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ABSTRACT

Components of the JET MkII Gas Box divertor have been analysed ex-situ after 18 months of operation with that divertor structure. The aim was to give an account on the distribution of the retained fuel along the poloidal crosssection of the divertor and, in particular, in the septum. Inside the gas box thick hydrogenated deposits were formed only on surfaces located in the near-plasma region from the inner divertor side whereas very little deposition was detected deep inside the gas box, i.e. on the support and divider plates.

INTRODUCTION

Safety and economy of a fusion reactor operation are the driving forces for the assessment of fuel accumulation in Plasma Facing Components (PFCs). The issue has been known for long time, but its full importance has been realised following the full D-T campaigns carried out at JET [1] and TFTR [2] operated with the carbon-based first wall. In the MkIIA divertor at JET vast co-deposition of hydrogen isotopes with chemically and physically eroded carbon was observed mainly in remote areas of the divertor, i.e. in places shadowed from the direct plasma line-of-sight [3-5]. The next divertor of JET was of a gas box type (MkIIGB) with a septum between the inner and the outer channel. Very detailed studies of that divertor components were performed in order to assess the material erosion, migration, re-deposition and fuel retention. Strong emphasis has been given to the analysis of deposition on surfaces in the gas box unit because its structure has been, so far, the closest to the planned geometry of the ITER divertor. Secondly, the inner part of septum has had a large surface area shadowed from the direct impact of confined plasma. Therefore, this region could be deemed as a potential trap for co-deposition leading to a significant fuel inventory.

The aim of this work is to give an account of fuel inventory along the poloidal cross-section of the Mk-IIGB divertor. A brief comparison to the deposition in the Mk-IIA configuration will also be made.

1. EXPERIMENTAL

1.1. STRUCTURE OF THE MK-IIGB DIVERTOR

Operation with the Mk-IIGB divertor lasted for about 18 months in the period 1999-2001. The total operation time was 193291s including 94299s of X-point plasma. Figure. 1a shows the cross-section of MkIIGB and the most typical position of strike points on the divertor tiles. In Figure. 1b the scheme of the septum module is depicted. Tile 5 and divider plates were positioned toroidally, whilst the three support plates of Tile 5 were oriented poloidally.

1.2. ANALYSIS METHODS

During the shutdown of JET in 2001 all septum modules and a number of other divertor tiles, including a full poloidal set, were removed by remote handling [6] and then examined *ex-situ* by means of Ion Beam Analysis (IBA) techniques. Nuclear Reaction Analysis (NRA) with a 2.5MeV $^{3}He^{+}$ beam was used to map and quantify the amount of beryllium, deuterium and carbon isotopes

(^{12}C and also ^{13}C injected to JET as a material transport marker on the last operation day with Mk-IIGB [7-9]) in the surface and sub-surface layer [10]. Under these conditions, the information depth of NRA is around microns, whereas thicker co-deposits were also formed. Secondary Ion Mass Spectrometry (SIMS) was applied for depth profiling of several elements and their isotopes [7,9] in layers of up to 90 microns thick.

2. RESULTS AND DISCUSSION

2.1. DEPOSITION ON VERTICAL AND HORIZONTAL TILES

Plots in Figure 2 a-c show deposition profiles of deuterium and beryllium in the inner divertor, i.e. on Tiles 1, 3 and 4. One observes significant variations in the distribution of species. On Tiles 1 and 3 it is strongly related to the flux deposition profiles. The fuel content is in the range from 3×10^{18} to 1.8×10^{19} D atoms cm^{-2}. The situation changes dramatically on Tile 4 where two distinct regions are clearly distinguished: i) very thick deposit in the area shadowed by Tile 3 and ii) moderate level on the part open to the plasma. The deposit thickness in the shadowed region reaches approximately 60 microns [9], whereas the results in Figure. 4c reflect the concentration in a layer 7.5-8 microns thick, i.e. the depth accessible by IBA. Therefore, the actual content total D in that region is at least 6 times greater and it amounts to about 7.2×10^{20} at cm^{-2}. Moreover, a complete lack of B_e in the shadow indicates that the deposit contains thick carbon film resulting from a long-range transport of hydrocarbons. Such a deposition pattern was identified and discussed following the studies of the MkIIA divertor [3,4].

Deposition and fuel retention on plates from the outer divertor (6, 7 and 8) has been significantly lower. The only exception was a narrow belt of strong deposition on Tile 6 in the region shadowed by tile 7. Assuming a toroidal symmetry in deposition, the integrated amount of retained fuel would be around 46.8×10^{23} D atoms including as much as 36.3×10^{23} D atoms trapped in the shadowed region on Tile 4. These numbers, however, should be treated as a lower limit of retention.

