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Performance of ^{3}He readout system dedicated to the powder neutron diffractometer for materials study at CENM

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Abstract. Developments in neutron detection technology during the recent past years have experienced an emphasis in their application in various fields. The performance test of one linear position sensitive ^{3}He detector coupled with a position decoder and multi-channel analyzer (MCA) was recorded. This system is used as the neutron powder diffractometer of CENM-Maamora. The wall effect and saturation of gas multiplication have been studied.

1. INTRODUCTION

Position sensitive ^{3}He proportional counters have been used in many fields, for example, neutron diffraction experiments.

The Morocco Reactor Mark II is a kind of inherently safe training, research and isotope-production nuclear research reactor that can promote nuclear physics, material science and particles physics. Among the 4 neutron beam ports of the reactor, one is dedicated to material structural studies using neutron powder diffraction.

2. DETECTOR DESIGN

2.1. Detection

Thermal neutrons can be detected by capture in ^{3}He gas according to the nuclear reaction [1]:

$$n + {}^3\text{He} \rightarrow {}^3\text{H} + {}^1\text{H} + 764\,\text{keV}.$$

The problem of achieving the highest possible detector efficiency was one of the first to be solved during detector construction. From this point of view, ^{3}He is very convenient gas for use because of its very large capture cross-section for thermal neutrons (5300 barns for 0.025 eV energy). The use of pure Helium-3 gives poor spatial resolution. The stopping gas is generally a heavy gas which does not detract from the ionization effect in the Helium-3. Our detector is filled with a ^{3}He + CF_4 mixtures, and has an active thickness of about 2.9 cm.

2.2. PSD Detector dimensions

The detector dimensions are as follow (see Figure 1):

- Active length: 600 mm
- Detection efficiency 65% for 2 Å neutrons
- Counting rate capability: 10^4 neutrons/s
- Body material: Aluminium 6061
- Window material: 2.5 mm thick Aluminium 6061
- Counting gas: ^{3}He-CF_4 at 400 KPa absolute pressure.

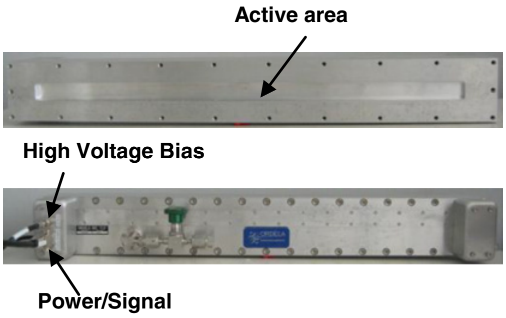

Figure 1. ORDELA Model 1600N (front and rear view).

2.3. Charge division encoding position detector

Position encoding is performed by charge division measurement; each end of the resistive line is linked to a charge amplifier. As described on Figure 2, the charges Q_A and Q_B are measured and converted to voltage through a charge amplifier. The neutron event X-position is obtained after a summation and a division:

$$X = V_A/V_A + V_B$$

R: Total resistance of anode wire
L: Total length of the detector
K: Charge amplifier gain.

3. ^{3}He READOUT SYSTEM

The main part of the detection system is shown in Figure 3 and the block diagram of the acquisition chain is schematized in Figure 4. It mainly consists of:

- Standard Nuclear Instrumentation Module (NIM)
- High voltage power supply Canberra model 3106D
- Position-decoder Ordela Model AIM-204
- Multichannel analyzer Canberra Multiport II
- Genie 2000 software.

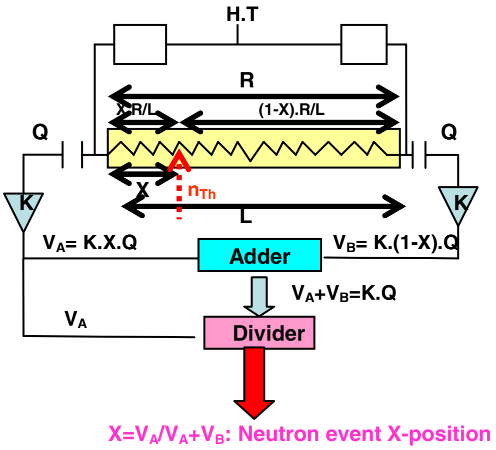

Figure 2. Principle of position encoding from charge division.

