Development of a neutron beam monitor for nuclear data measurement using spallation neutron source

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Neutron beam intensity for nuclear data measurement is increasing. The qualities of cross section measurements of radioactive nuclide were significantly improved. In neutron capture cross section measurement, the number of the incident neutrons is necessary to derive the neutron capture cross section. However, conventional neutron detectors do~~es~~ not have fast response to adapt high counting rate measurement with spallation neutron sources. To avoid possible failure of a proton pulse counting method and make measurement with ANNRI more robust, an additional neutron beam monitor is under development. A plastic scintillator ~~and ^{6}Li are~~ adopted for a detector. A test detector system was built to study the feasibility of the present method. Test experiments demonstrated that the new detection system was able to detect neutrons from the spallation neutron source.

I. Introduction

The qualities of cross section measurements of radioactive nuclide were significantly improved with high intensity neutron beams. It has been difficult to measure neutron-induced reaction cross sections of radioactive nuclide due to large background of the decay gamma-rays from radioactive samples. In recent years, with the advent of spallation neutron sources, the qualities of cross section measurements were significantly improved. The Japan Proton Accelerator Research Complex (J-PARC) was started in operation in 2008 and its beam power has been increased year by year [1]. To measure neutron-induced nuclear data using the high intensity neutron beam from the J-PARC spallation neutron source, the Accurate Neutron Nucleus Reaction Measurement Instrument (ANNRI) was built in the Materials and Life Science Experimental Facility (MLF) of J-PARC.

In neutron capture cross section measurement, the number of the incident neutrons is important physical quantity. To normalize the detected gamma-ray yield to the number of the incident neutrons, the neutron count is usually monitored by ~~detecting the incident neutrons with~~ a neutron detector. However, in measurement with ANNRI, the number of proton beam pulses injected into the spallation target has been used instead of ~~directly~~ neutron monitoring. This method is based on the assumption that the number of proton beam pulses is proportional to the number of incident neutrons. This assumption is mostly plausible but could fail when the conditions of the proton accelerator or the neutron source change. To avoid possible failure of the proton pulse counting method and make measurement with ANNRI more robust, an additional neutron beam monitor is under development.

II. Detector Design

To develop a neutron beam monitor for ANNRI, there are two requirements. Fast time response to adapt very high intensity neutron beam and low gamma-ray sensitively to reduce background. In order to fulfill the requirements, a thin sheet-type plastic scintillator combined with a thin ^{6}Li layer on an aluminum film is adopted for the present neutron monitor. The incident neutrons react with ^{6}Li and the ^{6}Li(n,t)^{4}He reaction occurs. The emitted particles, tritons and alphas, are detected with the plastic scintillator. The short ranges of tritons and alphas allow for using a thin plastic scintillator film, and the thin detector leads to low gamma-ray sensibility. Another requirement for fast detection is achieved by the fast response property of plastic scintillator with 3.7 ns decay time. Simulation studies using Monte Carlo simulation code PHITS [2] ~~was~~ performed to optimize the detector design, especially thickness of the ^{6}LiF layer. In Fig. 1, the concept of the detector system is shown schematically.

