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Development of Position Sensitive ^{3}He Proportional Counter for a Single Moderator Type Neutron Spectrometer

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A position sensitive ^{3}He proportional counter with 1 m length was developed to use for a single moderator type neutron spectrometer, which measures neutron spectrum from the depth distribution of thermal neutrons in the moderator. The counter is of the charge division type using an anode wire with resistance. The detection positions can be determined from the ratio of the pulse heights read out from both ends of the counter. The inner diameter and composition of the counting gas were optimized with a simple Monte Carlo calculation code. From the optimization the inner diameter of 25 mmϕ and the mixed gas of 130 kPa ^{3}He and 70 kPa CF_4 were adopted. A relationship between the detection position and the ratio of both pulse heights and a spatial resolution were measured using thermal neutrons. The relationship has a one-to-one correspondence. The spatial resolution was evaluated to be less than 10 mm all over the sensitive area, and the value is small enough for the spectrometer.

KEYWORDS: neutron, ^{3}He, position sensitive, proportional counter, spectrometer, spatial resolution, wall effect

I. Introduction

It is ideal for the measurement of neutron dose equivalent to use the dosemeter whose energy response is proportional to the fluence-to-dose equivalent conversion coefficients. However, such an ideal dosemeter does not exist, hence the dosemeters should be calibrated at neutron calibration fields which have similar energy spectra to those at practical workplaces.[1–3] As such fields have spectra with a very wide energy range, a spectrometer having sensitivity over wide neutron energy is desired to establish the fields. We are developing a single moderator type neutron spectrometer, which consists of a cylindrical moderator and a position sensitive thermal neutron detector embedded in the center of the moderator parallel to the long axis. In the moderator high energy neutrons penetrate further than low energy neutrons. This means the distribution of thermal neutrons in the moderator varies with the incident neutron energy. This spectrometer provides energy information of the neutrons by measuring the thermal neutron distribution in the moderator along the long axis.[4,5]

In this paper we describe the design and characteristics of a position sensitive ^{3}He proportional counter with a 1 m sensitive area developed to be used as the thermal neutron detector of the spectrometer. The counter is of the charge division type using an anode wire with resistance and the signals are read out from amplifiers placed at both ends of the wire. The charge produced by the ^{3}He(n,p)^{3}H reaction is divided with the ratio depending on the position of the reaction.[6] The detection position can be derived from the ratio of both pulses, x, defined by the following equation:

$$x = \frac{V_{\mathrm{right}}}{V_{\mathrm{left}} + V_{\mathrm{right}}} \tag{1}$$

where V_{right} and V_{left} are the pulse heights read out from the right and left side ends of the counter, respectively. The inner diameter of the counter and the composition of the counting gas were optimized by calculating pulse height distributions and intrinsic spatial resolution with a simple Monte Carlo code. The characteristics of the counter were measured using thermal neutrons from a graphite pile containing a ^{252}Cf source at the Japan Atomic Energy Research Institute (JAERI).

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II. Counter design

1. Method

In order to design the counter, a simple Monte Carlo code was developed, which could calculate pulse height distributions and intrinsic spatial resolutions. When a thermal neutron causes the ^{3}He(n,p)^{3}H reaction in the counter, a proton and a triton are produced by the reaction. They produce charges along their tracks in the counting gas region, and then the charges cause a pulse whose height is in proportion to the amount of the energy. The detection position is decided from the centroid of the charge distribution along the anode wire.[6,7] **Figure 1** shows a schematic view of the problems which should worsen the properties of the counter. The detection position varies according to the direction of the particles even when the reaction occurs at the same position. This causes dispersion of the detection position, which limits the intrinsic spatial resolution. When the reaction occurs near the counter wall and one of the produced particles strikes the wall, a part of the energy is not deposited in the counter and this reduces the pulse height of the signal, which is called wall effects.[6] The code samples the position of the reaction and the flight direction of the particles at random. The amount and the spatial distribution of the energy deposition along the track are calculated using the stopping power table by the SRIM code.[8] Then it outputs the distribution of the total deposited energies and the centroid of the energy deposition, which correspond to the pulse height distribution and the detection position in measurement, respectively.

