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Assessment of the flash-lamp photon-cleaning detritiation method tested at JET

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ABSTRACT

Flash-lamp photonic cleaning has been tested *in situ* and at the Beryllium Handling Facility (BeHF) at JET. Two adjacent number 4 divertor tiles have been exposed to numerous pulses up to the nominal energy of 500 J. Starting the photon-cleaning process with tile G4A and using energies up to 350 J did not appear to be efficient for detritiation. Consequently, the untreated tile G4B has been treated at the maximum energy of 500 J. Combustion measurements confirmed that the photon-cleaning was partly efficient as about 74% of the initial tritium concentration has been released. The average tritium concentration on the surface of the tile after treatment was 2.45×10^8 Bq/cm^3 which is only four times lower than the initial activity. However, it is remarkable to notice that the bulk activity of the tiles remains constant indicating that during the detritiation treatment there is no tritium diffusing into the bulk of the tile.

1. Introduction

In the ITER fusion machine, carbon-based target materials are foreseen to be used in the divertor area. However, using carbon tiles there is likely to be a major problem in terms of tritium retention in re-deposited carbon films. It is estimated that at least 2 g tritium per pulse (400 s) will be deposited to the first wall [1,2] and therefore, detritiation of Plasma Facing Components (PFCs) of such tritium installations will play an increasingly important role in the future development of fusion. In this respect, it is important to develop a technology for the *in situ* detritiation of the carbon tiles to meet the safety criteria for ITER which allow a total tritium amount into the vacuum vessel of 700 g. Fast and efficient tritium removal is therefore needed, for future DT machines having carbon tiles as plasma facing components. Among the various methods tested so far, photon cleaning is a potential *in situ* detritiation method. In order to assess the efficiency of the tritium-removal process, two adjacent divertor tiles (one treated and one untreated) were shipped to the Tritium Laboratory Karlsruhe (TLK) to evaluate and finally compare their total tritium content and their tritium depth profile, using calorimetry and full combustion, respectively. Similar tiles were also analysed for their relative deuterium contents by Ion Beam Analysis (IBA) methods [3].

In this paper, the tritium profiles obtained by combustion measurements for the treated 3BWG4A and partly untreated 3BWG4B divertor tile will be presented.

2. Experimental

2.1. Flash-lamp and calorimetry

To assess the efficiency of the photon-cleaning detritiation technique two adjacent divertor tiles, G4A and G4B, have been removed from the vacuum vessel and after been partially treated at JET using the flash-lamp (only ~2/3 of the surface was treated).

Flash-lamps are capable of delivering several hundred Joules of UV, visible and IR radiation in periods of less than 100 μs. The flash-lamp used at JET was based on a rapid charging capacitor bank to supply the flash-lamp discharge current at a maximum of 500 J with a pulse width of 140 μs and a repetition rate of 5 Hz. At lower energies (100 J) the maximum frequency can be increased up to 25 Hz, subject to a peak continuous power output of 2.5 kW. However, for tile G4A the maximum energy was limited to 350 J and each treated position had about 12 mm wide and 150 mm discharge length (treated area ~18 cm^2) [4,5].

After the treatment both tiles have been sent to the Tritium Laboratory Karlsruhe (TLK) for tritium analysis using coring followed by full combustion. Before any coring the total activity of both tiles has been measured using a large volume calorimeter available at the TLK.

Calorimetric measurements for the untreated divertor tile 3BWG4B gave an average total tritium activity of about

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1.619 ± 0.080 Ci or 59.9 GBq, while the calorimetric measurement for the 3BW4GA treated tile estimated a total tritium content averaging 1.089 ± 0.041 Ci or, 40.3 GBq. Assuming that both tiles had initially a similar activity, these measurements indicate that after the photon cleaning approximately 33% of the tritium activity has been released when treating tile G4A with energies up to 350 J. However, it must also be mentioned that tile G4A was only partially treated by the flash-lamp.

