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ABSTRACT

The deuterium inventory at Joint European Torus (JET) after the 2007-2009 experimental campaign has been evaluated using Nuclear Reaction Analysis (NRA) and Secondary Ion Mass Spectrometry (SIMS). A full poloidal set of divertor tiles were analysed providing estimation for the total deuterium retention of about 233 g. Deuterium is trapped mainly at the inner divertor floor tile and outer divertor floor tile. The total deuterium retention is ~10 %.

1. INTRODUCTION

A long lifetime of Plasma-Facing Components (PFCs) and keeping retention of plasma fuel in them at acceptable levels are key elements for successful operation of future fusion devices. Carbon or Carbon Fibre Composite (CFC) has been a plasma-facing material in many fusion devices, for example in Joint European Torus (JET), because of its excellent power-handling capabilities and small radiation losses due to carbon impurities. The major disadvantage of carbon based materials is its chemical erosion under hydrogen bombardment and, associated to this, the ability to trap large amounts of hydrogen isotopes from plasma. This is especially dangerous in the case of deuterium-tritium operation as it may lead to an unacceptable inventory of radioactive tritium. Safety limit for the inventory of tritium in the International Thermonuclear Experiment (ITER) is 880g and it would be reached in less than 2500 full performance ITER discharges without any cleaning effort [1]. Determining deuterium retention in PFCs is therefore crucial for the assessment of overall fuel inventory in the torus.

The disadvantages of CFC could be compensated by using high-Z materials such as tungsten (W). The CFC tiles can be coated with a thin layer of W. The erosion yield of W is orders of magnitude below those of low-Z materials like e.g. CFC or graphite with an erosion yield of a few percent [2]. Tritium retention is a genuine problem for CFC, whereas W does not show such a strong effect to tritium retention.

In the period 2007-2009 JET operated with the MkII-HD divertor. Configuration of the JET MkII-HD divertor and tile numbering are presented is Figure 1. A full poloidal set of CFC divertor tiles was analysed using Nuclear Reaction Analysis (NRA), Secondary Ion Mass Spectrometry (SIMS) and optical microscopy after the campaign for erosion and deposition studies. NRA analyses give quantitative deuterium/carbon ratio near the surface region (down a depth ~7μm) whereas SIMS provides information on the deuterium levels in principle all the way down to the substrate. Thickness of the co-deposited layers was determined both with SIMS and optical microscopy.

2. EXPERIMENTAL

During the 2007-2009 campaign JET was operated with plasma facing components (PFC) made of CFC (Concept I manufactured by Dunlop Ltd) during the 2007-2009 campaign. After the campaign, the tiles were removed for surface analysis with NRA and SIMS. The tiles were sent to VTT Technical Research Centre of Finland (VTT) for sample preparation. Core samples were taken from plasma facing surfaces of the tiles. Sampling took place in a glove box using a drill saw to cut cylinders with a diameter of 17 mm and a thickness of 10 mm. After the sample preparation, core samples were sent to University of Sussex for NRA analysis. NRA measurements were carried out using a 2.5MeV ^{3}He beam produced by a Van de Graaff accelerator. The diameter of the ^{3}He beam was 1 mm. The carbon (C), beryllium (Be) and deuterium (D) concentrations in the co-deposited layers were analysed using the NRA reactions ^{12}C(^{3}He,p)^{14}N, ^{9}Be(^{3}He,p)^{11}B and ^{2}D(^{3}He,p)^{4}He. The analysis depth in the NRA measurements for C is ~1µm, ~2µm for Be and ~7µm for D, respectively. SIMS analyses of the samples, for their part, were made with a double focusing magnetic sector instrument (VG Ionex IX-70S) at VTT. A 5 keV O_2^+ primary ion beam with a current of 500nA was used and the ion beam was raster-scanned over an area of 300 ×4 30 µm^2 [3]. In addition, the cross-sectional samples were prepared by cutting part of the core samples poloidally and placing them into cold mounting epoxy (Epofix by Struers). Grinding and polishing were made using a Struers Tegrasystem grinding and polishing device with a pre-programmed preparation method. The thicknesses of the co-deposits were assessed from optical microscopy images and the goal of optical microscopy is to produce information about the thicknesses of the deposited layers for comparison with SIMS results and to investigate the structure of the deposited layers.

3. RESULTS

The thickness of the deposits decreases from the apron of the Tile 1 (~50µm) to the bottom of the tile (~5µm) and then increases on Tile 3 (~20µm). The thickness of the co-deposited layer on Tile 1 (6-52µm) is larger than in Tile 3 (14-26µm) resulting in a higher D retention. The D/C ratio determined from NRA results is shown in Figure 2. In Tile 1 the D/C ratio increases from the top of the tile (~0.01) towards the bottom (~1) while on Tile 3 the D/C ratio is generally low except for the lower part of the tile where the D/C ratio reaches ~1.

The divertor floor Tiles 4 and 6 show very thick co-deposited layers. Optical microscopy measurements showed that there is very thick deposition layer on Tiles 6 and 6, the thickest deposition layer being as high as ~340µm. Measurements also showed that retention f D is the highest in these tiles. Figure 3 shows typical SIMS depth profiles from the horizontal part of Tile 4. The D amount is high near the surface and the profile extends to a depth of ~ 40µm. Tile 6 has also a thick uneven co-deposited layer. The deposition pattern is similar to Tile 4 except on the flat inboard section where the deposition layer is thin. The amount of D in Tile 6 is smaller than in Tile 4 but notably larger than in Tiles 7 and 8.

