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Assessment of erosion, deposition and fuel retention in the JET-ILW divertor from ion beam analysis data

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A B S T R A C T

Post-mortem analyses of individual components provide relevant information on plasma-surface interactions like tungsten erosion, beryllium deposition and plasma fuel retention with divertor tiles via implantation or co-deposition. Ion Beam techniques are ideal tools for such purposes and have been extensively used for post-mortem analyses of selected tiles from JET following each campaign.

In this contribution results from tiles removed from the JET ITER-Like Wall (JET-ILW) divertor following the 2013–2014 campaign are presented. The results summarize erosion, deposition and fuel retention along the poloidal cross section of the divertor surface and provide data for comparison with the first JET-ILW campaign, showing a similar pattern of material migration with the exception of Tile 6 where the strike point time on the tile was $\sim$ 4 times longer in 2013–2014 than in 2011–2012, which is likely to account for more material migration to this region. The W deposition on top of the Mo marker coating of Tile 4 shows that the enrichment takes place at the strike point location.

1. Introduction

The future of fusion reactors will depend on the behaviour of the materials used in Plasma Facing Components (PFCs) which will determine their lifetime and also influence retention of hydrogen isotopes in the vessel. Among other processes, erosion of PFCs and subsequent re-deposition are critical for the operation of fusion devices and must be properly understood. The erosion and migration in the divertor is a complex system and determines the lifetime of PFCs in fusion devices. Erosion in the main chamber is the main source of impurities in the plasma, it occurs by sputtering of plasma ions with energies up to several keV and subsequent impact of eroded particles. The eroded material, mainly Be from the Be-coated tiles, enters the plasma, is ionised and transported by the SOL-flows towards the divertor during the X-point phase. This flow induces deposition of Be in the top part of the inner divertor. The process of re-erosion/deposition keeps going until it is deposited onto remote areas and no longer interacts with the plasma. The number of cycles of re-erosion/deposition decreases with the threshold energy of the element, this means that in remotes areas we expect more C than Be, and only a small amount of W [1]. The co-deposition of fuel particles with erosion products leads to an increase in the tritium inventory.

During the 2013–2014 JET-ILW campaign several marker tiles were installed in the main chamber and divertor to assess the global picture of erosion and re-deposition processes occurring during machine operation [2–4]. The divertor is the region where these processes are expected to occur at extreme conditions and post mortem analysis offers the possibility to reveal some of the major effects.

Fuel inventory, material erosion and melting have a major impact on the performance of the divertor. A large number of diagnostic tools have been used to study these phenomena. This study presents the results from Ion Beam Analysis (IBA) techniques such

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[1] See the Appendix of F. Romanelli et al., Proceedings of the 25th IAEA Fusion Energy Conference 2014, Saint Petersburg, Russia

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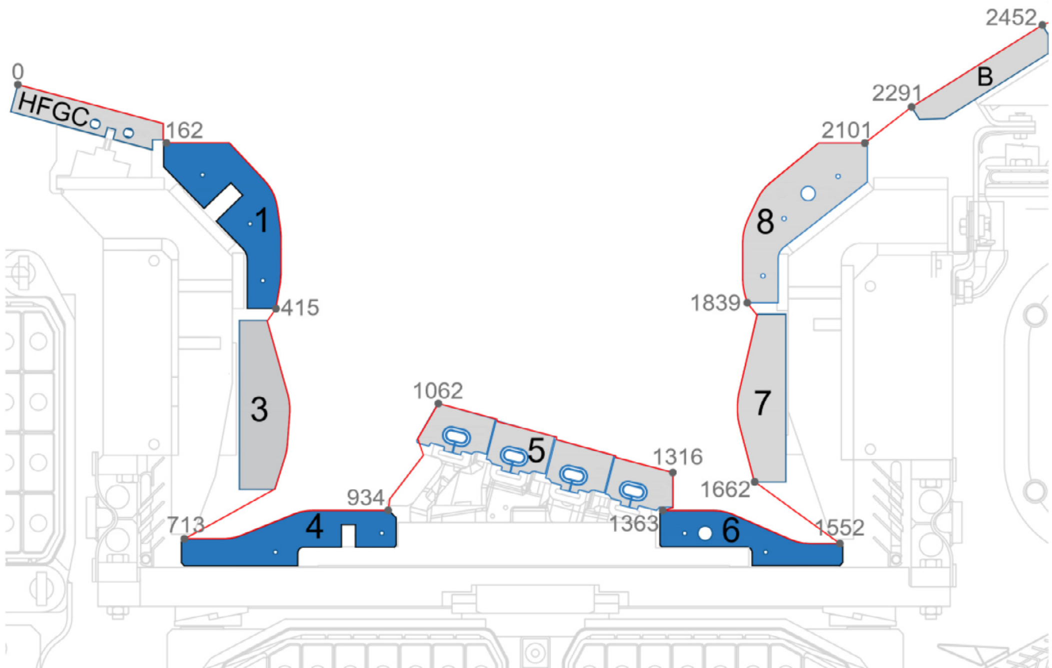

