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15.4
A large area neutron imaging method using rectangular scintillators with WLS fibers

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Abstract

A neutron detection element that consists of a ^{6}Li glass scintillator with size of 5mm x 5mm x 2mmt and wavelength shifting fibers (WLS) with 1mmϕ arranged on four sides of the scintillators was prepared to confirm the principle of novel neutron imaging method. By preliminary experiment, it was found that detection efficiency of this detection element was 13% for thermal neutron. A 4 x 4 ^{6}Li glass scintillator array neutron system was made to investigate the effectiveness of this imaging method. By neutron irradiation experiments, it is confirmed that neutron counting rates were proportional to the incident rate of neutrons for all ^{6}Li glass scintillators in the array and the counting rate up to 3 Mcps for a scintillators, namely, the counting rate up to 12 Mcps for one piece of WSL fiber can be measured.

1. Introduction

It is indispensable to develop neutron diffractometers and spectrometers with high-performance neutron imaging devices for neutron scattering experiments using a high intense pulsed-neutron source. These imaging devices require excellent time resolution, high counting rate, high detection efficiency, wide dynamic range and large imaging area in order to carry out neutron scattering experiments with time of flight (TOF) method.

Especially, the general materials diffractometer for powder diffraction and disordered materials require the imaging device with a large area, high counting rate, high efficiency and position resolution less than few mm. Moreover, the devices require simplicity and compactness for easy assemble and easy maintenance as an experimental system.

Corresponding to these requirements, we propose a novel neutron imaging method using rectangular scintillators with wavelength shifting (WLS) fibers.

2. Novel imaging method

The novel neutron imaging method is shown in Fig. 1. In this method, rectangular scintillators are arranged at longitudinal direction and transverse direction on the rectangular area and WLS fibers are attached along four sides of these scintillators. The luminescences shifted by the WLS fibers are detected by multi-channel photomultipliers. The incidence positions of the neutron in X axis and Y axis are decided by coincidence of two signals that are detected by WLS fibers put at mutual sides of the rectangular scintillator, respectively.

3. Preliminary experiment

A preliminary experiment was carried out in order to confirm the principal of the novel imaging method by measuring the detection efficiency for one pixel of rectangular scintillator.

The experimental equipment used for this measurement is shown in Fig. 2. A neutron detection element that consists of a ^{6}Li glass scintillator with size of 5mm x 5mm x 2mmt and 1mmϕ WLS fibers arranged on four sides of the scintillators was prepared. A GS-20 (Bicron Co.) was used as the ^{6}Li glass scintillator. The absorption efficiency of the 2mmt ^{6}Li glass scintillator was 95 % for thermal neutron. The wavelength of luminescence is 395 nm. A BCF-92M (Bicron Co.) with 1mmϕ was used as 4 pieces of WLS fibers. The luminescence was absorbed by the WLS fibers arranged on four sides and wavelength-shifted luminescence (490nm) was emitted at the edge of the WLS fiber. The luminescence is detected by multi-channel PMTs (Hamamatsu, H6568). The photon signals from the PMTs were amplified with a photomultiplier amplifier (HOSHIN, N018) and discriminated with an 8-channel discriminator (HOSHIN, N019). The discriminated signals (X1 and X2, Y1 and Y2) were inputted to two-coincidence circuits (ORTEC, 418A) for X axis and Y axis, respectively. The coincidenced signals for X axis and Y axis were inputted to other coincidence circuit. This coincidenced signal corresponding to the position-decision signal was measured with a counter (ASANO, N-2502). The coincidence time was 100ns for all coincidence circuits. Also, the coincidenced signals for X axis and Y axis were measured with counters. Furthermore, the X1 signal was measured in order to know the incidence rate of neutrons into the ^{6}Li glass scintillators.

