Development of a phoswich imaging detector to simultaneously acquire neutron and gamma photon images

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I. Introduction

In neutron detection or imaging environments, gamma photons also exist, so discrimination of neutrons and gamma photons is desired [1]. With contamination by gamma photons in a neutron detector, precise monitoring of neutron flux is difficult. To solve this problem, neutron measurement and gamma photon measurement are conducted independently. Simultaneous measurement of neutrons and gamma photons has the potential to reduce the labor and time required as well as to improve the accuracy in unstable or fluctuating neutron and gamma photon environments.

We previously clarified that ZnS(Ag) has high light production for alpha particles and extremely low light production for beta particles and gamma photons; the light output per MeV for gamma photons was ~5% of that for alpha particles [2]. Since Li-ZnS(Ag) detects neutrons by converting neutrons to tritons and alpha particles, it is possible to develop a neutron imaging detector that selectively detects neutron-induced particles while rejecting gamma photons.

Meanwhile, other scintillators, such as cerium doped yttrium aluminum perovskite (YAP(Ce)), do not detect neutrons but can detect gamma photons. By combining Li-ZnS(Ag) with YAP(Ce), it may be possible to construct an imaging detector that can simultaneously but independently acquire images of neutrons and gamma photons. One possible approach to separating the images is a phoswich technique that uses the decay time differences of the scintillators [3].

Consequently, we developed a phoswich imaging detector that can simultaneously acquire images of neutrons and gamma photons by stacking Li-ZnS(Ag) and YAP(Ce) plates and optically coupling them to a position sensitive photomultiplier tube (PSPMT).

II. Materials and Methods

(1) Scintillators used for imaging detector

We used two different scintillators for our imaging detector; Li-ZnS(Ag) and YAP(Ce). Li-ZnS(Ag) was used for neutron imaging detector while YAP(Ce) was used for gamma photon imaging detector. We show the basic characteristics of YAP(Ce) and Li-ZnS(Ag) scintillators in Table 1. Since the decay times are significantly different (27 ns for YAP(Ce) and 200 ns for Li-ZnS(Ag)), we could separate neutrons and gamma photons by using pulse shape discrimination. One of the reasons of the used of YAP(Ce) was its shorter decay time to obtain the larger difference of decay time when it combined with Li-ZnS(Ag).

Table 1 Basic characteristics of YAP(Ce) and Li-ZnS(Ag) scintillators

	Density (g/cm^3)	Peak wavelength (nm)	Light yield (photons /MeV)	Decay time (ns)
YAP(Ce)	5.35	370	18000	27
Li-ZnS(Ag)	NA	455	49400	200

The major properties of the Li-ZnS(Ag) used in the imaging detector are summarized in Table 2. The Li-ZnS(Ag) has the form of a flat, white, thin sheet consisting of a homogeneous matrix of fine particles of lithium-6-fluoride (^{6}LiF) and ZnS(Ag) dispersed in a binder (EJ-428-HD, Elgen Technology, USA). The Li is enriched in 6Li to a minimum of 95 atom %.

Table 2 Main properties of Li-ZnS(Ag) plates used for imaging experiments [3]

Fraction of 6Li	>95 %
6LiF:ZnS Mass Ratio	1:2
6Li Density (atoms/cm3)	1.0^7 x 10^{22}

(2) Developed phoswich imaging detector

A schematic drawing of the developed phoswich imaging detector is shown in Fig. 1. The imaging detector is composed of a thin Li-ZnS(Ag) plate and a YAP(Ce) plate stacked and optically coupled with a PSPMT.

Neutrons from neutron source such as ^{252}Cf are irradiated to the imaging detector, detected by ^{6}Li in Li-ZnS(Ag) plate and produce a triton and an alpha particle. These triton and alpha particle are detected by ZnS(Ag) in Li-ZnS(Ag) plate and emits scintillation light. Since YAP(Ce) is insensitive to neutrons, YAP(Ce) does not produce scintillation photons.

Gamma photons from gamma source such as ^{60}Co are irradiated to imaging detector and detected by YAP(Ce) plate. Since ZnS(Ag) in Li-ZnS(Ag) produce extremely low scintillation for beta particles and gamma photons [2], gamma photons are not detected by Li-ZnS(Ag). The scintillation light produced in these scintillators is distributed in the YAP(Ce) plate and the glass envelope of the PSPMT and detected by the several wire anodes of the PSPMT.

The analog signals of the anodes of the PSPMT are fed to the electronics for position, energy and pulse shape calculations with event-by-event basis. Position of the induced triton and alpha particle as well as gamma photons were estimated by Anger principle. The pulse shapes were calculated by dual integration method.

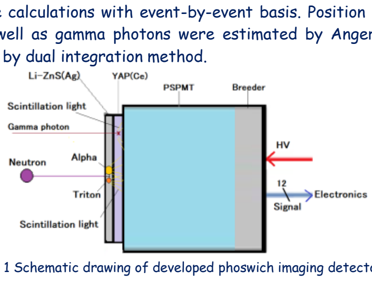


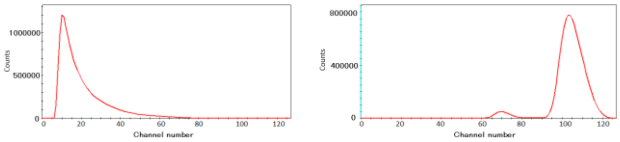
Fig. 1 Schematic drawing of developed phoswich imaging detector

The Li-ZnS(Ag) plate used in the phoswich imaging detector was 20 mm × 20 mm × 0.32 mm thick. The Li-ZnS(Ag) plate was optically couple to the YAP(Ce) plate of which size was 20 mm × 20 mm × 0.5 mm. Air coupling was used for the optical coupling of Li-ZnS(Ag) and YAP (Ce) plate. The YAP(Ce) plate was optically coupled to high quantum efficiency (HQE) PSPMT (R8900-100-C12, Hamamatsu Photonics, Japan) with a silicone rubber (KE420, Shin-etsu Silicone, Japan). The PSPMT was a 1-inch square metal package type with 6 × 6 cross-wire anodes. The voltage divider used was E7514 (Hamamatsu Photonics, Japan). High voltage of -700 V was supplied for the PSPMT for the imaging of neutrons and gamma photons from ^{252}Cf.

