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COMPACT THERMAL NEUTRON SENSORS FOR MODERATOR-BASED NEUTRON SPECTROMETERS

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In the framework of the NESCOFI@BTF project of the Italian Institute of Nuclear Physics, different types of active thermal neutron sensors were studied by coupling semiconductor devices with a suitable radiator. The objective was to develop a detector of small dimensions with a proper sensitivity to use at different positions in a novel moderating assembly for neutron spectrometry. This work discusses the experimental activity carried out in the framework of the ERINDA program (PAC 3/9 2012) to characterise the performance of a thermal neutron pulse detector based on ^{6}Li.

INTRODUCTION

The NESCOFI@BTF project of the Italian Institute of Nuclear Physics aims at developing new neutron spectrometers able to measure in real time and over a wide energy range (eV–GeV) the spectral fluence distribution of neutrons in complex fields[1]. Two different prototypes characterised by a different angular response, i.e. directional and isotropic, were designed and fabricated. Both of these detectors exploit the use of devices sensitive to thermal neutrons located at proper positions within a novel moderating assembly.

Different types of thermal neutron pulse detector (TNPD) were studied by coupling semiconductor devices with different radiators. The objective was to design an innovative detector of small dimensions with a proper sensitivity and photon rejection to use at different positions within the moderating assembly. To test and validate experimentally the performances of the sensors at study in terms of sensitivity, both a TNPD and a reference LiI(Eu) scintillator were used as central elements of an extended range Bonner sphere system (ERBSS)[2] and their response to high-energy neutron fields was directly compared. The experimental campaign was carried out at TSL in the framework of the ERINDA programme (PAC 3/9 2012).

It should be underlined that the characterisation of the TNPD performances in terms of photon rejection is under study and will be published in a future work.

IRRADIATION FACILITY AND EXPERIMENTAL SET-UP

The measurement campaign was carried out at The Svedberg Laboratory (TSL), Uppsala, Sweden, with the aim of testing the performance of the TNPD with respect to a reference, well-established technique. For this purpose, neutron fields generated by protons impinging on a 5-mm water-cooled beryllium target bare (‘total field’ in the following) and attenuated by a 10-cm polyethylene layer (‘attenuated field’ in the following) were exploited. Protons accelerated at a nominal energy of ~38 MeV were collimated with horizontal and vertical graphite slits with an aperture of 10×10 mm. At 60 cm from the slits an extra-collimator block (ECB) of graphite is placed in order to limit the broadening of the beam. The ECB had a circular aperture of 15 mm in diameter (see Figure 1).

The proton beam at the user area was monitored by a telescope (proton telescope in the following) consisting of two scintillators. The proton telescope detected protons scattered by a stainless steel foil at the end of the vacuum pipe. The response of the proton telescope count rate was demonstrated to be proportional to the proton beam current measured on a Faraday cup.

The measurements were performed by irradiating the different spheres of the ERBSS at ~180 cm from the target. A prototype TNPD and a reference ^{6}LiI(Eu) scintillator were used sequentially as central elements of the ERBSS. The TNPD is based on a low-cost commercial solid-state device that is sensitised to thermal neutrons through a customised physical–chemical treatment. Its active area is 1 cm^2 and its overall dimensions are ~1.5×1×0.4 cm (see Figure 2). The reference thermal neutron detector consists of a well-established and well-characterised 4×4 mm ^{6}LiI(Eu) cylindrical scintillator.

The signal generated by the two detectors at comparison were amplified and shaped through a standard electronic chain and were collected in streaming mode by a commercial digitiser

Figure 1. Picture of the irradiation facility at TSL. Thirty-eight mega-electronvolt protons were accelerated on a 5-mm water-cooled beryllium target. The neutron fields produced by the target bare and attenuated by a 10-cm polyethylene layer (see the black parallelepiped) irradiated the different spheres of the ERBSS (on the right side of the figure).