2.2. DEPOSITION IN THE SEPTUM

Surface morphology of all vertical support and divider plates of one septum module was examined. Figure 3a shows the appearance of the support plate (C-end, see Figure 1b). A dusty deposit covers the plate edge facing towards the inner divertor channel. Similar deposition pattern has been observed on other support plates. In some cases erosion by arcing has also been noted. Deuterium and beryllium distributions across the plate an order of magnitude. No significant deposition zone is formed on the outer divertor side, where a constant level below 1×10^{18} D atoms cm^{-2} is measured. The B_e content across the plate is in the range $0.5\text{-}1.5\times10^{18}$ atoms cm^{-2} and it is not increased at the edge facing towards the inner divertor. This indicates that the thick co-deposit in that region is composed mainly of a hydrogenated carbon film. There are some small variations in the D and B_e levels when all the analysed plates are compared, but the general distribution pattern remains unchanged.

Figure 4 shows a divider plate and the amount of deposited species. These results are representative for all the plates under examination, both for the inner and the outer divertor side. Again, the amounts of D and B_e are small and the coverage is fairly uniform over that surface: 0.5-1.5×10^{18} atoms cm^{-2}. The analyses of the support and divider plates have given highly consistent results showing low level of co-deposition and, as a consequence, small fuel retention. Moreover, no ^{13}C – above the background level – has been detected on any internal component of the gas box, showing that the material transport to that region is a multi-step process.

The total surface area of the gas box components is 14.85 m^2. Taking into the average D content of 1.5×10^{22} at cm^{-2} outside the deposition belts and 12 x 10^{18} at cm^{-2} in the belts and assuming the toroidal symmetry of deposition in the septum, the extrapolated upper limit of fuel retention would be 3.28×10^{23} atoms. When absolute numbers are compared, this amount is over one order of magnitude smaller than that assessed in the shadowed part of Tile 4, i.e. 36.3×10^{23} D atoms retained on an area of around 0.5m^2.

2.3. COMPARISON OF DEPOSITION IN MK-II DIVERTORS

Brief comparison of MkIIA and MkIIGB divertors allows for the statement that the general deposition patterns have been quite similar in both cases. Majority of retained fuel was found the inner divertor, especially in the zone shadowed from the direct plasma impact. However, there is one significant difference when the deuterium-to-beryllium concentration ratio in the surface layer is compared: $C_D/C_{Be} > 1$ in MkIIGB and $C_D/C_{Be} < 1$ in MkIIA. The difference can be primarily attributed to the end phases in operation with the divertors.

Immediately after the D-T experiment in JET with MkIIA, the vessel was intensively cleaned-up by various means in order to reduce the tritium retention [1]. This certainly reduced also the deuterium content in the surface layer. On the contrary, no special cleaning procedure was done after the operation with Mk-IIGB because discharges were fuelled only with deuterium and helium [9]. Another factor possibly influencing the fuel retention is associated with different wall temperatures during final stages of operation with the divertors.

CONCLUSIONS

Thorough analysis of components of the Mk-II Gas Box divertor was accomplished in order to determine the deposition pattern of co-deposited species and to assess the fuel retention. The assessment of the deposition and retention inside the gas box was particularly important because it resembles the structure of the planned ITER divertor. Secondly, many diagnostics in ITER plan to gain access through the septum structure and excessive deposition would obscure viewing capability of optical systems. Our measurements clearly indicate that the septum region should not be considered as a major trap for transported and co-deposited material. Fuel inventory in the septum is insignificant in comparison to that in the shadowed areas in the inner divertor corner. Therefore, the gas box plates can not be considered as the major trap for transported and re-deposited material. From the very small deposition found on the divider plates, one concludes that the direct cross-divertor transport of material (neutral atoms and molecules) through the dome, from the outer to the inner leg, can be considered negligible. These results should not be immediately translated into conclusions and predictions regarding the material migration and fuel inventory in the ITER divertor. However, the message allows for some optimism, especially that the use of carbon in the nextstep machine will be limited.