The inner diameter of the counter, the composition and the

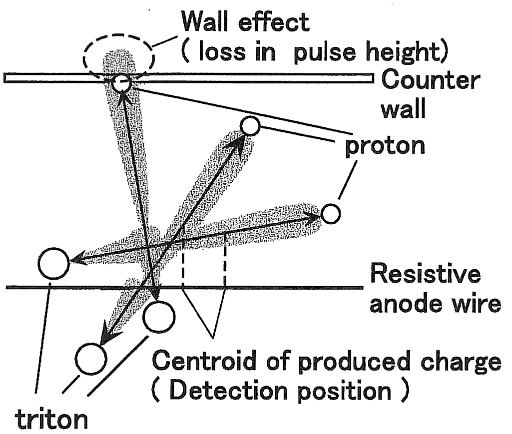

Fig. 1 Schematic view to explain wall effects and centroid of the produced charge distribution,
All reactions in figure occur at the same axial position. The gray regions mean charge production (energy deposition) and their widths mean the amount of charge production.

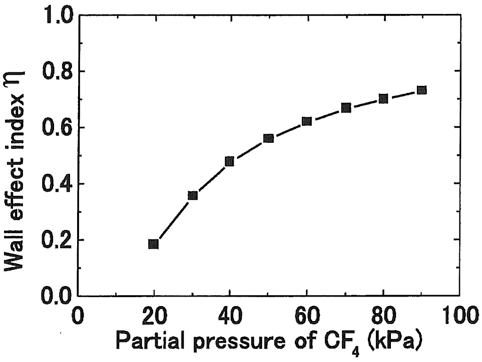

Fig. 2 Wall effect index η (defined as Eq.(2)) as a function of partial pressure of CF_4 additive,
the partial pressure of ^{3}He was 130 kPa and inner diameter was set to 25 mmϕ.

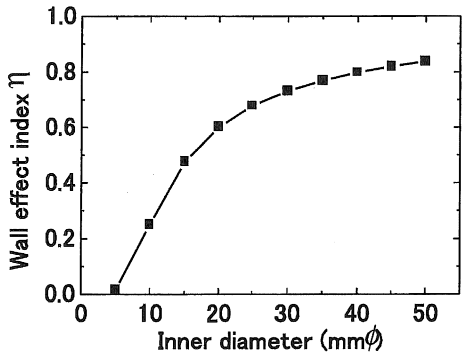

Fig. 3 Wall effect index η (defined as Eq.(2)) as a function of inner diameter of the counter,
the counting gas was a mixture of ^{3}He (130 kPa) and CF_4 (70 kPa).

pressure of the counting gas were optimized from the viewpoint of intrinsic spatial resolution and wall effects. The latter are important because they decrease the pulse height and worsen the signal-to-noise ratio. The wall effects were evaluated with a wall effect index η defined as the following equation:

$$\eta = \frac{N_{peak}}{N_{total}} \quad (2)$$

where N_{peak} means the counts within the region of full-energy peak, which is formed when all energy of produced charged particle is deposited in the counter, and N_{total} means the total counts including the continuum region due to the wall effects.

2. Intrinsic spatial resolution

The intrinsic spatial resolution was calculated for the various diameters and counting gases. The inner diameters were varied from 5 to 50 mmϕ. The counting gas of ^{3}He or BF_3 was selected, either of which is commonly used in proportional counters for thermal neutrons.[6] The CF_4 additives were mixed in the ^{3}He gas in order to improve the spatial resolution and mitigate the wall effects by reducing the range of protons and tritons with aditives having stopping power higher than ^{3}He.[7,9] The calculations showed that the intrinsic spatial resolution was submillimeter for counter diameters and gases considered in the calculation. The intrinsic spatial resolution is small enough for the aimed spectrometer, because the required spatial resolution for the spectrometer is estimated to be less than 10 mm from the spectrometer design.