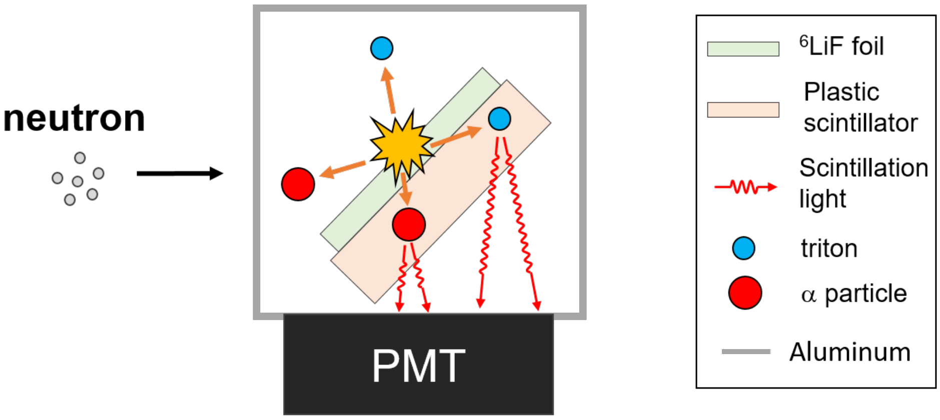

Figure 1: *Detector geometric design.*

III. Experiments

A test detector system was built to study the feasibility. LiF was deposited on an aluminum film by a vacuum deposition method. The LiF layer was thin enough for tritons and alpha particles to penetrate and reach the plastic scintillator. ^{6}Li was isotopically enriched 95 %. The photomultiplier tube was HAMAMATSU R1306-22ASSY. Test experiments were carried out at ANNRI. The detector was placed at a flight length of 29.62 m from the spallation neutron source. The beam power was about 500 kW. The pulse height (PH) and the time-of-flight (TOF) were acquired. TOF measurement was started by a signal from the J-PARC accelerator and stopped by PMT signal. In addition to measurement with the LiF foil, measurement without the LiF foil was conducted for background evaluation. Measurement time was about 11 min.

As shown in Fig. 2, pulse-height (PH) spectra are shown. The spectra were normalized with the number of proton pulses. In Fig. 2, the ^{6}Li(n,t)^{4}H reaction was successfully observed as a strong peak in the region from 22 ch to 36 ch. In Figs. 3, time-of-flight spectra are shown. Difference between with and without LiF is observed in the TOF region from 400 to 35000 μs that corresponds to the thermal neutron region. The peak of the resonance of ^{6}Li(n,t)^{4}He at 250 keV was also observed in the TOF region from 7 to 9 μs. The neutron energy spectrum was derived from TOF spectrum by dividing the detected neutron counts by the reaction rate calculated from the ^{6}Li(n,t)^{4}He cross section..

To evaluate the system performance, the present results were compared with neutron spectra measured with different methods in previous experiments. In Fig. 4, the neutron spectrum (red) measured in this work ~~data~~ was compared with a neutron spectrum (black) at 27.9 m obtained detection 478 keV gamma-rays from the ^{10}B(n,ag)^{7}Li reaction placing a ^{10}B sample. The neutron spectra agree well in the thermal neutron region but the present neutron spectrum is slightly higher than the previous measurement in the higher energy region, and deviates from 10 eV. The difference comes from insufficient subtraction of background that is mainly gamma-ray from the neutron source. The background subtraction must be improved in the future development. Statistical error was 0.68 % at 6 meV. Figure 5 shows another comparison of the present results (red) with a TOF spectrum (black) measured with a

Li glass detector in a previous experiment. The beam power of the previous experiment was 200 kW. A Pb filter with a thickness of 5 cm was inserted upstream to reduce the gamma flash from the neutron source while no Pb filter was used in the present experiment. Detector paralysis caused by the gamma-flash occurred in the present experiment. Detector paralysis leads to count loss observed in the TOF region from 3 to 20 μs in the previous experiment. On the other hand, detector paralysis did not occur and significant count loss did not appear in the present system, despite no use of the Pb filter. This study was successfully measured without detector paralysis at fast TOF region.