An Am-Li of 74 GBq neutron source with a paraffin block of 10cm thickness was used to obtain the detection efficiency for thermal neutron. Counting rates for the position-decision signal, the coincidenced signals for X axis and Y axis and the X1 signal were shown in Table 1. The counting rate for the position-decision signal obtained by 4 signal coincidence and the

X1 signal is 0.33 and 2.58cps. Consequently, it is confirmed that the intrinsic detection efficiency of this ^{6}Li glass scintillator was 13 %.

4. Neutron imaging experiments

A ^{6}Li glass scintillator array neutron system was made and neutron imaging experiments were carried out to confirm the effectiveness of the novel imaging method.

4.1 Experimental system

A 4 x 4 ^{6}Li glass scintillator array neutron system using the novel imaging method is shown in Fig. 3. 16 rectangular scintillators with size of 5mm x 5mm x 2mmt were made of GS-20 (Bicron Co.). 5 pieces of two WLS fibers with 0.5mmϕ (Bicron Co., BCF-92M) were arranged at the side of the scintillators from X1 to X5 of X axis and from Y1 to Y5 of Y axis, respectively. The 5 X-axis fibers and 5 Y-axis fibers were coupled with two multi-channel PMTs (Hamamatsu, H6568), respectively. The supplied bias voltage on the PMTs is 800V. The signals outputted from the PMTs were amplified with photomultiplier amplifiers (HOSHIN, N018) and discriminated with 8-channel discriminators (HOSHIN, N019). The discriminated signals were the input signals to 8-channel fast coincidence circuits (HOSHIN, N019). The schematic diagram of the coincidence circuits is shown in Fig. 4. The signals outputted from the coincidence circuits were counted with a 16-channel 120MHz counter (HOSHIN, N026) connected with a CAMAC crate controller (HOSHIN, CCP-F). Finally, 16 counting rates from C9 to C24 corresponding to 4 x 4 ^{6}Li glass scintillator array were measured.

4.2 Imaging experiments

The neutron imaging experiments using the 4 x 4 ^{6}Li glass scintillator array neutron system carried out in the thermal neutron radiography facility of JRR-3M. Thermal neutron flux is 2.0×10^{8}cm^{-2}s^{-1}. At first, characteristics of counting rate for this scintillator array were measured. It was found that the counting rate up to 3 Mcps for a scintillator, namely, the counting rate up to 12 Mcps for one piece of WSL fiber can be measured by the irradiation of neutrons. Next, characteristics of the neutron imaging for neutron beam of 3mmϕ collimated by a paraffin block of 5cm thickness were measured by changing the number of neutron absorbers containing Gd_2O_3. The experimental arrangement was shown in Fig. 5. The neutron images measured with no neutron absorber and one neutron absorber are shown in Fig. 6. Both neutron images are almost same with good contrast and have the maximum intensity in the position of X=3 and Y=3. Dependencies of the neutron images on the incident neutron flux were measured. Counting rates in the edge cell (X=1 and Y=1) and the center cell (X=3 and Y=3) were compared in condition of the no absorber one absorber and two absorbers. Results are shown in Fig. 7. The upper figure shows dependency of the counting rates in the edge cell and the center on the number of absorbers, and the lower figure shows the counting rate normalized based on the counting rate of no absorber in each cell. One can see that the decrease rates of edge cell and center cell is well agreed and the rate is about 0.15 in each absorber. Therefore, it is confirmed that neutron counting rates were proportional to the incident rate of neutrons for all ^{6}Li glass scintillators in the array.

5. Discussion

The photon counting method is applied on this imaging method. Therefore, it is important to evaluate the coincidence rate of one incident neutron in a ^{6}Li glass scintillator cell. Coincidence rate is given by $(1 - \exp(-N_n))^{N_c}$, where N_n is the average number of photon detected by the photomultiplier and N_c is the number of coincidences [1]. The calculation results were shown in Fig. 8. Since the coincidence rate for 4 coincidences was 0.13 in the experiments. It could be estimated that the average number of the photon detected was about 1.0. Therefore, it is necessary to increase the coincidence rate for 4 coincidences to the value more than 2 in order to obtain the neutron detection efficiency more than 50%.

