)	4	4.8	4	1.2
Total D_2GDC before plasma conditions (A h)	650	295	175	30

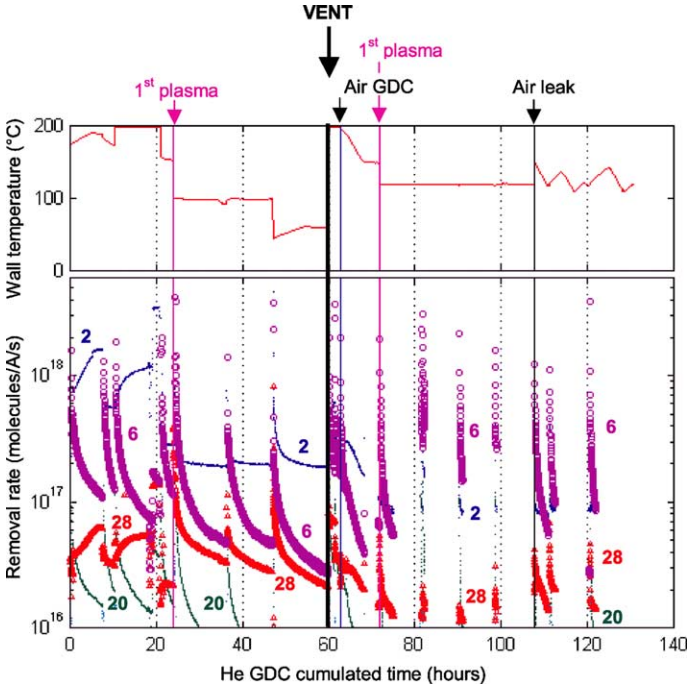

Fig. 5. Removal rate for the mass 2 (H_2), 6 (D_2), 20 (C_1 hydrocarbons) and 30 (C_2 hydrocarbons) and wall temperature as a function of the integrated HeGDC time during the HeGDC performed during 2001 (some data are missing out due to problems with the mass spectrometer acquisition system). Each spike in the removal rates corresponds to the start of a new HeGDC as time is compressed in between.

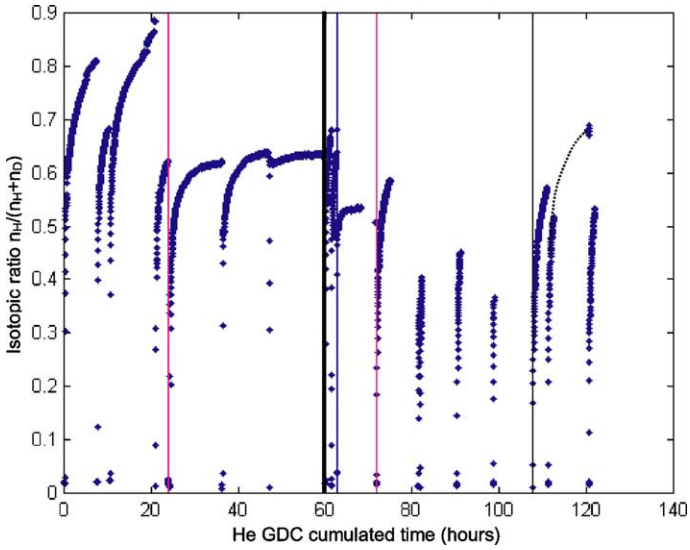

Fig. 6. Isotopic ratio $(n_H/(n_H + n_D))$ during helium glow discharge along the 2001 experimental campaign.

ratio begins to saturate, HeGDC efficiency can be considered negligible for the purpose of wall D_2 removal. It typically occurs when the D_2 production rates reaches 5×10^{16} molecules/A/s at 100 °C.

4. Conclusions

The conditioning of Tore Supra has been surveyed during the CIEL restart campaign by mass spectrometry.

The analysis of the mass spectra recorded over the whole campaign has permitted to estimate the impurity productions from the wall during the different phases of the conditioning. Despite the frequent variations of the wall temperature, some quantitative results have been obtained. The initial bakeout produced 50 g of water and 20 g of hydrogen. A CO production rate of 4×10^{16} molecules/s/A at 200 °C wall temperature during D_2GDC has been identified as a threshold value for possible plasma initiation. The influence of the wall temperature on the CO production has also been underlined. As expected, CO production in HeGDC was found to be smaller than in D_2GDC as well as hydrocarbons production. Indeed, D_2GDC leads to the removal of large amount of carbon. The isotopic ratio has been worked out during HeGDC showing a slow decrease of the hydrogen content of the wall at the benefit of deuterium content.

Acknowledgements

The authors wish to thank E. Gauthier and J.C. Hatchressian for helpful discussions.

References

[1] M. Lipa, P. Chappuis, P. Garin et al., Proceedings of the 16th International Symposium Fusion Engineering (IEEE/PSS), IEEE catalogue number 97CH36131, vol. 1, San Diego, CA, USA, 6–10 October 1997, p. 353.
[2] M. Missirlian et al., Fusion Eng. Des. 56&57 (2001) 439.
[3] P. Andrew et al., Proceedings of the 18th SOFT, Karlsruhe, 1994.
[4] C. Grisolia et al., Vacuum 60 (2001) 147.
[5] A. Cornut, R. Massot, Compilation of mass spectral data, Heyden, London, 1966.
[6] E. Gauthier et al., Vacuum 41 (1990) 1570.