V. 1. Fast Neutron Profiling with Imaging Plate (2)
-Response of IP with a Converter for Energy and the Converter Thickness-

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A systematic method of fast neutron profiling using an imaging plate with a polyethylene neutron converter is reported. The relation of the neutron energy and the converter thickness was investigated for the above combination. A fading curve was also obtained and proved to be similar to that by a proton beam. From these results, appropriate conditions were found for the neutron energy, a converter thickness and cooling time after exposure.

Introduction

A method of fast neutron profile measurement will be useful in various applications of fast neutron beam, such as neutron radiography for non-destructive inspection and medical application. To obtain the spatial profile, a two-dimensional fast neutron detector is indispensable. An imaging plate (IP) is an integral type two-dimensional detector which has very high sensitivity and position resolution for X, γ, β-ray and charged particles[1]. In addition, successful application of IP containing Li or Gd was reported for thermal neutrons [2]. For fast neutrons, however, there are few reports of application of IP since it has low sensitivity to fast neutrons despite of its high sensitivity to γ-rays associated with fast neutron.

We have developed a method to measure a fast neutron profile using IP with a polyethylene converter in front of IP (IP-CH_2). In this method, the image of fast neutrons is obtained by detecting recoil protons from the converter and γ-ray contamination can be eliminated by taking difference between the measurement with and without the converter[3]. By this method, we obtained a profile of the 14.1 MeV neutrons collimated by 20cm Cu collimator and the spatial profile of 1, 2, 5 and 15 MeV mono-energetic neutrons after passing acrylic steps of 1 to 5 cm thick or Fe slabs 3.5 and 5 cm thick. To compare the results among the measurements and to improve image quality (S/N), we studied fading property and an appropriate converter thickness.

In this paper, we report the response of IP-CH_2 for 1, 2, 5 and 15 MeV neutrons, the fading curve of IP-CH_2 for 15MeV neutrons, the relationship between the converter thickness and the output (PSL) of IP.

Response for neutron energy

The IP was irradiated by neutrons obtained with a 4.5 MV Dynamitron accelerator at Fast Neutron Laboratory in Tohoku University. In this facility, we tested the responses of IP-CH_2 for various neutron energies. Figure 1 shows the experimental setup. Incident neutrons of 1, 2, 5 and 15 MeV were produced via T(p,n), D(d,n) and T(d,n) reaction, respectively. The distance between the target and IP was fixed to 100 cm to obtain parallel neutron beam. The polyethylene converter was 0.5 cm thick for all the measurements. The converter was set on the surface of IP, X-ray type obtained from Fuji Film Co. Ltd. (BAS-UR), 12.5cm×12.5cm. An NE213 scintillation counter was used to monitor the target condition. The exposure time was about 2 hours with a 4 μA direct beam current for all the neutron energy. We scanned IP and analyzed PSL distribution about 1 hour after the exposure. Scanning was performed by the Bas 3000 system (Fuji Film Co. Ltd.) at CYRIC. Scanning parameters were same for all the scanning, i.e. latitude 4, sensitivity 10000 and gradation 4095. Scanned images were analyzed by Scion Image on Windows PC. From the image, we took values of Photo Simultaneous Luminescence (PSL) for both regions of IP with and without the converter, and deduced the ratio of these two PSL values (S/N) as the quality indicator of the image.

Table 1 summarizes the irradiation conditions and S/N values. Estimated neutron flux is calculated based on the reference data[4). Figure 2 shows the 300×300-pixel image around the converter edge in 5 MeV measurement. From these results, it is found that S/N becomes higher with neutron energy except for 15 MeV. It can be explained in terms of an effective thickness that is governed by the maximum recoil proton range. The effective thickness indicates the effective number of atoms contributing to the n-p conversion. The reason of lower S/N value for 15MeV is that the maximum proton range exceeds the converter thickness and the H(n,p) cross section is smaller than for 5 MeV. We would get better S/N for 15 MeV neutron, if we use a thicker converter. As a conclusion, 5 and 15 MeV neutron energies are suitable for the IP-CH_2.