On the outer divertor Tiles 7 and 8 D is retained mainly due to ion implantation resulting a small D inventory. In Tile 8 the highest amount of retained D is found its top part. Tiles 7 and 8 are normally in an erosion zone but on the last day of the campaign the ^{13}C puffing experiment turned the region into a net deposition zone. ^{13}C showed a maximum at the bottom of the Tile 7 and on the top of the Tile 8, while ^{13}C levels were small in the region between the tiles [4]. Also behaviour of D reflects the deposition profile.

The total amount of retained D was obtained by assuming toroidal symmetry in deposition and multiplying the area of the tile segment with the thickness of the co-deposited layer obtained from

SIMS and optical microscope measurements. The density of the deposited layers is assumed to be 1g/cm^3 [5]. The D amounts are summarized in Table 1. Tile 5 has not been analysed with optical microscope and SIMS. The amount of D is clearly bigger in divertor floor Tiles 4 and 6 than in other divertor tiles.

Conclusions

A set of divertor tiles exposed in 2007-2009 at JET have been characterised using NRA and SIMS techniques allowing determination of D inventory under the assumption of toroidal symmetry. In previous campaigns e.g. 2001-2004 the long-term D retention has been ~4% [6]. However, the thickness of the co-deposited layers was not determined for Tiles 4 and 6 where D retention is the highest [6]. Basically D amount on Tiles 4 and 6 was based on the NRA analyses which detects D to a depth of ~7μm. This means that most of the D retained on these tiles was not included in the data analysis.

During the 2007-2009 campaign the total D input was ~2333g. The total D retention in divertor tiles during 2007-2009 campaign is estimated to be ~233g which corresponds to a retention of ~10%. Most of the D is trapped on inner divertor Tile 4 (~40%) and outer divertor Tile 6 (~28%). The SIMS depth profile in Figure 3 shows that most of the retained D in Tile 4 is at the top part of the co-deposited layer to depth up to ~40μm. However, the amount of retained D was evaluated based on NRA measurements to a depth up to ~7μm. The concentration of D is assumed to be uniform through the co-deposited layer. This method overestimates the amount of retained D.

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Location	Amount of D (g)
Inner divertor Tile 1	2.0
Inner divertor Tile 3	0.6
Divertor floor Tile 4	163
Divertor floor Tile 6	66
Outer divertor Tile 7	0.4
Outer divertor Tile 8	1.0

Table 1. Amounts of D trapped in different areas of JET.

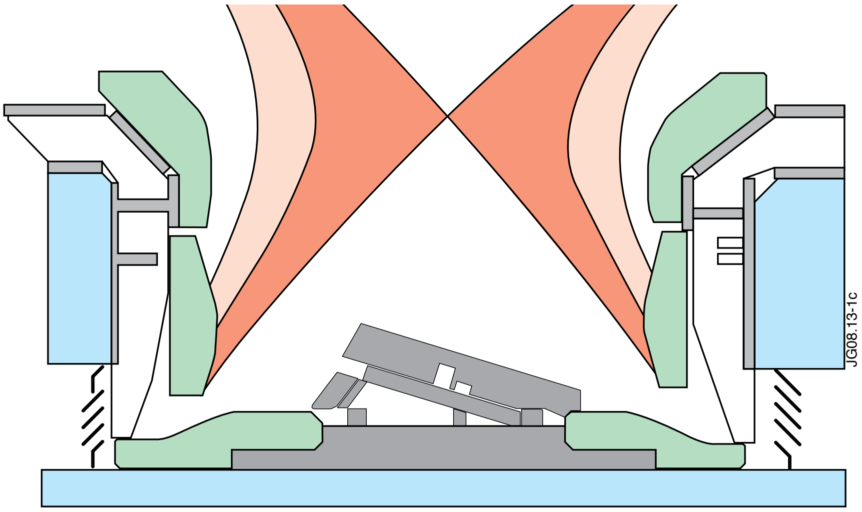

Figure 1:The JET MkII-HD divertor tile set and tile numbering.

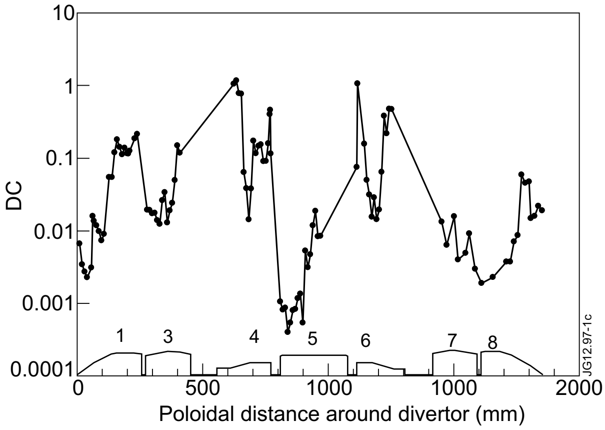

Figure 2: D/C ratio as a function of poloidal distance around divertor measured with NRA.

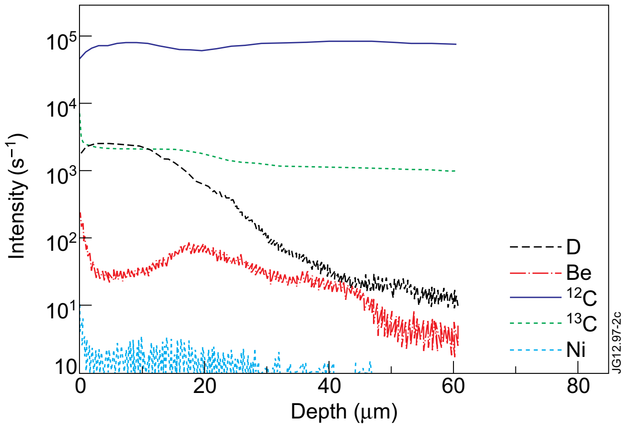

Figure 3: SIMS depth profile from Tile 4 sample 1.