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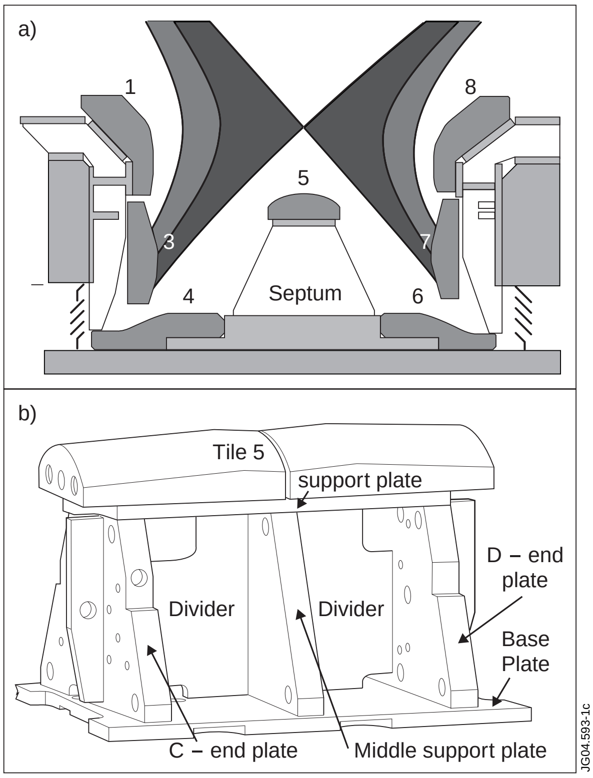

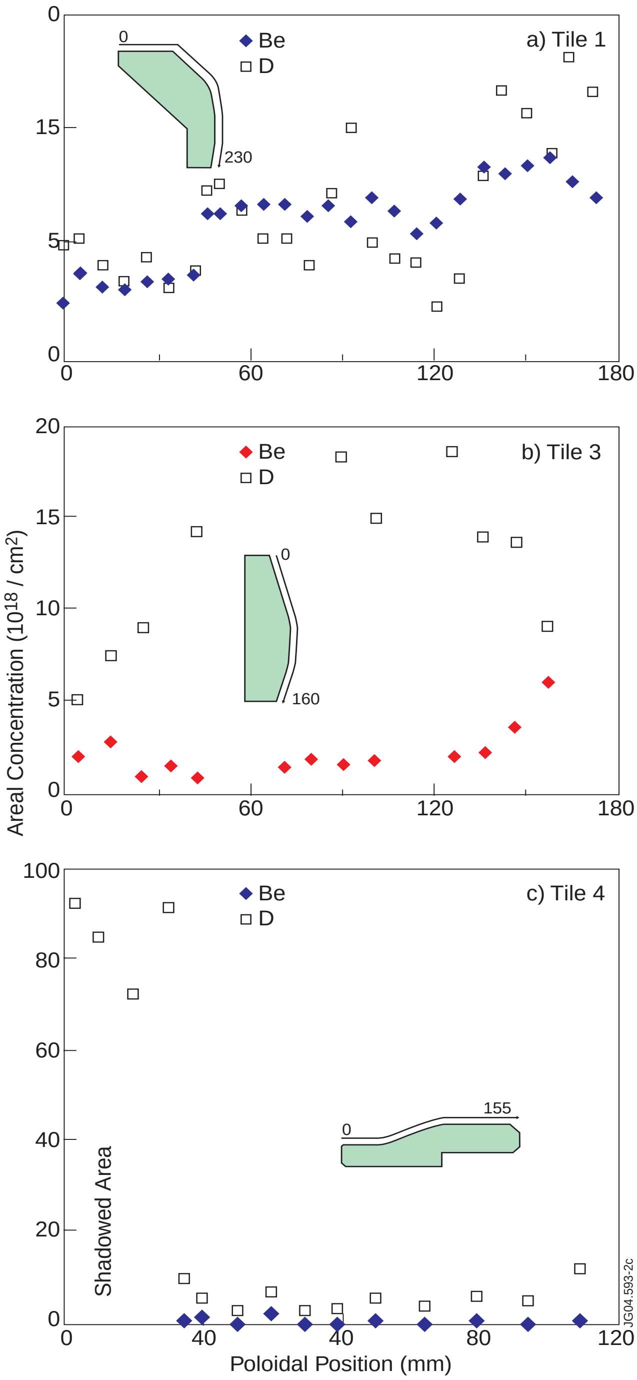

Figure 1: Cross-section of the MkII Gas Box divertor (a) and the structure of septum (b).

Figure 2: Poloidal distribution of deuterium (open squares) and beryllium (filled diamonds) distribution Tiles 1, 3 and 4 in the inner leg of the MkIIGB divertor. Geometry of respective tiles is shown in inserts.