2.2. Full combustion measurements

2.2.1. G4A treated tile

After the photon-cleaning treatment, eight cylindrical cores, having a diameter of 7.8 mm, have been removed from various positions from the tile's surface (Fig. 1). In order to evaluate the surface and bulk tritium activity at the various locations of the tile, each cylinder was sectioned into two discs: the plasma facing disc having a thickness of 1 mm and the rest cylinder. Both specimens have been ultimately combusted and their tritium content determined by scintillation analysis. The combustion results obtained for tile G4A are illustrated in Fig. 2.

As it is illustrated in Fig. 2 the higher tritium release has been observed for cylinders 1–3. Cylinders 1 and 2 are corresponding to positions which have been photon cleaned, whereas cylinders 3, 6, 7 and 8 are belonging to untreated zones of the tile. Among them only cylinder 3 is located in the shadowed area of the tile and therefore its tritium concentration on the very surface is the highest measured for this tile. On the other hand, despite the fact that cylinders 6, 7 and 8 are belonging to non-treated area of the tile, their tritium concentration is much lower compared to the treated part of the tile (cylinders 1 and 2). This is related to the fact that cylinders 6–8 are located in an erosion area (private area for cyl-8) where there is only little or, no co-deposition at all.

If we compare the tritium surface activities for the positions 1–3, we realise that even after the tile was 'flashed' with 80–100 pulses at 250 J (cylinders 1 and 2) the average tritium activity remaining on the surface is ~1.39 ± 0.7 × 10^9 Bq/cm^3 which is very similar to the 1.47 × 10^9 Bq/cm^3 measured for the cylinder 3 which was untreated. Therefore, we can draw the conclusion that the photon-cleaning process using pulses at the maximum energy of 250 J is not efficient.

As these results showed that using the flash-lamp at the energies ranging from 250 to 350 J, the photon-cleaning process is only able to ablate part of the co-deposited layer (~30%), even though the tile was submitted to many pulses, sometimes up to 100, it was decided to repeat the treatment for the other tile but using the flash-lamp at its maximum available power. Therefore, tile G4B has also photon cleaned using higher energies up to 500 J per pulse. However, in order to assess the detritiation process for this single tile it was also agreed to irradiate only part of the tile (~2/3), across the poloidal direction, while the rest of the tile (1/3) will remain untreated and will serve for comparison.

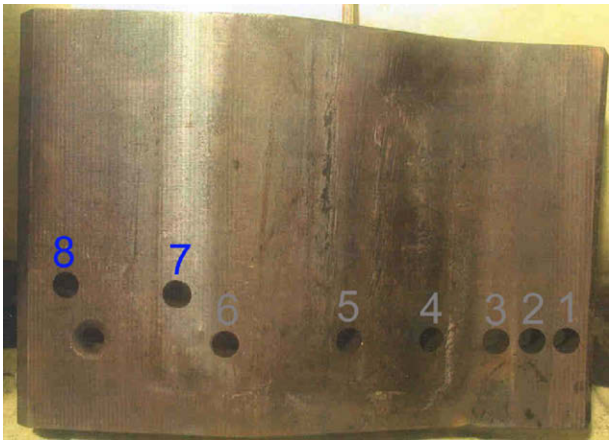

Fig. 1. Tile G4A after coring.

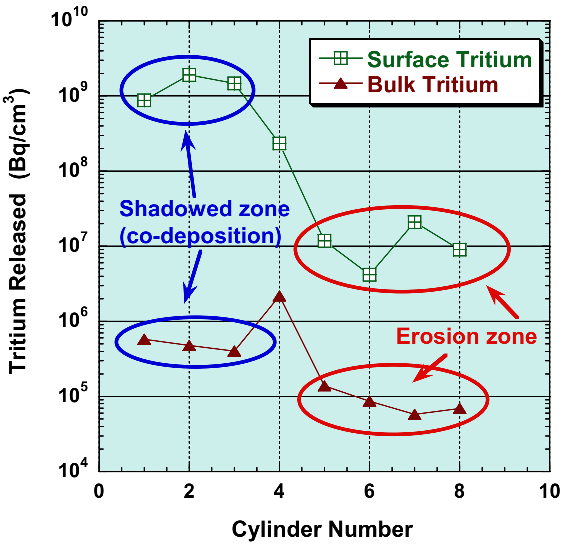

Fig. 2. Combustion results for samples retrieved from the G4A treated tile.

