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Development of Ce:LiCAF Scintillator System for High Precision Nuclear Data Measurement Using Short Pulsed X-Band Electron Linac Based Neutron Source

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Abstract. We are developing a new neutron source at Tokai campus of University of Tokyo. In order to measure high precision nuclear data using this system, the neutron detector should have a large neutron cross section and fast decaying time. An inorganic scintillator Ce:LiCAF has a great characteristic in time resolution. However, an electron Linac emits intense gamma-rays, and this is an important issue for precise neutron measurement. There are two methods of discriminating between neutrons and gamma-rays. The first is the method using a difference of the spatial range of secondary particles. The ranges of the secondary particles of neutron are shorter than that of gamma-rays. The calculated results of Geant4 show the crystal thickness must be less than 5 mm for discrimination. However, the crystal size should be larger than 1 mm x 1 mm to keep reasonable signal-to-noise ratio. The improvement of discrimination due to the change of the size is confirmed by experiment. The other is the method which uses a difference of the light decaying time. The rising time of the signal of gamma-rays is shorter than that of neutrons. By using two shaping amplifiers having different time constants, the signal of gamma-rays can be eliminated.

1. Introduction

A short pulsed X-Band electron Linac based neutron source has been under development as an incoming neutron source of a research reactor Yayoi in Tokai campus. After the decommissioning of the Yayoi reactor, we have decided to install the Linac in the core space of the reactor. Schematic drawing of allocation of the Linac to the Yayoi area is shown in Figure 1[1]. Because of the compactness of the X-Band Linac, we can move it in the reactor. Accelerated electron collides with the neutron target, and because of the generation of the bremsstrahlung X-ray, photon neutron reaction is occurred. Generated neutron are irradiated with the measurement sample and detected by the neutron detector. High precision nuclear data can be obtained by this new neutron source. In order to measure high precision nuclear data, the neutron detector should have a large neutron reaction cross section and fast decay time. ^{10}B or ^{3}He gaseous detector has a large neutron reaction cross section and low gamma-ray sensitivity, but due to the slow rise time of those detectors, they are not able to be used in high precision Time of Flight (TOF) measurement. On the other hand, inorganic neutron scintillators have a great characteristic in timing resolution. Especially, the light decay time of inorganic scintillator Ce:LiCAF is about 40 ns, and that is superior to other neutron scintillators [2]. However, an electron Linac driven neutron source emits intense gamma-ray, and gamma-ray sensitivity of inorganic scintillators would be an issue for precise neutron measurement.

