COMPARISON OF EROSION AND DEPOSITION IN JET DURING CARBON AND ITER-LIKE CAMPAIGNS

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Erosion of plasma facing elements in fusion devices is an important question affecting their lifetimes. Redeposition of eroded materials may lead to accumulation of hydrogen isotopes, which makes it an important problem from the perspective of radiological safety. Redeposition in layers with carbon and beryllium could be a channel for hydrogen isotope accumulation.

In 2010, first wall of JET tokamak (Britain) has been completely changed from fully carbon to ITER-like, comprised of Be and W covered tiles [1]. Comparing erosion and deposition in various areas of the installation, such as the inner wall, inner and outer divertor, shadowed areas in the divertor, with data obtained during the carbon phase [2-4], is a priority. Some results dealing with new ITER-like wall have been published already [5-8], but there are still a lot of questions. Among them is carbon redeposition in the divertor. Carbon has been observed in "fully metal" systems, including JET, and its presence can lead to formation of hydrocarbon and mixed carbon-containing films with high hydrogen isotope content. It is also possible that beryllium films could be co-deposited with hydrogen isotopes in shadow regions of the divertor. Erosion distribution on the inner wall in comparison with carbon campaigns is also an important question.

In this work, erosion and deposition of plasma facing materials in JET tokamak during carbon phase campaigns and ITER-like campaign are compared for such areas as inner wall between inner limiter, inner and outer divertors, shadowed areas in inner and outer divertor, as well as under the load-bearing tile.

For quantitative surface analysis, ion beam analysis (IBA) was used. Rutherford backscattering (RBS) using protons p^+ and $^4He^+$ ions at various energies was used to analyze the surface composition of samples from all investigated areas, mainly to study material erosion. Nuclear reaction analysis (NRA) with $^{3}He^{+}$ ions at various energies were used to complement RBS and to obtain deuterium content and depth distribution in the studied samples. In addition to IBA methods, scanning electron microscopy (SEM) was used for divertor analysis.

Inner wall erosion was studied using long term samples (LTS) [8]. The samples were spread over the inner wall: four samples were mounted in octant 4 at different poloidal locations (tiles 2, 5, 8 and 11), five samples were mounted close to the inner midplane in the 8th tiles in different octants (octants 1, 3, 5, 6 and 8 for carbon phase campaigns and octants 1, 2, 5, 6 and 8 for ITER-like campaign). LTS surface was coated with beryllium, carbon and tungsten, depending on the experimental campaign (Be and W during ITER-like campaign, C, Be and W during carbon phase campaigns). Net erosion rates were calculated from the amounts of the eroded material for all samples, using total successful (Ip>0.7 MA) discharge times obtained from JET discharge statistics.

The average erosion rate of W markers during the discharge campaign 2011-2012 (9.2×10^{11} atoms/cm^{2}s) was very close to the one for the discharge campaign 2001-2004 (8.4×10^{11} atoms/cm^{2}s). In both campaigns both toroidal and poloidal erosion distributions were mostly homogeneous.

The toroidal erosion distribution of Be was similar for both 2005-2009 and 2011-2012 campaigns. The erosion distribution had small maxima in the 1st, 4th and 8th octants. The carbon net erosion rate distribution during the 2005-2009 campaign had a similar shape except for the first octant, with small maxima at the 4th and 8th octants.

The poloidal distribution had a maximum near the midplane (8th tile) and a sharp decrease in erosion towards the bottom (11th tile) during the 2011-2012 campaign and was mostly homogeneous (with a maximum difference of 15% in erosion between tiles) during the 2005-2009 campaign.

The average net erosion rate of the Be markers during the discharge campaign 2011-2012 (0.55×10^{14} atoms/cm^{2}s) was about 50% of that for the discharge campaign 2005-2009 (1.2×10^{14} atoms/cm^{2}s). This means that the net erosion rate for the ITER-like inner wall of JET was about 1/5th - 1/4th of that for the carbon-coated inner wall. Be redeposition from the limiters or from the recessed inner wall tiles is a possible explanation of this decrease, compared to the net erosion rate of Be during the 2005-2009 campaign. Chemical erosion of C by low energy particles is the most probable explanation for the comparatively lower Be net erosion rate during the 2005-2009 campaign.

Seven tiles from JET inner and outer divertor have been analyzed after 2011-2012 campaigns – three from inner divertor (tiles 1, 3, 4), three from outer divertor (tiles 6, 7, 8) (see fig. 1) and one adjacent to tile 1 of the inner divertor (tile 0).). Tiles were made out of carbon fiber composite (CFC), covered in a thick layer of tungsten (10-20 μm). The analyzed tiles, except tile 0, were further covered with a tungsten marker layer 3 μm thick with a 3 μm thick molybdenum interlayer between the marker layer and the main protective layer. To study tungsten redeposition, there was no tungsten marker layer deposited on top of molybdenum layer on tile 3. Erosion patterns have been compared to those observed in divertor during carbon phase campaigns with the same divertor configuration.

No indications of strong erosion were observed anywhere but at the center of the vertical area of the inner divertor (tile 3) after the ITER-like campaign; this strong erosion area was not observed in prior carbon campaigns. Lack of strong erosion in the outer divertor is also characteristic for the carbon phase campaigns [2]. While some rough correlation could be drawn between deposition patterns and strike point distribution, they can not be said to correspond fully.

Most of the deposition occurred on the tiles 0 and 1 of the inner divertor, with more than 66% of all deposits located in the divertor deposited there. In total, 52 g of Be, 12 g of C and 0.9 g of D were located in the divertor after the experimental campaign. These data were compared to those obtained during carbon phase campaigns.

To study deposition in the shadowed areas of the divertor, cavity samples were used during 1999-2001, 2005-2009 and 2011-2012 campaigns. They consisted of two parallel silicon plates in a metal frame, forming a cavity. The top plate had an entrance slit of a known width. Particles entering the cavity through the slit could either stick to the bottom plate and form a precursor for film deposition, or could be reflected from it, or could transform into a non-reactive molecule. These processes gave a film thickness distribution, from which information about the sticking coefficient can be acquired. If the sticking coefficient is high, then the probability for sticking at the first hit surface is large. In this case the cavities act as pinhole cameras which allow to reconstruct the source distribution of the radicals.

The deposition profiles were compared for carbon and ITER-like campaigns, as well as the particle sources, and absolute amounts of deposits. Lower deposition and deuterium accumulation was observed during IER-like campaign.

Erosion and deposition in JET was studied both during the carbon phase and after ITER-like wall was installed. Overall, lower erosion was observed on the inner wall and lower deposition and deuterium accumulation were observed in the divertor during 2011-2012 campaign with ITER-like wall.

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