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ARTICLE

Determination of neutron fluence in 1.2 and 2.5 MeV mono-energetic neutron calibration fields at FRS / JAEA

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A highly efficient silicon semiconductor detector with a polyethylene convertor (CH_2-SSD) was developed and the neutron fluences were precisely evaluated with it at 1.2 and 2.5 MeV mono-energetic neutron calibration fields at the Facility of Radiation Standard (FRS) in the Japan Atomic Energy Agency (JAEA) using an accelerator. The CH_2-SSD was designed to have a higher detection efficiency than that of the conventional one in order to measure the neutron fluencies at the calibration point of more than 100 cm from the target. The NRESP-ANT and PHITS codes were used to calculate the efficiency of the CH_2-SSD and its uncertainties. The maximum neutron fluence rates at 100 cm from the target were evaluated to be 1.0×10^3 and 2.0×10^3 cm^{-2} s^{-1} in the 1.2 and 2.5 MeV fields, respectively. They are high enough to calibrate dosemeters used for radiation protection purpose.

Keywords: ***accelerator; mono-energetic neutron; calibration field; neutron fluence; polyethylene converter ; semiconductor detector; PHITS; NRESP-ANT***

1. Introduction

Mono-energetic neutron calibration fields were developed between 8 keV and 19 MeV at the Facility of Radiation Standards (FRS) in the Japan Atomic Energy Agency (JAEA) using a 4MV Pelletron accelerator [1-3]. The 1.2 and 2.5 MeV neutrons, which are the two of 12 energies specified in ISO 8529-1 [4], are produced by the $^3H(p,n)^3He$ reaction. For the calibration of neutron dosemeters, the reference neutron dose equivalent is the most important parameter. Therefore, the neutron fluence, which is the fundamental quantity to determine the dose equivalent, needs to be precisely evaluated.

A silicon semiconductor detector with a polyethylene converter (hereinafter CH_2-SSD) are appropriate for the determination of the neutron fluence in the energy range from 1 MeV to 5 MeV. However, the detection efficiencies of conventional CH_2-SSDs are not high enough to determine the neutron fluence at the calibration point where dosemeters are placed at more than 100 cm from the target for neutron production. Then the fluence has been usually determined by measuring neutrons at a small distance, around 10 cm, from the target with the CH_2-SSD[5-8]. In this case a large correction of the distance from the target is necessary and it may increase the uncertainty on the fluence.

Therefore, we developed a high efficiency CH_2-SSD with a large silicon semiconductor detector. This makes it possible to determine the neutron fluence at the calibration point with satisfactory accuracy. This paper describes the developed CH_2-SSD and the procedure to determine the neutron fluence in the 1.2 and 2.5 MeV neutron fields.

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2. Structure of the CH_2-SSD

Figure 1 shows a cross-sectional drawing of the developed CH_2-SSD detector. A large silicon detector (SSD), CANBERRA Model PD3000-60-100AM, was employed to detect recoil protons. The sensitive region of the SSD is 3,000 mm^2 in area (61.8 mm in diameter) and 0.1 mm in thickness. Recoil protons produced in the polyethylene convertor are collimated into 58 mm diameter by an aperture made of 0.5 mm thick stainless steel.

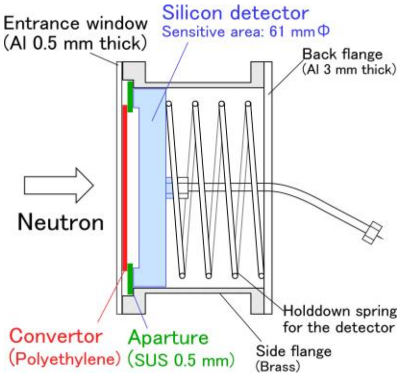


Figure 1. Cross-sectional drawing of the CH_2-SSD detector.