Fading property of IP with a polyethylene converter

The experimental setup is same as the above experiment. Imaging Plate (BAS-UR) covered with a 2mm thick polyethylene converter was exposed to 15 MeV neutrons at 840 mm from the neutron producing target. The exposure time was about 1 hour with 4 μA direct beam current. Estimated neutron flux on the IP was 1.5×10^7 #/cm^2. After the exposure, we cut the IP into nine pieces and scanned each piece in every fifteen minutes. The Bas 1000 scanning system was used since it can scan IP with the various sizes.

Figure 3 shows the experimental result and its fitting result using following equation;

$$PSL = A_1 \exp(-\ln 2 \cdot t / B_1) + A_2 \exp(-\ln 2 \cdot t / B_2)$$

In this equation, A_1 and A_2 are amplitude factors for each exponential, B_1 and B_2 are time constants of exponential decay and t is time. The result is B_1 = 24.50 and B_2=2428 min. From this result, it is shown the fading curve has two components. After 1 hour, the fading curve becomes almost flat level, since the first term exponential has rather short decay time constant and the second one has very long. Therefore, to compare the PSL values among the different exposure times, we had better to scan the IPs after cooling time of at least 1 hour. Recently, a fading curve for tens MeV proton was reported by Nohtomi et al.[5] and shown in figure 3. The parameters of the curve is B_1 = 15.5 and B_2=3400 min. Their results are slightly different from ours, but also supports the adoption of 1 hour cooling time.

Response of converter thickness

We measured the PSL value as a function of converter thickness to check the response of IP-CH_2, and compared with the Monte-Carlo calculation.

Experiments were carried out for 5 and 15 MeV neutrons. The step converter was set in front of IP (BAS-UR) that located at 840mm from target. The converters are 60μm to 300 μm thick in 60 μm steps for 5MeV, and, 60μm to 300 μm thick in 60 μm steps and 100μm to 500μm thick in 100 μm steps for 15 MeV. The thickest converter of each step is almost equivalent to the maximum range of recoil protons. Estimated neutron flux on the IP is 3.3×10^7 and 1.4×10^7 for 5 and 15 MeV, respectively. Scanning was carried out by Bas 3000 system after 1 hour exposure. Figure 4 shows two-dimensional image obtained by the 15 MeV experiment.

To estimate PSL values for converters with different thickness and the neutron energy, we developed a program that calculates the energy deposit in IP by Monte-Carlo method. The program calculates the energy deposit under the following assumptions: (1) The protect layer of IP (BAS-UR) is a 10 μm thick polyethylene-terephthalate, (2) the effective area of IP is made of $BaFBr_{0.85}I_{0.15}$ (Ba:33%, F:33%, Br:28%, I:6%), (3) γ-ray contamination is eliminated completely by subtraction, (4) all deposited energy is measured as PSL (ignoring the depth effect), (5) amount of PSL is proportional to LET (ignoring the LET effect). The energy loss data were calculated by the TRIM code based on the equation of Ziegler.

Figures 5 and 6 show comparison between experiment and calculation for 5 and 15 MeV neutrons, respectively. The calculation is normalized to the experimental data at maximum PSL value. The calculations are in fair agreement with the experimental ones in both neutron energies. It indicates that the above assumptions are appropriate and the dominant components on the PSL value are the incident number of protons and total energy deposit in the effective layer of IP. In addition, we can conclude that almost all the PSL is originated by recoil protons. It is preferable to use the converter which is as thick as the maximum proton range, to get better S/N result. However, we have to check the effects of converter thickness to spatial resolution.

Conclusion

To obtain fast neutron spatial distribution, we have investigated a method to measure the fast neutron profile with IP using a polyethylene converter. From the effect of a neutron energy and a converter thickness, it was found that good S/N is achieved using 5 or 15 MeV neutron and the converter whose thickness is equivalent to the maximum proton range. The response to the different thickness converter was in fair agreement with the Monte-Carlo calculation.

