Isotope wall content control strategy in the upcoming D, H and T experimental campaigns in JET-ILW

I. Borodkina[1], D. Douai[2], D.Alegre[3,4], D. Borodin[1], S.Brezinsek[1], E.de la Cal[4], Y. Corre[2], A.Drenik[5], J. Gaspar[2], E. Joffrin[2], C.C. Klepper[6], T. Loarer[2], M.Maslov[7], G.Sergienko[1], S. Vartanian[2], T. Wauters[8], and JET Contributors*

[1] *Forschungszentrum Jülich GmbH, IEK – Plasmaphysik, TEC Partner 52425 Jülich, Germany*
[2] *CEA, IRFM, F-13108 Saint Paul Lez Durance, France*
[3] *Departamento de Ingeniería Energética, UNED, C/ Juan del Rosal 12, 28040 Madrid, Spain*
[4] *Laboratorio Nacional de Fusion, CIEMAT, Avda. Complutense 22, 28040 Madrid, Spain*
[5] *Max-Planck-Institut für Plasmaphysik, D-85748 Garching, Germany*
[6] *Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831-6169, USA*
[7] *CCFE, Culham Science Centre, Abingdon OX14 3DB, United Kingdom*
[8] *Laboratory for Plasma Physics, ERM/KMS, 1000 Brussels, Belgium, TEC Partner*
* *See the author list of X. Litaudon et al., Nucl. Fusion 57 (2017) 102001*

1. Introduction

JET is the largest tokamak in use and currently the only one capable of handling radioactive tritium (T). Equipped with the ITER-like wall (ILW) comprised of the tungsten (W) divertor and cladded with beryllium (Be) main chamber, JET will soon operate with hydrogen isotopes (D-H-T-H-D campaigns) in order to prepare scenarios for the 2nd JET DT campaign (1st one was in 1997) and to answer the urgent ITER needs [1]. The total budget of 10^{20} 14 MeV fusion neutrons is allocated for all these isotope campaigns and could be reached in 250 high power plasma pulses (40MW/5s) with just 1%D in the T plasma (or 1%T in D plasma). Therefore, the unwanted isotopes (D or T) from the vessel should be removed prior to the operations with pure T or pure D afterwards. Based on the experience obtained in previous JET-ILW experiments a strategy to reduce and control the D (or T) wall inventory down to the required level before the T (or D) campaign is elaborated. The efficiency of the different methods composing it is evaluated and their combination is considered aiming at maximizing access to the different D retention areas in the JET-ILW, yielding information for the control of the isotope purity and residual fuel content in a Be/W environment especially relevant in view of ITER operation. We also provide a review of the experimental data and diagnostics undertaken in order to reliably control the isotope ratio in the wall and the plasma and, thus, the strategy efficiency.

2. Fuel retention distribution in the JET-ILW from post-mortem analysis

There are two mechanisms responsible for long-term fuel retention: implantation into plasma-facing components (PFCs) and co-deposition [2]. Post-mortem analysis of JET PFCs after the first two ILW campaigns revealed that large fraction (45%) of fuel is retained at the inner divertor baffle in the deposited Be layers [3]: erosion of Be from main chamber PFCs and its migration into the inner divertor [2] leads to efficient co-deposition of the fuel particles. The main wall limiters have less deposits due to re-erosion and D is retained there dominantly due to the implantation [4].

The retained fuel could be partially recovered by baking up to 240°C and to 350°C at the ITER first wall and divertor, respectively [5]. However, thermo-desorption analysis of inner top divertor tiles after the 2nd experimental campaign in JET-ILW reveals that up to 90% of the fuel remains trapped in the deposited layers with thicknesses up to 40μm on inner top divertor tiles 0 and 1 after baking at 350°C whereas complete thermo-desorption of the fuel requires surface temperatures beyond 550°C [4]. Similarly, up to 90% of the fuel remains trapped in Be limiters after 15 hours baking at 240°C. The release of the fuel particles could be slowed down by the morphology of deposited layers and the presence of additional impurities, such as oxygen and carbon [2, 4].