We haven't optimized the neutron imaging system in this time, yet. The optimization methods aiming to the excellent performance for detection efficiency, counting rate and position resolution were described as follows;

1) Selection of the material and the size of the scintillator
2) Selection of optimal WLS fibers (matching of wavelength between scintillator and WLS fiber and wavelength between WLS fiber and PMT photocathode)
3) Improvement of the reflector of the scintillator and the free edge of WLS fiber
4) Adjustment of the coincidence time.

6. Conclusions

A novel neutron imaging system using rectangular scintillators with wavelength shifting (WLS) fibers was proposed for a large area neutron imaging. A neutron detection element that consists of a ^{6}Li glass scintillator with size of 5mm x 5mm x 2mmt and 1mmϕ WLS fibers arranged on four sides of the scintillators was prepared. The detection efficiency of this detection element for thermal neutron was measured by using a neutron source. The detection efficiency was 13%.

A 4 x 4 ^{6}Li glass scintillator array neutron system using the novel imaging method was made to investigate the effectiveness of this imaging method. By neutron imaging experiments in the thermal neutron radiography facility of JRR-3M., it was found that the counting rate up to 3 Mcps for a scintillators, namely, the counting rate up to 12 Mcps for one piece of the WSL fiber can be measured. By changing the thickness of neutron absorber, it is confirmed that neutron counting rates were proportional to the incident rate of neutrons for all ^{6}Li glass scintillators in the array.

By these results, it is confirmed that the novel imaging method can be applied on a neutron imaging system with large area and high counting rate.

Reference

[1] K. Kuroda, I. Manuilov, Nucl. Instr. and Meth. A **430** (1999) 311.