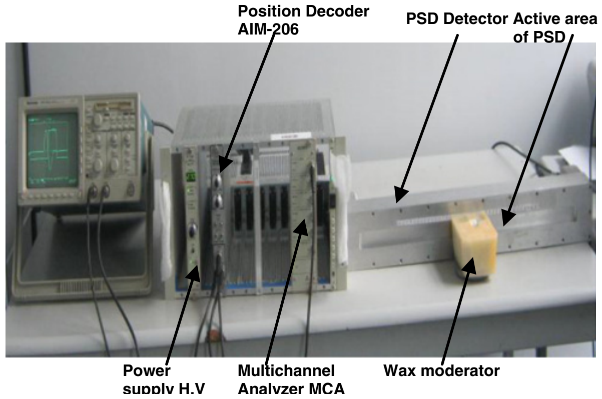

Figure 3. PSD readout system and detector.

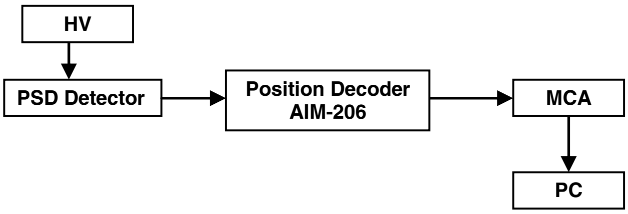

Figure 4. Block diagram of acquisition chain.

4. NEUTRON SOURCE

The ^{252}Cf source used is a cylindrical sealed source with 10 mm height and 8 mm diameter, 5 μCi (185 KBq) activity at supplied date (15th Oct 2010) from Eckert& Ziegler. The spontaneous neutron fission spectrum constructed by the Watt fission spectrum can be expressed by [2]:

$$f(E) \propto \exp\left(-\frac{E}{1.025}\right) \sinh(2.926E)^{1/2}$$

where E is the neutron energy in MeV. The corresponding energy spectrum is shown in Figure 5. The ^{252}Cf is a fast neutron source, which requires the use of moderator, such as paraffin, to slow the fast neutrons down to the thermal energy range.

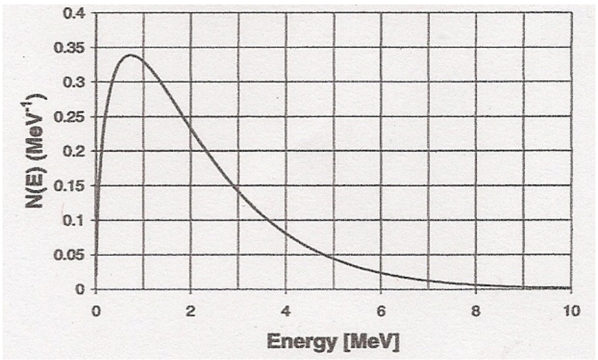

Figure 5. ^{252}Cf fission neutron spectrum approximated by Watt distribution.

5. DESIGN AND CONSTRUCTION OF MODERATOR

5.1. Experiment method

The paraffin layers were arranged by piling-up a different number of 1 cm thick paraffin blocks. The ^{3}He detector response was recorded according to the number of paraffin blocks used. A series of 600s counts was performed starting from the detector direct exposition to the neutron source i.e. with no paraffin blocks placed. The paraffin blocks slow the neutron down changing the neutron energy spectrum at the detector location.

5.2. MCNP simulation

The experimental system was simulated with MCNP (Monte Carlo N-Particle transport) code [3,4] which is a Multi-purpose Monte Carlo based Radiation Transport code to simulate the interaction of radiation with matter.