Table 1 summarizes the range of the protons in polyethylene calculated with the TRIM code [9] and the convertor thickness. The thicknesses of the convertors were selected to be thick enough to fully stop the recoil protons in the convertor. The reason for this is that it can achieve the highest detection efficiency and reduce the uncertainty caused by the uncertainty of thickness. The thicknesses were precisely determined by measuring the weight of the convertor with the micro balance, Mettlar Toledo MT-5. They were 45.04 and 227.2 μm for 1.2 and 2.5 MeV neutron measurements, respectively.

Table 1. Proton range in polyethylene and selected convertor thicknesses.

Neutron energy [MeV]	Range of recoil proton (max) [μm]	Convertor thickness [μm]
1.2	30	45.04±0.29
2.5	100	227.2±1.8

3. Measurements

Figure 2 shows the setup of the fluence measurement in the 1.2 or 2.5 MeV mono-energetic neutron fields. The CH_2-SSD was placed at 100 cm from the tritium target at an angle of 0 degree with respect to the beam line. During the irradiation, neutron emission rate from the target was monitored by the Long Counter installed in the irradiation room [1].

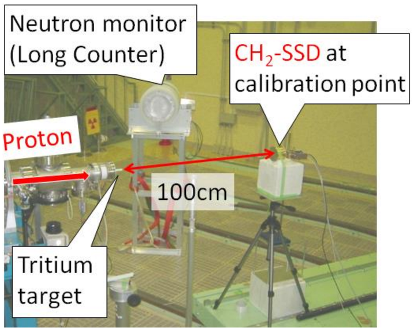
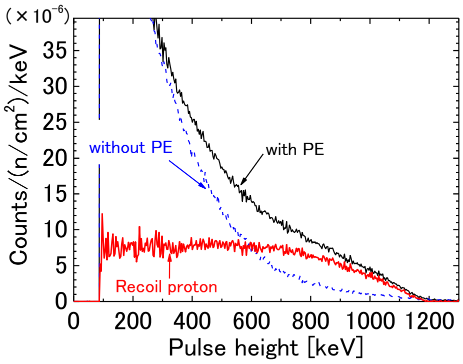


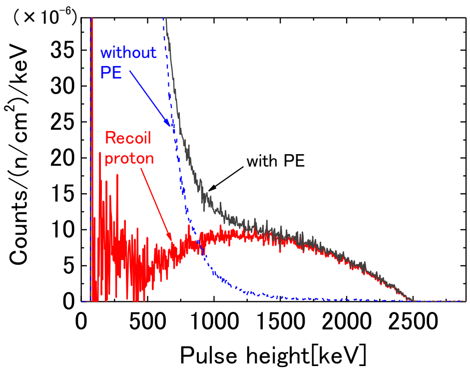
Figure 2. Photograph of the measurement setup.

Figure 3 shows the pulse height spectra of the CH_2-SSD measured with and without the polyethylene (PE) convertor in the 1.2 and 2.5 MeV neutron fields. These spectra were obtained with a preamplifier (ORTEC 142C), an amplifier (ORTEC 572) and a multi channel analyzer (FastComTek MPA-3). The bias voltage of the SSD was set to +50V.

Many kinds of particles other than protons, such as photons, recoil silicon in the SSD, etc., increase the counts in the low pulse height region. Among these particles, the recoil silicon is dominant in this region. Then the pulse height spectrum of the recoil proton produced in the PE convertor was obtained by subtracting the spectrum measured without the PE convertor from that with the convertor. Recoil carbons are also produced in the PE convertor, but they contribute not at all to the pulse height spectra because their energy is too low to pass through the air gap between the PE convertor and the SSD.



(a) 1.2 MeV mono-energetic neutron field



(b) 2.5 MeV mono-energetic neutron field

Figure 3. Pulse height spectra measured by using the developed CH_2-SSD with and without the polyethylene (PE) convertor at the calibration point.

