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著者	Miura T., Hiroishi T., Aoki T., Sanami T., Nakamura T., Baba M., Yamadera A.
journal or publication title	CYRIC annual report
volume	1999
page range	203-207
year	1999
URL	http://hdl.handle.net/10097/50142

V. 2. Fast Neutron Profiling with Imaging Plate (4) -Neutron Scattering Effects in Fast Neutron Imaging-

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INTRODUCTION

Measurement of fast neutron spatial distribution (neutron profiling) is required in various fields, *i.e.,* neutron fields characterization and neutron radiography. Fast neutron radiography will be effective to the nondestructive inspection of deep parts of bulk objects.

We continued a study on the neutron profile measurement using a combination of an imaging plate (IP) and a polyethylene or polypropylene (CH_2) film as a converter of fast neutrons^1,2)^, and applied the device to the neutron field characterization^2)^ and fast neutron radiography for an accelerator-based neutron source^3)^. In our study, the performance of the technique was evaluated by radiography method by using mono-energetic neutrons with various energy from 1 MeV to 15 MeV, and test samples with multiple steps. By optimizing experimental conditions^2,3)^, we obtained fairly clean images. Nevertheless, there still remained problems of 1) deformation and 2) insufficient contrast of images which should be eliminated for further improvement of the technique. This year we have traced the problem.

Method and Problems

The profiling measurements were carried out at the Tohoku University 4.5 MV Dynamitron facility. Fast neutrons of 1-15 MeV from the neutron production target were first collimated by a 15 cm-long copper collimator and entered into CH_2-IP through a step type sample. The step type samples were used for the convenience to inspect the quality of the profile and made of stainless steel (SUS) and acrylic resign with 1 cm wide steps. The sample was placed in close contact with CH_2-IP.

In our experiments for fast neutrons of 1-15 MeV, the best results were obtained for 5 MeV neutrons which are produced by the D(d,n) reaction at the D_2 gas cell with a platinum beam-stop (1 cm-diam and 3 cm-long, 1.2 atom D_2 gas) due to low γ-ray contamination. Therefore most experiments were carried out for 5 MeV neutrons. The distance between the target and the CH_2-IP was ~80 cm, and the neutron flux was $\sim 3.5\times10^4$ $cm^{-2}s^{-1}$ at the place of the CH_2-IP.

Employed IP was of X-ray type BAS-SR manufactured by FUJI Photo Film Co., LTD. The polypropylene film as a proton converter should be thicker than the recoil proton range to avoid sample-protons entering IP-CH_2. We employed 0.5 mm-thick one for 5 MeV neutrons whose recoil proton range is ~0.35 mm.

The neutron profile image was obtained by irradiation of CH_2-IP for 1-2 hrs. Typical projected result in this setup is shown in Fig. 1. The image reproduces the shape of step samples qualitatively. However there remained problems that 1) there was rounding in images even for the flat parts in the steps, and 2) the contrast was not so good as expected from the neutron transmission ratio. We looked for the reasons of the deformation and the way for improvement.

Reduction of Rounding

In the present imaging, we expect detection of neutrons transmitted the sample without any collision. Neutrons detected on CH_2-IP after collision in the sample makes distortion. In the present case, the rounding was traced to be due to neutrons scattered in the sample which act as backgrounds overlapping on the transmitted neutrons. The shape of rounding is explained by the pass-length of scattered neutrons within the sample as shown in Fig. 2 which illustrates an example for a simple sample with only 2-step. By this scheme, smaller deformation around the lateral surface in the experimental result is interpreted because no scattered neutrons come in from outside.

The effects of neutron scattering inside a sample in the fast neutron radiography was discussed by Yoshii and Kobayashi[4)] for a simpler right cylinder sample. The present interpretation is consistent with their one. In the fast neutron cases, the effect of neutron scattering is more serious than in thermal neutron cases because of much larger ratios of scattering to capture cross sections.

As the way to reduce the effects of scattered neutrons, a honeycomb-shaped collimator is useful for the case of thermal neutrons[5)]. In the present case, however, a collimator in front of the CH_2-IP will result in worse contrast because it will increase scattered neutrons and γ-rays in IP.