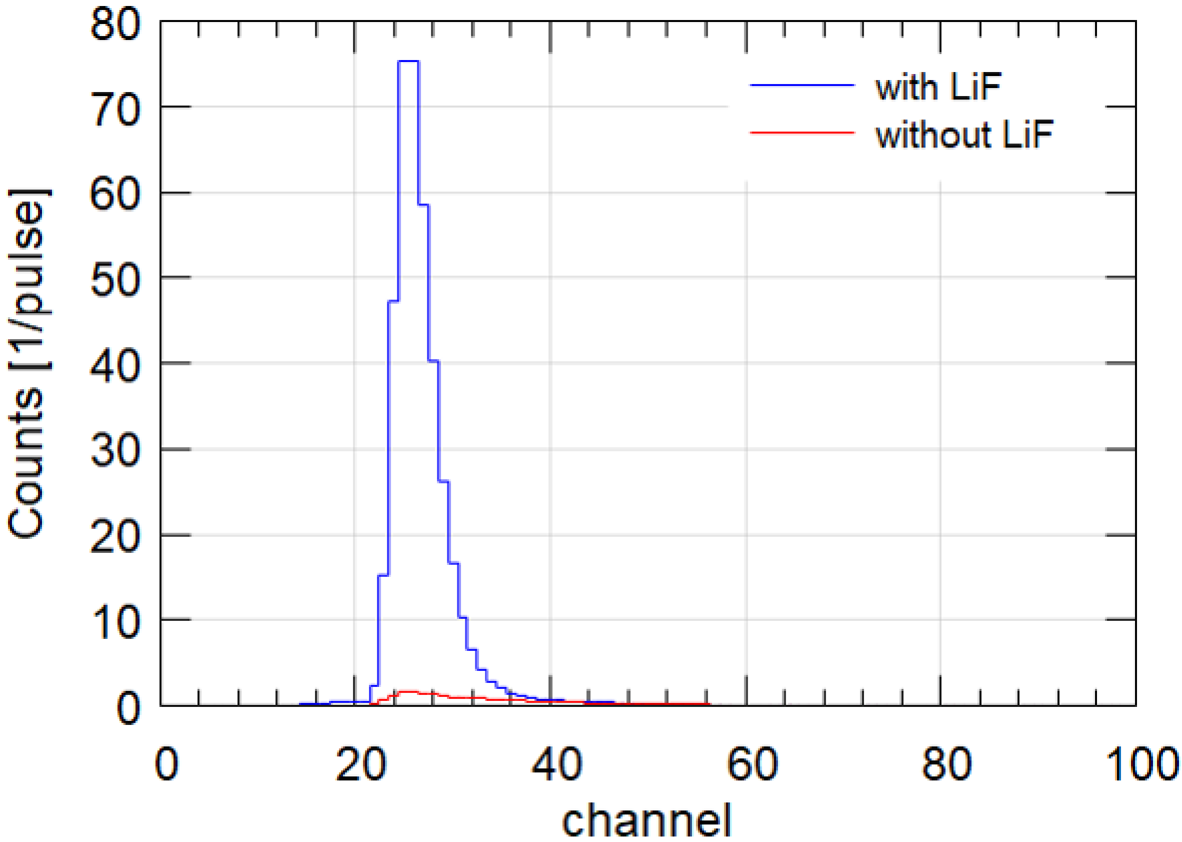

Figure 2: *Pulse height spectra with and without LiF.*

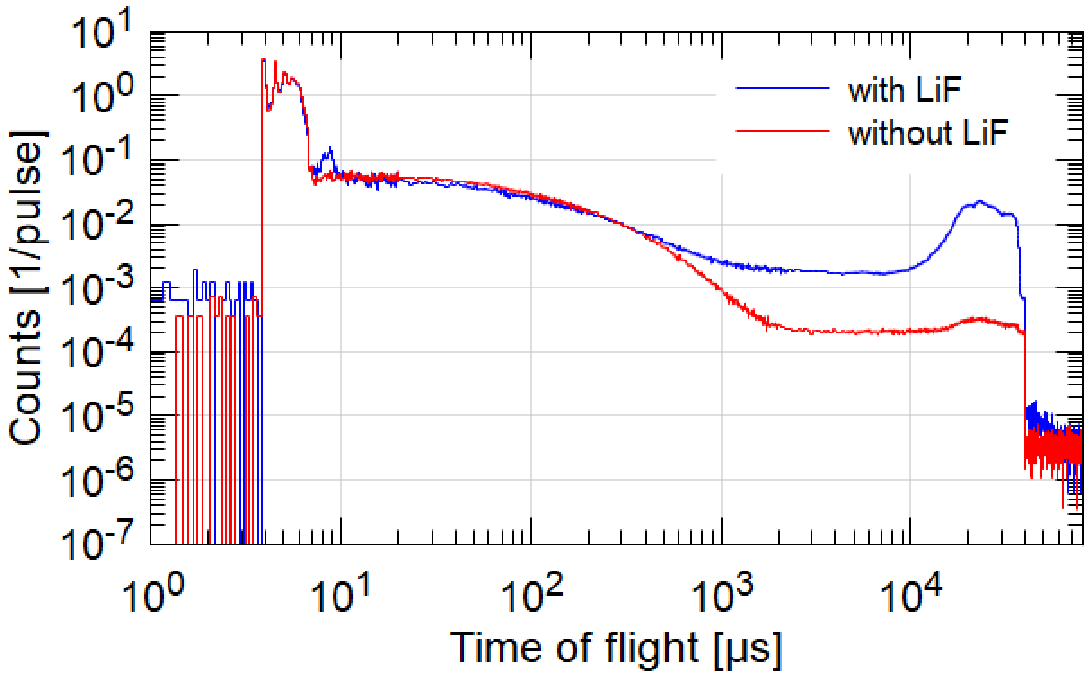

Figure 3: *TOF spectra with and without LiF.*

