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Development of an high resolution neutron spectroscopy system using a diamond detector and a remote digital acquisition methodology

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HIGHLIGHTS

- We studied the response of a diamond detector connected, to a prototype preamplifier developed by our group.
- The response was studied for quasi mono-energetic neutron energies between 5 and 20.5 MeV.
- About 50 m of coaxial cable was interposed between the detector and the preamplifier.
- This technique was developed in order to have the electronics located far from the high radiation zone.
- Such approach could be interesting for hash environment like the Radial Neutron Camera of ITER.

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ABSTRACT

The need of performing high resolution fast neutron spectroscopy in a very harsh environment like that of the Radial Neutron Camera (RNC) of ITER, requires to develop new detectors and methodologies. Diamond detectors have been proved to be excellent candidates but the electronics needs a substantial improvement. Because of the high radiation level and the temperatures expected near the detector positions in the RNC, the electronics must be placed several meters away. A novel Fast Charge Amplifier (FCA) was developed that, connected to a diamond detector using several tens of meters of low capacitance coaxial cable, is able to produce fast output signals suitable to be processed by digital electronics. These fast output signals allow to operate at high count rates avoiding pile-up problems. This novel amplifier connected to a digitizer is here tested in the neutron energy range from 5 to 20.5 MeV using the mono-energetic neutrons produced by the Van de Graaff (VdG) accelerator of the EC-JRC-IRMM and by the PTB cyclotron. From the measurements the experimental response functions of the diamond detector at different neutron energies were obtained. The shape of the response functions have been compared with that predicted with a routine which was implemented for the Monte Carlo code MCNPX with the scope to validate the calculations versus the experimental data. The goal is to develop a tool which allows to calculate the diamond detector response functions also in term of absolute efficiency. This methodology along with the ability to measure at high reaction rates and the insensitivity to radiation damage launches the system described in this paper as a promising method for neutron spectrometry in the RNC of ITER.

1. Introduction

In a previous paper it was reported on the performances of a single crystal diamond detector (SCD) exposed to the mono-energetic neutron field produced by the Van de Graaff (VdG) accelerator of the EC-JRC-IRMM laboratory [1]. In this work Pulse Height Spectra (PHS) were collected using a conventional electronics system, i.e. a charge sensitive preamplifier located close to the detector, a spectroscopic shaping amplifier and a PC based multi-channel acquisition system (MCA). The response functions of the diamond detector were obtained for neutron energies range 5–20.5 MeV, demonstrating an excellent linearity between the charged particles

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deposited energy resulting from the $^{12}C(n,\alpha)^{9}Be$ reaction and the energy of the impinging neutrons which produce the observed reaction. An upper limit of 56 keV FWHM of energy spread was also measured for the peak produced by the above reaction. Thus the potential application of diamond detectors as high resolution neutron spectrometer in a wide energy range was pushed forward. One of the most interesting field of use of these devices is the thermonuclear controlled fusion research where there is the need of performing high resolution neutron spectroscopy. But in an experimental fusion reactor like ITER a very harsh environment will be present (high level of radiation, high temperature, magnetic field) and thus the electronics, if placed close to the detectors, will suffer of radiation damage and maybe impossibility to work. For this reason a new type of amplifier was developed. This amplifier can be connected to a diamond detector using several tens of meters of a low capacitance coaxial cable and it is able to produce output signals which are fast (few tens of ns) but are suitable to be processed by commercial fast digitizers in order to obtain the PHS produced by the diamond detectors under neutron irradiation. Such technique was already first tested on a couple of diamond detectors which are operating at JET tokamak [2]. At JET it was also demonstrated that this approach can be used for the time dependent neutron emission from a tokamak at high count rare.

The experimental results are presented in this work together with a comparison with computer simulations of the PHS, obtained with an “ad hoc” routine implemented in the code MCNPX, the general-purpose Monte Carlo radiation transport code for modeling the interaction of radiation with everything [3]. The routine is able to calculate the PHS that is built up by the neutron elastic and inelastic scattering and the (n,a), (n,p), (n,d) reaction channels which occur in a diamond detector [4].