Instead, separation of CH_2-IP from the sample will be effective for reduction of the effect. We made simulation of the phenomena using the MCNP code to confirm the above argument. Calculations were made for parallel incident neutron flux to the 3-step acrylic sample as a function of distance between the sample and CH_2-IP. The calculation results are shown in Fig. 3. In the case of direct contact (0-cm), the result is similar with the observation in above experimental results. As the distance increases, the rounding structures become smaller. Separation of ~3cm is enough to reduce the rounding structures to a negligibly small level.

Improvement of Contrast (n/γ)

In the present CH_2-IP configuration, the intensity of PSL (Photo Stimulated Luminescence) for the area without CH_2 is provided by γ-rays alone while those at the area with a CH_2 film are due to both neutrons and γ-rays. Therefore, PSL values for CH_2-IP and bare IP correspond approximately to n + γ and γ yields, respectively. For the reason, the contrast of profile becomes worse with increasing contribution of γ-rays. Hence reduction of γ-to-neutron ratio is important to obtain clear profiles.

We performed two attempts to improve the contrast.

1) Shielding by lead-blocks around CH_2-IP was performed in order to decrease environmental γ-rays. However, the result was even worse than the case without shielding, probably because lead produced a larger number of γ-rays by inelastic reactions with 5 MeV neutrons. Therefore, γ-rays reduction should be done around neutron production target employing collimators with low γ-rays emission but good shielding ability for fast neutrons.

2) Then, appropriate collimator was looked for. A combination of copper (10 cm long) + paraffin (30 cm long) has heavier shielding effect for 5 MeV neutrons than the paraffin alone. Then, we measured neutron to γ-rays ratio on the IP. However, the experimental result of $(n+\gamma)/\gamma$ was 4.8 for the former and 7.4 for the latter, respectively. The collimator using copper resulted in higher γray ratio than paraffin despite of higher shielding effect for both neutrons and γ-rays. From the results, the inferior contrast in previous experiment is supposed to be caused by a copper collimator with higher γ-ray production cross sections.

Improved experimental results

According to the results in the above described experiments, the experimental geometry was modified as follows to reduce deformation and improve contrast in image;

1) the sample-CH_2-IP distance was extended to ~20 cm,
2) the neutron collimator material was changed to paraffin,
3) source neutrons were collimated more tightly not to illuminate the floor and stage of the sample to avoid floor-scattered neutrons from the images.

Typical result is shown in Fig. 4.

The step type sample was a combination of SUS step 3 cm (1cm-wide step) and acrylic resign (1cm step). Irradiation time was ~2 hrs, and the neutron fluence at the place of CH_2-IP was ~1.35×10^8 n/cm^2. The image became much more uniform and the rounding structure became much smaller than in the previous setup. Furthermore, the background level is also improved markedly owing to tighter neutron collimation. In the case of this background level, this method enables to analyze the sample up to 19~20 cm in thickness.

Therefore, this technique will be useful for nondestructive inspection of bulk materials

Summary

We have improved the experimental conditions for the fast neutron profile technique using CH_2-IP.

1) Rounding structure in profiles proved to be caused by neutrons scattered in the sample, and can be reduced by separating the sample from the CH_2-IP.
2) To improve the contrast, reduction of γ-rays fraction is essential. For improved contrast, it is important to adopt shielding and collimator materials with low γ-ray emission for fast neutrons.

By improving the experimental conditions according to the above findings, we obtained good profiles for fast neutrons of 5-15 MeV. This method will be applied to neutron filed characterization and radiography.

However, CH_2-IP profile-detector has essential problems of a) very low sensitivity to lower energy neutrons2), E_n<1MeV, and b) no information on energy deposits which is important for particle selection. We are designing another active type profile-detector to complement the CH_2-IP detector.

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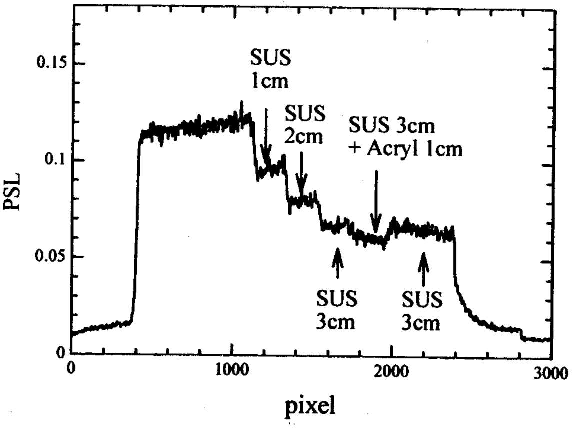

Fig. 1. Result in previous experimental geometry.

