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ABSTRACT.
In 2011-2012, an experimental campaign with a significant yield of fusion neutrons was carried out on the JET tokamak. During this campaign the facility was equipped with two diamond detectors based on natural and artificial CVD diamond. These detectors were designed and manufactured in State Research Center of Russian Federation TRINITI. The detectors measure the flux of fast neutrons with energies above 0.2MeV. They have been installed in the torus hall and the distance from the center of plasma was about 3m. For some of the JET pulses in this experiment, the neutron flux density corresponded to the operational conditions in collimator channels of ITER Vertical Neutron Camera. The main objective of diamond monitors was the measurement of total fast neutron flux at the detector location and the estimation of the JET total neutron yield. The detectors operate as threshold counters. Additionally a spectrometric measurement channel has been configured that allowed us to distinguish various energy components of the neutron spectrum. In this paper we describe the neutron signal measuring and calibration procedure of the diamond detector. Fluxes of DD and DT neutrons at the detector location were measured. It is shown that the signals of total neutron yield measured by the diamond detector correlate with signals measured by the main JET neutron diagnostic based on fission chambers with high accuracy. This experiment can be considered as a successful test of diamond detectors in ITER-like conditions.

1. INTRODUCTION

The measurement of neutrons produced by fusion is one of the most important diagnostics of high temperature plasma. Neutron diagnostics play an important role in the future of ITER. They will provide key information on plasma physics, machine protection and control issues. Several ITER neutron diagnostic systems operate in a harsh environment; namely strong radiation exposure, strong magnetic field, high vacuum. This makes it difficult to use the silicon and scintillation detectors previously applied in tokamaks TFTR, JT-60, FTU, JET. Currently diamond detectors of high energy resolution are being developed to meet the needs of some ITER systems [1,2].

The scope of this paper is a description of neutron measurements with diamond detectors on a largest tokamak JET at high count rates. To provide such rates detectors were placed in torus hall and the distance from the center of plasma was about 3m. High level of electromagnetic noises at the detector location requires developing a specific electronics. Detectors operate as a threshold counters. Detector's signal of total neutron yield compares with a neutron diagnostic based on fission chambers. Using different threshold levels allowed us to evaluate fluxes of DD and DT neutrons, additionally a spectrometric measurement channel has been configured for this purpose.

In this paper we describe the technique of measurement with diamond detectors. The response spectra of the detectors are derived using MCNPX calculations of neutron spectra at their location. The neutron sensitivity of these detectors was determined in our laboratory using AmBe source.

2. EXPERIMENT

During the experimental campaign JET was equipped with two diamond detectors. Diamond detectors were made in a body based on coaxial connectors. We use crystals splitted in films 180 and 500 thick. On the diamond surface 30nm gold electrical contacts were deposited. There is thin copper diaphragm with 2mm in diameter aperture from the front side to provide alpha irradiation. Am241 source is used for energy calibration.

Detectors with alpha sources and preamplifiers were installed in the JET torus hall in main horizontal port as close as possible to the tokamak port. In this case the distance from plasma center is about 3m. During the campaign neutron flux at the detector's location was up to 10^7 n/cm^2. High level of electromagnetic noises especially when the ICRH is on as well as high count rates requires us to develop specific charged preamplifier. Signal from preamplifier to processing electronics is transmitted by 150m coaxial cable. The same cable is used to apply the HV detector bias.

Signal from preamplifier goes to the input of shaping amplifier. We use Ortec 673 with shaping time = 0.25µs. Detectors mainly operate as a threshold counters. There are three threshold levels: 20mV, 50mV, 160mV. That corresponds the energy deposited in crystal: 120keV, 300keV, 900keV. First threshold is chosen to reduce the noises in measuring circuit. We experimentally estimate that the response of detectors to gamma background is sufficient in a range of energy below 300keV. This response is probably caused from runaway electron bremsstrahlung. So second threshold in 50mV allows us to reduce the influence of gamma radiation background on the detector's signal. 160mV threshold is used to estimate the amount of neutrons from triton burn-up. The maximum absorbed energy from the neutrons with energies of 2.5MeV is about 800keV. For threshold adjustments CAEN N413 fast discriminator is applied. Additionally we connect spectrometric ADC Lecroy 3512 to receive pulse height spectra.

3. DIAMOND DETECTORS

When fast neutrons interact with carbon nuclei part of their energy spends to the ionization of atoms and formation of hole-electron pairs. Main processes of this interaction are elastic and nonelastic scattering, (n,alpha) and other nuclear reactions. Under the applied electric field electric current signal occurs in detector body and its amplitude linearly depends on the absorbed energy. Consider the diamond detector response spectrum. When the crystal irradiated by neutron flux with spectrum $F(E_1)$ the total number of neutrons interacted with diamond is $\alpha\sigma_i(E1)F(E_1)dE_I$. Here E_I is a neutron energy, i - process of interaction, $\sigma_i(E_1)$ - its cross-section [3], $\alpha = nVt$, n – concentration of carbon, V – detector volume, t –exposure time. Fraction of neutrons having energy E_1 (that being transferred to crystal energy E_p) is

$$f_i(\mu, E_1)\,\frac{\partial\mu}{\partial E_p}\,\mathrm{d}E_p\,.$$

Here $f_i(\mu,E_1)$ is a probability mass function for the neutron to be scattered in cosine of the angle from μ to $(\mu + d\mu)$. In the form of Fredholm equation the response spectrum looks like

$$W(E_p) = \frac{dN(E_p)}{d(E_p)} = \int_{E^1_{min}}^{E^1_{max}} K(E_p, E_1)\,F(E_1)\,dE_1 = \int_{E^1_{min}}^{E^1_{max}} \alpha \sum_i \sigma_i(E_1) f_i(\mu, E_1)\,\frac{\partial\mu}{\partial E_p}\,F(E_1)dE.$$