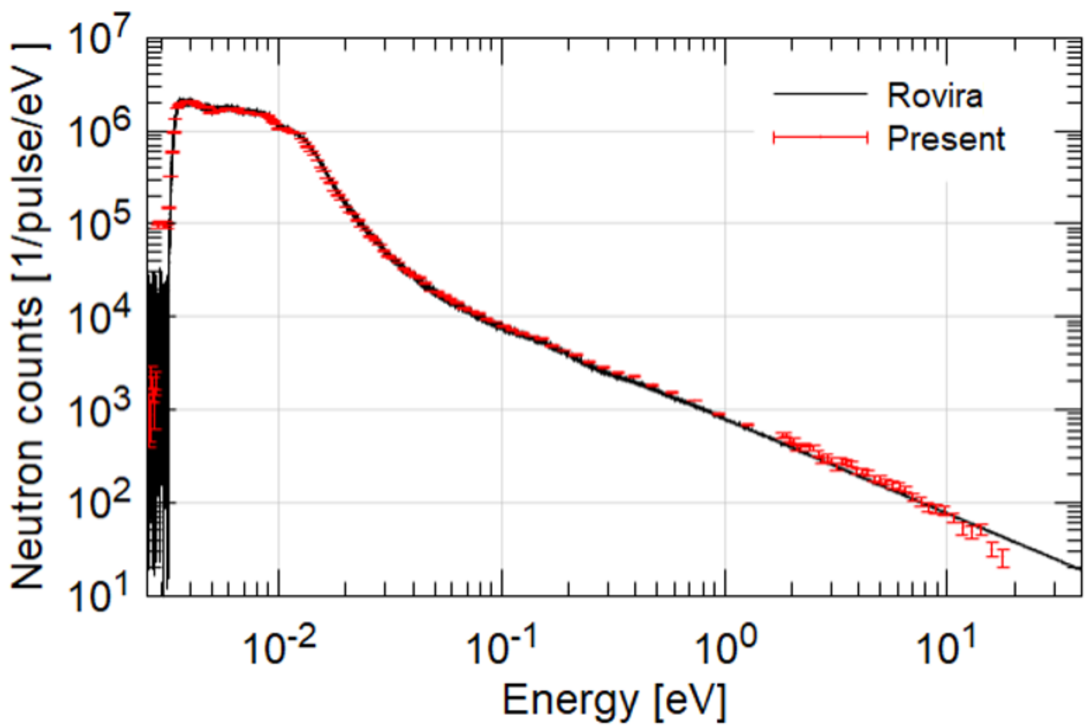

Figure 4: *Comparison of neutron spectra of the present work with the previous measurement by Rovira [3].*

