VI. 1. Fast Neutron Profiling with Imaging Plate (3)

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Introduction

We have continued a study of fast neutron profile measurement using an imaging plate (IP) coupled with a polyethylene plate (IP-CH_2)[1,2] which will be useful for fast neutron radiography, non-destructive inspection of bulk objects, and medical applications. In this method, neutrons are converted to protons by a polyethylene converter and detected in IP, and the effects of γ-ray backgrounds can be eliminated by taking difference between the data with and without the converter. We have reported[1,2] that this device is useful to measure profiles of 5, 15 MeV neutrons, while not so sensitive to 1-2 MeV neutrons. Following the above studies, we extended the study to 1) an effective dynamic range of the sensitivity in a neutron field, 2) spatial resolution, and 3) applied the method to radiography of bulk media. Improvement of the sensitivity to lower energy neutrons was also attempted.

Experiments were carried out using a 4.5 MV Dynamitron accelerator at Fast Neutron Laboratory[3]. Figure 1 shows an experimental setup. Incident neutrons of 5 and 15 MeV were utilized for experiments. They were produced via the D(d,n) and T(d,n) reactions[3].

The IPs employed were X-ray type from Fuji Film Co. Ltd. (BAS-UR), 12.5 cm×12.5 cm. Polyethylene or polypropylene converters with appropriate thickness were placed in front of IP in a stepwise or flat shape. The flat converter was employed to correct for the effect of neutron flux non-uniformity on the converter. The IP was scanned to analyze a PSL (Photo Stimulated Luminescence) distribution using BAS-3000 system (Fuji Film Co. Ltd.) at CYRIC. Scanning was done about one hour after irradiation to reduce the effect of fading. Scanning parameters were the same for all the scanning, i.e., latitude 4, sensitivity 10000, and gradation 4096.

Dynamic Range

Dynamic range of IP is known to be larger than 10^4 for X-rays. In the case of neutron irradiation, however, much more γ-rays may be present in the field and reduce the effective dynamic range for neutrons. We measured the dynamic range of IP-CH_2 for 5 MeV neutrons. The neutron (proton) fluence incident on IP-CH_2 was varied over a digit by 1) placing the IP in three different distances from the neutron target, 245 mm, 345 mm and 725 mm, and 2) employing converters with five steps between 60 μm and 300 μm thick (60 μm steps). The exposure time was about one hour with a 3.7 μA direct beam current.

Figure 2 shows the results for net PSL versus neutron fluence3), where net PSL means PSL value subtracted with γ-ray backgrounds. In the figure, the linearity between PSL and fluence is confirmed from 10^7 to 10^9 neutron fluence. Consequently, the dynamic range is larger than 10^2 even in this neutron field. Furthermore, we can expect that the ultimate dynamic range is larger than 10^3 if we take account of the fact that the largest PSL in this measurements is only about one half of the allowable upper limit, 4096, and the detectable low limit is a few PSL4).

Spatial Resolution

Spatial resolution which is of prime importance for a two dimensional detector is 50 μm for the present IP. In the case of neutron profiling, however, several factors degrade the spatial resolution, e.g., dispersion of recoil-angles and ranges. Therefore, we inspected the influences of these factors experimentally.

The spatial resolution was measured from the dispersion of PSL in a sharp cutoff of neutron beam provided by an iron shadow-bar (10 cm thick). The target-IP distance was extended to about 800 mm, and one half of the IP-CH_2 was irradiated by 5, 15 MeV neutrons with the other half being shadowed by the iron block. The converters for 15 MeV neutrons were 0.5 mm to 2.5 mm thick in 0.5 mm steps.

Table 1 summarizes the results. The spatial resolution is given in FWHM which was evaluated in the manner shown in Fig. 3. The spatial resol account. Among the factors for resolution degradation, the dispersion in recoil-angles will be dominant one because it introduces about 0.1 and 0.6 mm spatial spread for 5 and 15 MeV neutron, respectively. The result for 15 MeV neutrons is accounted for by the factor, but only about 10 % in the case of 5 MeV neutrons. Mis-alignment of neutron beam from the iron block edge will be the main reason of the discrepancy because the observed edge of the iron block deviated from the center of the beam. Consequently, the intrinsic resolution for 5 MeV neutrons will be much higher than observed. The spatial resolution was found not to be very sensitive to the converter thickness, while average ranges of recoil protons depend on the converter thickness.