2.2.2. G4B partially treated tile

For this series of experiments, the full energy of the flash-lamp has been used, i.e. 500 J. The nominal energy density of the lamp was 0.12 MJ/m^2, however, due to losses in the system 500 J/pulse results in a peak energy density of 0.06 MJ/m^2 with a peak power density of 375 MW/m^2.

Three zones on Tile 4 were treated; *zone 1* was at the edge of the tile, *zone 2* was in the centre of the shadowed area, whereas *zone 3* was at the beginning of the sloping part of the tile (Fig. 3). A mask

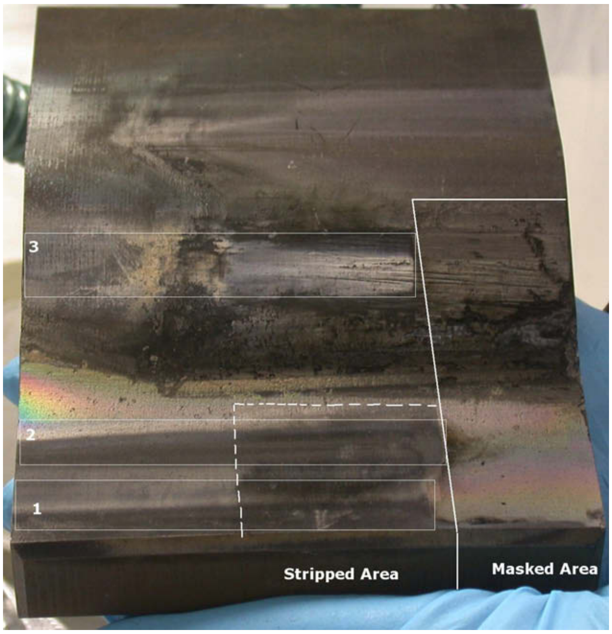

Fig. 3. Picture of the G4B after photon cleaning. The positions of treatment and masked area are indicated (see also Table 1).

was placed at the right end of the tile to prevent removal of tritium and thus provide a reference between treated and untreated regions.

As part of the tile is masked the length of treated region has been reduced to approximately 125 mm from 150 mm possible giving a treated area of approximately 15 cm^2. Each zone was subject to a series of pulses from the flash-lamp. The total number of pulses for zones 1, 2 and 3 were 2460, 2785 and 1838, respectively. The detailed description of the treated zones and the corresponding number of pulses is illustrated in Table 1. The photon-cleaning treatment for this tile was investigated and reported in details by Widdowson et al. [5].

After the photon-cleaning treatment the tile was sent to Finland where eight cylindrical cores (cylinders 1–8) have been removed, after what it was send to the TLK, Germany, where another eight cylindrical cores (cylinders 9–16) have been removed (Fig. 4).

The Fig. 4 illustrates the position of the various cores. Cores 1–8 have been used for SIMS and IBA analysis while cores 9–16 have been used for tritium analysis using full combustion and scintillation.

As it was mentioned above, the tile has been partially photon cleaned (~2/3 treated, starting from left side of the Fig. 3 and ~1/3 untreated). That means that cylinder 11, 14 and 15 are belonging to the masked untreated area of the tile and therefore, they are expected to exhibit the highest tritium concentration. On the other hand cylinders 9, 10, 12, 13 and 16 belong to the zones of the tile which have been photon cleaned.

The combustion results are illustrated in Fig. 5. From that figure we can clearly see that the photon-cleaning was inefficient even though the maximum energy of 500 J has been used. The treated surface of each zone had a surface of approximately 15 cm^2 (1.2 cm × 12.5 cm). Combustion measurements show that for the masked zone, the average tritium concentration on the surface of the tile was $9.34 \pm 2.78 \times 10^8$ Bq/cm^3, while for the photon-cleaned part of the tile, the surface tritium concentration is about four times lower, giving an average value of $2.45 \pm 0.68 \times 10^8$ Bq/cm^3. Of course this represents ~26% of the initial tritium concentration and this means that 74% of the surface tritium has been released during the treatment.