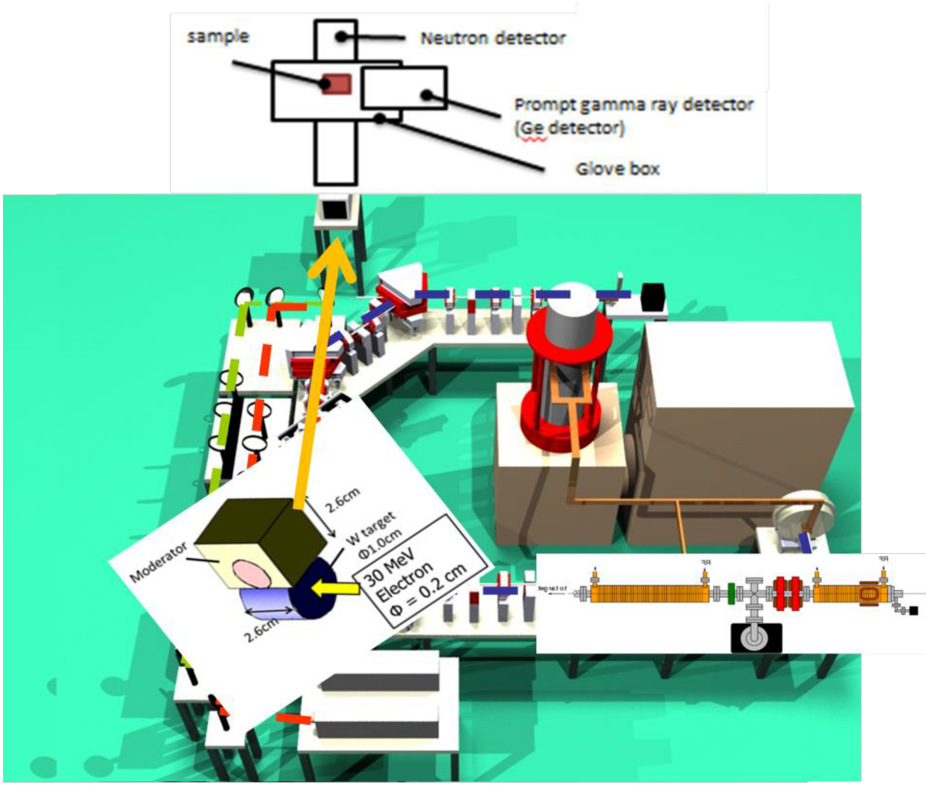

Figure 1. Allocation of the Linac to Yayoi area (from Reference 1)

2. Discriminating between neutron and gamma-ray

There are two methods of discriminating between neutron and gamma-ray. One is a method using the difference of the range of the secondary particles. When Ce:LiCAF crystal is irradiated with neutron, ^{6}Li absorb neutron and emits charged particles, such as alpha-particle and triton. These secondary particles are absorbed in the crystal and they excite the crystal and emit photons. When it is irradiated with gamma-ray, the secondary particle would be electrons. The range of alpha-particle and triton are 10 µm orders of magnitude, however, that of electron is 1 mm order [3]. Therefore, by controlling the Ce:LiCAF crystal size that alpha-particle and triton will be absorbed but electron will be not, the discrimination ability will be improved.

The other is a method which uses the difference of the light decay time of scintillator. The rise time of the signal caused by neutron is slower than that of the signal caused by gamma-ray [4]. A signal whose rise time is slow will be attenuated more than a fast signal by electronic circuits that have small time constant. Therefore, when two electronic circuits are prepared and one has a small time constant and the other has a big one, the signal caused by neutron is only counted by selecting the signal which has small pulse height in small time constant electronic circuit and big in big time constant electronic circuit. A signal caused by gamma-ray is big in two electronic circuits.

3. Change of the size of the scintillator

Using Geant4 Monte Carlo simulation code, energy deposition of neutron and gamma-ray in the Ce:LiCAF are calculated. Figure 2 shows the result that the size of square measure of the crystal is fixed at 10 mm × 10 mm and the thickness is changed from 0.5mm to 20mm. When the thickness of the crystal is changed from 0.5 mm to 5 mm, the detection rate of neutron is changed in proportion to the thickness. In the range of the 5-20 mm thickness, which of gamma-ray is also changed in proportion to the thickness, but in the range of 1-5 mm thickness, the detection rate is extremely decreased, from 1.55×10^{-2} to 1.35×10^{-4}. Figure 3 shows the result that the thickness of the crystal is fixed at 2 mm and the size of square measure is changed from 2 mm × 2 mm to 20 mm × 20 mm. The change of the detection rate of neutron is only 36%, from 1.22×10^{-3} to 1.57×10^{-3}, but 20 mm × 20 mm crystal detect gamma-ray about four times as much as 2 mm × 2 mm crystal, from 6.00×10^{-4} to 2.64×10^{-3}. So if the sizes of crystal become small, the number of the gamma-ray signal in neutron signal become small, but if the size of square measure become small, the number of irradiating neutron become small, and measuring time become long. In order to keep the measuring time short, and discriminate gamma-ray, the size of square measure should be large, and the thickness should be smaller than 5 mm. The simulation result was confirmed by neutron/gamma-ray measurement experiment by pulse height analysis using Multi Channel Analyzer. Figure 4 shows the result of the experiment that 2 mm × 2 mm × 2 mm crystal and 10 mm× 10 mm × 2 mm crystal is irradiated by neutron and gamma-ray. Radiation sources of neutron and gamma-ray are ^{60}Co and ^{252}Cf.The γ-ray signal level of 2 × 2 mm crystal is lower than that of 10 × 10 mm crystal, so the small crystal has a better discriminating characteristic, and this result agrees with the result of numerical simulation.