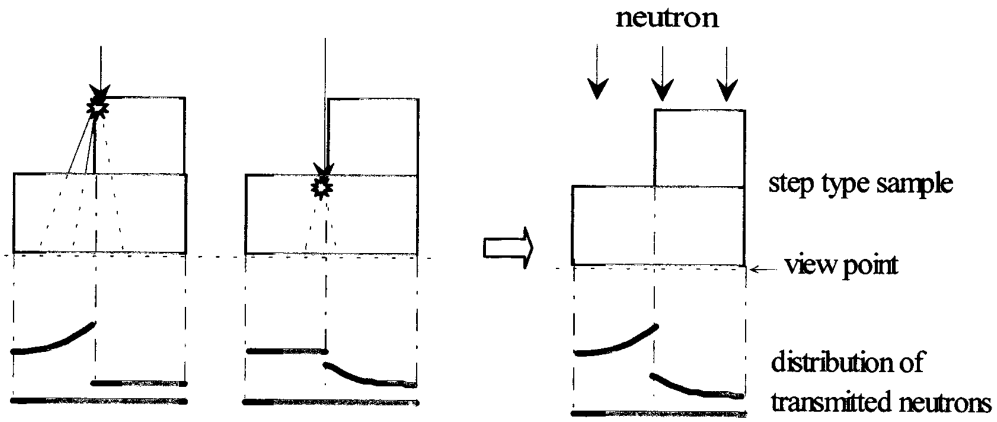

Fig. 2. Deformation due to neutrons scattered in the sample.

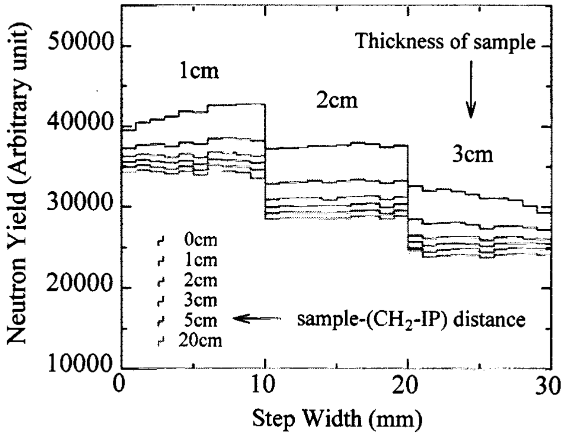

Fig. 3. Simulation result as a function of sample-IP distance.

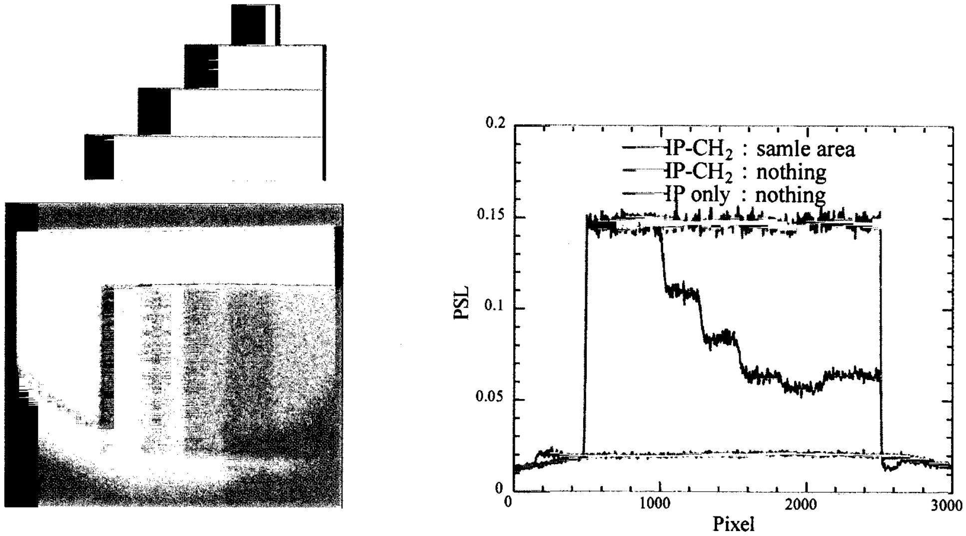

Fig. 4. Result of profile (SUS-3step & Acryl 1-step) and its projection.