4. Detection efficiency

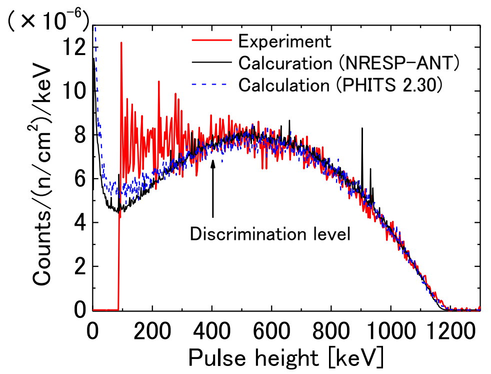
It is necessary to evaluate the detection efficiency of the CH_2-SSD for measurement of the neutron fluence. Then the efficiency was calculated with the NRESP-ANT [10] and PHITS codes [11]. The precise efficiencies for 1.2 and 2.5 MeV neutrons were determined using the NRESP-ANT code because this code is practically used to determine the neutron fluence at the primary standard institute in Japan and is highly reliable in calculating the detection efficiency [12].

As geometric factors such as the distance between the convertor and the surface of the SSD may affect the efficiency, the uncertainty caused by this should be evaluated. This evaluation requires a lot of calculations with various geometries. The NRESP-ANT code can only calculate the problem with a simple cylindrical geometry, whereas the PHITS code can treat complex 3D geometry. In addition, its calculation time is shorter than that of the NRESP-ANT code. Therefore, the PHITS code was employed to evaluate the uncertainty caused by the geometric factors. The event generator mode was used in these calculations because it was necessary to precisely simulate the production of recoil proton based on the nuclear data.

5. Results and discussions

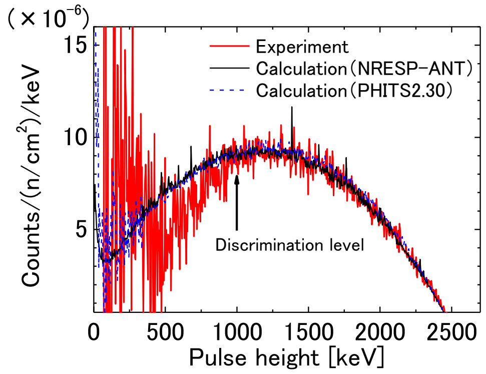
5.1.Pulse height spectra of SSD

Figure 4 shows the measured and calculated spectra of the recoil proton. There is little difference in the calculated spectra between the two codes. The measured spectra have large errors in the low pulse height region due to the small difference in two spectra measured with and without the PE convertor in this region as described in section 3. The discrimination levels were set at 400 and 1000 keV for 1.2 and 2.5 MeV fields, respectively, to eliminate this unreliable region of the spectra. Though there is some difference in the low pulse height due to the measurement errors, the calculated spectra agree with the measured one above the discrimination level shown in the Figure 4. This consistency proves the validity of the calculated spectra. The detection efficiency of the CH_2-SSD was calculated to be 4.4$\times 10^{-3}$ and 9.7$\times 10^{-3}$ counts per neutron fluence for 1.2 and 2.5 MeV neutrons, respectively. They are high enough to measure the neutron at 100 cm from the target with satisfactory accuracy within a feasible measuring time.



(a)

1.2MeV mono-energetic neutron field



(b) 2.5MeV mono-energetic neutron field

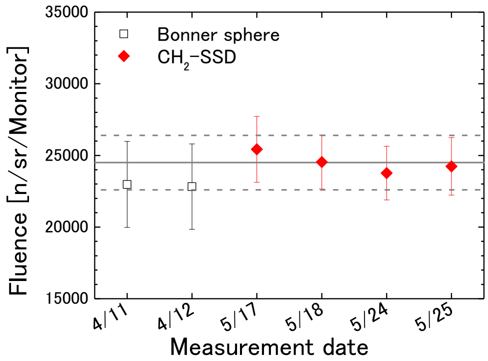
Figure 4. Experimental and calculated spectra of the recoil proton produced in the polyethylene convertor.