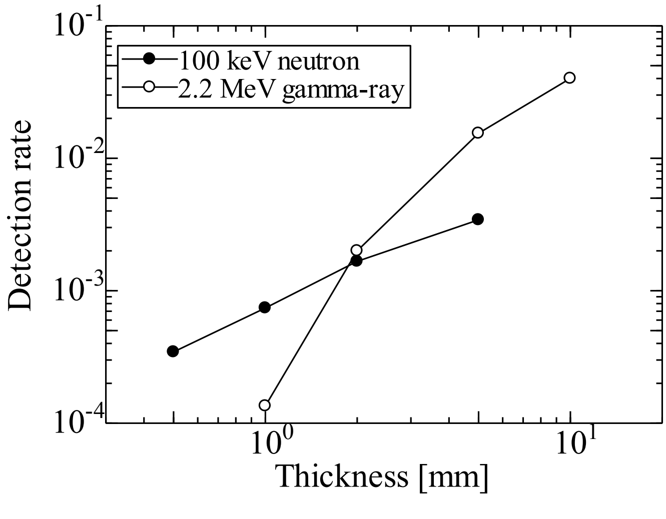

Figure 2. Change of detection rate following the change of the thickness of crystal

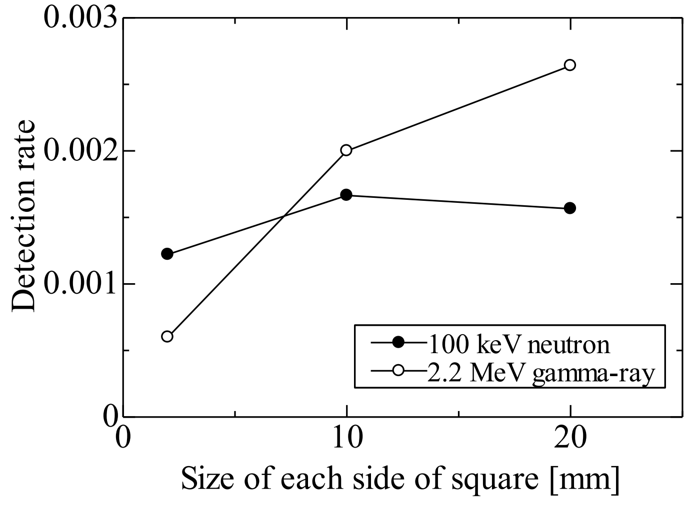

Figure 3. Change of detection rate following the change of the size of the crystal

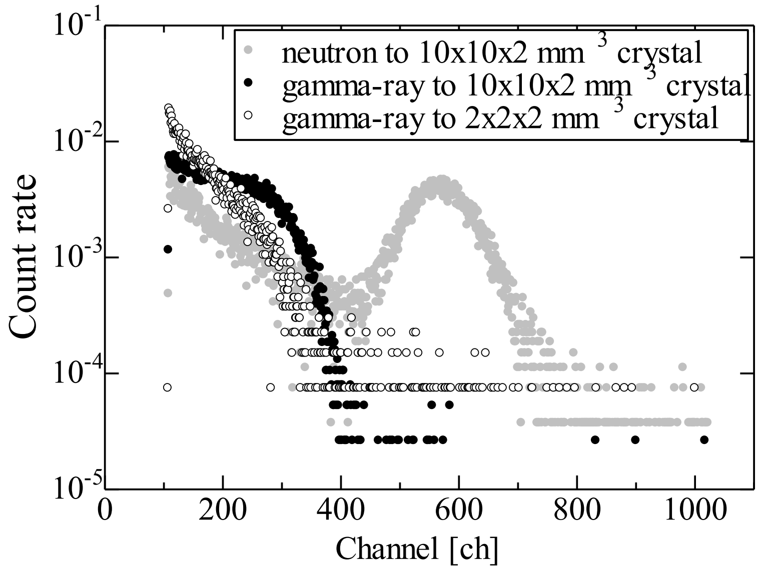

Figure 4. Change of gamma-ray signal level following the square measure of crystal

4. Change of the time constant of the electronic circuit

The rise time of the signals which are caused by neutron and gamma-ray were obtained by measurement experiment, the former is about 300 ns, and the latter is about 450 ns. In order to use the difference of these rise times and discriminate them, an electronic circuit which has a small time constant and attenuates the neutron signal more intensely than gamma-ray signal is needed. Figure 5 shows the principle of the discriminating electronic circuit. If input signal is gamma-ray signal, the signal is large in both small time constant circuit and large time constant circuit, but NOT circuit is connected to the big time constant circuit, so AND circuit outputs negative signal. If input signal is neutron signal, the signal become small in small time constant circuit and the signal cannot exceed the threshold of the comparator, so NOT circuit outputs a signal and AND circuit outputs too. Finally, only neutron signal is counted.