A remarkable point concern the tritium activities measured for the bulk of the tile. Combustion shows that, no matter the type of samples, photon cleaned or not, the tritium concentration into the bulk remains constant averaging the $2.59 \pm 0.62 \times 10^5$ Bq/cm^3, which is three orders of magnitude lower than the tritium activity measured for the surface samples.

This is consistent with previous observations [6–9] which have shown that during the treatment there is no tritium diffusing inside the tile. Indeed, in such a case the tritium bulk concentration for the treated samples would have been higher than the untreated samples, but this has not been observed.

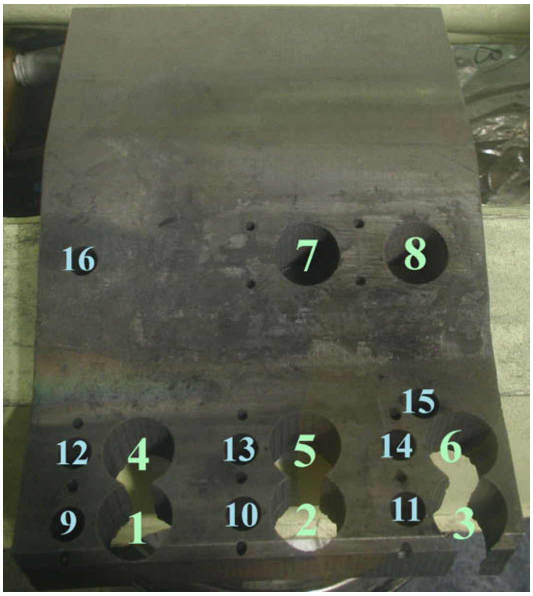

Fig. 4. Picture of the cored G4B after photon cleaning.

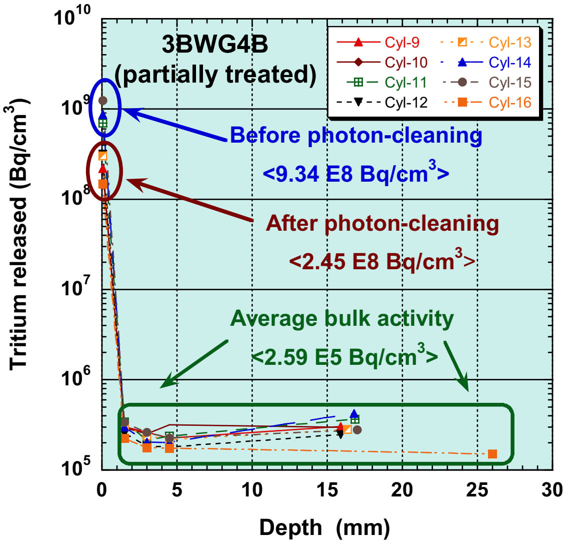

Fig. 5. Comparison of tritium depth profiles for tile G4B before and after photon cleaning.

In Fig. 6 the combustion results for the plasma exposed samples for the both tiles 4, G4A and G4B are compared. For tile G4A, the cylinders 1–3 exhibit a tritium concentration which is very much similar to what has been measured for tile G4B for the non-treated samples and this despite that these cylinders have been submitted

Table 1
Photon-cleaning description of the individual position for tile G4B. The corresponding combustion cylinders are also indicated (see also Fig. 3).