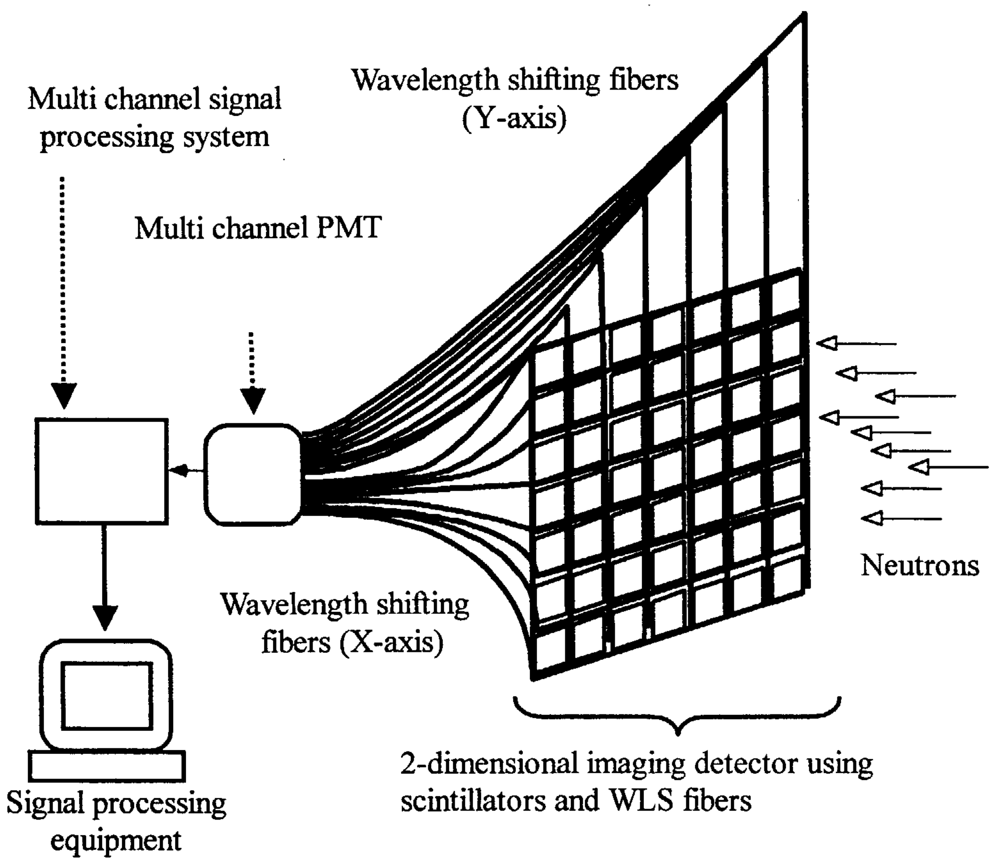

Fig. 1. 2-dimensional neutron imaging system using rectangular scintillators and WLS fibers with 4 coincidences method

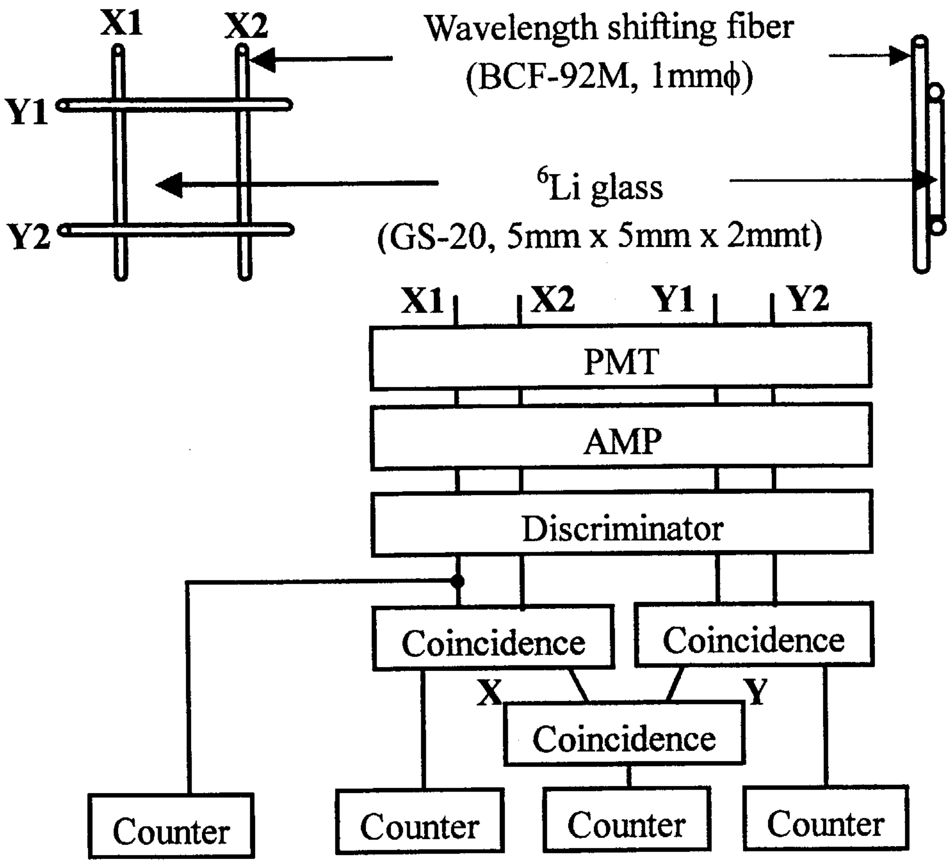

Fig. 2. Experimental system for the measurement of neutron detection efficiency using one ^{6}Li glass scintillator and four WLS fibers