Here $W(E_p)$ is the amount of events with energy E_p, $K(E_p, E_1)$ - the conversion operator of neutron energy to the absorbed energy of diamond crystal. In our calculation spectrum $F(E_1)$ is performed using MCNPX Monte Carlo code. We use in the model DD and DT plasma sources with 20 keV temperature.

To determine the effective volume and sensitivity of the detectors calibration procedure using AmBe neutron source has been developed and used. In details it is described there [4, 5]. In this calibration it has been shown that the effective volume of natural diamond detector is 1.95mm^3 and the volume of CVD diamond detector is 7mm^3 or almost the whole volume of diamond material located between electric contacts.

RESULTS

As the MCNP calculations show at the detector location the most neutron flux is caused by scattering neutrons with energy below 1.5MeV. The fraction of primary neutron flux is about 20%. The results of calculation of diamond detector response for DD plasma operation is presented in Fig.2. One can see that the energy response of the detector to DD neutron is in the range below 0.8MeV.

When the response spectrum of detectors is known it is possible to restore the neutron yield from the detector's counts. In our case the discrepancy of such restoring is about 50% in comparison with fission chambers (main JET neutron diagnostics). To provide the absolute value of neutron yield in future fusion experiments diamond detectors need to be calibrated with the known neutron source. Nevertheless the shape of a signal from diamond correlates with fission chamber's signal with high accuracy (Fig.3).

For different JET scenarios we also can observe correlation between two neutron diagnostics (Fig.4).

For total neutron yield signal the counter with threshold level corresponding to 0.3MeV was applied. Using higher threshold of 0.9MeV allows separation of events caused by DD neutrons and measure the only DT yield. In this DT signal weak correlation with fission chamber diagnostics was observed because this signal is more dependent on the confinement condition of burn-up tritium in the plasma center. Further investigation in this direction are required.

ACKNOWLEDGMENTS

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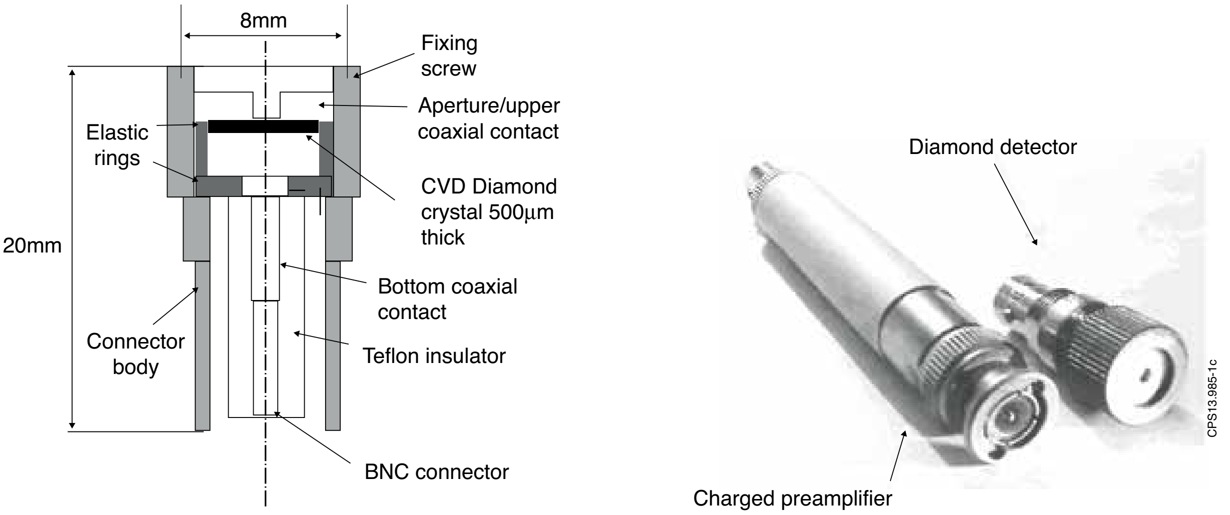

Figure 1: Diamond detector and preamplifier.