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References

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Table 1 Irradiation neutron flux and output values of IP in various energies. Distance from target to IP is 100cm and converter thickness is 0.5 mm

En [MeV]	Neutron Flux [#/cm^2]	With converter [PSL/pixel]	Without converter [PSL/pixel]	S/N [without/with]
1	2.58E+06	0.67	0.64	1.05
2	4.99E+06	1.73	1.49	1.16
5	2.94E+07	2.50	0.75	3.57
15	1.83E+07	3.03	1.73	1.75

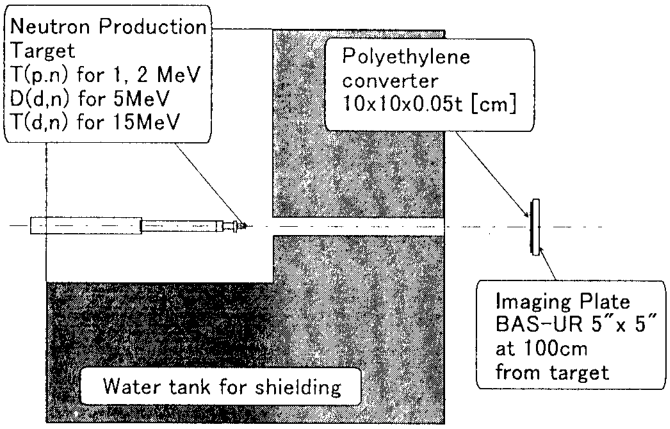

Fig. 1. Experimental setup for exposure IP.

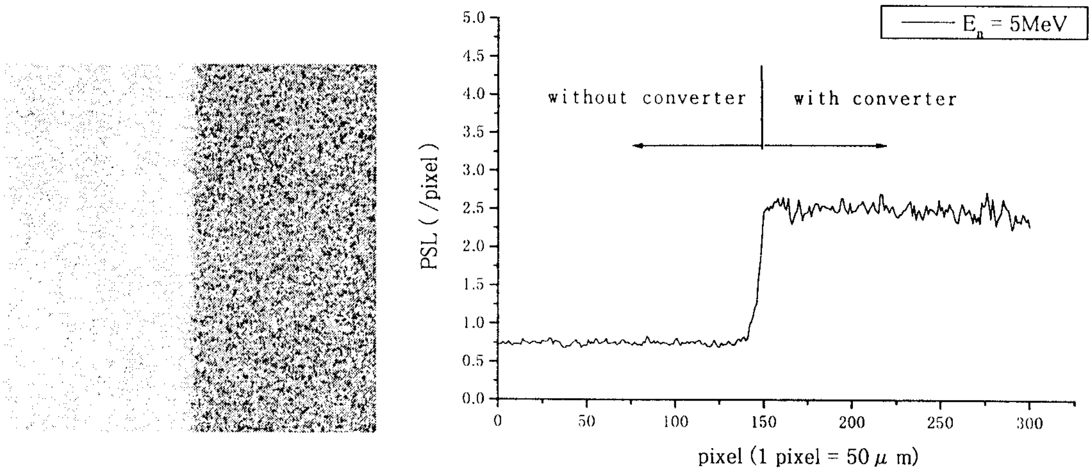

Fig. 2. 300x300pixcel image around converter edge in 5MeV measurement.

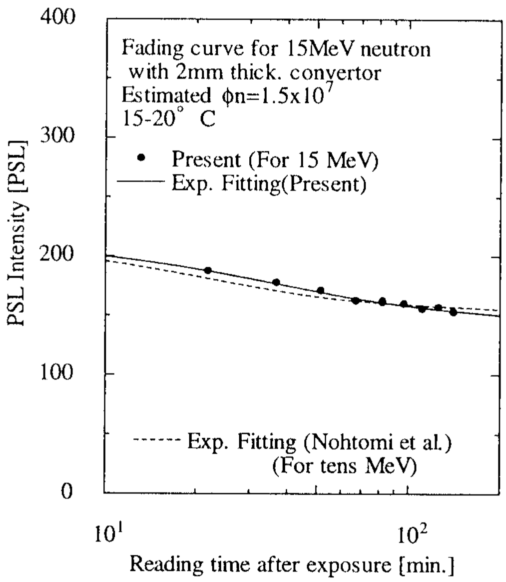

Fig. 3. The experimental result of fading curve for IP with polyethylene converter.

