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Tritium Deposition at TEXTOR-94

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Abstract

In TEXTOR, tracer amounts of tritium are generated from beam-plasma interaction in high performance discharges (I-mode, RI-mode). At the plasma current available in TEXTOR, the high energetic tritium ions are not confined by the plasma but quickly lost towards the walls where they are buried rather permanently. Different analysing methods for carbon limiter tiles have been applied: Nuclear Reaction Analysis (NRA) by an external ion beam, chemical transfer into liquid phase and detection by γ-spectroscopy, tritium- β-Ray Induced X-ray Spectrometry (BIXS), and tritium imaging plate technique. The unique combination of these methods at TEXTOR results in an absolute space resolved analysis of the Tritium deposition.

1. Introduction

Tritium retention in plasma facing components as well as in remote locations is an important safety issue of fusion devices [1]. Even after excessive tritium removal procedures remaining long-term tritium retention has been observed. Refined methods of tritium detection can help to identify the location of tritons imbedded into reactor wall material. In this paper we combine several methods to get an overview of tritium deposition on TEXTOR-94. Besides tritium detection on TEXTOR for safety issues like wipe tests and exhaust air analysis, more refined techniques have been applied at TEXTOR. These methods give absolute information about the tritium content of a carbon limiter tile at a certain location and can be combined with space resolved measurements.

At TEXTOR, tracer amounts of tritium are generated from beam-plasma interaction mainly in high performance discharges with deuterium beams into deuterium plasmas by

$$D + D \quad \rightarrow \quad T\ (1.01\ \text{MeV}) + p\ (3.03\ \text{MeV}).\ (50\%)$$
$$\qquad\qquad\quad {}^{3}He\ (0.82\ \text{MeV}) + n\ (2.45\ \text{MeV})\ (50\%)$$

Because of the limited plasma current (I_P<500 kA), these high energetic tritons are not confined but quickly lost towards the wall. The large gyro-radius of about 0.08 m at a magnetic field B_T = 2.2 Tesla together with the vertical drift motion requires a detailed orbit calculation. The particles can even hit the backside of the ALT-II limiter tiles or the inner bumper limiter tiles. The drift orbits intersect relatively soon (in less than 10 m) the wall components, as the poloidal field is in the order of 0.2 Tesla and consequently the poloidal gyroradius is about 0.8 m. On their path, the tritons loose practically no energy and the implementation range will amount to about 10µm [2]. It is not expected that diffusion of tritium for the usual temperatures at TEXTOR change the concentration considerably.

2. Experimental investigation

The tritium concentration in TEXTOR which is checked before every vessel opening depends on the experimental programme. In 1993 it amounted to 7.4×10^4 Bq/m^3 as determined in the flushing gas. After about three hours no effect besides background is measurable which is confirmed by wiping tests. After this cleaning procedure tritium may remain deeply implemented inside the plasma facing vessel components like in the Inconel liner and the graphite tiles. In 1993, the carbon tiles have been cleaned by sandblasting with B_4C. The leftover material has been analysed by chemical transfer into liquid phase and detected by γ-spectroscopy. Assuming a removal of roughly 100 µm about 0.5×10^{10} atoms/cm^2 can be found as an average value. The examination of ALT-II limiter graphite tiles can be refined by applying nuclear reaction analysis by an external ion beam. This measurement has been done at Sandia National Laboratory (SNL) where several line scans for the deuterium content have been undertaken which are compared to tritium point measurements. The T-density amount to about $c_T = 1.5 - 2\times10^{10}$ T/cm^2 on the plasma facing side and to about 3×10^9 T/cm^2 on the front edge of the backside of the tile, agreeing qualitatively with the sandblasting results. The deuterium areal concentration at the same location are about 1×10^{18} D/cm^2 and 12×10^{18} D/cm^2 for the front and back side respectively. It is remarkable that the relative distribution (plasma to rear side) of tritium is opposite to the one of the other investigated elements like deuterium, molybdenum, nickel, iron, chromium, and titanium. These elements are mostly deposited on the back side where redeposition may be the dominant process as compared to the high heat flux areas where erosion may be dominant. Following these results the total tritium content is about 7×10^{16} T in agreement with the integrated neutron yield at that time.

The tritium β-ray induced x-ray spectroscopy [3,4] opens new possibilities of non-destructive measurement of plasma facing components. The graphite tile is put into a argon filled chamber where the β-particles produce two types of radiation: bremsstrahlung and characteristic x-rays. An x-ray pure Ge detector measures the characteristic x-ray coming from the interaction of the tritium β-rays with Argon, which are emitted either from the surface or the sub-surface of the graphite sample. These can be distinguished from the bremsstrahlungs continuum resulting the bulk material. An example of a measurement is given in figure 1. The counting rate is displayed versus the energy. From the characteristic and bremsstrahlung x-rays a tritium activity of about 130 Bq/cm^2 for an ALT-II limiter tile has been quantified. The period of irradiation for this tile has been from the middle of 1998 – 1999 after the flux swing increase of TEXTOR-94. The measurement is consistent with the previous ones as the increase in radiation can be explained by the improved plasma performance of TEXTOR-94. Point measurements (ca. 0.5 cm^2) can be performed with this method, but the resulting measurement times for the low activation in TEXTOR is around 100 hours for each point.