The performed simulation reproduced the experiment realized in the laboratory. Each component of the experiment was simulated. Neutron energy and the neutron flux reaching the detector were determined by running simulation with 1 MeV incident neutrons.

5.3. Results

Through the experiment performed in the laboratory it was possible to measure the ^{3}He detector counting when the blocks were inserted in front of the system. Figure 6 displays our measured results.

Figure 6 shows an increasing in the number of counting between 0 and 35 mm paraffin due to loss of fast and epithermal neutron energy when they interact with the Hydrogen atoms of the paraffin, becoming low energy neutrons and being more counted by the detector. Between 35 mm and 50 mm registered counting neither increase nor decrease remaining quite constant. From 50 mm the recorded counting decreases due to both the absorption of neutrons in the paraffin and the loss of some particles that are scattered away from the detector.

MCNP simulations retrieved results which were not attained by the experiment. These simulated data provided

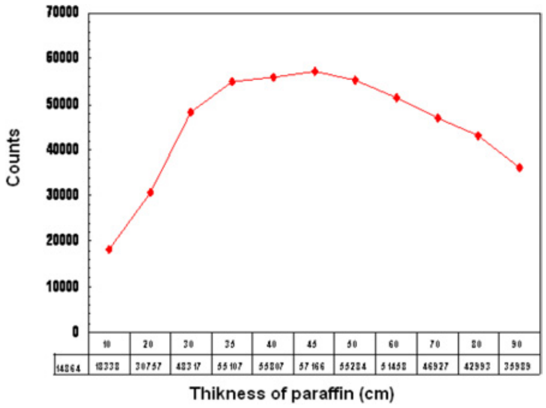

Figure 6. ^{3}He counting rate versus paraffin thickness placed between the source and the detector.

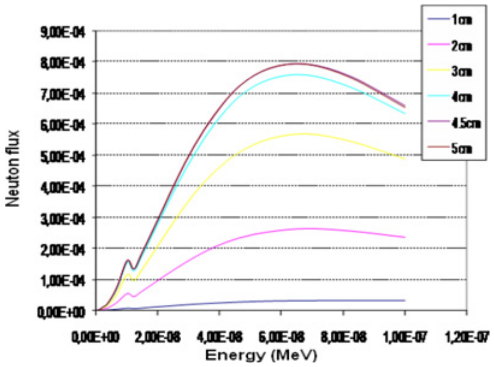

Figure 7. Simulated neutron fluxes versus neutron energy for different paraffin thicknesses.

a better insight of the carried experiment. One set of the simulated data is shown in Figure 7. This figure shows the neutron fluxes as function of the paraffin thickness placed between the source and the detector.

One can see the changes on both neutron spectra and neutron field intensity with the addition of paraffin blocks. It is possible to verify that as the number of paraffin blocks increases the fast neutron flux decreases. The highest amount of particles in the energy of thermal neutrons was obtained of about 45 mm of paraffin.

5.4. Construction of moderator

The paraffin was melted in rectangular form of dimension 13 cm long, 9 cm large and 5.5 cm height. The source was placed in the hole taped at 4.5 cm in front of the detector and at 4.5 cm height so that is in middle of active area. The hole (2 cm large) is surrounded in each side by 3 cm of graphit to eliminate neutrons that have undergone multiple scattering. So we improved relatively the peaks resolution.

6. EXPERIMENTAL RESULTS

The fundamental characteristics such as output plateau characteristics and output linearity were measured. The output plateau characteristics as a function of applied voltage applied to PSD detector are shown in Fig. 8.