3. Composition and pressure of counting gas

We considered BF_3 (100 kPa) and a mixture of ^{3}He (130 kPa) and CF_4 (70 kPa) as the counting gas. When ^{3}He is used in the counting gas, the partial pressure of ^{3}He needs about 130 kPa in order to satisfy the sensitivity required from the spectrometer design. In the case of BF_3, the pressure needs to be about 1.4 times as high as that for ^{3}He because the cross section of the ^{10}B(n,α)^{7}Li reaction for thermal neutrons is lower than that of the ^{3}He(n,p)^{3}H reaction. However it is difficult to use BF_3 gas with higher than 100 kPa as the counting gas because the gas has a chemical hazard and a possibility of causing corrosion. The resultant wall effect indexes η were almost the same for both gases. Therefore we decided to use the ^{3}He gas with the CF_4 additives as the counting gas from the viewpoint of the sensitivity and the chemical stability.

The wall effect indexes η were calculated for various partial pressures of CF_4 from 20 to 90 kPa. In the calculations the partial pressure of ^{3}He and the inner diameter were fixed to be 130 kPa and 25 mmϕ, respectively. The results are shown in **Fig.2**. The figure shows that the higher partial pressure suppresses the wall effect. However, high voltage needs to be higher with the increasing CF_4 pressure, and it becomes too high to operate the counter with conventional electronics modules. In this point of view, the partial pressure of CF_4 should be as low as possible. We decided the partial pressure to be 70 kPa, where the index η began to be saturated.

4. Inner diameter

The inner diameter of the counter was also optimized based on the wall effect index η. The relationship between the index η and the inner diameter was calculated with changing the diameter from 5 to 50 mmϕ as shown in **Fig.3**. In the calculations the counting gas was the mixture of ^{3}He (130 kPa) and CF_4 (70 kPa) as decided in the previous section. The figure shows that the larger diameter suppresses the wall effect, while the large diameter needs a large hole in the moderator of the spectrometer. Such a large hole decreases moderation efficiency and increases the streaming which means neutrons enter the counter directly. Therefore the diameter should be as small as possible. We decided the inner diameter to be 25 mmϕ where the index η began to be saturated.

III. Experimental

1. Description of counter and measurement system

A position sensitive ^{3}He proportional counter was fabricated according to the design calculation in the previous section and tested with thermal neutrons from the graphite pile. A schematic view of the experimental setup and the measurement system is shown in **Fig.4**. The resistive anode wire of the counter was a 15 μmϕ nickel–chrome wire with 5 kΩ resistance per 1 m length. Two 510 Ω resistances were put at both ends of the wire as offset resistances.

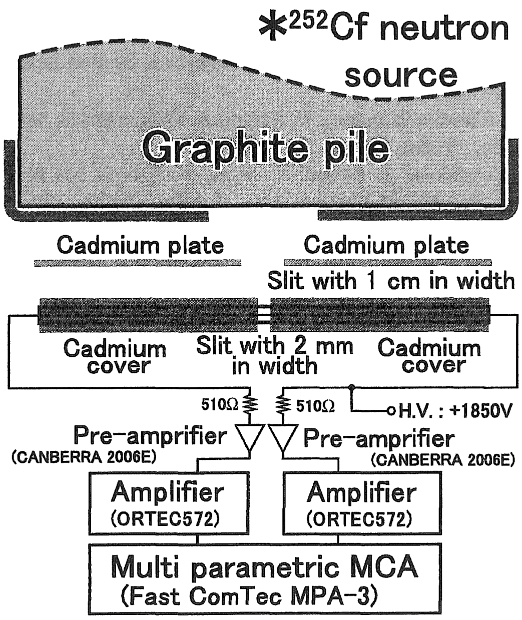

Fig. 4 Schematic view of experimental setup and measurement system

The output pulses were amplified with two sets of preamplifiers (CANBERRA 2006E) and amplifiers (ORTEC 572), and then they were acquired with a dual parametric multi channel analyzer (Fast ComTec MPA-3). The distribution of detection position was calculated using Eq.(1).

2. Measurement of pulse height distribution

In order to evaluate the wall effect of the counter, pulse height distributions were measured using thermal neutrons from the graphite pile. In this experiment, the signals were read out only from one side. The wall effect index η of the measured distribution was derived with Eq.(2).

3. Measurement of detection position distribution

A relation of the detection position to the ratio of the pulse heights read out from both ends of the counter and the spatial resolution were measured with the collimated beam of thermal neutrons from the graphite pile. In the measurement, the counter was covered with 0.5 mm^t cadmium plates that have a slit of 2 mm in width, and an additional cadmium sheet with a slit of 1 cm in width was set between the counter and the pile as shown in **Fig.4**, in order to reduce the neutrons incident on the counter with angles other than 90-deg. The relationship was obtained by changing the positions of both slits along the counter.