Zone of treatment	Description of treatment	Combustion cylinder	Tritium activity (Bq/cm^2)
1	Total 1230 pulses @ 500 J/pulse: no stripping	9	2.19E+07
1	Total 1230 pulses @ 500 J/pulse: stripped but not re-treated after stripping	10	2.38E+07
1	Masked/untreated	11	6.96E+07
2	Total 2785 pulses @ 500 J/pulse: no stripping	12	3.18E+07
2	Total 2785 pulses @ 500 J/pulse: 2500 before stripping, further 285 after stripping	13	3.01E+07
2	Masked/untreated	14	8.66E+07
	Masked/untreated	15	1.24E+08
3	Total 1838 pulses @ 500 J/pulse	16	1.48E+07
3	Masked/untreated	–	–

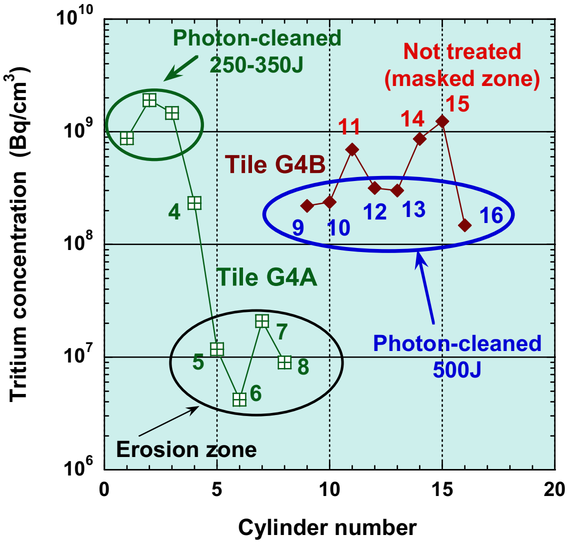

Fig. 6. Comparison of tritium concentration measured for the plasma exposed side of tile G4A and G4B (MKII-GB). The position of each cylinder is illustrated in Figs. 1 and 4.

to several tens of photon-cleaning pulses with an energy ranging between 250 and 350 J. It is very clear that such treatment was totally inefficient. However, cylinder 4 which also received a similar treatment as cylinders 1–3, exhibit a much lower tritium concentration, lower than average. This is more related to its position (beginning of the sloping part of the tile) which is mostly an erosion area while positions 1–3 are deposition areas. The same is also true for cylinder 5–8 which also exhibit much lower tritium activities event though some of them have not been treated.

Concerning tile G4B it is obvious that the photon cleaning process had some limited effect. Indeed, the cylinders 9, 10, 12, 13 and 16 belonging to the treated area of the tile (see also Figs. 3 and 4) are exhibiting a very similar tritium concentration averaging $2.45 \times 10^8 \pm 0.68 \times 10^8$ Bq/cm^3, while cylinders 11, 14 and 15 belonging to the untreated masked area of the tile, are exhibiting an average tritium concentration of $9.34 \times 10^8 \pm 2.78 \times 10^8$ Bq/cm^3.

3. Conclusions

Flash-lamp photonic cleaning has been tested *in situ* and at the Beryllium Handling Facility (BeHF) at JET. Two adjacent number 4 divertor tiles (G4A and G4B) from the MKII-GB configuration have been exposed to numerous pulses up to the nominal energy of 500 J.

As the first experiments with employing energies ranging between 250 and 300 J indicated that in such conditions the detritiation method is inefficient, the experiments using the maximum available energy (500 J) were conducted. To allow a comparison with a non-treated tile about 1/3 of the tile was left untreated putting a mask on the plasma exposed surface of the tile.

By visual inspection, it appears that under these conditions, using higher energy densities of 0.06 MJ/m^2 with a peak power density of 375 MW/m^2, only '*part*' of the deposited film (~100 μm thick), has been removed.

Combustion measurements showed that the second photon-cleaning was still inefficient as the 'part' of the tritium released is about 74% of the initial tritium concentration. This indicates that 26% of the surface tritium remains on the surface of the tile. Indeed, the average tritium concentration on the surface of the tile after treatment was 2.45×10^8 Bq/cm^3 which is only four times lower than the initial activity (9.34×10^8 Bq/cm^3). However, it is remarkable to notice that the bulk activity of the tiles did not change. Combustion measurements show that, no matter the type of samples, photon cleaned or not, the tritium concentration into the bulk of the tile remains remarkably constant averaging the $2.59 \pm 0.62 \times 10^5$ Bq/cm^3, which is three orders of magnitude lower than the tritium activity measured for the surface samples.

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