3. Discharges with the raised inner strike point position

To eliminate D from the co-deposits at the inner divertor baffle which necessitates to achieve high surface temperatures there, pulses with the inner strike point (SP) raised towards the top divertor tiles are foreseen (figure 1). Analysis of IR measurements in earlier plasma discharges with raised SP position shows that surface temperatures beyond 550°C can be reached (figure 2). Whereas spectroscopy in the these discharges reveals an enhancement of D_α, Be I and Be II emission intensities close to the inner SP, the BeD emission intensity is much lower than if the inner SP is at lower (more usual) position. This indicates that these BeD molecules are formed in the plasma by the interaction of Be ions with D molecules [6], instead of being generated as a product from chemically assisted sputtering of the co-deposited layers, which is inhibited for surface temperature higher than 520ºC [2]. As no NBI heating will be available for the first H campaign, it is foreseen to operate long L-mode discharges with the inner SP on tile 1 with 4-5 MW RF during 20 seconds, in order to bring the inner divertor temperature above the necessary level.

Though fuel retention in the outer tiles is much lower than in the inner top tiles of the JET-ILW divertor, the D level was still found to increase with surface temperature in NBI heated H plasmas with SPs on the both vertical targets (VT). Another scenario designed with SPs on VT aiming at depleting D stored in the outer divertor is therefore foreseen, by bringing the bulk of tiles 6 and 7 to 600-700°C with 20 seconds long RF heated discharges at high repetitive rate.

4. GDC and ICWC

Glow discharge cleaning (GDC) and Ion Cyclotron Wall Conditioning (ICWC) have been operated several times in either Deuterium or Hydrogen for isotope changeover experiments in JET-ILW, allowing to assess the efficiency of the fuel removal techniques for the ITER materials mix [5, 7]. Both methods were found to access the comparable fuel reservoirs by isotopic exchange. About 6-10·10^{22} fuel atoms could be removed with these techniques, preferentially from the main chamber [5, 7]. Earlier experiments were however performed with walls at 200°C. Since isotopic exchange efficiency in Be layers increases with surface temperature [8], GDC and ICWC are proposed to be operated with walls baked at 320°C.

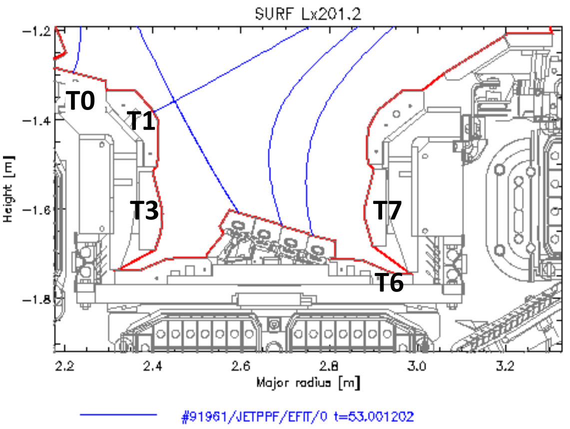

Figure 1. Magnetic configuration with the raised inner strike point position on the tiles 0/1

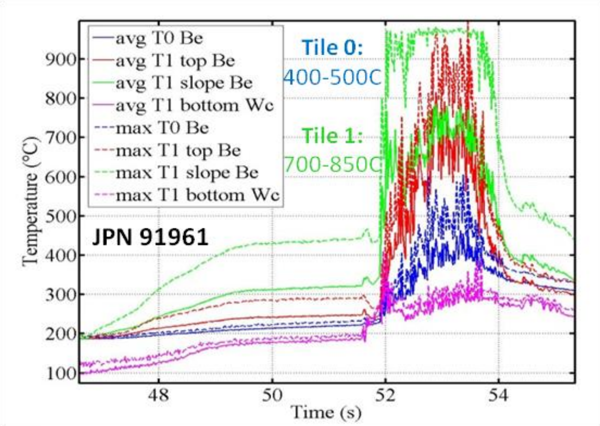

Figure 2. IR measurement of surface temperature of tiles 0 and 1 in pulses with the raised inner SP position