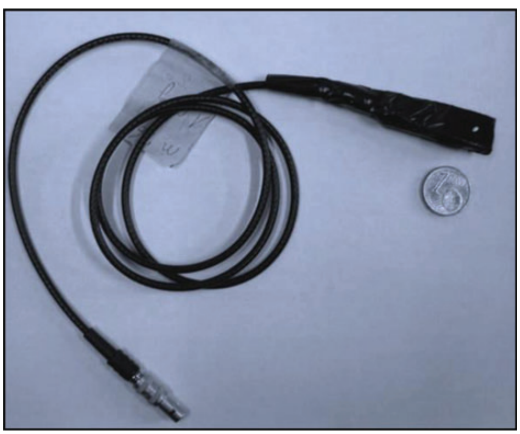

Figure 2. The thermal neutron pulse detector (TNPD).

(PICOSCOPE 4227, 12 bit, up to 125 MS/s) controlled via laptop through a simple USB connection and by a custom LabView application.

The experimental results were normalised to counts given by the monitor proton telescope.

RESULTS AND DISCUSSION

Total neutron field

The first set of measurements was performed by irradiating the system with the total neutron field. The results, expressed in terms of counts per monitor units, obtained through the ERBSS based on the

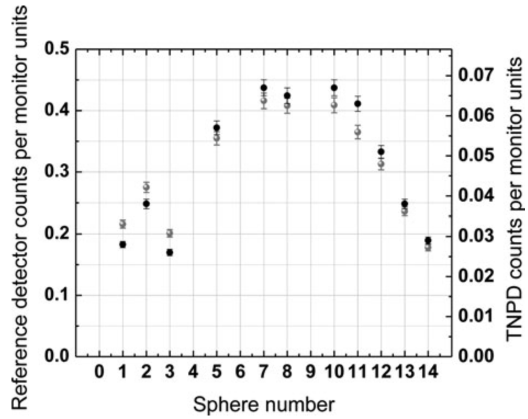

Figure 3. Counts per monitor unit obtained by irradiating with the total neutron field the ERBSS equipped with the reference detector LiI(Eu) (grey points) and with the TNPD (black points).

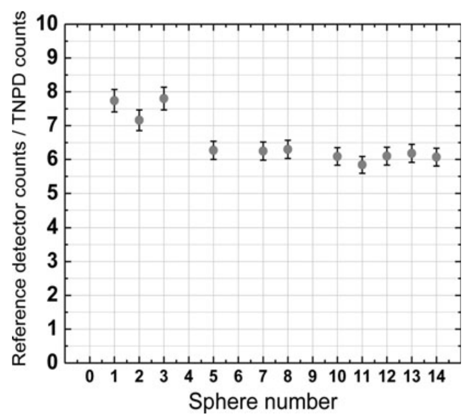

Figure 4. Ratio of the response of the reference ^{6}LiI(Eu) scintillator and the one of the TNPD at each sphere type. The value results to be 6.65 ± 0.51.

reference LiI(Eu) scintillator and on the TNPD are shown in Figure 3.

To test the performance of the TNPD, the ratio of the response of the reference ^{6}LiI(Eu) scintillator and the one of the TNPD at each sphere type was calculated. As can be observed in Figure 4 the value of the ratio is fairly constant and equals to 6.65 ± 0.51.

The spectral fluence distribution of the impinging neutron field was calculated by unfolding results shown in Figure 3 by means of the FRUIT-SGM code[3,4].

Results are shown in Figure 5, where the spectra obtained through the reference detector (grey line) and by the TNPD (black line) are directly compared. The distributions agree very well for fast and high-energy neutrons, while a difference of about a factor of 2 is evident at low energies. This discrepancy

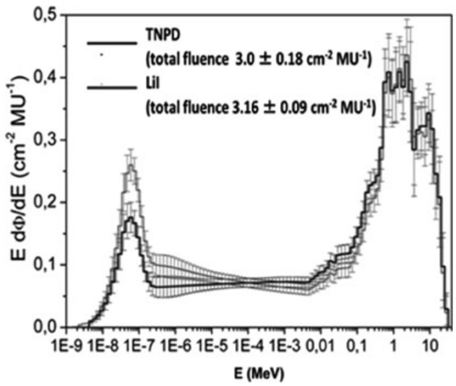

Figure 5. Total neutron field: spectral neutron fluence distribution per monitor units derived through the reference detector (grey line) and by the TNPD (black line). The total neutron fluence per monitor unit is also indicated.