5.2.Neutron fluence

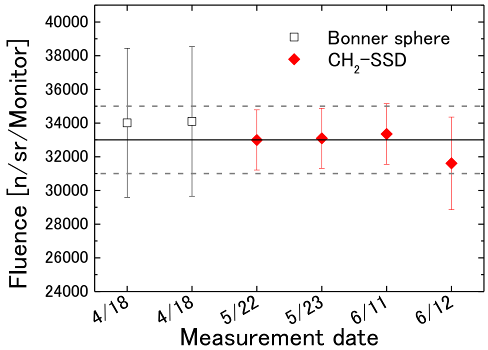
The neutron fluences were derived from the measured and calculated counts above the discrimination levels in the Figure 4. The fluences were normalized to the counts of the neutron monitor (Long Counter) placed in the neutron field.

In order to validate the fluence determined by the CH_2-SSD, the Bonner sphere was used to measure the fluence. The Bonner sphere was calibrated at the 565 keV and 5.0 MeV mono-energetic neutron fields [1]. Its responses for 1.2 and 2.5 MeV neutrons were interpolated based on the response calculation using the MCNP-4C code [13].

Figure 5 compares the normalized neutron fluences measured with the CH_2-SSD and the Bonner sphere. The solid and broken lines in the Figure 5 mean the fluences and their uncertainties, respectively, which were determined by averaging the results from the CH_2-SSD. The fluences measured with the CH_2-SSD are in good agreement with those measured with the Bonner sphere within the uncertainty in both 1.2 and 2.5 MeV fields. The maximum neutron fluence at 100 cm from the target were evaluated to be about 1.0$\times 10^3$ and 2.0$\times 10^3$ $cm^{-2}s^{-1}$ in the 1.2 and 2.5 MeV neutron fields, respectively.



(a) 1.2MeV mono-energetic neutron field



(b) 2.5MeV mono-energetic neutron field

Figure 5. Neutron fluence determined with the CH_2-SSD and the Bonner sphere. The fluence was normalized to counts of the neutron monitor (Long Counter) installed in the fields.

5.3. Uncertainty

Uncertainties of the neuron fluences were evaluated as shown in **Table 2**. The components used in the evaluation are counts of the CH_2-SSD, statistics of simulation for the efficiency, cross section of the neutron-hydrogen elastic, distance from the target to the CH_2-SSD, diameter of the aperture, distance from convertor to the silicon detector and thickness of the convertors. The uncertainty of the efficiency caused by that of the convertor-SSD distance was the largest. This was explained as follows: the recoil proton from the convertor loses its energy in an air gap between the convertor and the SSD and the energy loss is large for lower-energy protons. Therefore, the uncertainty of the gap length affected that of the detection efficiency considerably. Though this uncertainty can be effectively decreased by pumping air out of the gap, we decided not to create a vacuum. This is because it requires a thick entrance window of the CH_2-SSD which increases the uncertainty.

Table 2. Uncertainty evaluated for the fluence determination.

Factor	1.2 MeV	2.5 MeV
Measurement		
CH_2-SSD counts	1.2%	0.5%
Detection efficiency		
Simulation statistics	0.7%	2%
Cross section of Elastic	0.87%	0.87%
Target-CH_2-SSD distance	0.2%	0.2%
Aperture diameter	0.2%	0.2%
Convertor-SSD distance	3.5%	1.3%
Convertor thickness	0.6%	0.8%
Total	4%	3%
Expanded standard uncertainty(k=2)	8%	6%

6. Conclusion

A CH_2-SSD detector with high detection efficiency was developed in order to accurately measure the neutron fluence at the calibration point in the 1.2 MeV and 2.5 MeV mono-energetic neutron fields. The maximum neutron fluences were evaluated to be 1.0×10^3 and 2.0×10^3 cm^{-1} s^{-1} for 1.2 and 2.5 MeV, respectively. The maximum ambient dose equivalent rates calculated from the fluences are 1.5 and 3.0 mSv h^{-1} for 1.2 and 2.5 MeV fields. These dose rates are high enough for the calibration of neutron survey meters and dosemeters.

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