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A NEW ACTIVE THERMAL NEUTRON DETECTOR

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This communication presents the main results about the design and in-house fabrication of a new solid-state neutron detector, which produces a DC output signal proportional to the thermal neutron fluence rate. The detector has been developed within the framework of the 3-y project NESCOFI@BTF of INFN (CSN V). Due to its sensitivity, photon rejection, low cost and minimum size, this device is suited to be used in moderator-based spectrometers.

INTRODUCTION

The development of low-cost, minimum-size, active thermal neutron detectors is one of the main tasks of the NESCOFI@BTF project of INFN. These detectors are needed to produce the active, final versions of the newly developed SP^2 (SPherical SPectrometer) and CYSP (CYlindrical SPectrometer)[(1)]. Whilst the CYSP only requires seven thermal neutron detectors allocated along its cylindrical axis, the spherical device SP^2 will embed 31 of them, symmetrically positioned along the 3 orthogonal axes of a 25-cm diameter sphere. Thus, miniaturisation and cost are crucial elements in the choice of the thermal neutron detector. In addition, the detectors have to be as photon insensitive as possible and their response should be linear over several orders of magnitudes in terms of thermal neutron fluence rate. The final decision was to modify commercially available, low-cost, solid-state devices in order to make them sensitive to thermal neutrons.

Two detector types were developed, namely thermal neutron pulse detector (TNPD) and thermal neutron rate detector (TNRD). The TNPD, through dedicated acquisition electronics, produces a pulse-height distribution on which basis the neutron-to-photon discrimination is performed and the net thermal neutron signal is extracted. Differently, the TNRD produces a DC voltage level that is proportional to the thermal neutron fluence rate. Adequate photon rejection is achieved through an intrinsic compensation effect (constructive details on the TNRD are not given here due to pending patents).

Compared with the TNPD, the TNRD shows simplified readout and reduced cost. In contrast, its sensitivity is lower than that of the TNPD[(2)]. The performance of the TNRD in terms of sensitivity, linearity, isotropic response and photon rejection is described in this paper.

THE DETECTOR AND ACQUISITION SYSTEM

The detector is based on a low-cost commercial solid-state device made sensitive to thermal neutrons through a customised physical–chemical treatment. Its active area is 1 cm^2 and its overall dimensions are $\sim$1.5 cm$\times$1 cm$\times$0.4 cm. Its output is a DC voltage, which is proportional to the thermal neutron fluence rate (for this reason the device is called 'rate detector'). This signal is amplified in a low-voltage electronics module especially developed by the project team. The amplified output is sent to a programmable ADC (NI USB-6218 BNC, 16 bit, up to 250 kS/s) controlled by a PC through a LabView application. The detector and its typical time-dependent output are shown in Figures 1 and 2.

CALIBRATION PROCEDURE

TNRDs are individually calibrated in the moderating assembly as shown in Figure 3. This consists of a high-density polyethylene cylinder with a diameter and height equal to 25 cm associated with a calibrated ^{241}Am–Be source (2.09E+6 s^{-1}). The photons from the source are attenuated by a 6-mm thick lead sheet. A cavity (4 cm diameter$\times$10 cm depth) along the cylindrical axis of the assembly allows exposing the detector to the thermalised neutron field. The neutron field in the point of test at the centre of the cavity was simulated with MCNPX 2.6[(3)]. Table 1 resumes the results of the simulation. The neutron spectrum is reported in Figure 4. It should be noted that the epithermal and fast components of the spectrum

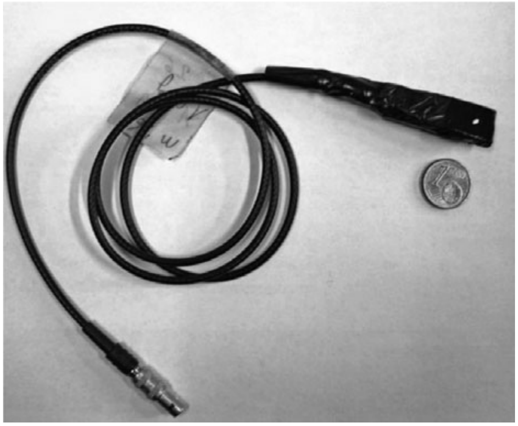

Figure 1. The thermal neutron rate detector (TNRD).