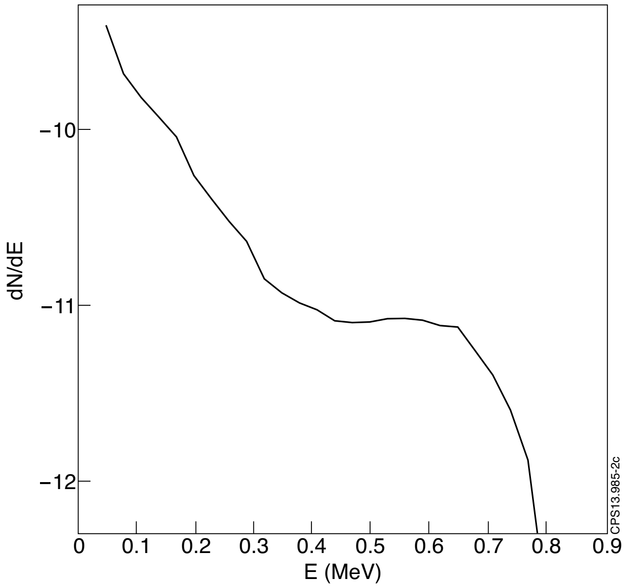

Figure 2: Calculated response of the CVD diamond detector for DD-plasma based on MCNP spectra.

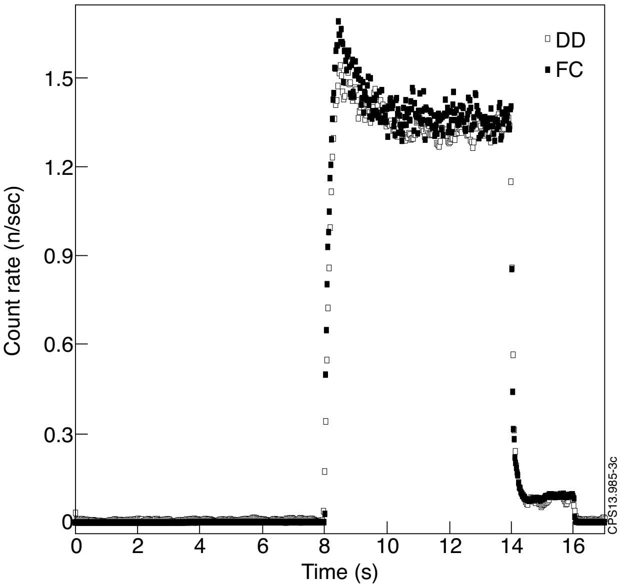

Figure 3: Comparison of total neutron counting rate F recalculated from CVD diamond detector (solid dots) and from KN1 fission chambers. Pulse No: 83693.

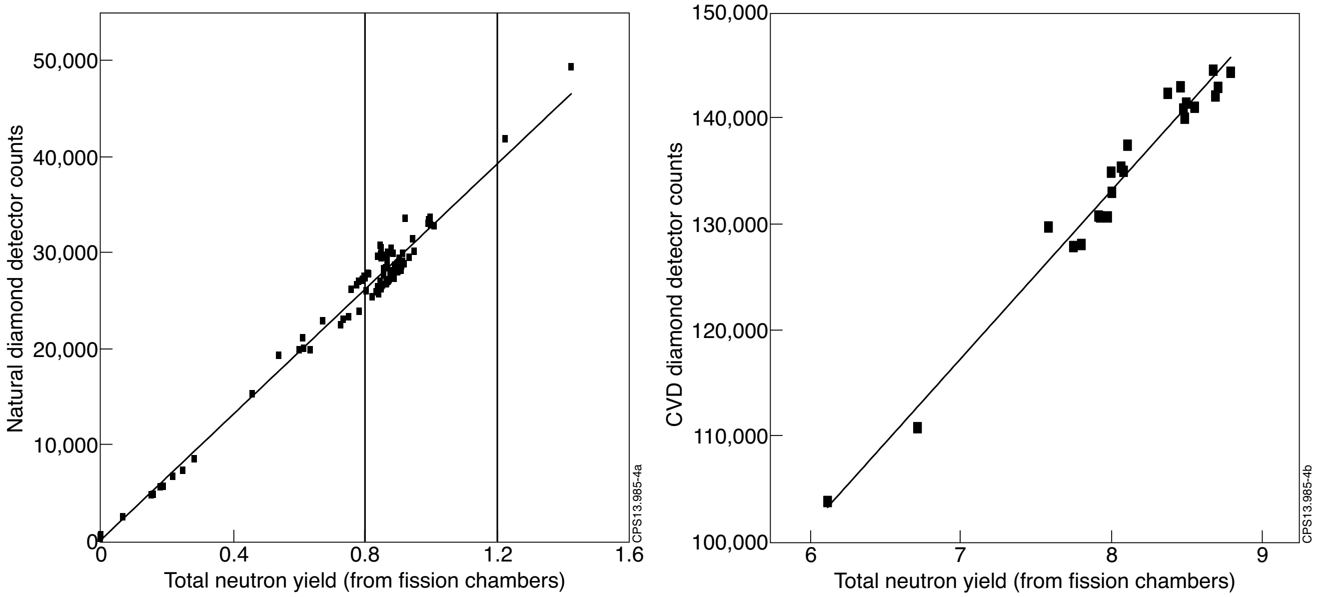

Figure 4: Counts of natural (left) and CVD diamond detectors and total neutron yield calculated from fission chambers JET diagnostic in different JET pulses.