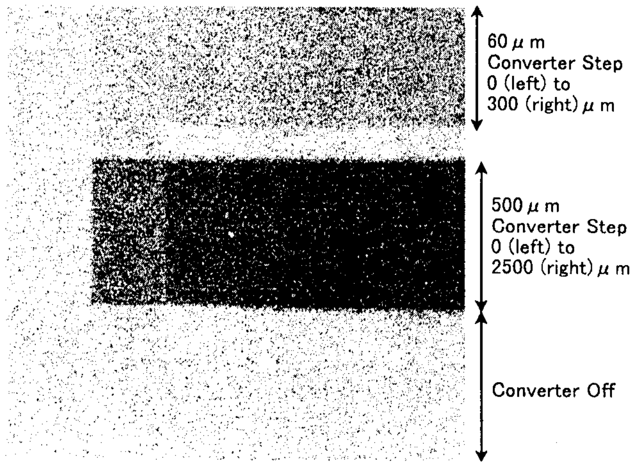

Fig. 4. Two-dimensional image of 15 MeV measurement for converter steps.

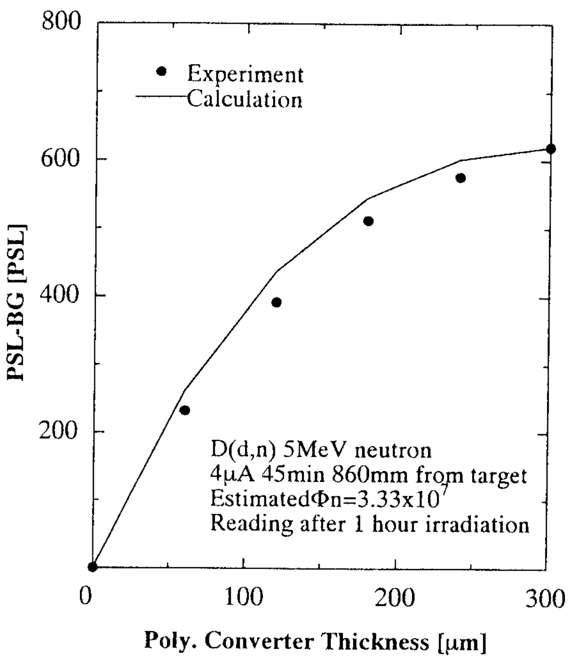

Fig. 5. The relationship of converter thickness and PSL 5MeV neutrons.

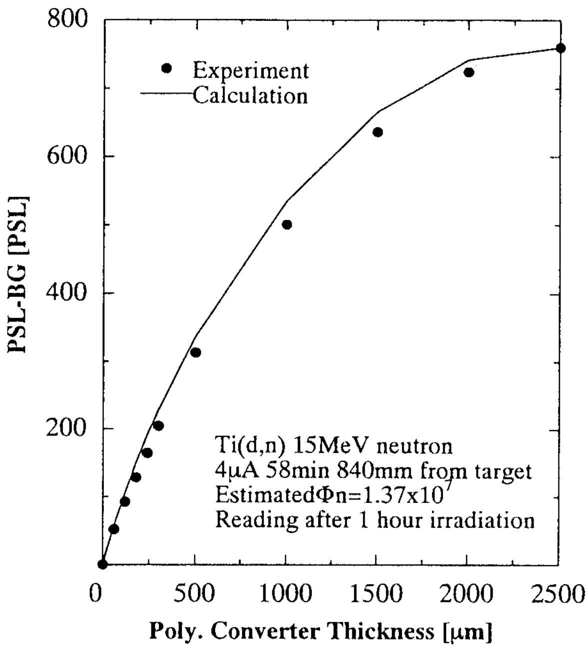

Fig. 6. The relationship of converter thickness for and PSL for 15MeV neutrons.