Fast Neutron Radiography

The IP-CH_2 was applied to radiography for 5 and 15 MeV neutrons. Converter thicknesses were 0.5 mm and 2.5 mm for 5 and 15 MeV neutrons, respectively. Objects of radiography were an iron block with voids (hidden holes) shown in Fig. 4 and cans filled with water partially.

Figure 5 shows the radiography image and the PSL distribution for the iron block by 5 MeV neutrons. The voids in the iron block is distinguished clearly, and the PSL distribution corresponds reasonably to the cylindrical shape of hole and voids. This fact suggests that smaller voids will also be detected by the present system. The result was also good for cans with water. Therefore, the IP-CH_2 method enables fast neutron radiography of thick metal and water which are too thick for the X-ray radiography.

The image contrast for 15 MeV neutrons were found to be generally lower than that for 5 MeV ones, probably because of too high penetrability of 15 MeV neutrons for the object thickness. Therefore, there should be optimum neutron energy corresponding to the macroscopic cross section and thickness of each object.

In some cases, PSL distribution deviates from the neutron transmission particularly in the edge region. It is attributed to the effects of scattered neutrons and charged-particles emitted from the objects. It is difficult to eliminate by the IP-CH_2 method unless the energy and species of particles are known. To solve the problem, we are developing a neutron counter which is position sensitive in two-dimensions and sensitive to the energy deposited in the counter.

Improvement for 1 MeV Neutron Detection

The low sensitivity of the IP-CH_2 to 1-2 MeV neutrons is attributed to short ranges of recoil protons and proton attenuation in the protection layer on the IP surface made of PET (Polyethylene Terephtalete). Improvement of the sensitivity was attempted by employing a BAS-TR film which has no protection layer. A BAS-TR film coupled with converters of 4 μm to 20 μm in 4 μm steps was irradiated by 1 MeV neutrons via the T(p,n) reaction. A signal-to-noise ratio (S/N) was improved about three times by using BAS-TR. Nevertheless, absolute PSL value was still too small to obtain clear images with practical irradiation time (a few hours).

References

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3) Baba M., Takada M., Iwasaki T., Matsuyama S., Nakamura T., Ohguchi H., Nakao N., Sanami T., and Hirakawa N., Nucl. Instrum. Methods, **A376** (1996) 115.
4) Nohtomi A., Terunuma T., Kono R., Takada Y., Hayakawa Y., Maruhashi A., Proc. 1998 Spring Meeting of Japan Atomic Energy Society **C25** (March 1998) p.115.

Table 1. Relation of converter thickness and spatial resolution (FWHM).

En = 5MeV

Converter Thickness (μm)	60	120	180	240	300
Resolution (mm)	1.42	1.32	1.25	0.99	0.87

En = 15MeV

Converter Thickness (mm)	0.5	1.0	1.5	2.0	2.5
Resolution (mm)	(0.67)	0.79	0.90	0.90	0.68

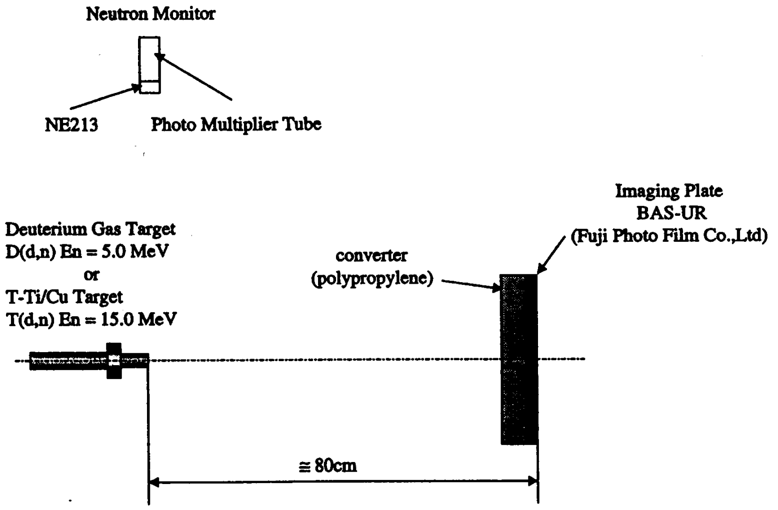

Fig. 1. Experimental setup in the present experiment.