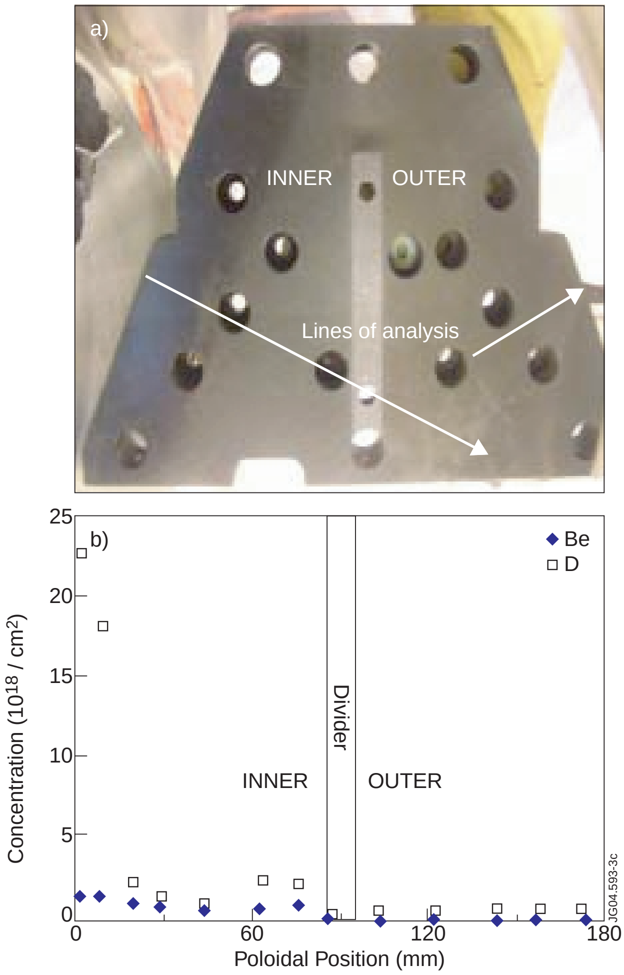

Figure 3: A poloidal support plate of the gas box (a) and distributions of deuterium and beryllium on the plate (b).

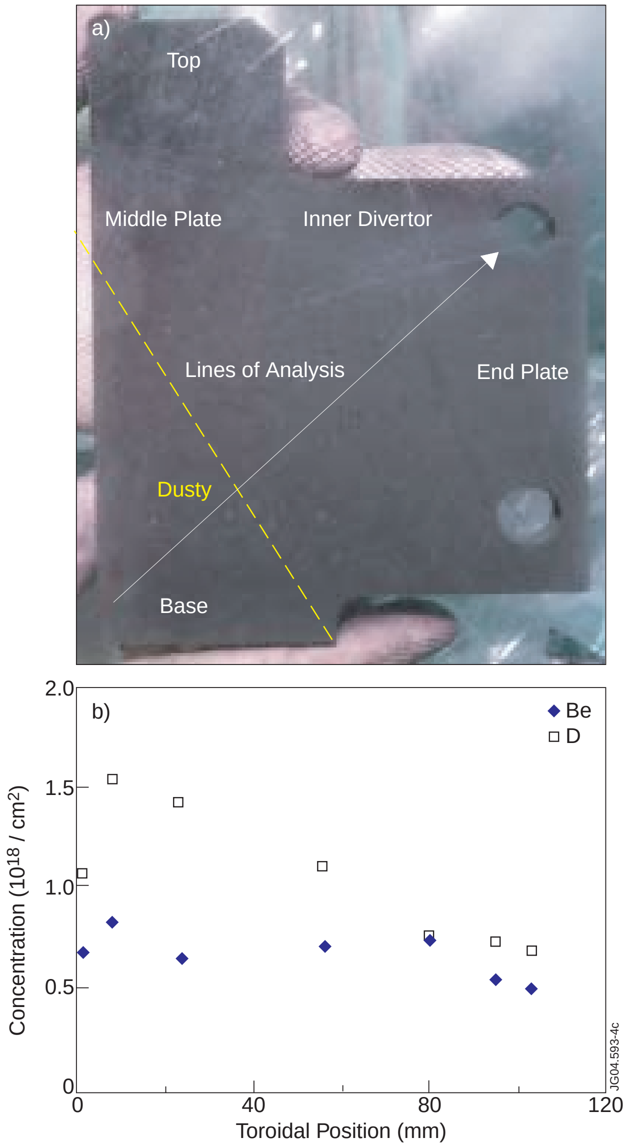

Figure 4:A divider plate of the gas box (a) and distributions of deuterium and beryllium on the plate (b).