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Monitoring the leakage of 3.0 and 14.7 MeV protons from a fusion plasma

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ABSTRACT

An experiment to study, separately, the leakage of protons of 3.0 and 14.7 MeV in the JET Tokamak, is presented. The activity of the activation products induced by the plasma in different samples that were placed inside the Tokamak was measured using ultra low-level gamma-ray spectrometry (ULGS). Stacking of some of the samples during activation allowed differentiating between the protons of 3.0 and 14.7 MeV that originated in two different reactions in the plasma. For the B_4C sample the ratio of the 3.0 and 14.7 MeV proton flux could be determined as 0.17(10) assuming normal incidence and 0.31(16) assuming 45° incidence. For LiF the result obtained was that, within the uncertainty, there was no contribution from the 3.0 MeV protons.

1. Introduction

The confinement time for a fusion plasma is mainly determined by the rate of loss of charged particles across the magnetic field. Charged particles in the MeV range are produced in large quantities in fusion reactions. The leakage of these particles is a potential hazard to the reactor walls and material structures that contain the fusion plasma. Because of the extreme conditions inside the JET Tokamak there is still no standard technique to analyse the leakage of charged particles from the plasma. The short range of these particles prevents any attempt to measure them outside the Tokamak walls, as it is done for neutrons. The most promising solution for retrospective studies is to place samples of different materials inside the Tokamak and afterwards analyse the activation products.

This approach for studying the charged particles inside the JET Tokamak was carried out for the first time in 2004 [1]. A second experiment was carried out in 2006 [2–4] in which for the first time conclusive evidence of proton induced activity was discovered. The third experiment was carried out in 2008 and had three aims: (i) search for alpha particle induced reactions, (ii) determine the angular distribution of proton induced reactions and (iii) study the possibility of quantifying the relative amounts of protons with 3.0 and 14.7 MeV. The first two points were described in Ref. [5]. The aim of this paper is to describe the third part of the experiment from 2008.

The number of samples used in this experiment was forty-five. In order to measure the very low activities that were induced (in the order of mBq) it was essential to use ULGS and to measure each sample for a relatively long period of time (typically one week per sample). In order to measure relatively short-lived radionuclides (half-lives in the order of a few days), logistical issues and the access to many underground High Purity Germanium (HPGe) detectors was crucial.

2. Materials and methods

2.1. Experiment at JET Tokamak

Forty-five samples of nine different materials were placed inside the JET Tokamak. Nineteen of these samples were placed in five stacks. Each of the stacks was of a different material: HAVAR (a cobalt based alloy), lithium fluoride (LiF), boron carbide (B_4C), rhodium (Rh) and yttrium (Y). The holder for these samples was a boron nitride (BN) probe with hexagonal cross-section. Fig. 1(a) shows the cross-section of the probe and its orientation with respect to the toroidal magnetic field (B_t) and the major radius of the Tokamak (R_{in}). The numbers

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indicate the six slots where the samples could be placed. Fig. 1(b) shows a picture of the BN activation probe and Fig. 1(c) shows a schematic diagram of the sample layout. It was the same holder as was used in the experiments from 2004 to 2006. The holder was hanging from the ceiling of the JET Tokamak. The distance from the tip of the probe to the plasma was 140 mm. At each of the faces of the hexagonal holder was a slot in which to put the samples. The probe was 10 cm long. Each slot was 1.0 cm wide and could hold samples that were 1 mm thick. The materials of the samples and probe were carefully selected to resist the harsh conditions inside the Tokamak and to obtain, after the exposure to the plasma, activation products that were gamma-ray emitters with half-lives long enough to measure the activity in a reasonable time after the irradiation.

The number of samples in each stack and the thickness of them were different for each material. An overview of the thicknesses, length and masses of these samples is presented in Table 1. Note that vanadium foils (0.02 mm thick and 5.0 cm long) were used to cover all samples in slots 1, 3, 4 and 5 (at 0°, 120°, 180° and 240° with the internal radius, see Fig. 1). The main aim with the vanadium foil was to detect alpha particles via the $^{51}V(\alpha,n)^{54}Mn$ reaction, which was discussed in Ref. [5]. No positive evidence of alpha particles could be detected. A main reason for this is the very low yield of this reaction at 3.6 MeV.

For some of the samples that were not placed in stacks (TiVAl, Ti and V) a study of the angular distribution of the proton flux was carried out [5]. The conclusion of this study was that the flux of protons was at its maximum for the slots 1, 2 and 6 (at 0°, 60° and 300° with the internal radius, see Fig. 1). It was significantly lower (about 2 orders of magnitude) for the other orientations. This angular distribution could later be obtained from computer calculations [6] and provided information on the behaviour of the plasma.

