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Characterization of a diamond detector to be used as neutron yield monitor during the in-vessel calibration of JET neutron detectors in preparation of the DT experiment

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HIGHLIGHTS

- A diamond detector has been characterized for use as neutron yield monitor of a portable 14 MeV neutron generator.
- The system will be used for the 14 MeV calibration of JET neutron detector.
- The results and the performances of the monitor are very satisfactory in term of accuracy and reliability.

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ABSTRACT

A new Deuterium-Tritium (DT) campaign is planned at JET. An accurate calibration for the 14 MeV neutron yield monitors is necessary. In order to perform the calibration a 14 MeV Neutron Generator with suitable intensity ($\sim 10^8$ n/s) will be used. Due to the intensity change during the Neutron Generator lifetime it would be necessary to monitor continuously the neutron emission intensity during the calibration using a compact detector attached to it. A high quality diamond detector has been chosen as one of the monitors. This detector has been fully characterized at the 14 MeV Frascati Neutron Generator facility. The characterization procedure and the resulting 14 MeV neutron response of the detector are described in this paper together with the obtained uncertainties.

1. Introduction

A new Deuterium-Tritium (DT) campaign is planned at JET. The JET neutron emission monitoring system, consist of some fission chambers and of an activation system. It was recalibrated in 2013 for the 2.5 MeV neutrons, using a ^{252}Cf neutron source moved remotely to about 200 positions inside the JET vacuum vessel. However, it is not possible to proceed with a direct extrapolation to the 14 MeV neutron energy because this would lead to larger uncertainties. Therefore, an accurate calibration of JET neutron detectors at 14 MeV neutron energy must be performed using a DT Neutron Generator deployed inside the JET vacuum vessel by remote handling. The calibration, that will take advantage of the experience gained with the recent calibration at 2.5 MeV neutron energy, will also benchmark the calibration procedure envisaged in ITER. A 14 MeV Neutron Generator (NG) with suitable intensity ($\approx 10^8$ n/s) will be used. The NG intensity and energy spectrum will have to be calibrated and accurately pre-characterized versus the emission angles. Due to intensity change during the NG lifetime, it would be also necessary to monitor continuously the neutron emission intensity during the in-vessel calibration using a compact detector attached to it.

An ad hoc project has been lunched for this purpose which started as part of the JET component of the EFDA 2013 Work Programme. This project continuing in the EUROfusion activities in 2014–15 and beyond until the execution of the in-vessel calibration of JET neutron detectors. The target accuracy for the JET neutron detector calibration is ±10%, which requires an even better accuracy for the NG calibration.

A Single Crystal Diamond detector (SCD) has been chosen by ENEA as one of the small compact detectors to monitor the NG yield. The SCD detector was fabricated by Istituto di Struttura della Mate-

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[1] See the Appendix of F. Romanelli et al. Proceedings of the 25th IAEA Fusion Energy Conference 2014, Saint Petersburg, Russia.

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Fig. 1. Diamond detector sketch.

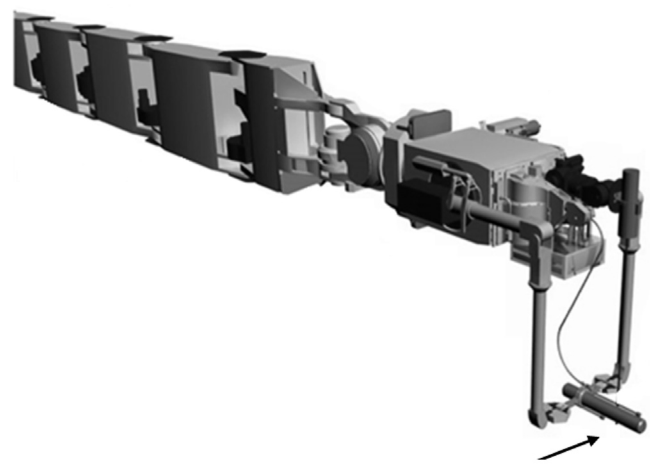

Fig. 2. Sketch of the MASCOT carrying the neutron generator. The MASCOT will go inside JET vacuum vessel.