5. Strategy for isotope wall content control

The strategy for reducing the D wall inventory below 1% in the different retention areas in the JET-ILW at the beginning of H campaign preceding the T campaign is based on the combination of the wall conditioning methods described above. It is shown in figure 3. It includes the whole week of vacuum vessel baking at 320°C, combined with isotopic exchange by hydrogen GDC and ICWC, predominantly accessing D retained in the main chamber in the preceding to H D campaign. The long plateau of baking at 320℃ with several gas collection measurements (e.g. between the ICWC and GDC) should allow estimating the outgassing rates and provide validation material for D inventory and recycling modelling.

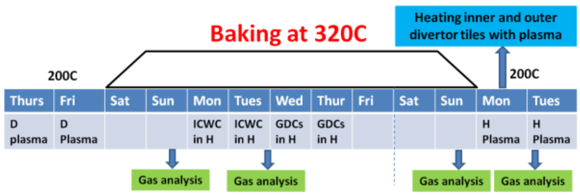

Figure 3. Isotope wall content control strategy proposed to be tested at the beginning of the first H experimental campaign

The top inner divertor tiles 0 and 1 (figure 1) are the main area where D will still be stored after the baking. Indeed, baking to 320°C should not allow thermal desorption of the D fuel trapped in the thick Be:D layers deposited there. Similarly, neither ICWC nor GDC can heat surfaces much beyond this temperature. Thus, three JET sessions with the 20 seconds 4-5 MW RF discharges with SP on tile 1 are also included in the strategy allowing eliminating D from co-deposits at the upper inner divertor. Cryopump regeneration and gas analysis will take place after three raised SP sessions for the evaluation of the D removed from these layers. For depleting the fuel stored at the outer divertor RF-heated discharges with SPs on the VTs will be used.

6. Overview of the JET diagnostics for the strategy efficiency assessment

Reliable isotope ratio measurements inside the vessel are essential for the assessment of the strategy efficiency. Existing experimental data and diagnostics have therefore been reviewed. Isotope ratio obtained from Residual Gas Analysis (RGA) signals is found to agree in general with that determined from optical spectroscopy in the divertor. A new algorithm for the fitting of the Balmer-α line separation in the optical Penning of residual gas pumped out of the outer divertor was developed providing isotopic ratio accuracy of 0.5%. The analysis of the earlier optical Penning data reveals the large error bars for H/[H+D] ~ 1% as well as a systematic error of 1% due to hydrogen isotope trapping in the Penning electrode surfaces [9]. Corrective actions including optimized light collection and mitigation of viewport coatings produced by the Penning plasma source allow detecting fuel isotopic minority specie concentrations <~1%. Determination of recycled hydrogen isotopomers released in the W divertor (H_2, HD, D_2) and from the main chamber wall (the same and BeD, BeT, BeH) allows assessing the local isotope ratio with accuracy below 0.5% better than other diagnostics [10, 11]. Produced synthetic spectra of BeH, BeD well reproduce those measured by JET high resolution spectrometers, yielding information on their rotational temperatures allowing the determination of plasma parameters like local electron densities [12].

7. Conclusion

A strategy for the controlled reduction below the 1% of the D (or T) wall inventory before the T (or D) campaign has been elaborated. The strategy includes one week of vacuum vessel baking at 320°C, combined with isotopic exchange by hydrogen GDC and ICWC, followed by plasma pulses in the optimized configurations to access the deposits at the divertor baffles.

The existing diagnostics have been reviewed and improved to provide the reliable isotope ratio estimations in the vessel for the strategy efficiency assessment and insuring acceptable wall isotope content in T-containing experiments including the upcoming JET DT campaign.

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