IV. Results and discussion

1. Pulse height distribution

From the pulse height distribution measured with thermal neutrons, the wall effect index η of 0.62 was obtained. This value was consistent with the value obtained from the calculation shown in **Fig.2**. This shows that the influence of the wall effects was suppressed as expected in the design of the counter.

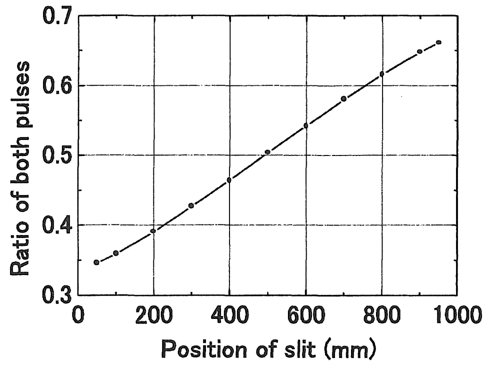

Fig. 5 Ratio of the pulse height read out from both ends of the counter as a function of the position of the cadmium slit with 2 mm in width

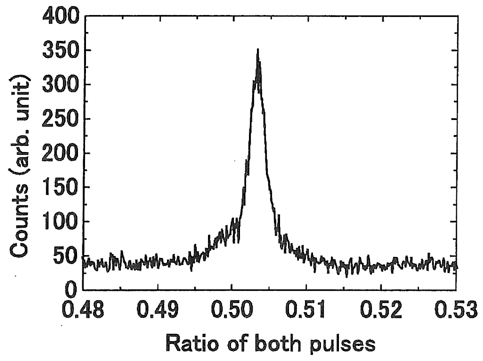

Fig. 6 Distribution of the ratio of the pulse height read out from both ends of the counter,
The cadmium slit was set at the center of the sensitive region (50 cm from one end).

2. Detection position distribution

The relationship between the position of the slit and the ratio of the pulse heights is shown in **Fig.5**. It has a one-to-one correspondence, so that the detection position can be determined from the ratio. However, a slight nonlinearity was observed especially at both ends. This should be explained as follows. The gain of the pre-amplifier depends on the frequency of input signal and it decreases with increasing of the frequency. When a thermal neutron is detected close to one end, the rise time of the pulse from the end is faster than that from another end. This means that the former pulse contains a high frequency component more than the latter. Therefore the gain of the pre-amplifier for the former becomes lower than that for the latter and it introduces the nonlinearity in particular at both ends of the counter.

Figure 6 shows the distribution of the ratio of the pulse heights read out from both ends of the counter, when the cadmium slit was set at the center of the sensitive area. The spatial resolution at this position was 8 mm in the full width at half maximum (FWHM). The results in other positions also showed that the resolution was less than 10 mm all over the sensitive region. This resolution is good enough for the aimed one of the spectrometer.

V. Conclusion

A position sensitive ^{3}He proportional counter with a 1 m sensitive area was developed to be used for the single moderator type neutron spectrometer. In designing the counter, the inner diameter of the counter and the counting gas were optimized with a simple Monte Carlo calculation code from the viewpoint of the wall effects and the intrinsic spatial resolution, which is due to the dispersion of the detection position caused by the variation of the direction of charged particles. The calculated results showed that the intrinsic spatial resolution remained within 1 mm and it was small enough compared to the required resolution of 10 mm for the aimed spectrometer. The diameter and the composition of the counting gas were optimized to suppress the wall effects. The size and the gas composition of the counter were optimized as follows, diameter 25 mmϕ, the gas composition ^{3}He (130 kPa) and CF_4 (70 kPa).

The relationship between the detection position and the ratio of the pulse heights from both ends of the counter were measured using thermal neutrons from the graphite pile at JAERI. It has a one-to-one correspondence, so that the detection position can be determined from the ratio of the pulse heights. The spatial resolution was also measured and evaluated to be less than 10 mm all over the sensitive region. The value is good enough for the aimed spectrometer.

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