ria (ISM), Consiglio Nazionale delle Ricerche (CNR), Rome, (Italy), while the electronics are standard CAEN [1] catalogue components. These electronics are a single channel charge sensitive preamplifier, up to 200 pF input capacitance, 45 mV/MeV (Si) sensitivity and the DT5780, a Dual Digital Multi Channel Analyzer (MCA) based on a 14-bits 100 MS/s flash ADC. DT5780 accepts directly pulses from the charge sensitive preamplifier performing a digital trapezoidal shaping on exponential decaying signals. Complete control of all the shaping parameters like trapezoid rise time, flat top, etc is possible. Two HV channels able to supply a bias voltage up to ±0.5 kV, 300 μA and two connectors to power preamplifier are part of the DT5780 bought by ENEA.

ISM-CNR has produced the detector using an "electronic grade" (with [N] < 5 ppb and [B] < 1 ppb) Chemical Vapour Deposition (CVD) single crystal diamond plate ($4.5 \times 4.5\,mm^2$, with thickness d = 500 μm), provided by Element Six Ltd [2]. ISM-CNR deposited square 200 nm thick multilayer gold finished contacts, $4.2 \times 4.2\,mm^2$, on both plate faces and then mounted the plate in an anodized aluminium casing using an alumina plate holder. A standard Sub Miniature version A (SMA) connector is then used to pick-up the signal output, see Fig. 1.

As said before this detector and the electronics will be used to monitor the neutron yield of the NG that will be moved inside JET vacuum vessel using an articulated boom named MASCOT. A sketch of the MASCOT holding the NG is shown in Fig. 2. For this purpose, the NG will be absolutely calibrated in a neutron laboratory. The diamond detector will be located close to the NG in a well-defined and fixed position both during the NG calibration and during the in-vessel calibration of JET neutron detectors.

The MASCOT remote handling has a limit to the maximum weight it can carry. As a consequence, a requirement for the neutron yield monitors was that their total weight must be lower than one kg. This was one of the reasons why a small SCD and a compact MCA digitizer have been chosen.

2. Studies of the monitor response

2.1. Response of the monitor to alpha particles

A preliminary characterization of the monitor was performed using a standard triple nuclide alpha source. The diamond detector was enclosed in a vacuum chamber and the electronics was connected using the cables with the length that will be necessary during the operation with the MASCOT. Tests were performed at positive and negative bias polarity applied at the detector in the range 200–400 V. It was found that the peaks positions, the energy resolution and the time stability were similar for the range ±300–400 V with a little improvement using a negative bias and the alphas entering the grounded diamond plate face. The typical response to alpha particles for −300 V bias is shown in Fig. 3. The total measuring time was one hour long, no "polarization effects" were observed.

2.2. Response of the monitor to 14 MeV D-T fusion neutrons

The monitor response to D-T fusion neutrons was measured using the Frascati Neutron Generator (FNG) [3]. FNG was employed with an acceleration voltage of 260 kV and a ~14 MeV neutron output of about 7 × 109 n/s. With this acceleration voltage the energy of the produced neutrons span the range 13.1–15.2 MeV for angles 180°–0° with respect to the deuteron beam direction [4]. In order to study the response of the monitor to different energies the diamond detector was positioned at 22 different angles in front of FNG neutron target using a step motor which can perform a 360° rotation in 2 × 104 steps. The angles investigated spam from −90° to 120°, in 10° angle step. Other angles were not accessible due to the presence of obstacles. The nominal distance of the centre of the diamond plate from the neutron production plane of FNG target was 31.5 cm. An uncertainty on this distance however exists and will be discussed later. The charge preamplifier and the MCA were located about 2 m far from the neutron target. In Fig. 4 a photo of the diamond detector assembly is shown. The SCD was biased at −300 V in all the runs, the bias voltage was never switched off during the whole experiment which was lasting about three hours. Again no "polarization effects" were observed.