To realize this system, the small time constant electronic circuit must attenuate the neutron signal more extremely than the gamma-ray signal. Using 5 ns time constant electron circuit, neutron signal become about 12% smaller than gamma-ray signal.

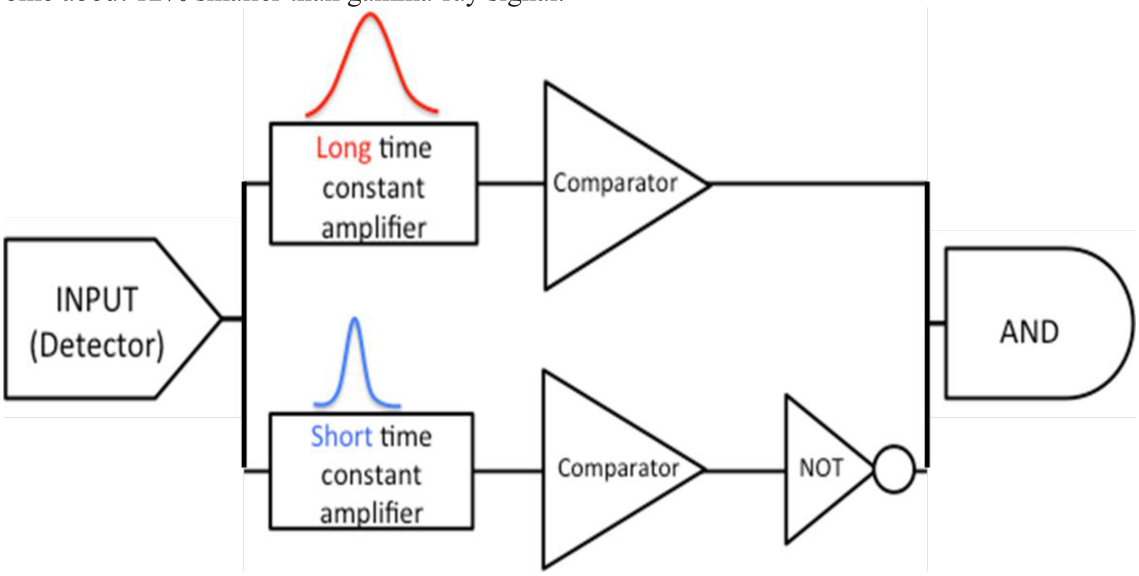

Figure 5. Composition of the discriminating electronic circuit

5. Conclusion

The neutron gamma discrimination method with the inorganic scintillator Ce:LiCAF is researched for high precision nuclear data measurement. In order to discriminate neutron and gamma-ray, the crystal size should be small. As a result of the numerical simulation, when the crystal thickness is shrunken from 1 mm to 0.5 mm, about 85 % of gamma-ray effect is eliminated. In order to get the same result, the crystal size must be shrunken from 20 mm x 20 mm to 2 mm x 2mm (83 % gamma-ray effect is eliminated), however, then the number of irradiated neutron is decreased to 1/100, so the measurement time become longer. So crystal thickness should be shrunken for the discrimination and it should be less than 5 mm.

Discrimination method using the difference of the rising time of each signal is researched. As the result of simulation, using two electron circuits that have large and small time constants, each signal level of neutron and gamma-ray is changed selectively. However, using the electron circuit that have a much smaller time constant than the rising time, the change of signal level is only 12 %. It is needed to research more suitable time constant and the composition of the electron circuit to achieve larger change of signal level. Using these methods, we plan to obtain precise nuclear data by X-Band electron Linac based neutron source at Tokai campus.

Reference

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