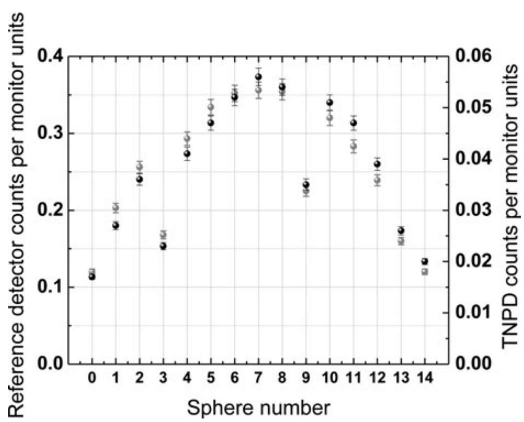

Figure 6. Counts per monitor unit obtained by irradiating with the attenuated neutron field the ERBSS equipped with the reference detector LiI(Eu) (grey points) and with the TNPD (black points).

is related to the lower response of TNPD for spheres of small dimensions (see Figures 3 and 4).

Attenuated neutron field

The second set of measurements was performed by irradiating the system with the attenuated neutron field. The results, expressed in terms of counts per monitor units, obtained through the ERBSS based on the reference LiI(Eu) scintillator and with the one based on the TNPD are shown in Figure 6.

The ratio of the response of the reference ^{6}LiI(Eu) scintillator and the one of the TNPD at each sphere type was calculated. Figure 7 shows that the value of the ratio is pretty constant, but tend to decrease

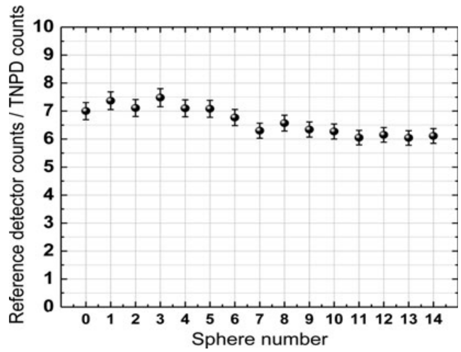

Figure 7. Ratio of the response of the reference ^{6}LiI(Eu) scintillator and the one of the TNPD at each sphere type. The value results to be 6.53 ± 0.70.

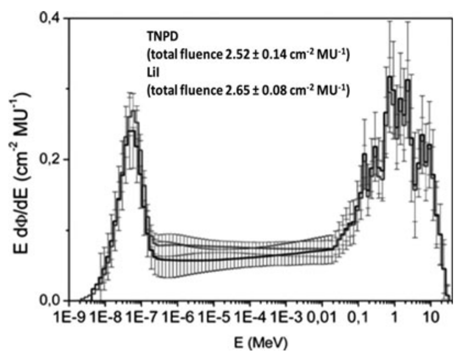

Figure 8. Moderated neutron field: spectral neutron fluence distribution per monitor units derived through the reference detector (grey line) and by the TNPD (black line). The total neutron fluence per monitor unit is also indicated.

slightly with the increase of the sphere dimension. The mean value of the ratio is 6.53 ± 0.70.

The unfolded spectral fluence distributions of the impinging neutrons obtained through the reference detector (grey line) and by the TNPD (black line) are directly compared in Figure 8.

In this case, the spectrum obtained with the TNPD shows a good agreement with that obtained with the reference detector over the entire energy range. The underestimation of the thermal component is lower than that observed with the total field (Figure 5). Monte Carlo simulations are in progress to investigate this experimental evidence.

CONCLUSIONS

A new thermal neutron detector called TNPD was developed and tested with the primary purpose of using it in multidetector single-moderator spectrometric assemblies within the NESCOFI@BTF project. Its main advantages are low cost, simplified readout, small size, sensitivity, linearity and fabrication reproducibility.

Its performance in terms of thermal neutron response compared with a well-established reference LiI(Eu) scintillator are shown in this work.

Although further experiments are needed to complete the device characterisation, especially concerning the response isotropy and the minimum detectable flux, the present results qualifies the TNPD as a promising device for the NESCOFI@BTF project as well as for a number of applications in neutron measurements.

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