Fig. 1. JET divertor during the JET-ILW campaign 2013–2014. The s-coordinate (in mm) starts at the upper left corner of Tile 0 and follows the tile surfaces. In blue, the tiles studied in this paper; the Tile 1 is between s-coordinates 162 mm and 415 mm, Tile 4 between s-coordinates 713 mm and 934 mm and Tile 6 between s-coordinates 1363 mm and 1552 mm.

as Rutherford Backscattering Spectrometry (RBS) and Nuclear Reaction Analysis (NRA) for fuel retention and erosion patterns in JET. The results give information on the processes occurring at the inner and outer divertor corners as well as at the transition from the inner main chamber wall (high field side) to the inner divertor.

2. Experimental details

A selection of passive diagnostic components and marker tiles were installed in the JET chamber for the 2013–2014 campaign. The tile numbers and location in the divertor are shown in Fig. 1. In this work, results for divertor Tiles 1, 4 and 6, are presented, discussed and highlighted. The tiles are solid structures where the plasma facing surface is shaped with flat segments at different angles. This introduces some difficulties in mounting each tile for IBA which were overcome by measuring each of the flat segments separately, i.e. the tile was mounted in the chamber several times using specially designed holders to orient each surface perpendicular to the ion beam as shown in Fig. 2. All positions on divertor tiles are located using the s-coordinate system (Fig. 1), starting at the upper left corner of the High Field Gap Closure tile (Tile 0) and following the tile surfaces from the inner to the outer divertor.

The divertor tiles, with the exception of Tile 5, consist of CFC coated with 10 to 20 µm tungsten (W) on the plasma-facing surfaces [5,6]. Marker tiles, like Tile 1, used to study erosion and deposition in the divertor were coated with a W marker layer with a thickness of about 3 µm with a 3 µm thick molybdenum (Mo) interlayer between the W marker layer and the thick W coating [6]. The Mo interlayer is necessary to distinguish the W marker layer from the W coating for depth profiling methods, therefore enabling the erosion of W to be measured and the quantitative determination of deposition of all elements. The data presented for Tile 4 are from a marker tile where the top layer is 3 µm thick Mo (similar to Tile 1 but where the top W layer is omitted), which is used to enable the analysis of re-deposited W.

Erosion and deposition were analysed by Ion beam Analysis (IBA) techniques using the 2.5 MV Van de Graaff accelerator installed at the Laboratory of Accelerators and Radiation Technologies of Instituto Superior Técnico. Analyses for JET were performed in a chamber dedicated to fusion research, where samples, including full JET tiles, contaminated with tritium (T) and beryllium (Be) can be handled.

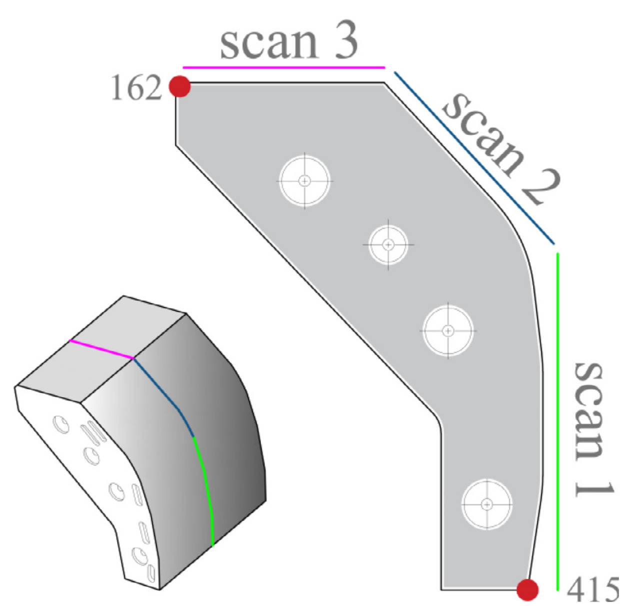

Fig. 2. Schematic view of a marker Tile 1. Due to the tile geometry three analysis scans were made as indicated in the diagram, in order to minimize the effect of the angle between the sample normal and the direction of the incident beam.

Elastic Backscattering Spectrometry (EBS) and Particle Induced X-ray Emission (PIXE) were performed with 2.3 MeV incident protons. RBS and NRA were performed using ^{3}He ions at an energy of 2.3 MeV in order to measure the amounts of ^{2}H (D), Be and C. The D(^{3}He, p)^{4}He reaction was used to measure the D content, the ^{9}Be(^{3}He, p_x)^{11}B (x = 0,1,2,3) reactions [7] for Be and the