2. Experimental set-up

The measurements were carried out in two different accelerator facilities, the Van de Graaff (VdG) accelerator of the EC-JRC-IRMM in Geel, Belgium and the cyclotron at PTB in Braunschweig, Germany. These facilities were operated in a different way. At the VdG a continuous deuteron beam of 4 MeV energy was fired on a thin Ti-T target (0.493 mg/cm^2). The neutrons were produced through the $d + T \rightarrow {}^{4}He + n$ reaction and the neutron energy was varied changing the angle respect to the beam direction where the diamond detector was positioned, keeping fixed the distance of the detector from the target center (7.5 cm). At the cyclotron a cyclic pulsed deuteron beam impinging on a deuterium gas target (pressure 1.8 bars, length 30 mm) was used. The neutrons were produced through the $d + D \rightarrow {}^{3}He + n$ reaction and the neutron energy was varied changing the beam energy. The distance of the diamond detector to the target was fixed at 1.6 meters. For deuteron beam energies above ~5 MeV, the deuteron breakup leads to a low-energy continuum in addition to the monoenergetic neutron peak. The separation of these neutrons from the d + D reaction neutrons requires the use of time-of-flight techniques. Due to these different operation conditions the PHS acquisition methodology was different at the two accelerators while the diamond detector used was the same, a commercial one, produced by Diamond Detector Ltd (UK). It consists of a high purity single crystal plate packaged in aluminum alloy 6061-T6 detector box with 2 SMA female connectors in a dual ended isolated configuration. The diamond plate comes from the same batch of that used in [1]. The plate is 0.5 mm thick, with two metallic electrical contacts top and bottom. The active area of the detector is 172 mm^2. The detector was connected to our novel amplifier using 50 m of low capacitance 50 Ω coaxial cable. This unit is a Fast Charge Amplifier (FCA) of a conceptually new type developed in collaboration with the Department of Physics, of Rome “Tor Vergata” University and Istituto di Fisica Nucleare (INFN), “Tor Vergata” section. A very high performance two stage front-end was developed with extremely high lock-in capability for the fast signals such as the ones produced by the diamond detectors. More details concerning this FCA can be found in ref. [2]. The output signal of the FCA was directly connected to one input of a CAEN digitizer DT5751 operated at 2 GS/s. This digitizer has four input channels which operate in a synchronous way. The digitizer transfers the collected pulse time traces to the hard disk of a PC using USB or optical link. Due to the small detector active volume and the limited neutron source strength of both accelerators the data collecting rate was in the range 10–200 Hz thus USB data transfer method was sufficient and it was used. Proper software was developed in order to have a real time display of the PHS while all the collected pulse traces were stored on a PC hard disk. At the VdG the digital acquisition was started just prior the start of the beam and thus of the neutron production. The acquisition was left running till enough counts, from the statistic point of view, were recoded in the PHS. Only one input channel of DT5751 digitizer was used for acquiring the signals. At PTB cyclotron because of the cyclic pulsed beam operation a trigger signal from the cyclotron correlated with the beam pulse was used as input of the first channel of the digitizer while a second channel acquire the amplifier output. The first channel triggers the start of the digitizer acquisition while the second channel records the detector pulse time trace. The time difference between the trigger and the amplifier output signals correspond to the neutron Time of Flight (TOF) to cross the 1.6 m distance of the target to the detector. All the time traces of both digitizer inputs were stored on the PC hard disk because a subsequent analysis has permitted to discriminate the monoenergetic source neutron from the gamma signal and from the continuous neutron produced by deuteron break-up. In Fig. 1 an example of TOF spectrum is reported.

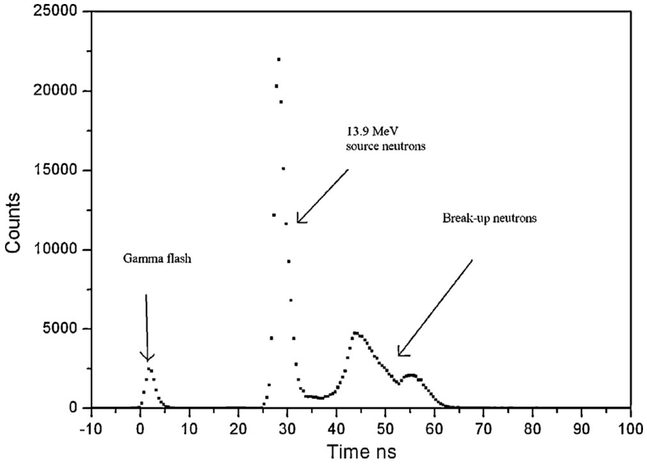

Fig. 1. Time of Flight spectrum recorded at PTB cyclotron during the 13.9 MeV run.

With both the information of the PHS and the TOF it has been possible to clean the PHS from pulses produced by break-up neutron in the way described in the next paragraph.

3. Experimental results

The first experimental campaign was carried out in June 2011 at IRMM using the VdG accelerator. An example of PHS recoded with the electronic chain configuration described above is shown in Fig. 2. The spectra reveal the typical shape produced by neutrons interacting with diamond [5]. The peak due to the $^{12}C(n,\alpha)^{9}Be$ reaction is clearly visible at the high energy end of the spectra. An edge and continuum due to the $^{12}C(n, n'3\alpha)$ reaction can be observed together with the continuum created by the carbon recoil after