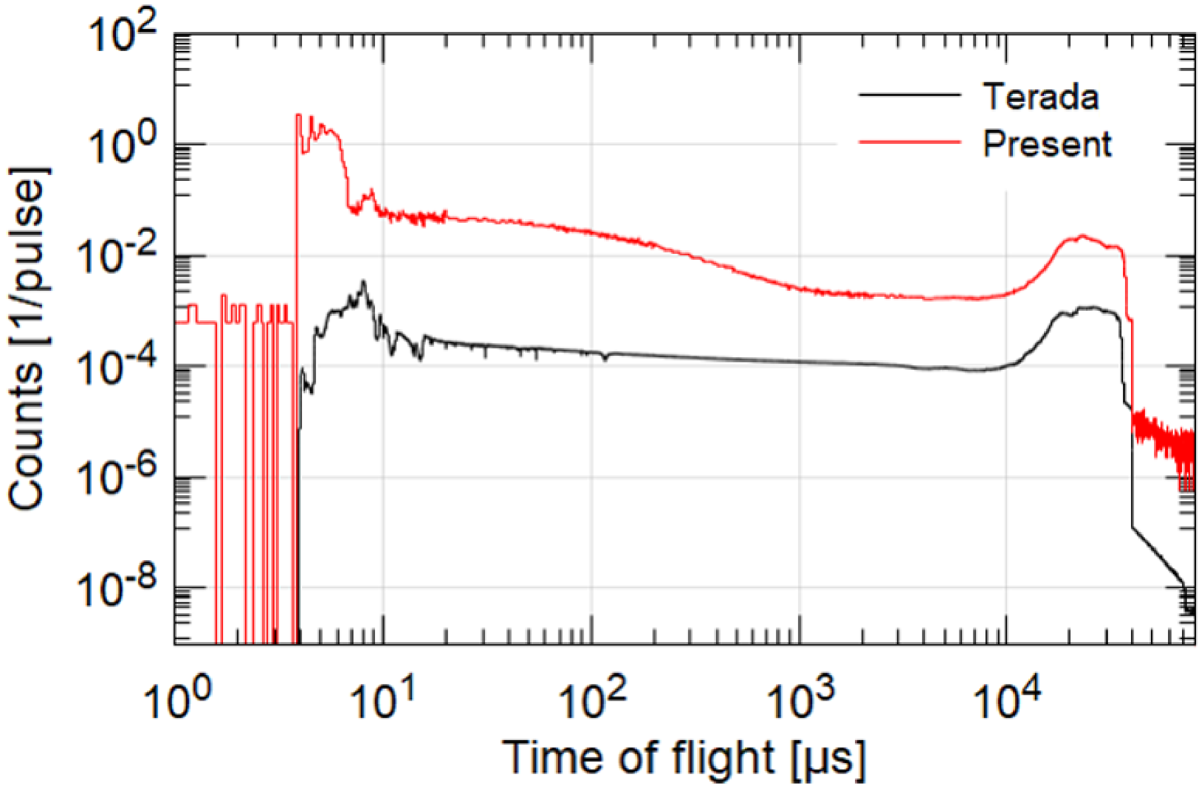

Figure 5: *Comparison of TOF spectra of the present work with the previous measurement by Terada [4].*

IV. Summary

A new neutron monitor system was designed and built. Signal from the ^{6}Li(n, t)^{4}He reaction was clearly observed. Neutron spectrum was driven from TOF spectrum in data analysis. Statistical error was 0.68 % at 6 meV. In the future plan, this system will be used as an incident neutron monitor in nuclear data measurement. Moreover, application to other nuclear cross section measurement is planned.

References

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