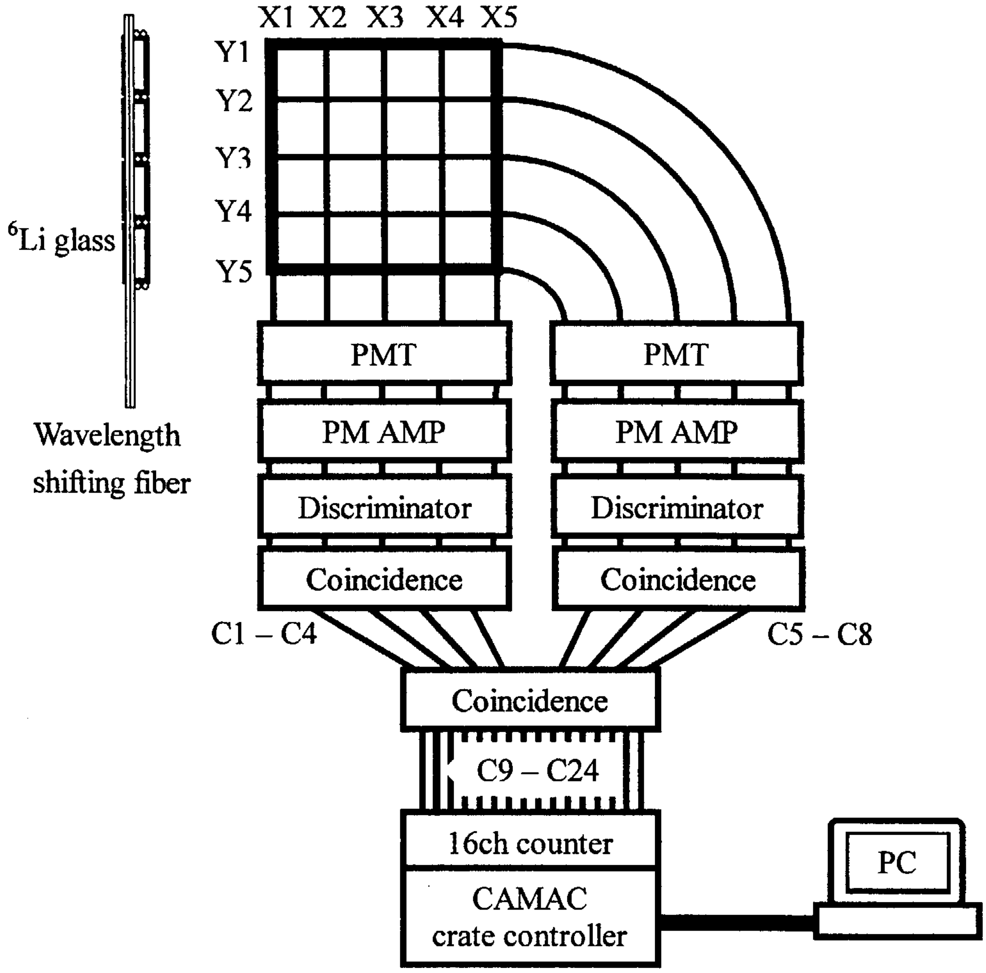

Fig. 3. 4 x 4 ^{6}Li glass scintillator array neutron imaging system

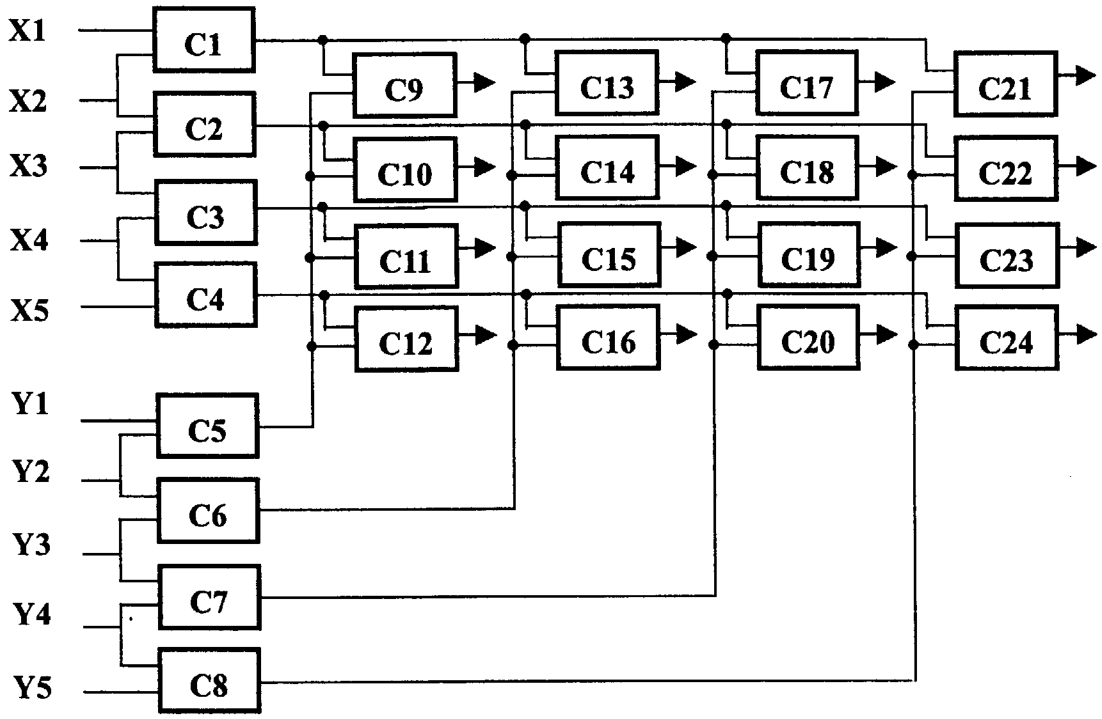

Fig. 4. Schematic diagram of coincidence circuits