III. Results

(1) Energy and pulse shape spectra

We show the energy spectrum for neutrons and gamma photons from ^{252}Cf in Fig. 2 (A). We could observe a distribution similar to an exponential curve. We show the pulse shape spectra for neutrons and gamma photons from ^{252}Cf in Fig. 2 (B). We could observe two peaks, one was small in left and the other was large in right. The left peak was from the slower decay scintillation light of Li-ZnS(Ag) that detected neutrons, and the right peak was that for the faster decay of YAP(Ce) that detected gamma photons. From the pulse shape spectra, the threshold level to divide Li-ZnS(Ag) and YAP(Ce) was determined to be 85 channel.



(A) (B)

Fig. 2 Energy spectra (A) and pulse shape spectra (B) without discrimination

(2) Spatial resolution

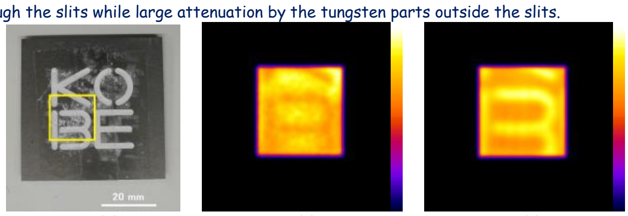
Spatial resolution was measured by setting 1 cm cube gadolinium (Gd) and tungsten (W) blocks on the phoswich imaging detector, A ^{252}Cf source was positioned 3 cm from the Gd block and two layers of polystyrene plates set between the source and imaging detector as well as behind the source. With this set-up, neutrons are absorbed by Gd block while gamma photons are absorbed by W block. By the pulse shape discrimination, two types of images attenuated by Gd for Li-ZnS(Ag) (neutron window) and W for YAP(Ce) (gamma photon window) are obtained. Spatial resolution for Li-ZnS(Ag) (neutron window) image was evaluated from the differential profile of these two types of images. Spatial resolution for Li-ZnS(Ag) image was 2.6 mm FWHM. Spatial resolution for YAP(Ce) (gamma photon window) image was also evaluated from the differential profile shown in Fig. 10 (B). Spatial resolution for YAP(Ce) (gamma photon window) image was 2.6 mm FWHM.

(3) Imaging experiments

We conducted simultaneous imaging of neutron and gamma photons for a phantom using the developed imaging detector. We show a photo of the phantom used for simultaneous neutron and gamma photon imaging in Fig. 3 (A). The phantom was made of 4 mm thick tungsten plate with slits. Gadolinium oxide (Gd_2O_3) powders were filled in the slits to absorb the neutrons while the tungsten parts absorb gamma photons. Thus the neutron image by the Li-ZnS(Ag) (neutron window) showed darker parts (low counts) in the character slit parts where $Gd2O_3$ powders filled, while gamma photon image by the YAP(Ce) (gamma photon window) showed brighter parts (high counts) in the character parts because the attenuation there was smaller than tungsten. We used a ^{252}Cf neutron source (870 kBq) for the imaging experiments because ^{252}Cf emits neutrons and gamma photons.

Figure 3 (B) shows images of character phantom measured by developed phoswich imaging detector discriminated for Li-ZnS(Ag) (neutron window). We could observe the characters of "B" and lower part of "K" in the image with darker (smaller counts) lines on the characters due to the attenuation of neutrons by Gd_2O_3 powder.

Figure 3 (C) shows images of character phantom discriminated for YAP(Ce) (gamma photon window). We could observe the characters of "B" and lower part of "K" in the image with brighter (larger counts) lines on the characters due to the transmission of gamma photons through the slits while large attenuation by the tungsten parts outside the slits.



(A) (B) (C)

Fig. 3 Photos of phantom used to measure images of phoswich imaging detector for simultaneous imaging of neutrons and gamma photons (A), images of phantoms measured by developed phoswich imaging detector discriminated to Li-ZnS(Ag) (neutron window) (B) and discriminated to YAP(Ce) (gamma photon window) (C)

(4) Spillover measurements

We measured count rates, sensitivity and percentage sensitivity (gamma photon fraction) of the developed phoswich imaging detector. The count rate was relatively small for these measurements; they were less than several hundred cps. The sensitivity of Li-ZnS(Ag) (neutron window) for ^{60}Co gamma photons of the developed phoswich imaging was 0.016 % that of YAP(Ce) (gamma photon window), thus the contamination of gamma photons in Li-ZnS(Ag) (neutron window) was negligible.

IV. Conclusion

We developed a phoswich imaging detector that can simultaneously but independently acquire images of neutrons and gamma photons. The spatial resolution was ~2.6 mm FWHM for both neutron and gamma photon images. The developed phoswich imaging detector is promising for use in neutron and gamma photon detection and imaging in various types of research and applications.

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