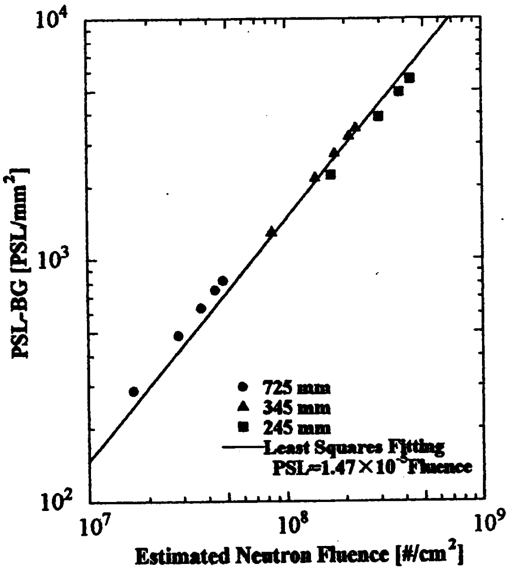

Fig. 2. The relation of background-subtracted PSL versus neutron fluence.

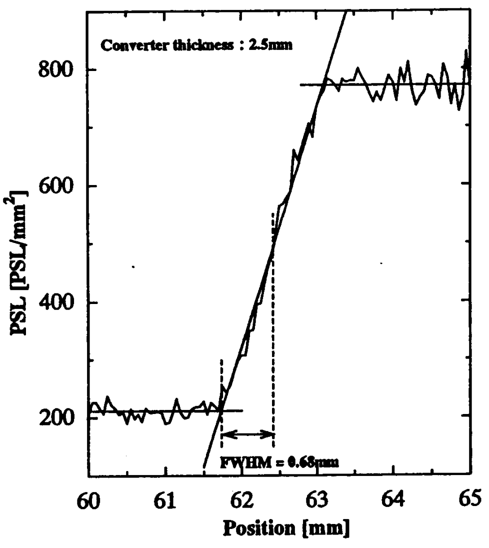

Fig. 3. Evaluation scheme of spatial resolution: The low value in the left corresponds to PSL for shadowed region and the higher values in the right to un-shadowed region.

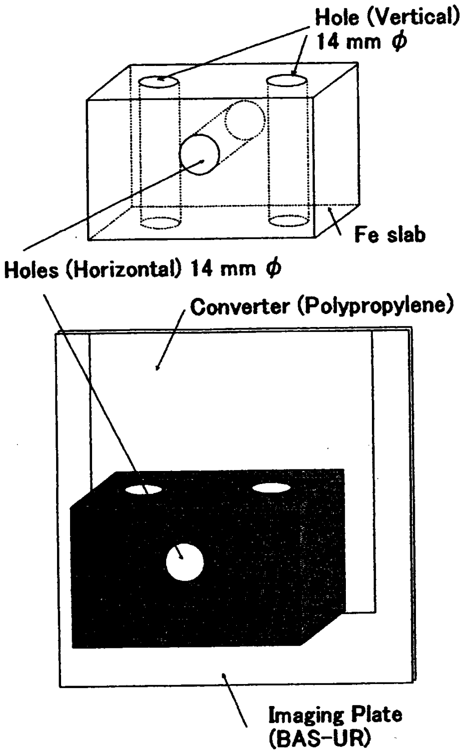

Fig. 4. Schematic view of iron block object and the setup of the IP-CH_2 for neutron radiography.
A neutron beam is incident perpendicularly to the block from the front side of the block.

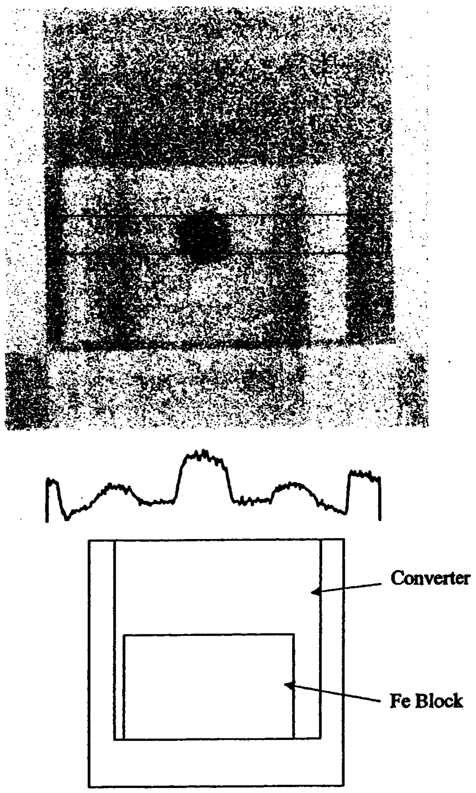

Fig. 5. Radiography image (upper) and PSL distribution (middle) for iron block in fig.4. The PSL distribution shows values in the area surrounded by lines in the image figure.