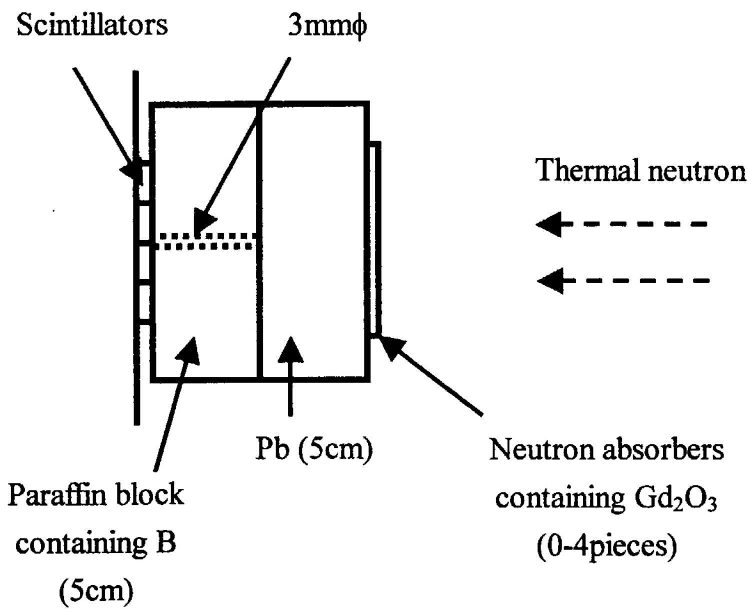

Fig. 5. The experimental arrangement for measurement of neutron imaging

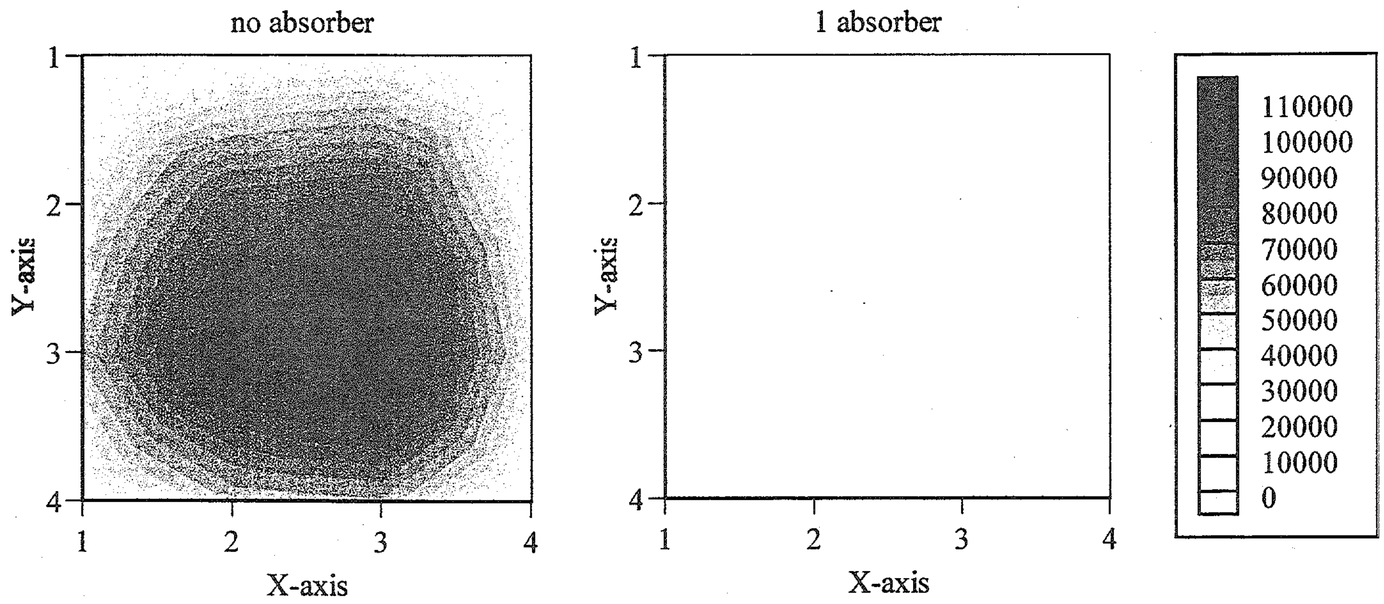