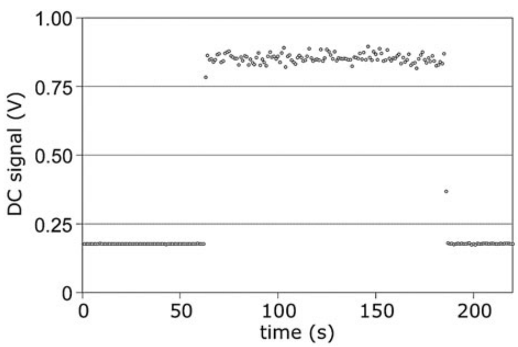

Figure 2. Time-dependent output of the TNRD when exposed in an ex-core thermal neutron beam from the ENEA Casaccia TRIGA reactor at power 46 kW. The step is produced when opening and closing the neutron shutter. The conventional fluence rate is ∼E+4 cm^{-2} s^{-1}. The constant voltage level measured in the 'shutter closed' configuration corresponds to an offset in the operational amplifier-based circuit used to treat the detector signal.

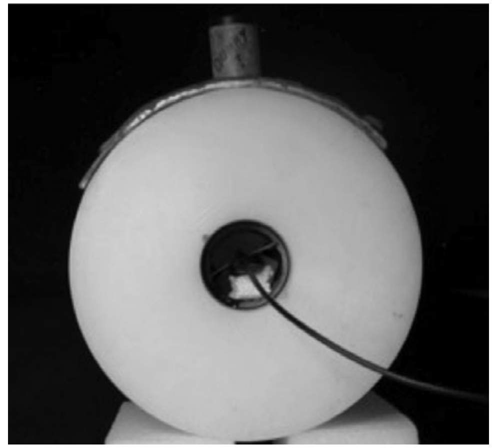

Figure 3. The moderating cylinder used to test and calibrate the TNRDs. The Am–Be source is located on top of the cylinder and is shielded with a 6-mm lead sheet.

Table 1. Results of the MCNPX simulations for the moderating cylinder.

Conventional thermal fluence rate (cm^{-2} s^{-1})	1270 ± 40
True thermal fluence rate (cm^{-2} s^{-1})	1440 ± 40
Total neutron fluence rate (cm^{-2} s^{-1})	3300 ± 100
'Non-thermal' contribution to detector reading	1.6 %
Photon kerma rate (μGy·h^{-1})	44 ± 2

Thermal neutron fluence rate is given in terms of the ISO 8529-1[(4)] quantities. The photon kerma rate was measured with TLD-700 passive detectors.

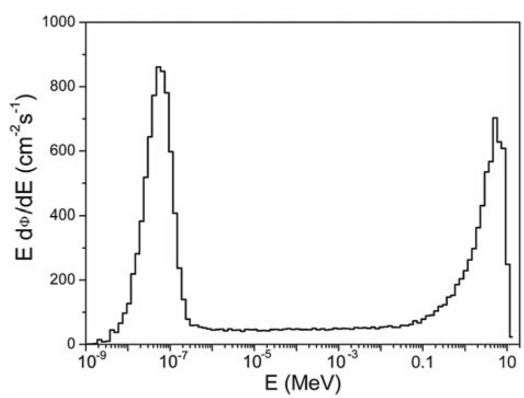

Figure 4. The neutron spectrum at the point of test located at the centre of the moderating cylinder as shown in Figure 3.

represent approximately half of the neutron fluence, but their contribution to the TNRD reading is only 1.6 % (estimated with MCNPX). The photon kerma rate at the point of test, almost completely due to the 2.2-MeV photons from neutron capture reactions in hydrogen, was measured with TLD-700 passive detectors previously calibrated in a reference ^{137}Cs field.

The direction distribution of the thermal fluence in the calibration cavity of the moderating cylinder was determined through MCNPX simulations and represented in Figure 5. Here the quantity $\Delta\Phi_{th}$, defined as the conventional thermal fluence included in the cosine interval from μ to $\mu+\Delta\mu$, is reported as a function of $\mu = \cos(\theta)$. θ is the angle formed by the particle direction and the axis from the point of test to the neutron source. It can be seen that the field is not isotropic, with a factor of ∼2 from $\mu = -1$ to $\mu = 0$.

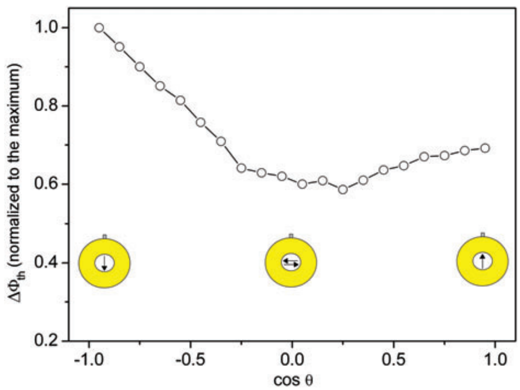

Figure 5. Direction distribution of the thermal fluence in the calibration cavity of the moderating cylinder determined through MCNPX. Values are normalised to the maximum, corresponding to the top-down direction. Arrows in the sketch indicate particle directions at the point of test.