The other samples that were not placed in stacks, such as the LiF and B_4C placed in the slots 2, 3 and 4 (at 60°, 120° and 180° with the internal radius, see Fig. 1), were used to monitor the charged particle flux dependence on the distance from the plasma. From previous experiments of Ref. [2] it is known that the proton flux decreases with the distance from the plasma. Due to the better confinement of the lower energy particles in the plasma it is expected that the flux of the 3.0 MeV protons is lower than that of the 14.7 MeV protons.

The samples were exposed to twelve plasma pulses. The irradiation started the 8th of May 2008 14:11 and lasted until 20:49 (UTC). Deuterium was used as fuel for all pulses. In addition, ^3He was added from the second to the ninth pulse. The reactions that occurred in the plasma were

$$D+{}^3He \rightarrow p\ (14.7\ \text{MeV}) + \alpha\ (3.7\ \text{MeV})$$

$$D+D \rightarrow p\ (3.0\ \text{MeV}) + T\ (1.0\ \text{MeV})$$

$$D+D \rightarrow n\ (2.5\ \text{MeV}) + {}^3He\ (0.8\ \text{MeV})$$

$$D+T \rightarrow n\ (14.1\ \text{MeV}) + \alpha\ (3.6\ \text{MeV})$$

Thus, the possible projectiles to react with the samples were: p (3.0 and 14.7 MeV), n (2.5 and 14.1 MeV), α (3.6 and 3.7 MeV), ^3He (0.8 MeV), D (less than 0.1 MeV) and T (1.0 MeV). At the position of the probe the flux of neutrons is three orders of magnitude higher than the proton flux, thus, neutron induced radionuclides are more likely. Only when there was no neutron induced reaction to

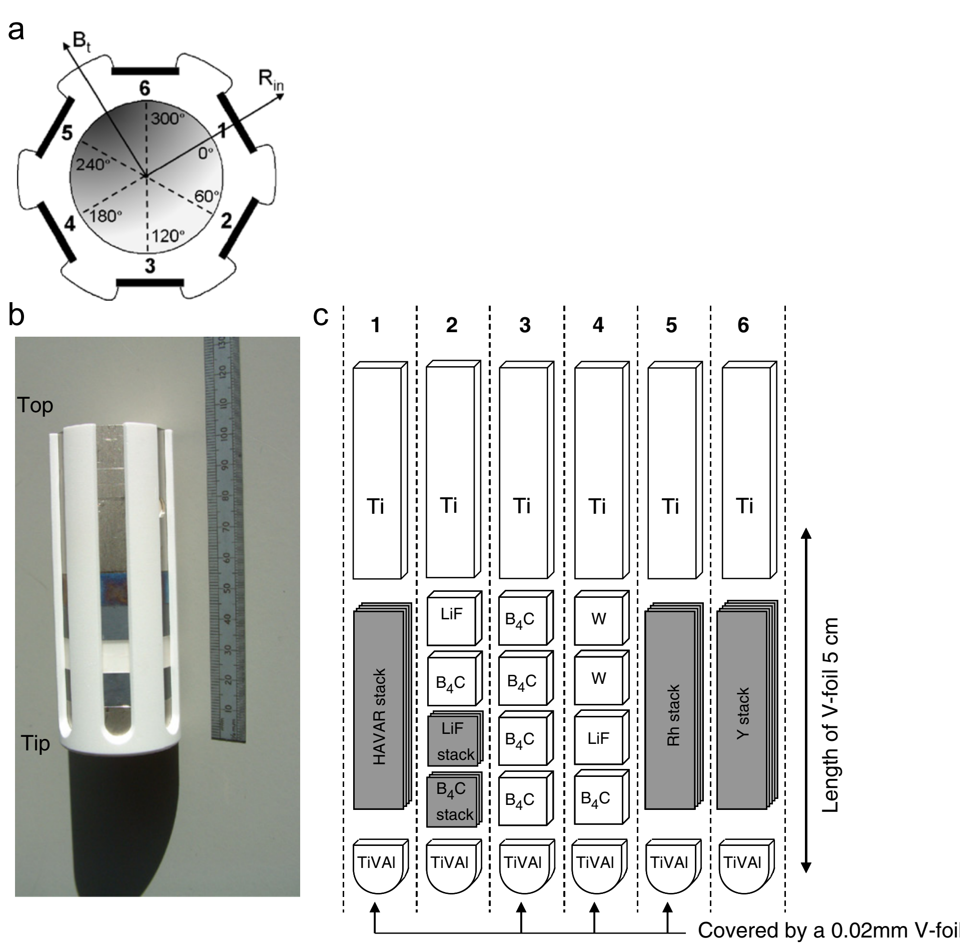

Fig. 1. (a) Cross-section of the probe and its orientation with respect to the toroidal magnetic field (B_t) and the major radius of the Tokamak (R_{in}), (b) picture of the BN activation probe and (c) schematic diagram of the sample layout. The numbers in (a) and (c) indicate the six slots where the samples were placed.