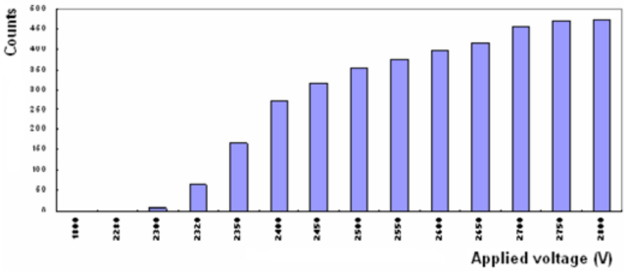

Figure 8. The output plateau characteristics as a function of applied.

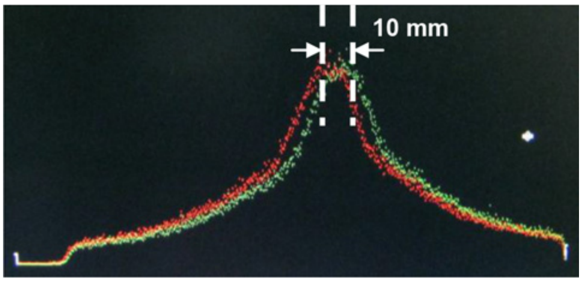

Figure 9. Illustration of the peak shifts with moderator+source movement (10 mm).

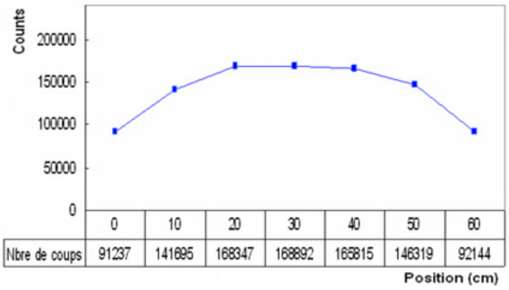

Figure 10. Intrinsic efficiency of the PSD as function of the position. 30cm corresponds to the middle of the detector.

It can be seen that the output, i.e. logic pulses after in the Position Decoder, was almost constant and independent of the applied voltage when the voltage was more than 2700 V.

Also, Fig. 9 shows the detector output(decoder output) when neutron beam was irradiated on the detector at two different positions obtained by shifting the block moderator-source by 10 mm. One can see that an intense signal was observed only in the neutron incident channel. This mean there is no coding error in the detector and decoder manufacturing.

In the other hand the detector shows a drop in efficiency close to the edges. Figure 10 demonstrates the dependence of the efficiency on the position where neutrons hit the gas. The peripheral position has a little smaller efficiency than the central parts. This can be explained by the wall effect [5].

Although there is big requirement on the uniformity, we evaluated the uniformity of neutron detection efficiency. The PSD detector was irradiated by thermal neutrons generated by a ^{252}Cf source. The results are

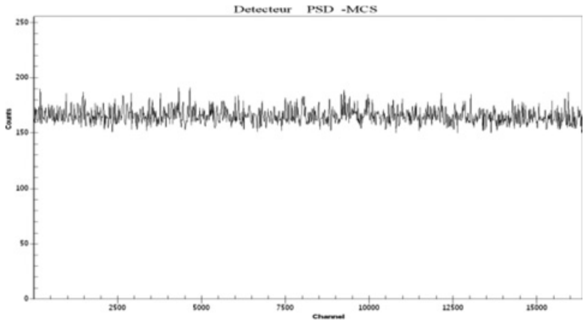

Figure 11. The uniformity of neutron detection efficiency.

shown in Figure 11. The detector had good uniformity for neutron detection efficiency between channels, with standard deviation of 6.3%.

7. CONCLUSIONS

In this paper we recorded the experimental study which was carried out on a linear position-Sensitive Detector Proportional Counter dedicated for neutron powder diffractometer of CENM. A system of PSD coupled with a position decoder and multi-channel analyzer was described. The response of the detector to a neutron emitted by ^{252}Cf source and thermalized by a paraffin moderator has been studied. Other experimental results are presented as output plateau characteristics, the efficiency of the PSD and the electronic stability. This last parameter was found excellent. Also the wall effect was observed.

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