Fig.6. Nneutron images of no absorber and one absorber

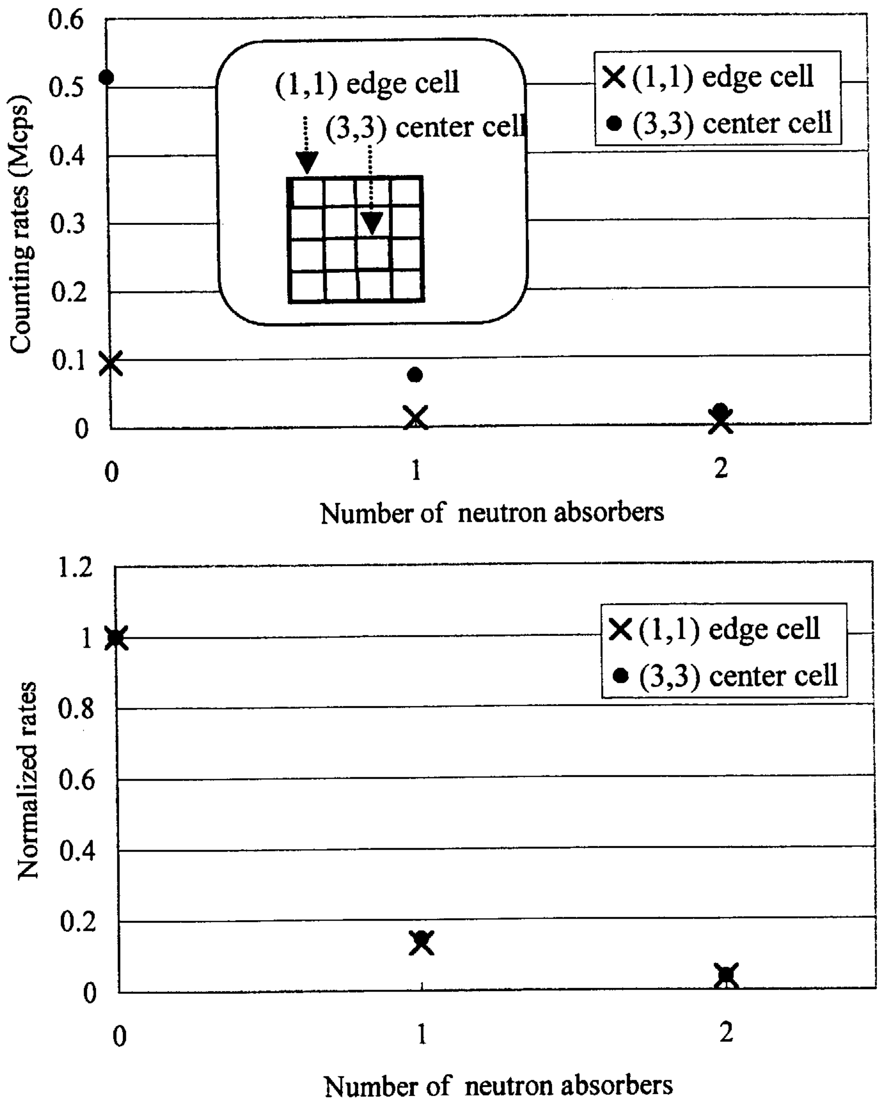

Fig.7.Comparison results for counting rates and normalized rates in the edge cell and the center cell

