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Low-level gamma-ray spectrometry for analysing fusion plasma conditions

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Abstract

A new method, combining activation by neutrons and charged particles with ultra low-level gamma-ray spectrometry, aimed at obtaining a better understanding and more adequate measurements of MeV particle leaks in magnetic fusion devices was studied here. A total of 36 samples containing Ti, LiF, B_4C and W were placed in a boron-nitride holder mounted on the ceiling of the JET Tokamak. The samples were activated by 63 pulses from a D–^{3}He plasma and were later measured using underground gamma-ray spectrometry. The radionuclides ^{7}Be, ^{46}Sc, ^{54}Mn, ^{56}Co, ^{57}Co, ^{58}Co, ^{124}Sb, ^{181}Hf, ^{182}Ta, ^{181}W and ^{185}W were detected in several of the samples, with very low levels of activity of ^{47}Sc and ^{48}V found in a few of the samples. The various production channels for the radionuclides in question are discussed.

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1. Introduction

Efforts to improve the confinement of a fusion plasma are usually aided by measurements of charged particle and neutron emission as close to the plasma as possible. Neutron emission is presently being studied at Joint European Torus (JET) using several neutron flux monitors and large neutron spectrometers located outside the vacuum chamber [1,2]. Until recently there was no way of measuring the emission of charged particles inside the Tokamak directly [3]. In 2004 a study of a ^{4}He plasma in which the concentration of residual D was raised to 50% was conducted at JET using an activation technique to investigate the flux of neutrons and charged particles inside the Tokamak [4,5]. A boron-nitride (BN) sample holder containing 18 small samples ($1 \times 1\,cm^2$) of three types, Ti, MgF_2 and TiVAl, was placed in one of the experimental ports in the vacuum chamber and irradiated by 49 plasma pulses. Many of the radionuclides produced had a very low level of activity due to (i) the small size of the samples, (ii) the small cross-section of some of the reactions, (iii) the low isotopic abundance of certain of the target isotopes and (iv) the limited time the samples were exposed to the plasma. In order to quantify these radionuclides, ultra

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low-level gamma-ray spectrometry (ULGS) was carried out in an underground laboratory [4].

A similar approach is used in the experiment described here, aimed at measuring the emission of neutrons and charged particles inside the Tokamak. Compared with previous measurements, the main differences are that in the present experiment a D–^{3}He plasma with a ^{3}He concentration of 8–20% was studied and the sample holder held 36 samples of the different materials Ti, LiF, B_4C and W. The samples were irradiated with 63 plasma pulses. Because of the greater number of samples and the time it would take to measure them successively, the measurements were carried out simultaneously in three underground laboratories, using a total of six ultra low-background HPGe-detectors.

2. Materials and methods

2.1. Sample materials and holder

The activation samples were mounted on a 10 cm long probe with a hexagonal cross-section (see Fig. 1). The probe was fixed to the ceiling of the JET vacuum chamber at experimental point 1, as shown in Fig. 2. The probe was made of BN since experience has shown that this material is well suited to the harsh environment inside the JET Tokamak [4,5]. The extreme conditions in the JET vacuum chamber place severe restrictions on the materials that can be used for the experiments. A material must be neither fragile nor brittle, and able to withstand a strong magnetic field and temperatures as high as 300 °C.

There were 12 samples of titanium (Ti), 12 samples of boron carbide (B_4C), six samples of lithium fluoride (LiF) and six samples of tungsten (W) used in the experiment (see Table 1). Each sample was of natural isotopic composition, meaning that in total the samples contained 17 different

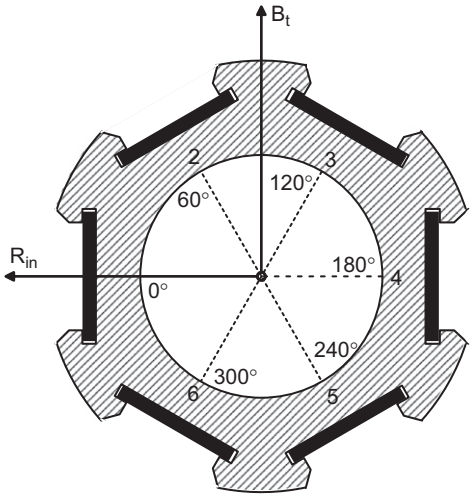

Fig. 1. A horizontal cross-section of the boron-nitride probe in which all the samples were held. B_t is the standard direction of the toroidal magnetic field and R_{in} is the direction along the major radius of the Tokamak and pointing radially inward. The numbers indicate the six sample positions.

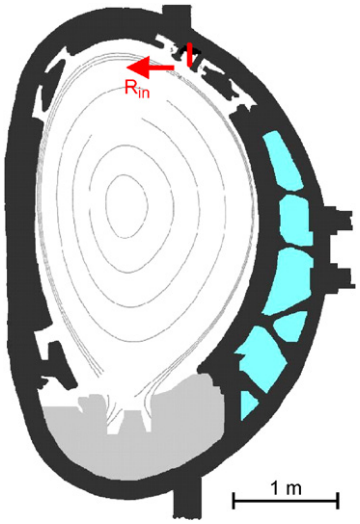

Fig. 2. A schematic drawing of the boron-nitride probe attached to the ceiling of the JET Tokamak.

Table 1
Details of the samples contained in the test probe, listed in the same vertical order as when they are mounted in the sample holder

Material	No. of samples	Name	Exposed area (cm^2)	Mass (g)
Ti	6	TiTop1–6	3.52	1.90
W	6	W1–6	0.825	1.95
B_4C	6	B_4C7–12	0.825	0.26
LiF	6	LiF1–6	0.825	0.33
B_4C	6	B_4C1–6	0.825	0.26
Ti	6	Ti1–6	0.680	0.39

naturally occurring isotopes of titanium, lithium, boron, carbon, fluorine and tungsten (see Table 2). One non-irradiated sample of each type was analysed at StudieCentrum voor Kernenergie•Centre d'Etude de l'energie Nucleaire (SCK•CEN) in Mol, Belgium [6], by means of k_0-neutron activation analysis (k_0-NAA). This analysis procedure showed that there were relatively high concentrations of certain impurities in some of the samples (see Table 3). All the samples in one series were from the same batch, so it was assumed that their impurity levels would be approximately the same.

Each sample was 1 mm thick and had a surface area of 1×1 cm^2, except for the 12 Ti samples which had different surface dimensions. As shown in Fig. 3, the Ti samples located in the lower portion of the sample holder were rounded at the lower end, whereas the Ti samples at the top were each approximately 44 mm long, some of them with a hole in them in which a stainless steel screw was affixed. The materials were placed in the positions indicated in Figs. 1 and 2. The samples were placed in their slots by sliding them along the holder. Consequently, a portion of the sample about 8.25 mm in width was uncovered, whereas the remainder of the width was covered by the edges of the slot. The angled edges (see Fig. 1) were 1–2 mm