First escaping fast ion measurements in ITER-like geometry using an activation probe

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1. Introduction

More research is needed to develop suitable diagnostics for measuring alpha particle confinement in ITER[1] and techniques relevant for fusion reactor conditions need further development[2-5]. Based on nuclear reactions, the activation probe is a novel concept first tested in JET [6 -15]. It may offer a more robust solution for performing alpha particle measurements in ITER. This paper describes the first escaping fast ion measurements performed at ASDEX Upgrade (AUG) tokamak using an activation probe. A detailed analysis, outside the scope of this contribution, will be published in a journal paper.

2. AUG Activation probe

The probe consists of a graphite sample holder and cover with a slit (see in Fig.1). The sample holder has four slots spaced 90^0 apart in which to place the samples. The samples arrangement, size and material, are presented in table 1. The probe is mounted on a manipulator slightly above the tokamak mid-plane. The geometry is similar to that foreseen for an ITER activation probe[11]. The distance between the first sample and the plasma separatrix is ~ 80 mm.

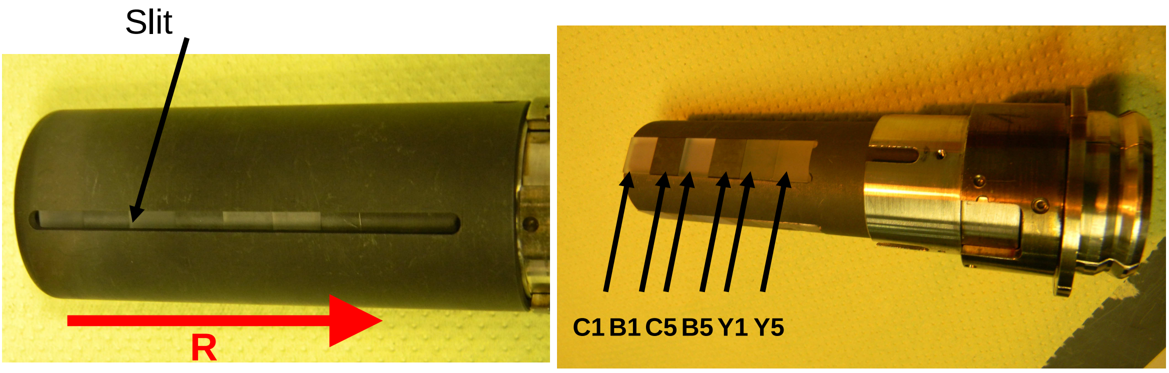

Figure 1. *Pictures of the new AUG activation probe. a) Left: The cylindrical graphite cover with 4mm wide slit. b) Right: View of Inner sample holder and six samples placed in slot 1*

We analyzed our samples using ultra-low level gamma-ray spectrometry (ULGS) at 1) IRMM (Institute for Reference Materials and Measurements) in the 225m deep underground laboratory HADES located at the Belgian nuclear centre SCK•CEN in Mol, Belgium [17] 2) Rossendorf, in the underground laboratory Felsenkeller located at a depth of 47m close to Dresden, Germany [18], 3) Laboratoire souterrain de Modane (LSM) [19] located circa 1700 m under Fréjus mountain, France and 4) Laboratori Nazionali del Gran Sasso (LNGS) in the 3800 water meter equivalent (mwe) low background counting facility located in the Gran Sasso nearby Assergi in Italy[20].

3. Results and discussion

Each sample (see fig.1 and tab.1) was exposed to one plasma except the last row that was kept for background reference. Two H-mode deuterium plasmas (B_t =2.5 T, $I_p = 10^6$A) with long flat-top phases and high DD fusion yield were performed. The measured 2.5 MeV neutron emission is 7.0 10^{15} in #29226 and 1.1 10^{16} in #29228. The fusion reactions are:

$$D + {}^3He \rightarrow p\ (14.7\ MeV) + \alpha\ (3.7\ MeV) \qquad (1)$$

$$D + D \rightarrow p\ (3.0\ MeV) + T\ (1.0\ MeV) \qquad (2)$$

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

$$D + T \rightarrow n\ (14.1\ MeV) + \alpha\ (3.6\ MeV) \qquad (4)$$

Two proton activation products – ^{7}Be and ^{89}Zr – were found. ^{7}Be is mostly produced by 3 MeV protons, see in reaction (2) above. ^{89}Zr was measured on the Y7 sample and is produced by the the 14.7 MeV protons (1). We identified four neutron induced products – ^{90m}Y, ^{47}Ca, ^{88}Y and ^{48}Sc. Due to its short half-live (3.19h), ^{90m}Y could only be measured on-site. Due to its low activity and relatively short half-live (4.54d), ^{47}Ca was measured on C4 sample only and through its daughter ^{47}Sc on other C samples. ^{88}Y is produced by 14 MeV neutrons (4) and ^{48}Sc is produced mostly by 2.5 MeV neutrons (2). The measured 3 MeV proton fluence in units of 10^8 cm^{-2} are: B1: 5.1±1.7, B3: 8.3±2.2, B5: 5.1±2.2 and B7: 5.5±2.8. A fit over six experimental $^{10}B(p,\alpha)$ cross section data and TENDL2011 is used for this work[28-33].

Table I. *Left:Overview and location of samples. The color refers to which laboratory analysed the sample – see in text above - (light grey-LNGS, pink-Modane, black-Felsenkeller and light blue-IRMM). The sample size is 10x10mm and thickness 2mm. The materials: Boron carbide B: B_4C, Calcium fluoride C:CaF2 and Yttrium orthovanadate Y: YVO4.* **Table II**. *Right: Detected activation products ordered by mass number*

Sample row	**1**	**2**	**3**	**4**
Plasma number	**29226**	**29227**	**29228**	**n/a**
CaF2	C1	C2	C3	C4
B4C	B1	B2	B3	B4
CaF2	C5	C6	C7 no data	C8 no data
B4C	B5	B6	B7	B8
YVO4	Y1	Y2	Y3	Y4
YVO4	Y5	Y6	Y7	Y8

RN[a]	**PR**[b]	**Thr**[c]	**S**[d]
^{7}**Be** $(t_{1/2=\ 53.22d})$	^{10}**B(p,α)**	--	B1,B2,B3, B5,B6,B7
^{47}**Ca**$(t_{1/2=\ 4.54d})$	^{46}**Ca(n,γ)** ^{47}**Ca(n, 2n)**	- 10.2	C1, C3,C4 C5,C6
^{48}**Sc**$(t_{1/2=\ 1.82d})$	^{51}**V(n, α)**	2.1	Y1,Y2,Y3, Y5,Y6,Y7
^{88}**Y**$(t_{1/2=\ 106.63d})$	^{89}**Y(n,2n)**	11	All Y
^{89}**Zr**$(t_{1/2=\ 3.27d})$	^{89}**Y(p,n)**	3.7	Y7
^{90m}**Y**$(t_{1/2=\ 3.19h})$	^{89}**Y(n, γ)**	-	Y[e]

[a] RN: Radionuclide found, [b] PR: Main production reaction, [c] Thr: Energy threshold in MeV for the reaction ,[d] S: Sample, [e] Measured at IPP-Garching, integrated measurement of all samples

As shown in table II, ^{7}Be is detected on all B samples except B4 and B8. Although B4 and B8 were exposed to gamma and neutron radiation, they were not exposed to escaping fast ions. The absence of ^{7}Be on B4 and B8 further confirms that it is due to escaping protons. These results suggest a higher proton loss for plasma #29228. If the loss per source proton is constant for both plasmas due to near-identical magnetic fields, the increase may be due to the proton source increase which is ~ 50% higher in #29228 than #29226. The comparison with ASCOT code Monte Carlo calculations [21, 22] which is an important goal of these experiments will provide detailed answers. Please see in the accompanying paper [23]. The ^{89}Zr detection is a new interesting result. It must be produced from reactions (1) due to confined ^{3}He ions. A spectral line corresponding to ^{91m}Nb, produced by the ^{89}Y (^{3}He,n) reaction –no threshold- was found. However this reaction cross section is unknown and the observed line may also be a statistical fluctuation.

4. Conclusions Results from the first activation probe experiment performed at AUG are reported. For the first time, single plasmas are measured. Absolute measurements of mid-plane alpha-like escaping 3 MeV protons were performed. These measurements are extremely valuable for the benchmark of ASCOT Monte Carlo calculations. We found some evidence for ^{3}He induced activation but more research is needed to confirm this new result. The ^{3}He burn-up products measurement is also a new result. Finally, our experimental technique could easily be optimized by using a modified optimized aperture and larger samples area. We also opened up the possibility at AUG to measure alpha particles from reactions (1) without the need for tritium.

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