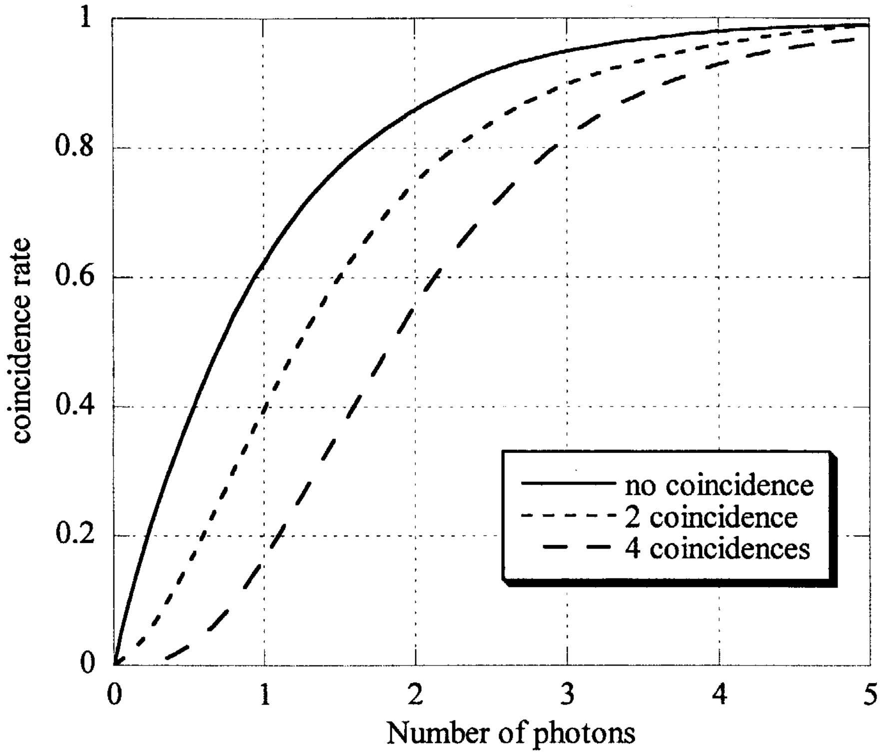

Fig. 8. Coincidence rate vs number of photon detected by a photomultiplier in case of no coincidence, 2 coincidence and 4 coincidences