THE RESPONSE OF THE TNRD

The reading from the TNRD, V_{net} (volts) is obtained from the following equation.

$$V_{net} = \bar{V} - \frac{1}{2}(\bar{V}_{left} - \bar{V}_{right}) \qquad (1)$$

where $\bar{V}$ is the time-averaged voltage output during the neutron shot. $\bar{V}_{left}$ and $\bar{V}_{right}$ are the time-averaged voltages before and after the neutron shot, representing the background.

After manufacturing, every TNRD is exposed at the point of test of the moderating cylinder to measure its response in terms of conventional thermal fluence rate. The specimen used to produce the data reported in this work has response (96 ± 3) cm^{-2} s^{-1} mV^{-1}. To estimate the reproducibility of the manufacturing process, the responses of 10 TNRDs with nominally identical fabrication characteristics were compared, and the variability was found to be ± 5 % (1 s.d.).

An experimental campaign at the ENEA Casaccia TRIGA reactor allowed evaluating the response linearity of the TNRD in the range from 7.6E+2 to 2.6E+5 cm^{-2} s^{-1} (corresponding to reactor power from 0.5 to 200 kW). The results are shown in Table 2. The stability of the neutron yield from the reactor, evaluated from the fixed monitor instruments (the so-called ‘linear amplifiers’) ranged from ± 1 to ± 3 %.

Uncertainties on the conventional thermal fluence rate measured with the TNRD are the quadratic combination of two contributions, respectively, coming from the TNRD calibration in the moderating cylinder (± 3 %) and from the reading statistics in the reactor field. The latter contribution decreases as the reactor power increases. Its value is ± 6 % at 500 W

Table 2. Conventional thermal fluence rate measured with the TNRD as a function of the reactor power.

Reactor power (W)	Conventional thermal fluence rate from TNRD (cm^{-2} s^{-1})	Fluence rate per unit power (cm^{-2} s^{-1} W^{-1})
(5.05 ± 0.10)E+2	(7.6 ± 0.5)E+2	1.51 ± 0.10
(4.93 ± 0.05)E+3	(6.74 ± 0.24)E+3	1.37 ± 0.05
(4.62 ± 0.05)E+4	(6.40 ± 0.23)E+4	1.38 ± 0.05
(1.02 ± 0.03)E+5	(1.44 ± 0.05)E+5	1.41 ± 0.06
(1.49 ± 0.03)E+5	(2.03 ± 0.07)E+5	1.36 ± 0.05
(2.04 ± 0.07)E+5	(2.63 ± 0.09)E+5	1.29 ± 0.06

The constancy of the fluence rate per unit power ratio proves the linearity of the device.

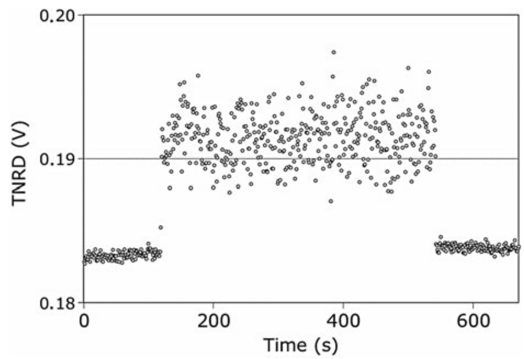

Figure 6. Time-dependent output of the TNRD when exposed in an ex-core thermal neutron beam from the ENEA Casaccia TRIGA reactor at power 0.5 kW. The step is produced when opening and closing the neutron shutter.

and lowers to less than ± 1 % at 5 kW, as it can be seen by comparing the signal fluctuations in Figure 2 (obtained at 46 kW) with those of Figure 6 (0.5 kW). The linearity of the TNRD response can be deduced from Table 2. The response to photon radiation, measured in a reference ^{137}Cs field, is (0.51 ± 0.02) mGy h^{-1} mV^{-1}.

The isotropy of the TNRD response was tested by rotating the detector in the calibration cylinder. The measured values are constant within ± 3 %, thus indicating a good enough isotropic response. Further experiments, to be performed in a very stable radionuclide-based thermal field, are planned to measure the minimum detectable thermal fluence rate, which is expected to be < 100 cm^{-2} s^{-1}.

CONCLUSIONS

A new thermal neutron detector called TNRD 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, fabrication reproducibility and good photon rejection.

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

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