An improvement in the areal distribution measurement is possible with the tritium imaging plate technique (TIPT) [5] which has been successfully applied to TEXTOR graphite tiles. The method bases on photo-stimulated luminescence [6]. An imaging plate with an emulsion for low energy β-rays emitter such as tritium is exposed to the graphite tiles with a face-to-face contact for a week in a dark shielded room. After the exposure the imaging plate is processed and a space resolved picture with a pixel size of 100x100 µm^2 is obtained. The resulting picture is shown in figure 2. The colour of the picture corresponds to the radiation level and is about 100 Bq/cm^2 for the red colour. The green is just above the detection limit. The two blue circles correspond to the mounting holes and show the background level of the measurement. The figure is dominated by the uniform emission of low energy β-rays on the top ¾ of the limiter tile. The green area with lower detected radiation matches with a region of deposited layers. The thickness of this layer is about 12 µm, assuming the same deposition as for a similar tile [7]. The layer consists mainly of carbon with less than 10 % of boron, iron, chromium, and nickel. At several points of the sample (marked by an arrow) the layer starts to flake off and the red points are visible. This finding is consistent with BIXS measurements at the black marked points, which give a near uniform distribution of tritium over the whole surface of the limiter tile. Due to the different implantation mechanism tritium can be found below codeposited layers. A first analysis of inner bumper limiter tiles show a radiation level similar to the ALT-II limiter tiles. A comparison of a top a bottom bumper limiter tile show a higher radiation level on the bottom, as expected from the gyration of the tritons.

The TIPT gives a very accurate picture of the tritium distribution on the surface of the material and can help to evaluate local influences of high heat load on plasma facing material [5], but the measurements gain in evidence if they are combined with methods, which also can give information about the implementation of tritium into the bulk material.

3. Conclusions

The applied methods are rather different from each other and each method has its advantage and its disadvantage; some methods are more quantitative than others but therefore only few spots can be analysed while the film method allows an overview over several tiles. All methods are analysing at the lower detection limit. The different techniques obtain their strength from the combined application and from the fact that they give altogether consistent results; even the measurements taken 7 years ago show about the same values as the recent ones (the tritium is not accumulated over many years because the tiles are sandblasted for cleaning every 2 – 3 years). The measured tritium density amounts to a few time 10^{10} tritons/cm^2; extrapolating this value to the whole surface of the inner wall results in 10^{16} –10^{17} tritons or an activation of 200 MBq.

The tritium is preferentially deposited at the lower part of the tokamak in consistency with the drift orbit of the newly born tritons. In addition, the uncovered back side of lower tiles shows an higher activation than the symmetric top tiles; this asymmetry is expected from the large Larmor radius of the energetic tritons.

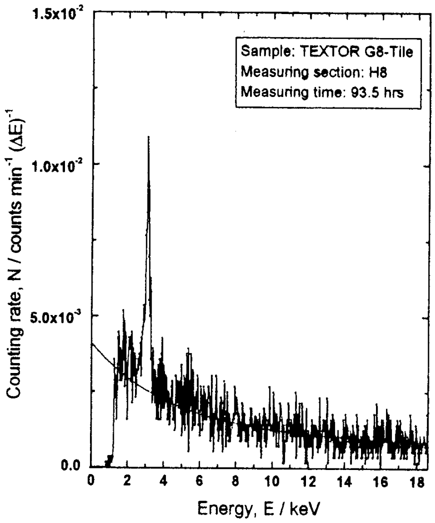

Figure 1: Characteristic x-ray and bremsstrahlungs spectrum of a carbon ALT-II limiter tile. The analysed point (H8) is marked in figure 2. The tritium activity at this point is about 130 Bq/cm^2.

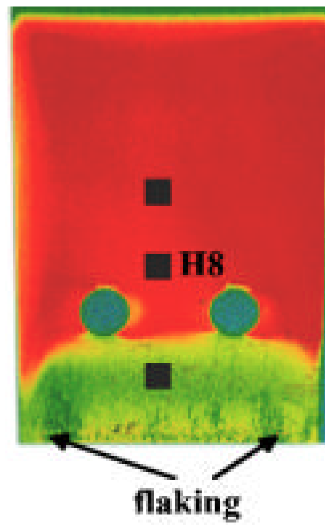

Figure 2: False colour picture of a carbon ALT-II limiter tile analysed by the imaging plate technique. The red colour corresponds to an activity of about 100 Bq/cm^2, the blue circles are the background level, measured at the mounting holes. The arrows indicate points of flaking, where higher β-radiation is found.

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